The Specification of a Consumer Design Toolkit to Support Personalised Production via Additive Manufacturing

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Certificate of Originality

This is to certify that I am responsible for the work submitted in this thesis, that the original work is my own except as specified in acknowledgments or in footnotes, and that neither the thesis nor the original work contained therein has been submitted to this or any other institution for a degree.

M. Sinclair

11.07.2012

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ABSTRACT

This thesis stems from the future scenario that as additive manufacturing (AM) technologies become cheaper and more readily available, consumers without formal design training will begin to customise, design and manufacture their own products. Much of this activity is likely to infringe on brands' intellectual property. The research explores the feasibility of a situation in which, rather than attempting to prohibit such activity, manufacturers engage with consumers to facilitate it, thus retaining control (albeit reduced) over their brand's image and the quality of products offered.

The research begins with a literature review encompassing AM technologies and their adoption by consumers; mass customisation (MC) and the management of variation in product offering; and traditional models of industrial design (ID), including user-centred design and co-design. It finds that conventional definitions of MC and ID are unable to provide for the possibility of consumer intervention in the shape and non-modular configuration of products. Further research was then conducted in the areas of Open Design (including crowdsourcing, open sourcing and 'hardware hacking') as well as bespoke customisation, which were found to be much more accommodating of the scenario proposed. A new term, 'consumer design', is introduced and defined, together with the hypothesis that in future, the role of the industrial designer may be to design 'unfinished' products. An original classification of consumer involvement in ID is presented.

Empirical research, undertaken with consumers using an iterative design software package (Genoform), demonstrated a preference for designing within pre-determined boundaries. Action research was conducted to assess consumer-oriented 3D CAD software, and compare its capabilities with that of MC toolkits. A survey of senior designers and brand managers revealed strategies for implementing and managing a brand's product design language, and a guide was created to show the relative importance of designed features.

Using these findings, a prototype toolkit was created to demonstrate how a brand might facilitate consumer interaction with the shape design of a complex consumer electronics product (in this case a mobile phone). The toolkit was tested with both consumers and experienced designers to assess its viability.

The research finds that it is possible to create a consumer-design toolkit which enables untrained users to change the form of a product, whilst maintaining brand equity and ensuring the product's functionality and manufacturability.

Keywords: Additive Manufacturing, Consumer-Design, Industrial Design, Mass Customisation, Toolkit

LIST OF PUBLICATIONS

Sinclair, M; Campbell, R.I; Ariadi, Y. and Evans, M.A. (2011), 'AM-Enabled Consumer Design, *Proceedings of the 12th Annual Conference of the Rapid Product Development Association,* Vanderbijlpark, South Africa.

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GLOSSARY OF TERMS

Additive Manufacture (AM) and Computer Aided Design (CAD)

3D Printing - Originally referring to just one type of AM technology, 3D Printing is now commonly used to describe all such technologies.

Boolean - In CAD modelling, boolean operations involve the union, difference or intersection of two or more solid objects.

Computer Numerically Controlled (CNC) - The use of computer generated data to drive a machine tool along a path.

Direct Digital Modelling - The production of end use parts directly from a digital model, without intermediary tooling. Additive manufacture and laser cutting are both examples.

Fabbing - Popularised by Neal Gershenfeld's book *Fab*, Fabbing is the production (fabrication) of products by hobbyists and interested amateurs.

Fused Deposition Modelling (FDM) - a type of AM in which molten material is extruded along a path. Most low-cost 3D printers utilise this technology.

G0, G1, G2 and G3 Continuity - In CAD modelling, continuity between surfaces is defined as one of four types:

G0 - positional continuity, in which the surfaces are touching

G1 - tangent continuity, in which the surfaces are touching and meet at a common angle

G2 - curvature continuity, in which the surfaces are touching, meet at a common angle and share a common radius value.

G3 - acceleration continuity, in which the surfaces are touching, meet at a common angle, share a common radius value and change at the same rate.

Laser Sintering - A type of AM in which a laser is used to melt and fuse a powdered material (commonly polymer or metal, but also increasingly ceramic).

NURBs - Non-Uniform Rational B-Splines, commonly used in CAD modelling where the shape of a surface is determined by control points on a curve.

.obj - A file format extension denoting a Wavefront model, it is often included as an import/export option in CAD modellers, meaning it can be used to transfer a model from one software package to another.

Rapid Manufacturing - The previously popular term for Additive Manufacturing.

Rapid Prototyping - Similar to Rapid Manufacturing, but referring only to prototype (rather than end-use) parts.

Solid Freeform Fabrication - An alternative to Additive Manufacturing.

Stereolithography (SLA) - A type of AM in which a laser is used to cure a liquid resin.

.stl - A file format extension native to stereolithography, it is widely used in all types of additive manufacturing.

Sub-division - In CAD modelling, sub-division is a method of representing a smooth surface by a series of tessellating polygons. The greater the number of polygons, the smoother the surface appears (but also the greater the file size).

.wrl - A file format extension denoting a Virtual Reality Modelling Language (VRML) model, it can often be used as a substitute for the .stl extension.

Watchmaking

Automatic (also known as Self-Winding) - a mechanism that winds the mainspring by using the movement of the arm to cause a rotor to rotate and which, via specific gears, winds the mainspring.

Back - In a watch case, the cover, transparent or not, opposite the dial.

Bezel - A ring around the case middle that secures the crystal.

Bridge - A metal plate under which the pivots of the wheels and pinions turn.

Case - The container that protects the watch movement from dust, damp and knocks

Complication - Any function other than the indication of hours, minutes and seconds, such as the Perpetual Calender and Tourbillon. Complications were instrumental in the rediscovery of the watchmaker's art in the 1980s and the consequent development of mechanical watchmaking into a luxury goods industry.

Crown - A knurled or fluted button of various shapes, held between the thumb and forefinger and used to wind the watch.

Crystal - A thin sheet of glass or a transparent synthetic material to protect a clock or watch dial [in high-end watchmaking this is typically sapphire crystal]

Dial - A plate of metal or another material which, in a standard clock or watch, serves to indicate hours, minutes and seconds.

Jacquemart - an animated, mechanised figure of a person, which strikes the hours on a bell with a hammer.

Jewels - The synthetic rubies in a watch movement used as bearings for pivots to reduce friction. As a general rule, a simple mechanical watch, i.e. one that indicates hours, minutes and seconds, should have at least fifteen jewels at the points most exposed to friction.

Mechanism - A configuration of parts to perform a function. The watch is a mechanism whose various parts are themselves mechanisms, each with a specific function.

Movement - The duly-assembled organs and mechanisms of a watch, meaning the winding and hand-setting mechanism, the mainspring, the gears, the escapement and the regulating organ (spring balance).

Pavé - A group of gems set closely together to cover an entire surface.

Perpetual Calender - A watch whose calendar automatically takes the number of days in the month into account: 30 or 31 and the 28 or 29 days of February for ordinary and leap years.

Quartz - Silicon dioxide. Quartz has the specific property of vibrating at a very high frequency (32 MHz) placed under electric current. Under certain conditions, it imparts its own vibration frequency to the circuit. This property has been used in electronic watches since the 1970s.

Rotor - A semi-circular disc that freely rotates with each movement of the arm to automatically wind the mainspring.

Tourbillon - A system devised and patented by Abraham-Louis Breguet in 1801 to compensate for errors of rate caused by the Earth's gravitational force in upright positions, tourbillon pieces are often the most expensive models a brand will offer.

From the Fondation de la Haute Horlogerie. http://www.hautehorlogerie.org/en/glossary

Phone Design

A-Cover - The front cover, i.e. the one which contains the window.

Active Area - The area of an LCD containing display pixels. Typically a high resolution LCD will have at least 2mm of non-active area on three sides, and considerably more on the side where the flexible cable attaches.

Antenna - A specific part of the RF responsible for digital signal transmission and reception. Modern mobile phones typically have three (combined) antennas (two for GSM frequencies and one for 3G) as well as Bluetooth and GPS antennas.

B-Cover - The rear cover. Generally this must be non-metallic to allow RF transparency.

C-Cover - To overcome the restriction on non-metallic materials, the rear cover is often split into two parts, thus creating a B- and C-Cover.

Chassis - The part which the engine is assembled and fixed into, it may be either hidden or visible to the user.

Engine - The circuit board and all electronic components.

Ground Plane - In radio antenna theory, the ground plane is a structure whose relationship to the antenna permits the antenna to function. In design terms it means the antenna must be a certain distance from the circuit board, which then governs the thickness of the phone.

Hardware - That part of the engine not dedicated to digital signal transmission, it includes the LCD, memory, battery, SIM-card etc.

RF - Radio Frequency. This generally refers to that part of the engine which transmits, receives and processes digital signals.

Send/End Keys - The keys used to initiate and end a call, they are redundant in a touchscreen phone

Soft Keys - Software-configurable keys are keys whose function changes according to on-screen instructions, such that a single key may have multiple functions. The buttons surrounding a cash-point machine's display are soft keys, whereas the number pad used to enter a pin number uses non-configurable 'hard' keys.

Touchscreen (Capacitive) - The type of touchscreen used in most consumer electronics products. It offers good brightness and contrast, but does not work with non-conductive materials (e.g. a plastic stylus) or if the screen is wet.

Window - The transparent part through which the LCD display is viewed.

CHAPTER 1

Introduction to the Research.

1.1 RESEARCH BACKGROUND

In March 2011, the Royal Society for the encouragement of Arts, Manufacture and Commerce (RSA) hosted a debate around the subject of 21st Century Manufacture. In his introduction, the design historian Hugh Aldersey-Williams (2011) proposed that

> **"In the coming decades, what we may see is that design and manufacturing look less like they did in the 20th Century, and more like they did in the 14th."**

What Aldersey-Williams was alluding to was the possibility that, as direct digital manufacturing technologies (in particular, additive manufacturing) become increasingly prevalent, design and manufacture may change from a system concerned primarily with the mass production of identical objects, to one whose focus is the individualised production of goods unique to their owners.

Additive Manufacturing (AM) can be defined as the direct production of finished parts or products, most often utilising one of a number of 3D printing technologies (Hague et al, 2007). The most important difference between AM technologies and traditional mass manufacturing technologies such as injection moulding is the absence of tooling (Mansour and Hague, 2003). This has a number of important implications. One of the common features of mass manufacturing processes is that the means of production require substantial initial investment, however once in place the cost of manufacturing a single part or product (relative to the initial investment) is negligible. This inevitably leads to uniformity, since the costs of repetition are extremely low, whereas even small design changes require significant reinvestment in tooling.

Today's product development process is ideally suited to (and a consequence of) the requirement of manufacturers for small numbers of designs that can be reproduced identically in high volume. However without the need for tooling, additive manufacturing offers the theoretical possibility that every concept can be produced. Such a possibility would have profound consequences for the long-established industrial design process.

Understanding how the industrial design (ID) process and profession might change to accommodate Aldersey-Williams' vision has provided the motivation for this PhD research. Traditionally, since products must be produced in high volume, it is inevitable that a product's function and aesthetics must be appealing to many, not just to a few. Mass customisation (MC) has demonstrated the possibility of designing for niche markets, in small production runs, but it is impossible for a designer, or even a design team, to be an expert in all these niches. Consequently MC systems commonly place responsibility for a product's appearance in the hands of the consumer. The purpose of the traditional design process is not just to impose a uniform aesthetic however - it also refines and rejects on the basis of ergonomics, durability, integration with other products and systems, cost etc. These are all areas in which the designer's expertise is likely to remain the best tool to resolve the conflicting demands of a product brief. The apparent conflict which arises between these positions, made more pertinent by the increasing availability of additive manufacturing technologies, forms the basis of this PhD.

1.2 AIMS AND OBJECTIVES

The overall aim of the research was to investigate how consumers, as untrained designers, can be enabled to engage in the design of their own products prior to purchase. A necessary first objective was therefore to review the literature in three areas, and to understand the tripartite relationship between them:

- Additive Manufacturing
- Mass Customisation
- The Industrial Design Process

Following this review, a number of specific objectives were formulated:

1. To review the literature further and critically analyse the role of the consumer in design processes outside of those traditionally employed by professional industrial designers.
2. To explore the process and outcomes of bespoke design and customisation, and understand how these might be applied within a design toolkit.
3. To understand how a product design language affects brand equity, how design languages are developed and maintained, and what conflicts might arise from consumers' interventions in design.
4. To investigate, through user trials, non-designers' abilities and preferences with regard to a number of design methods.
5. To further investigate consumer oriented product design and development software.
6. To develop a specification for a toolkit capable of being used by consumer-designers, which at the same time satisfies the requirements of professional designers and brand managers.

1.3 SCOPE OF THE WORK

This research is limited to the field of industrial design, excluding, for instance, graphic, fashion or interior design. ID nonetheless offers a potentially overwhelming array of product areas to investigate, including such disparate specialities as sports footwear, transportation, furniture and medical devices. It was therefore necessary to limit the scope of the research to ensure the results were not diluted and that the conclusions would not over-state their validity. Thus this PhD concentrates on the area of industrial design of consumer electronics, a specialism which was chosen for two reasons:

- It is the area in which the author has most expertise and experience.
- It is an area in which consumers generally regard products as personal (rather than shared) items.

However, in the same way that the research borrows from other fields where appropriate, it is hoped that industrial designers from specialisms other than consumer electronics will also perceive the findings to be interesting and relevant.

1.4 THESIS STRUCTURE

Figure 1.1 shows the structure of the thesis. Chapters 2, 3 and 4 report the initial Literature Review and identify gaps and contradictions in knowledge between these three domains. Based on this review, Chapter 5 sets out the theoretical foundation of the thesis and identifies the research questions which inform the rest of the work. It also provides a justification of the research methodology employed.

Chapter 6 investigates emerging design processes and proposes a classification of consumer involvement in industrial design. Chapters 7 and 8 then explore the strategies utilised by professional designers to enhance brand equity. To complement this, Chapters 9 and 10 examine the abilities of untrained consumers to engage in design activities including concept generation, detailing and modelling. Chapter 11 then presents a specification and prototype concept of a Consumer Design Toolkit. Chapter 12 concludes the thesis by reflecting on the findings of the research and suggesting areas for future investigation.

STRUCTURE OF THESIS	SUMMARY OF CHAPTER(S)
Chapter 1: Introduction	Introduces the research, its scope, aims and objectives, and the structure of the thesis.
Chapter 2: 3D Printing Technologies and their Adoption by Consumers	Literature Review to understand the interplay between Additive Manufacturing, Mass Customisation and Industrial Design. Identifies gaps in prior knowledge.
Chapter 3: Mass Customisation	
Chapter 4: The Place of the Consumer in the Industrial Design Process	
Chapter 5: Research Methodology	Sets out the theoretical foundation of the thesis, identifies research questions and justifies the research methodology.
Chapter 6: The Emergence of the Consumer as Designer	Reviews consumer integration in emerging Industrial Design processes and proposes a classification of consumer involvement.
Chapter 7: Design for Bespoke Customisation	Presents a case study and survey to understand the design strategies used to enhance brand equity through customisation and product design language. Identifies conflicts between product personalisation and brand image.
Chapter 8: The Construction, Maintenance and Value of a Brand's Product Design Language	
Chapter 9: A Trial to Assess Consumer Preferences and Abilities in Methods of Self Design	Documents a trial to assess consumer capabilities in design. Analyses a number of consumer-oriented CAD software systems to identify standards and assess best practice, and compares these to mass customisation toolkits. Proposes recommendations for inclusion in a consumer design toolkit.
Chapter 10: A Comparison of Consumer-Oriented CAD Software and Mass Customisation Toolkits	
Chapter 11: The Specification and Prototyping of a Consumer Design Toolkit	Explains the conceptual approach to the toolkit's specification, describes the prototype toolkit's design, and presents initial feedback.
Chapter 12: Conclusions and Future Research	Reflects on the design of the prototype toolkit, identifies weaknesses and proposes areas for future investigation.

Figure 1.1. Thesis Structure

CHAPTER 2.

3D Printing Technologies and their Adoption by Consumers.

2.1 INTRODUCTION

In seeking to understand the history and evolution of 3D Printing a good deal is revealed by the profusion of names and descriptions which surround its development. Within academic and industry literature, Additive Manufacturing (AM) has previously been referred to as Layer Manufacturing (e.g. Stotko and Snow, 2007), Laminated Object Manufacturing (Suping, Murkami and Nakajami, 2000), Additive Fabrication (Hague et al. 2007), Solid Freeform Manufacturing (Malone and Lipson, 2007a; Watson, Peterson and Crockett, 1999) and Rapid Manufacturing (Hague, Campbell, and Dickens, 2003; Upcraft and Fletcher, 2003; Hopkinson, and Dickens, 2006), the latter being the most widely used term before AM was adopted (Additive Manufacturing Research Group, 2011). For many outside of the industry however, the first they read of AM was in Neil Gershenfeld's (2005) book *Fab: The Coming Revolution on your Desktop*, and consequently 'fabbing' has also become a widely used descriptor (together with other digital manufacturing technologies such as laser cutting and CNC machining), of the use of AM by non-professional designers and engineers. More recently however, a growing awareness of the industry has seen the near ubiquitous journalistic adoption of the term '3D Printing', to the extent that Terry Wohlers, publisher of the influential Wohlers Report[1], has commented (2012) that "3D printing will become the de facto term for additive manufacturing, whether we like it or not."

What all these terms reveal is a rapidly developing industry whose qualities and potential have grabbed the public's imagination, but where a universally agreed definition has yet to appear. The first part of this chapter therefore clarifies what is meant by 3D printing and additive manufacturing and contrasts them to other digital manufacturing technologies. Some of the more common AM technologies are briefly introduced. The chapter then goes on to explore the consumer adoption of AM, the routes by which this is beginning to happen, and possible future developments.

2.2 DEFINITION

One of the problems in seeking a definition of additive manufacturing is that whilst a general consensus appears to exist, it is rarely stated explicitly. This is due in part to the speed of development of the industry, which is readily expressed by two definitions from the Wohlers Report. In the first, Wohlers (2008a) refers to "the use of a computer aided design (CAD) based automated additive manufacturing process to construct parts that are used directly as finished products or components." This may be compared to a definition from only five years before, in which rapid manufacturing (RM) was defined as “the direct production of finished goods from a rapid prototyping device” (Wohlers, 2003 quoted in Bak, 2003). Whilst the earlier definition is helpful only in conjunction with a definition of rapid prototyping (RP), it clearly demonstrates the provenance of RM as a technology which grew from systems which previously had been used to manufacture only prototype parts. Subsequently, as material properties and system capabilities improved, the possibility of using additive processes to manufacture end-use parts was recognised (Hopkinson and Dickens, 2006).

In an early effort to define the subject, Hopkinson and Dickens (2001) state that “rapid manufacture uses LMT’s [Layer Manufacturing Techniques] for the direct manufacture of solid 3D products either as parts of assemblies or as stand-alone products.” This definition is

1. The Wohlers Report is available from: http://www.wohlersassociates.com/state-of-the-industry-reports.html

largely supported by Hague et al. (2007) who write “The definition is clear and precise: rapid manufacturing is the direct production of finished goods using additive fabrication techniques… to deliver end-use parts directly from digital data.”

Although this definition appears unambiguous, and indeed was the commonly accepted term for a number of years, it nonetheless raised questions as to why RM had been defined so specifically. The laser cutting of sheet plastics and metals, for example, is rapid (indeed it is generally faster than additive fabrication techniques), capable of delivering end-use parts, and works directly from digital data without the need of intermediary steps. An equal claim could be made for the CNC machining, particularly where multi-axis milling machines are used. Furthermore it has been proposed that “by far the most important feature of RM is the tool-less manufacturing of parts” (Mansour and Hague 2003), which would also apply to both laser cutting and CNC machining. It is only the ‘additive’ component of Hague et al.’s definition which excludes the subtractive technology of laser cutting, a technology which is currently being used to create many innovative end-use products[2].

For this reason, together with a general perception that 'rapid manufacturing' had been a term of convenience rather than an accurate description, in recent years efforts have been made to adopt 'Additive Manufacturing' as a universally recognised term (AMRG, op. cit.). Unfortunately this has not necessarily brought clarity to the situation: ASTM International (previously known as the American Society for Testing and Materials), for example, has defined AM as "the process of joining materials to make objects from 3D model data, usually layer upon layer," (ASTM International, 2012); a definition which could seemingly apply to RP parts. The Centre for Innovative Manufacturing in Additive Manufacturing (2011), in contrast, insists on the exclusion of RP when it defines AM as "the production of end-use component parts made using additive layer manufacturing technologies."

For the purpose of this thesis then, AM is understood to mean the production of end-use parts directly from digital 3D data by the use of additive layer manufacturing technologies. However as the chapter and thesis begins to consider the consumer use of AM, and in line with Wohlers' advice, the more popular term '3D Printing' will be substituted as a synonym.

2. See for instance the gallery of Ponoko: www.ponoko.com/showroom.

2.3 AN OVERVIEW OF CURRENT AM TECHNOLOGIES

Hopkinson and Dickens (2006) note eighteen distinct rapid manufacturing technologies, many of which have been commercialised in different ways by different manufacturers. This section briefly introduces the most common processes.

2.3.1 Stereolithography (SLA)

Generally considered to be the first rapid prototyping process, 3D Systems launched the first stereolithography machine in 1987. The process uses an ultra-violet laser which is focussed onto a photo-curable liquid resin in order to build a solid part. The part rests on a platform which is successively lowered inside the liquid resin, typically by 0.1mm, whereupon the laser scans a new layer which bonds to the previous one. This process is repeated until the part is complete. Support structures are automatically generated in regions where features overhang; these supports must be removed, usually by hand, once the part is complete. SLA parts are typically clear and usually exhibit a blue or yellow tint. The surface finish is relatively good, especially with modern high resolution machines; however as with most additive technologies, the resolution in the Z-direction is different to that in the X-Y plane, thus experience is needed to determine the best orientation of the part before building. This is particularly true where extensive support structures are required, as these usually leave surface imperfections after removal. Uncured resins are hazardous and therefore require careful handling and storage (Upcraft and Fletcher, 2003; Mansour and Hague, op.cit.; Hopkinson and Dickens, op.cit.).

2.3.2 Laser Sintering

Laser sintering (also known as laser melting and laser fusion) works in a similar way to stereolithography except it uses powder as a build medium rather than liquid. The part is again supported on a platform which moves downwards in successive steps, after which new powder is spread over the part. A laser scans over the powder, which can be either polymer- or metal-based, melting material and fusing it to the previous layer. In some systems the powder bed is pre-heated to just below the material's melt temperature to allow faster scanning, however this can mean machines take longer to reach operating temperature and subsequently to cool down. The unfused powder material supports the part during building which makes the removal of support structures unnecessary (there are exceptions to this in some metal systems), but care must be taken with hollow parts or parts with enclosed volumes, to ensure all unfused material can be removed. The unprocessed powders used in these systems are generally less hazardous than SLA liquids although some can be explosive if suspended in air. Final parts typically exhibit a slightly porous surface finish, and the issue of different resolutions in different planes also applies (Upcraft and Fletcher, op.cit.; Mansour and Hague, op.cit.; Hopkinson and Dickens, op.cit.).

2.3.3 Electron Beam Melting (EBM)

This relatively new process is similar to Laser Sintering except that it uses an electron beam to melt the powdered material. The power developed by the beam is very high, meaning a wider range of materials can be sintered; additionally the speed of scanning is much higher than with laser scanning, which decreases build times. However surfaces generally require extensive finishing. (Hopkinson and Dickens op.cit.).

2.3.4 Fused Deposition Modelling (FDM)

The FDM system works by extruding a flament of plastic through a heated nozzle, momentarily melting the material and allowing it to weld to the underlying layer. The nozzle moves in the X-Y plane depositing material where required, before moving up a distance equal to one layer in the Z-direction. Since the nozzle must physically move about the build area (rather than a laser or electron beam) the process is comparatively slow, however a FDM machine is easy to set up and clean enough to operate in an office or studio environment. Support structures used in building are often water soluble, making their removal a simple operation. Parts are generally opaque, and in the past surface finishes have been poor, though recently launched machines are capable of much smoother surfaces. A fused deposition modeller will typically be capable of finer resolutions in the Z-direction than in the X-Y plane. (Upcraft and Fletcher, op.cit.; Mansour and Hague, op.cit.; Hopkinson and Dickens, op.cit.).

2.3.5 Multi Jet Modelling

Multi-jet modelling uses an array of ink-jet-style print heads to deposit a photosensitive polymer which is cured by an ultra-violet lamp which follows the print head. The print-heads move in the X-Y plane depositing material to create one layer, then move upwards to create the next, and successive, layers. As with other systems, this results in a different resolution in the Z-axis. Support structures are commonly made from partially cured polymer, though some systems use a separate wax structure. Polymers are available in clear, opaque and coloured materials, and exhibit relatively good surface finish, although parts are not particularly strong. Multi-jet modelling machines are clean and relatively compact which makes them very suitable for placement in offices or studios (Mansour and Hague, op.cit.; Hopkinson and Dickens op.cit.).

2.3.6 Z-Corp Process (3DP Process)

Originally developed at M.I.T., the 3DP process was commercialised by Z-Corp and works by successively spreading a layer of white powder before printing a liquid binder. The process uses conventional inkjet printing technology, and by using four different colour binders is able to create multi-coloured parts which are often used by designers as presentation models. The Z-Corp process is significantly faster than many other AM technologies, and as the technology matured improvements provided for simulated materials including polymers and flexible, rubber-like materials. However parts are generally structurally weak and so not suitable for use as functional products, although the Z-Corp process has opened a niche in the manufacture of character models such as those provided by Figureprints[3] (Z-Corp, 2005).

3. See: http://www.figureprints.com/wow/

2.3.7 Perfactory Process

Perfactory is a registered name of EnvisionTEC, and is essentially a hybrid process used to create very finely detailed parts. A liquid photosensitive polymer is cured using a digital light process (DLP) projector which provides very high resolution. The resulting model is relatively weak, but can be polished and used in an investment casting process, during which the resin melts into a liquid wax-like material. Although the process requires significant 'hands-on' intervention, the quality of detail and surface finish is close to that achievable by tooling, and the process is increasingly being used by jewellers and designers to create precious metal parts (Altair Consulting, 2012; i.materialise, 2012).

2.4 THE CONSUMER ADOPTION OF AM TECHNOLOGIES

Writing in *Fab: The Coming Revolution on Your Desktop,* Gershenfeld (op. cit. p.9) has commented that

> "The adoption of PC's was driven by "killer apps", applications that were so compelling they motivated people to buy the systems to run them... the killer app for personal fabrication is fulfilling individual desires rather than merely meeting mass-market needs."

Whilst 'fabbing' refers not just to AM but to any industrial manufacturing process which has been put in the hands of non-professionals, the book makes clear Gershenfeld's enthusiasm for the consumer appropriation of AM means of production. This is an enthusiasm shared by Lipson and Kurman (2010) in a report commissioned by the U.S. Office of Science and Technology Policy, who write

> "Within a few years, personal manufacturing technologies will be commonplace in small businesses and schools. Within a decade or two, every household and office will own their own machine. Within a generation, you will have a hard time explaining to your grandchildren how you were able to live without your own fabber, when you actually had to buy ready made things online, and wait a long 24 hours before they showed up in your mailbox."

This eagerness for an imagined world of consumers as producers, prosumers as Tofler (1980) termed them, is not shared by all. Writing on his personal blog, Wohlers (2008b) expresses the opinion that

> "Many years ago, at least one person predicted the use of additive fabrication (AF) to "3D print" household items. If the bread toaster breaks, a new one - or part of one - would be created on the home 3D printer. The convenience and speed would make it compelling. I disagreed then and I do now. If the toaster breaks, a new one is purchased for $15-20. Even if a person or family owns or has access to a 3D printer, the system would probably not accommodate the type of material needed for the replacement part(s). Also, 3D model data, needed to drive the system, would need to be created or downloaded. This would not be impossible, but few consumers would want to mess with it."

In some respects the positions of Gershenfeld and Wohlers are not as far apart as they may seem. Wohlers makes clear he does believe there is a future that involves consumer manufacturing, but he sees this future as one of small businesses supplying the market. It is the question of whether the market itself (i.e. consumers) will engage in the design and manufacture of products which divides the two.

Malone and Lipson (2007a op.cit., 2007b) echo Gershenfeld's argument in describing the rationale behind the Fab@Home project. Their belief is that, in order to spur the industry along, nascent AM technologies must be placed in the hands of interested amateurs who will innovate in ways that established industry players are unwilling to try. The use of Fab@Home machines (Figure 2.1) to experiment with printing in materials such as chocolate and cream cheese suggests they are right. This kind of experimentation and innovation, Malone and Lipson, and Gershenfeld believe, will lead to the adoption of personal fabricators in the same way it led to the adoption of personal computers in the early 1980's.

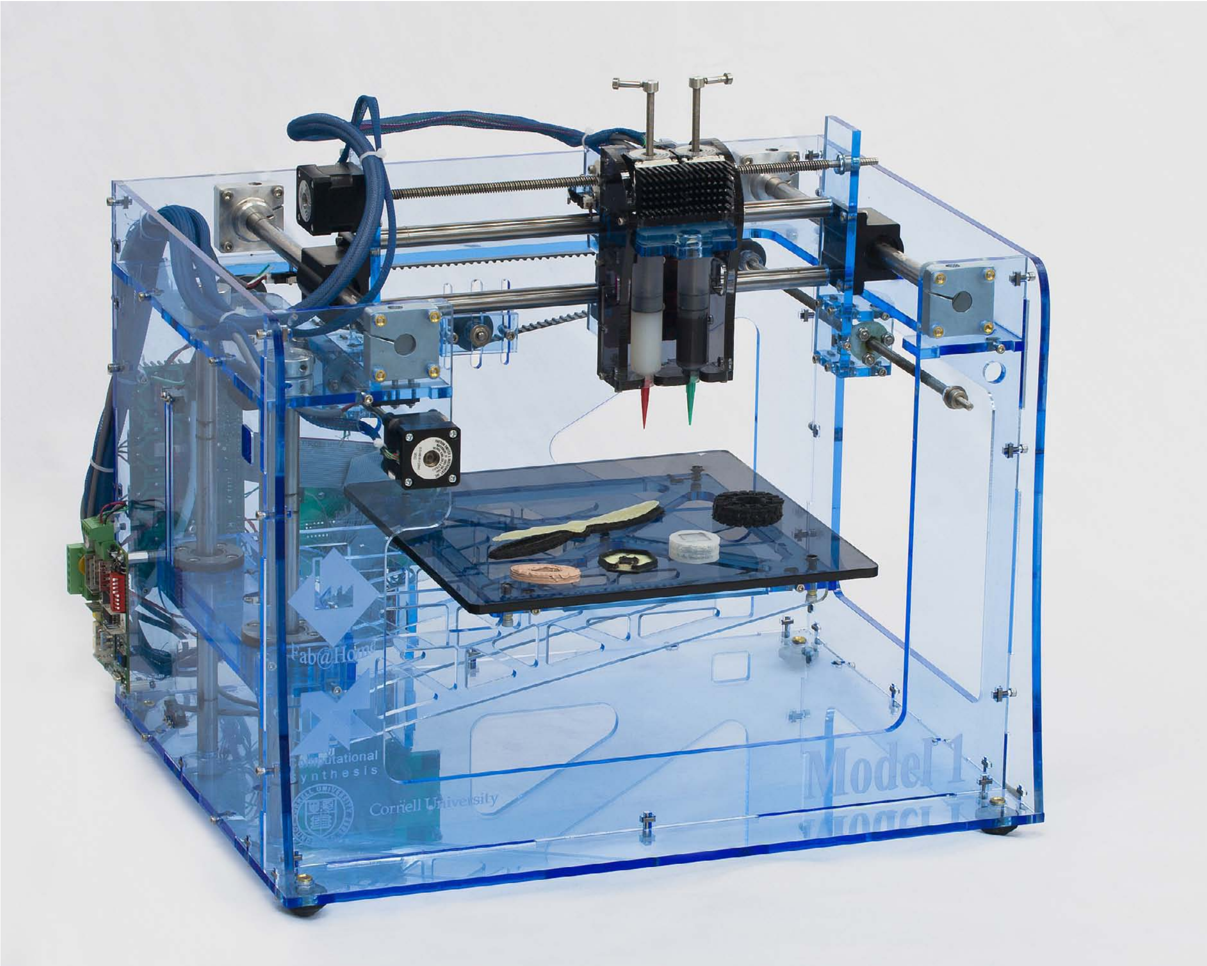

Figure 2.1. Fab@Home 3D printer ver.1

2.4.1 Possible Routes to the Consumer Adoption of AM Technologies

In 1977 Ken Olsen, founder and CEO of Digital Equipment Corporation (DEC), said in a speech to the World Future Society that he saw "no reason for any individual to have a computer in his home" (BBC News, 2007). Olsen has since insisted that his prediction should be seen in the context of what was widely understood at the time by the term 'computer' - the mainframe and 'mini' computers with proprietary operating systems of the type which DEC were manufacturing. Nonetheless it is a good illustration of the consequences of failing to recognise the consumer's changing relationship to technology.

A year before Olsen made his statement, Apple had released its first computer. The Apple-1 was essentially a circuit board, some parts and an instruction manual on how it should be assembled and programmed. The user needed to add a case, a keyboard and a display. But what the Apple-1 allowed, together with other early personal computers such as the Altair 8800 and the IMSAI 8080, was the opportunity for electronics hobbyists to program machines for the first time. Olsen was undoubtedly aware of the Apple-1, but DEC and other established names such as IBM, Xerox, NCR and Honeywell were unable to break free of the mindset that computers were machines for processing data. As such they were destined to play catch-up with companies such as Apple, Atari, Sinclair and later, Microsoft, who saw the potential of home computers for games, spreadsheets and word processing. As Adrian Bowyer, one of the instigators of the Rep Rap project (see below) pithily states, "When people first thought that everyone might have a personal computer at home, what they envisaged was that people would do their accounts on it, not watch pornography and talk to their friends", (quoted in McGuirk, 2009).

Malone and Lipson (2007a, op.cit.) argue that current AM technologies are the present day equivalent of 1970’s mainframe- and mini-computers. The AM industry is currently dominated by a number of established players, with proprietary systems, selling expensive machines and maintenance contracts to large corporations. In promoting the Fab@Home project, their aim is to “promote SFF technology by placing it in the hands of hobbyists, inventors, and artists in a form which is simple, cheap, and without restrictions on experimentation.”

Of course, just because one particular technology developed in a certain way and allowed computers to break out of the well-funded corporate office into society beyond, that does not make it a certainty that additive manufacturing technologies will follow the same path. It is not a foregone conclusion that the established manufacturers of these technologies will wither into bankruptcy or takeover as new and as yet unheard of companies spot opportunities which the established players have missed. Other routes to consumer adoption exist, as another example shows; following on the heels of the computing revolution printing was also transformed, but in an entirely different manner.

The laser printer was invented by Xerox in 1969 (Reilly, 2003). At the time, with the exception of art prints, printing was synonymous with the high volume production of books, magazines, reports etc. It is therefore unsurprising that manufacturers focussed on accuracy and throughput: in 1977 the Xerox 9700 was capable of printing 120 pages per minute (da Cruz, 2002). Unlike the revolutionary disruption of home computers however, digital laser printing developed along an evolutionary path. Although it happened quickly (Hewlett Packard launched the first LaserJet model, which they dubbed the world's first desktop printer, in 1984), the industry was dominated by established manufacturers developing the technology in their own labs, rather than enthusiastic hobbyists in their garages. Gradually these printers found their way into smaller offices, graphic design firms, and high-street print bureaus, which meant almost anyone with a home PC could afford to produce professional looking documents. Colour laser printing was perfected, and demand inevitably led to cost reductions, such that today it is possible to buy a black and white laser printer for less than $100.

One factor often overlooked in the development of the laser printer is the role which software played in the technology's adoption. Before laser printing became the dominant computer printer technology, dot-matrix and daisy-wheel printers were commonplace. Daisy-wheel printers grew from electric typewriters and used a spinning wheel whose letters and numbers were struck by a hammer, transferring ink from a ribbon or tape onto the page. Print quality was relatively good, but the font and font size were fixed. Dot-matrix printers used an array of pins driven by a solenoid which would again transfer ink from a ribbon onto the page. Different fonts and font sizes were available, but print quality was poor as the resolution of the text was limited by the size of the pins.

Whilst word processors remained relatively crude, daisy-wheel and dot-matrix printers were acceptable. However the introduction of desktop publishing (DTP) software such as Quark Xpress and Pagemaker created a demand for much more sophisticated print technology. Using DTP software packages, graphic designers could create pages with different fonts of different sizes, with text that had been manipulated (stretched, mirrored, distorted etc.). They could create text in columns, in tables, in headlines and even in scripts such as cyrillic or kanjii. Designers could even insert images, which the text would then wrap around. But without access to professional presses, none of it could be printed. Software did not just create the demand however, it also enabled the laser printer to understand what it was required to print. Postscript was the first programming language to treat fonts as vector graphics, the key to the ability to scale and manipulate text. This in turn led to the notion of WYSIWYG (what-you-see-is-what-you-get) word processing, which had been inconceivable before laser printing (Perry, 1988).

Thus it can be seen that two alternative ways for AM technologies to enter the consumer market are (a) by established companies developing technologies to a point where the price reduces to a consumer-acceptable level, and (b) by less well known companies making cheaper, cruder models available to enthusiasts. There is a third possibility though - the introduction of a disruptive technology, perhaps one which has yet to be invented. At the same time that Hewlett Packard were developing and refining their LaserJet technology, a group of engineers within the company were proposing a new printing method which involved jetting liquid ink onto paper. This broke away from the mindset that printing was inevitably about speed, and argued that for home users printing relatively small numbers of documents, cost and reasonable accuracy were the main drivers. In doing so a market in printers and replacement cartridges worth billions of dollars was created (Gershenfeld, op.cit. p.16).

What the AM equivalent of the ink-jet printer might look like is of course unclear. One intriguing possibility is the Matrix 300 3D printer by Mcor Technologies, which uses standard sheets of A4 paper as the basic material for its models. Obviously the strength of parts is less than that achieved using plastic, but the resolution (0.1mm in all axes) is equal to some of the best commercial systems. What is truly impressive however are the running costs, which Mcor claim to be only 2% of conventional AM machines (Mcor, 2012).

Which of these three paths additive manufacturing technologies will take in their adoption by consumers is as yet unclear. It is possible that the differing technologies outlined in section 2.3 may follow different routes, as did the laser- and inkjet- printer, both of which are now widely used in the home or small office. Nonetheless historical precedent would suggest that if demand is strong, the technology will inevitably filter into the consumer sphere.

2.4.2 Part Design Complexity and its Relevance to the Consumer Adoption of AM Technologies

The development of ever more sophisticated DTP software, as well as driving demand for laser printers, had a secondary effect also. In the age of traditional lead type printing presses, the job of the typesetter, or compositor, was highly skilled and required a long apprenticeship; today the job is obsolete. Graphic designers, if required, can perform all of the typesetter's traditional tasks on-screen. But for the vast majority of computer users, operations such as 'justification' are simply a menu option, and 'kerning' is a totally unknown process which happens automatically.

The disappearance of typesetting is interesting because AM may have similar, as yet unforeseen, outcomes. Earlier in this chapter it was suggested that "by far the most important feature of RM is the tool-less manufacturing of parts" (Mansour and Hague, op.cit.). As this thesis explores in Chapter 10, easy-to-use, semi-automated CAD software is an essential driver of the widespread consumer adoption of AM technologies. In the same way that digital printing technologies had profound consequences for the job of the typesetter, it may be that consumer-friendly CAD software, in promoting AM, has unforeseen implications for the job of toolmaker. However there is another, more directly relevant consequence of AM - it makes the design of parts much easier, and therefore amenable to the consumer-design of products.

To understand the complexities involved in designing a part which is to be mass manufactured, it's useful to look at some of the design requirements of a typical mass manufacturing technology such as injection moulding. Some of the rules an industrial designer and mechanical design engineer will need to incorporate in a part's design include:

- Draft Angles to allow part removal from tool
- Minimisation of holes and features in non line-of-draw faces to reduce complexity and cost
- Minimisation of re-entrant features (undercuts) to reduce complexity and cost

- Uniform wall thicknesses to avoid stresses and weaknesses in part
- Avoidance of sharp corners to prevent stresses and weaknesses in part
- Avoidance of weld lines lines to prevent stresses, weaknesses and visual defects in part
- Design of wall thicknesses, ribs, bosses etc. to provide a structurally sound part
- Avoidance of visible witness lines to prevent visual defects in part
- Avoidance of sink marks to prevent visual defects in part
- Avoidance of ejector pin marks to prevent visual defects in part
- Siting of gating / sprue points on non-visual surfaces to prevent visual defects in part
- Avoidance of flashing at part line to prevent visual defects in part
- Minimal depth surface texture to allow part removal from tool

(Hague, Mansour and Saleh, 2003; Mansour and Hague, op. cit; Kalpakjian, 1997).

Although the designer must consider issues such as yield, cycle time, cost etc., essentially these design rules are aimed at achieving three things: that the part can be removed from the tool once it has been moulded, that the part does not break in use, and that the part looks acceptable to the consumer. Of the thirteen rules listed above, only one applies to the design of AM parts - that the wall thicknesses, bosses etc. must be designed to provide for a structurally sound part. The product must obviously perform and not break under normal use (however 'normal' might be defined in relation to the product in question). However none of the rules which govern how a plastic part is moulded from molten material, and which ensure the part has visual and structural integrity, apply to AM parts. This will make it much easier for designers and consumers alike to design products: most industrial designers will have experienced how a draft angle of just three degrees can have a profound influence on the fit of internal components or the way surfaces transition from one plane to another.

This is not to say there are not new rules. As mentioned a number of times previously in this chapter, 3D printers often manufacture parts at different resolutions in each of their three axes - this requires skill in understanding which surfaces are visually most important. Those technologies which utilise a support structure during a part's construction will in most circumstances require the structure to be removed, meaning enclosed (i.e. hollow) volumes must be avoided. But as the performance of AM technologies improves, and as software is developed which accounts for these requirements, they are likely to become less of an issue. Additive manufacturing will thus reduce significantly the complexity of designing a part for manufacture.

2.5 FACTORS INFLUENCING THE CONSUMER ADOPTION OF AM TECHNOLOGIES

Given that there are a number of different technologies currently able to produce rapid manufactured parts, one question to be answered is "which of these technologies might be most suited to use by consumers?" To some extent this depends on the model of adoption, discussed in the preceding section of this chapter. If consumers gain access to 3D printed parts through an external service such as Ponoko, the qualities of a particular machine are of little consequence - it is only the part they receive which matters. However if consumers are to gain access to these technologies through a high street bureau, as was the model of adoption with laser printer technology, or even through 3D printers in the home, there are a number of factors which influence the suitability of a particular technology. These are similar to considerations which would affect the decision to buy any type of machine equipment, namely:

Cost: In the past, the cost of both machines and materials has been a significant obstacle to consumer adoption. Typically AM machines have cost from tens to hundreds of thousands of dollars, along with mandatory maintenance costs. This caused a vicious circle in AM, whereby

> "the advancement of personal fabrication technology is being constrained by the high cost and proprietary nature of commercially available SFF systems. High costs limit experimentation and market scale, which in turn limit the development of new applications which would increase demand and reduce system and product prices."

(Malone and Lipson, 2007a, op. cit.).

The situation has changed dramatically since Malone and Lipson's gloom, however. Whereas in 2001 the cheapest 3D printer cost $45,000 (Mota, 2011), there are now numerous machines on the market which retail for less than $1000. In a comparison carried out at the end of 2011, Grand reports 19 such machines, with a further 32 retailing for less than $3000.

Quality of Parts: It is certainly the case that the quality of AM parts (both mechanical and aesthetic) has prevented their more widespread use in consumer products. The raw finish exhibited in high cost, low volume products such as those sold by MGX Materialise[4], for example, may be acceptable to consumers who buy these pieces partly because of their experimental nature, but it is difficult to imagine this would be the case in high volume consumer goods, where consumers have come to expect highly polished metal and plastic surfaces. Achieving this kind of finish requires that parts are post-processed, by polishing and/or painting the surface, and whilst this kind of finishing may be interesting for hobbyists, it is unlikely to appeal to most customers. Quality of surface finish is therefore likely to be a major inhibiting feature in consumers' acceptance of AM in the short - medium term (not precluding the introduction of an as yet unknown technology).

Ease of Use: The success of machines such as the Makerbot Thing-O-Matic[5] have demonstrated that issues of ease-of-use may be overcome, to a degree, if the product is compelling enough. Nonetheless for less committed consumers, the expectation will be of a machine which is relatively easy to use, both in terms of setting up and producing parts. Any user interface, for example that used to place and orient parts before building, should be understandable without specialist knowledge and compatible with standard consumer PC software. The machine should operate from domestic mains power and be relatively fast to start up and shut down.

Noise and Cleanliness: If machines are to be installed in office or studio environments they must operate almost silently - build times mean a machine may be running continually all day and so even low noise levels are likely to be unacceptable. Materials should be supplied in

4. See http://www.mgxbymaterialise.com/
5. See http://store.makerbot.com/thing-o-matic-kit-mk7.html

sealed cartridges and any waste should be collected in a sealed container.

Maintenance and Support: In an office or print bureau a maintenance contract may be acceptable, but in a small studio or home office this is unlikely to be the case. Machines aimed at this target market should therefore be capable of running diagnostic checks and reporting possible problems before they occur. Printer driver and firmware updates should download and install automatically. Web-based support forums, where users can suggest tips and offer advice, should be encouraged.

Safety: Any machine must be safe to use by an untrained operator. Exterior surfaces should not heat excessively, and any hazardous fumes or substances must be contained within the machine.

2.6 CURRENT STATE: CONSUMER ORIENTED AM HARDWARE

Grand's (ibid.) comparison of 3D printers clearly demonstrates the growing market for consumer-focussed AM hardware (as does the fact that it was out of date less than a month after publication). This growth has been reliant on two factors. The first of these is the RepRap project (Figure 2.2), started in 2004 by Adrian Bowyer (Sells et al, 2007) at Bath University, whose concept was for a machine which could build a copy of itself. Crucial to this concept, and the subsequent flourishing of consumer-oriented machines, was that RepRap was distributed under an open source license (RepRap, 2011), the terms of which allowed the freedom to re-use the software for any purpose (Smith, 2012), including commercial. Thus virtually all the 3D printers listed in Grand's comparison build on the software originally developed by the RepRap project.

The second factor explaining the availability of low-cost AM hardware is the expiration of the original FDM patents in 2011 (Castle Island, 2012; Stratasys, 2010), allowing any manufacturer to implement and sell a FDM-like system. Originally invented by Stratasys, fused deposition modelling is also the most 'user-friendly' AM process, using non-hazardous raw materials and without the need for expensive, high powered lasers. This makes it ideal as a hobbyist technology - inexpensive to buy and run and safe to modify - though whether the quality is sufficient to gain consumer acceptance remains questionable.

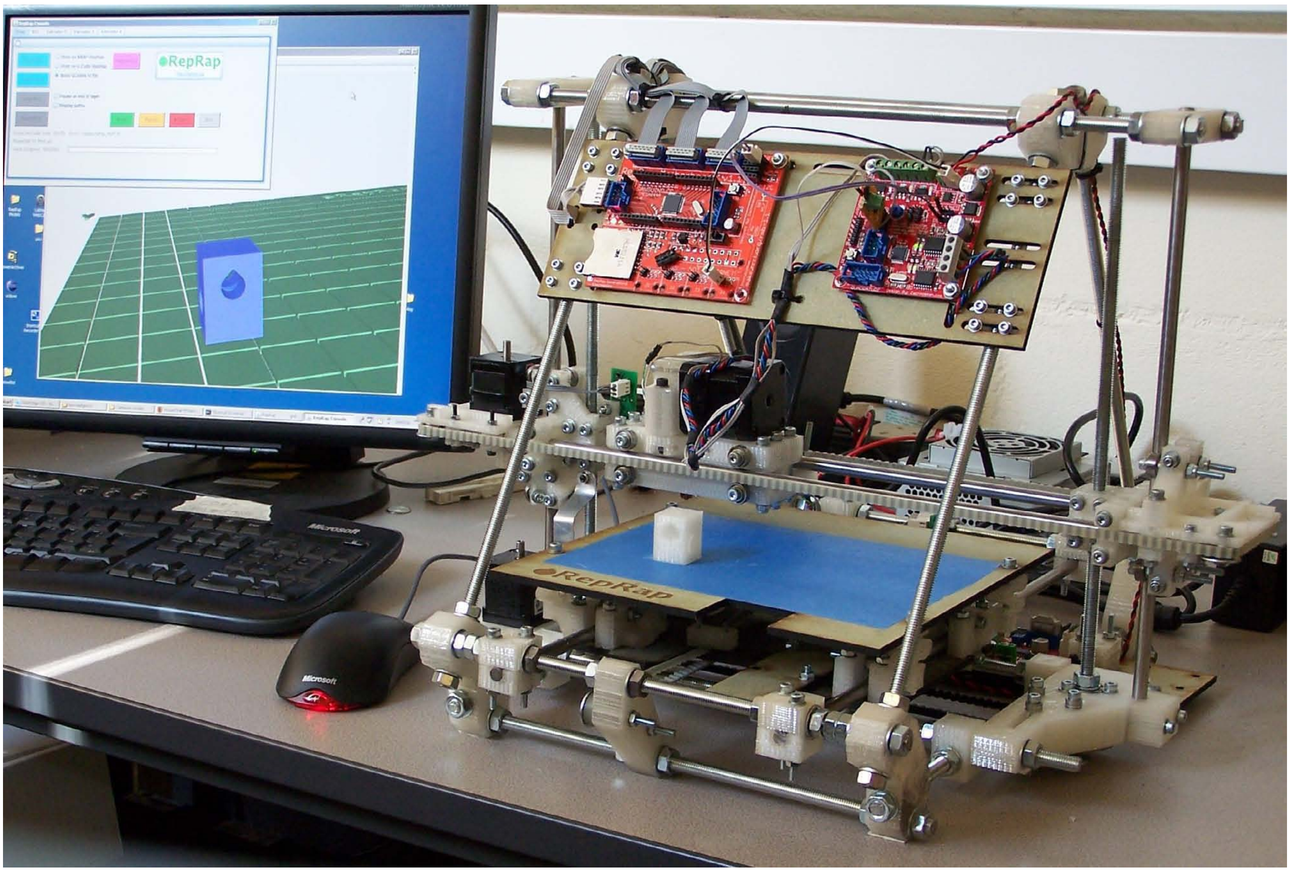

Figure 2.2. RepRap Mendel 3D printer

Of the companies exploiting the openings which FDM technology has created, two are especially interesting. The first of these is MakerBot, based in Brooklyn NY, whose recently released dual print-head Replicator (Figure 2.3) is the third product in the company's portfolio. Makerbot follows the open source ethos of the original RepRap in both hardware and software (Pettis, 2012), and although ready-assembled machines are offered, the expectation is that purchasers will tinker and experiment, and share their findings. Alongside MakerBot, Thingiverse - a website repository and forum for the sharing of 3D CAD models - allows consumer-designers to download, modify and 'mash-up' models, and discuss the results. MakerBot and Thingiverse therefore act as an ecosystem of consumer-design, each one encouraging the other to grow.

In contrast to MakerBot the Up! printer by Chinese manufacturer PP3DP follows a more

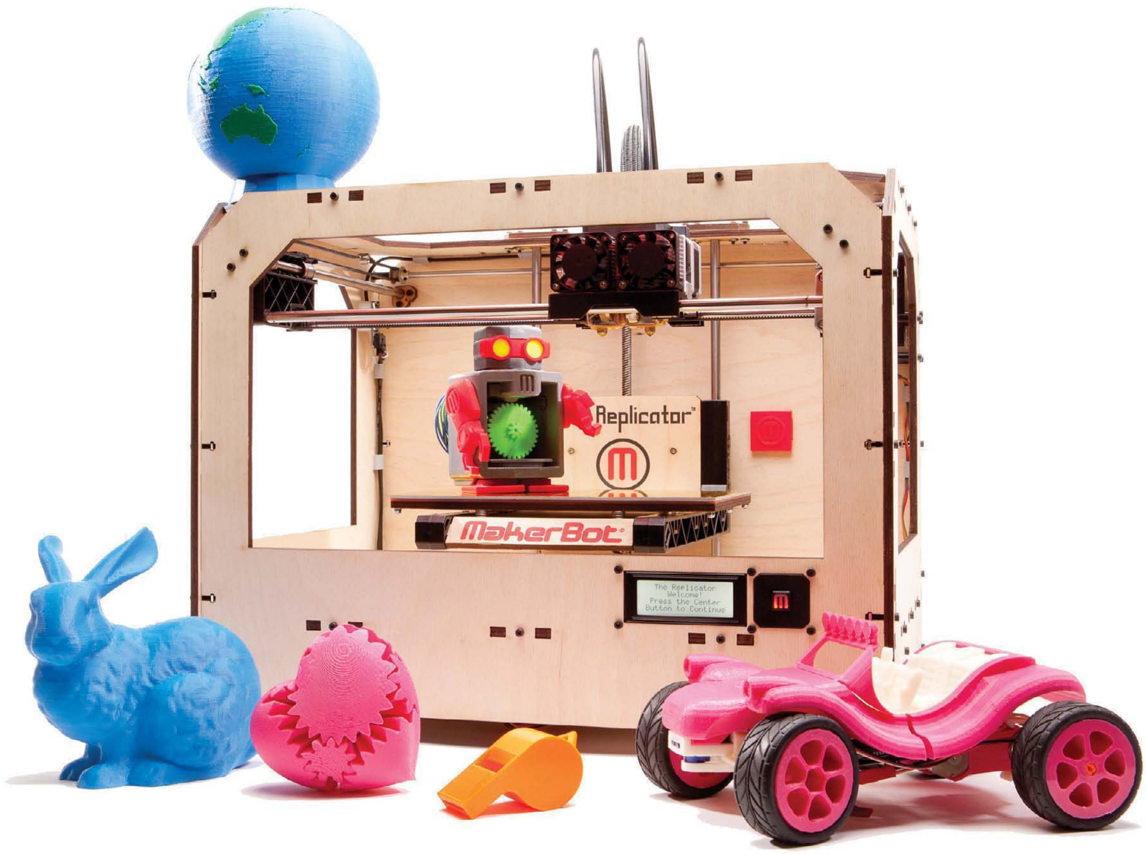

Figure 2.3. MakerBot Replicator

conventional, closed business model. Also utilising FDM technology, the Up! has gained a reputation as the closest product, so far, to a plug-and-play device, one in which the consumer is expected to do very little to set up and operate the printer. It's software also includes the capability to create support structures for overhanging structures, meaning its printed parts are generally regarded as being higher quality than similarly priced competitors. Interestingly the first consumer-oriented machine launched by an established manufacturer - the Cube by 3D Systems - also bears a striking resemblance to the Up! printer design.

The plug-and-play promise that the Up! printer (Figure 2.4) introduces is much more apparent in some of the more expensive machines included in the list referred to at the start of this section. Whilst not currently cheap enough to be considered as consumer-oriented hardware, they offer some clues as to how such consumer devices might develop in future. For the most part these are less expensive versions of more sophisticated offerings from AM

Figure 2.4 (above). Up! 3D printer by PP3DP

Figure 2.5 (below). DesignJet 3D printer by Hewlett Packard

equipment vendors; aimed at design and engineering studios, they may be seen as the 3D equivalent of the HP LaserJet printer previously mentioned. Indeed one such machine is sold by Hewlett Packard through a partnership with Stratasys. The DesignJet 3D (Figure 2.5) printer looks much more like a machine that would fit into an office environment than those by MakerBot or PP3DP. Unlike those hobbyist machines, which use standard spools of plastic material, the HP machine uses proprietary cartridges, indicating perhaps that HP believe the 2D printer-ink model will transfer to the 3D market.

2.7 CURRENT STATE: CONSUMER ORIENTED AM SERVICES

One significant restriction of all the low-cost AM hardware discussed above is that it only allows printing in plastic, and only one type of plastic per machine. For consumers who wish to experiment with alternative materials, especially metals, the only option is to use a service bureau. Rapid prototyping bureaus have existed for many years, but have tended to view their customer base only as professional designers and engineers, with a certain level of expertise, and have thus appeared intimidating to those with less formal skills; their pricing structure has also reflected this professional customer base. In recent years however, online services have appeared aimed specifically at consumer-designers and makers.

The first of these online providers, Ponoko, began by offering laser cutting services and expanded to offer 3D printing in 2010 (Mota, op. cit.). iMaterialise launched its beta program in 2009 (Sinclair, 2009) as a development of Materialise's successful industrial operations. The Cubify service by 3D Systems is also a recent entrant to field. However it is Shapeways, a spin-off company from a Philips incubator project, which currently offers the most comprehensive 3D printing service to consumers.

Shapeways, iMaterialise, Cubify and Ponoko share a number of characteristics: they offer dedicated tools for the creation of certain products, they allow consumer-designers to display and sell products, and they offer choice regarding the level of copyright that designs are given, i.e. whether designs should be downloadable and/or modifiable by others. The methods of ordering a 3D printed part are also similar. In the Shapeways system, for example, a 3D CAD model is uploaded to the site in any of the following formats: .dae,

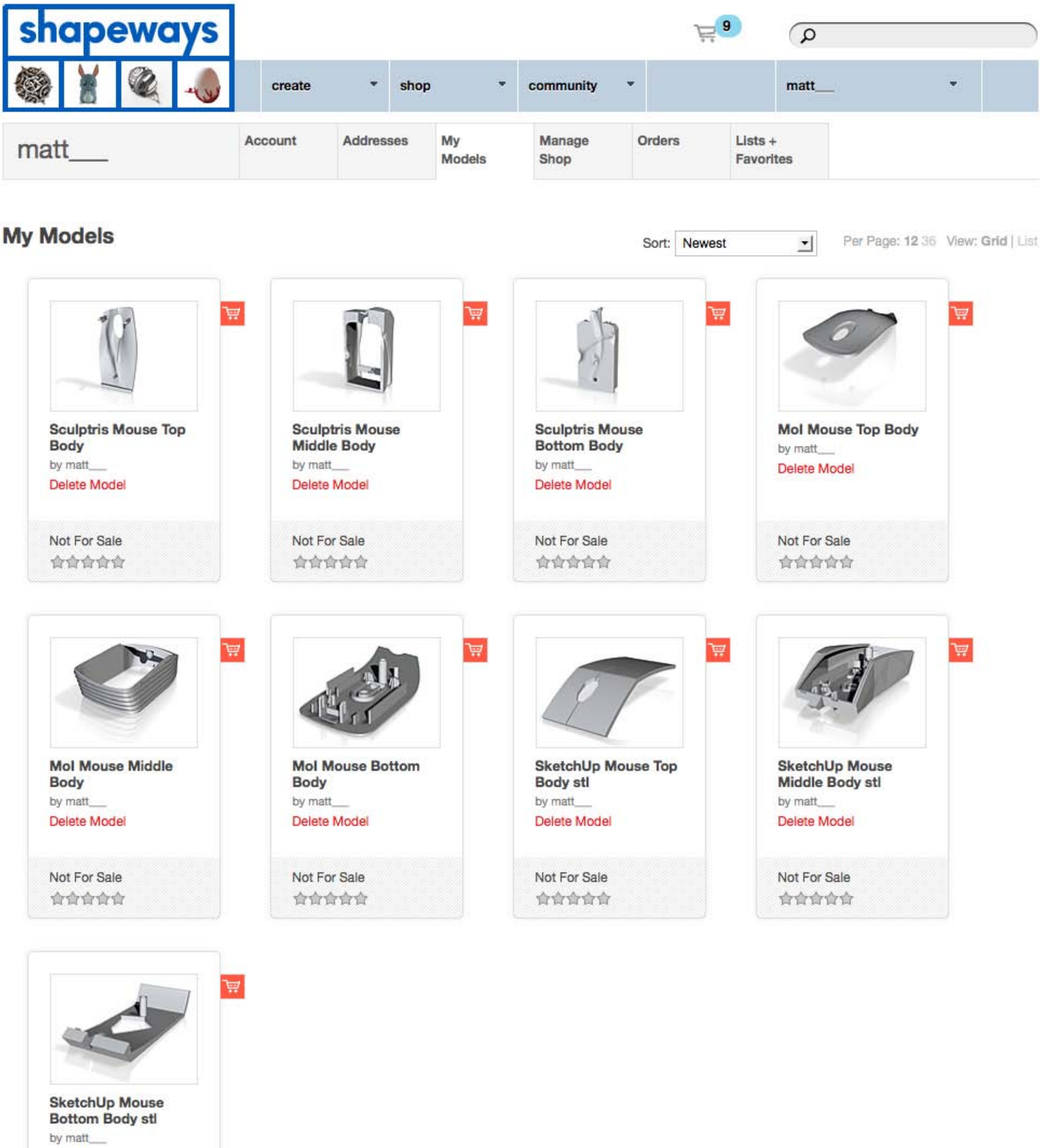

Figure 2.6. Shapeways gallery showing some of the author's uploaded models

.obj, .stl, .x3d, .x3db, .x3dv and .wrl. With the exception of .stl, these are all formats more often associated with non-professional modelling software, meaning products can be designed and manufactured using (for example) free software such as Google SketchUp. Once uploaded the file is checked, and if accepted is displayed in the customer's gallery (see Figure 2.6). Materials (including ABS, PMMA, stainless steel, gold, and ceramic) can then be assigned to the part whose price is automatically updated. Payment is taken online and parts delivered in approximately two weeks. The online service bureau clearly has less science fiction allure than the promise of a 'factory in your kitchen' (Malone and Lipson, 2007b, op. cit.). However it is likely that, in the short- to medium-term future, the availability of materials and the quality of parts compared to personal machines will ensure their continued success. Whether they are ever superseded by personal AM fabricators is a question on which there is currently little agreement.

CHAPTER 3.

Mass Customisation.

3.1 INTRODUCTION

'Mass Customisation' first appeared as a term in Stan Davis' (1987) book Future Perfect. What Davis foresaw was a time when notions of 'mass production' and 'mass markets' had ended, and where every customer could have goods and services tailored to their individual needs and wishes. In effect, each consumer would represent a market size of one.

Since its publication, Davis' predictions in Future Perfect have, at least in part, been proved correct. The model which computer manufacturer Dell pioneered has been copied extensively in the personal computer market, such that virtually every PC manufacturer offers the opportunity to configure a product to suit the consumer's individual requirements. A typical mid-range desktop computer from Dell, the Precision T1600 for example, offers customers the theoretical choice of 45,360,000 hardware configurations (see Appendix 3.1). This is before other options such as anti-virus software and customer care packages - what might be termed customised services - are considered. Similarly the type of sports shoe configuration initially offered by NikeID has been mimicked by many of Nike's competitors, such that a men's shoe by Reebok (the 'Ventilator' model) provides the mathematical possibility of 543×10^{28} colour combinations (see Appendix 3.2), plus a personal message stitched on the heel.

This chapter begins by defining mass customisation (MC) and introducing the benefits it brings to consumers who might be dissatisfied with a 'standard' mass produced item. An historic overview is given in order to illustrate the role of MC as a 'bridge between mass manufacture and individualised production. This status as a connector between two very different modes of production is explored further by looking at the value of MC, to both the consumer and the manufacturer, and highlighting its limits with regard to the consumer's involvement in design. Finally the chapter considers whether the concept of mass customisation can expand to include the kind of toolkit proposed by this thesis, or whether the consumer's role within MC is limited to configuration, rather than actual design.

3.2 DEFINITION

As mass customisation has been embraced by various industries, definitions of what mass customisation actually entails have also proliferated. Today, as Moser (2007) comments,

> **"Although much has been published about mass customization in the academic literature, commonly accepted definitions and frameworks have not yet been established. Many academic definitions exist, all of which differ in one or more aspects (Davis, 1987; Pine II, 1993; Piller, 2003). Consequently, there is currently no consistent understanding of mass customization."**

When Davis originally coined the phrase mass customisation, he envisaged a time when "the same number of customers can be reached as in mass markets of the industrial economy, and simultaneously treated individually as in the customized markets of pre-industrial economies" (p.169). This vision was expanded and refined by Pine II (1993) who defined mass customisation as a system "providing tremendous variety and individual customization, at prices comparable to standard goods and services."

Both these definitions fall into what Merle, Chandon and Roux (2007) describe as the 'visionary concept' of mass customisation. This concept, exemplified by Hart (1995) as "the ability to provide your customers with anything they want profitably, any time they want it, anywhere they want it, any way they want it," concentrates purely on what manufacturers adopting mass customisation would be able to deliver, and is common among earlier attempts to define the concept. Whilst mass customisation was still in its infancy, both as a concept and as an industrial reality, definitions tended to focus as much on what mass customisation was not (i.e. mass production) as what it was. In attempting to clarify this difference, Tseng and Jiao (1996) write that

> **"In high volume production, the volume is sufficient to defray the cost of investment in equipment, tooling, engineering, training, and others... However, in low to medium volume production, where production quantity cannot justify and leverage the investment, customers are otherwise willing to pay more because their special needs are satisfied. This is the area where we believe mass customization provides a tremendous advantage in business competition."**

As the subject was studied further, and as concrete examples such as that of Levi's Original Spin[6] customisation initiative were launched, definitions of mass customisation began to take a markedly different perspective by insisting on the involvement of the consumer, rather than simply the satisfaction of consumer needs. Whilst Davis' original definition had referred to the customer, these new definitions highlighted the role the consumer must play in the process of customisation. Moser (op.cit.) has commented that "an ideal classification of mass customisation must include a product and a consumer focus," a belief clearly shared by Merle, Chandon and Roux (op.cit.) who define mass customisation as "an offer that allows customers to: 1) participate in co-design by *personally* modifying several features of a product, from a predefined set, and 2) buy the co-designed product."

Whilst the inclusion of the consumer in a definition of mass customisation is welcome, the insistence on the customer's personal modification of a product's features is at odds with much of the literature. This is not helped by the development of an understanding of different types of mass customisation. Gilmore and Pine II (1997) list four approaches that a business might take to offer customers a mass customised product:

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6. Levis Original Spin program closed at the end of 2003. For a contemporary analysis see this article from January 1999: http://yjfile.tripod.com/levi1.htm

1. Collaborative Customisation, in which a company engages in a conversation with the customer, discovering that customer's needs and then supplying a product configured to meet those needs as well as possible.
2. Adaptive Customisation, where a standard product is sold to the customer who is then able to customise it to meet their own needs.
3. Cosmetic Customisation, in which a standard non-customisable product is presented in different ways.
4. Transparent Customisation, in which a product is customised to meet a consumer's needs without that customer's involvement or knowledge.

In case 4, that of Transparent Customisation, Merle, Chandon and Roux's (op.cit.) requirement for the personal involvement of the consumer is quite obviously absent. However this type of customisation is most frequently experienced in the provision of 'intangible' goods or services, for example the use of cookies on a website to remember the site visitor's previous choices, or a mortgage offer tailored to the applicant's age and income. If 'product' is defined in the way that an industrial designer would understand the notion, i.e. a physical, manufactured object, transparent customisation is very difficult to conceive of.

Similarly case 3, Cosmetic Customisation, tends not to be applicable to products in the industrial designer's sense of the word. Gilmore and Pine II use the example of the Planters Company, who supplied peanuts to Walmart, Safeway, 7-Eleven etc. These retailers wanted the standard product - peanuts - supplied in different size packaging, or with different promotional labels. Cosmetic customisation is also apparent within advertising, in which standard products are promoted differently to different groups or markets.

Case 2, Adaptive Customisation, is often seen in the case of operating systems such as Windows software for PC's or Series 60 software for mobile phones. Whilst the product offering is standard, the user is able to customise it post-purchase by activating certain features or disabling others, by changing colour schemes or ring tones, and by installing additional applications which themselves are likely to be customisable. Physical manifestations of adaptive customisation tend to be cases of adjustment to fit (such as the set-up of an office chair) or to suit certain conditions (e.g. the settings on a central heating thermostat), and as such are somewhat limited in scope.

It is clear then that the overwhelming majority of industrially designed products would currently fall into case 1, that of Collaborative Customisation. The examples previously mentioned of Dell and Reebok obviously involve a dialogue, albeit mediated through a custom designed website or toolkit, in which the manufacturer attempts to discover what the consumer wants, and then to supply it. Merle, Chandon and Roux's definition therefore becomes valid with the qualification that the type of mass customisation being discussed is collaborative.

It is also interesting to note that, of the four types of MC, collaborative customisation is most like the kind of collaborations seen between craftsperson and customer prior to industrialisation. As the industrial revolution saw the quality of machine-made goods begin not only to equal, but to surpass, that of craft-made items, so the notion of 'craft' began to diverge from that of design, particularly industrial design, and manufacture (Walker, 1989: pp. 38-39). A number of commentators have looked back to these more traditional interactions between designer/craftsperson and consumer in proposing a new model of how 3D printing might integrate with consumer design (Campbell et al, 2003; Aldersey-Williams, op. cit.), and these are explored further in chapters six and seven.

Given that the subject being defined is collaborative mass customisation, the one remaining factor in its definition is the question of where in the process the customer becomes involved. Pine recognised early on that a critical differentiator of mass customisation (compared to mass production) was where in the product creation process the customer entered. In a mass production system, the customer entered only at the end of the value chain, essentially buying what the manufacturer had already decided was wanted. Whereas in a mass customisation system, customers are at the end but "also at the *beginning* of the value chain, which exists to produce what customers want and value" (Pine, op. cit: p.194).

This statement is flawed however. Customers quite clearly do not enter the value chain at the beginning, where the product is being specified and conceived, but rather at a point further on where many design decisions have already been made, indeed often (as in the Dell and Reebok cases) where all that remains is to configure the options from a choice that the manufacturer has pre-determined. This has led to the observation that the degree to which a product might be considered customisable is determined by how early the customer is involved in the product creation process, rather than the number of options provided:

> **"The earlier the customer involvement in the production cycle, the higher the degree of customization. On the other hand, the closer the customer involvement is to the final product and distribution stage, the lower the degree of customization" (Spahi and Hosni, 2007).**

This question of where consumer involvement begins has ultimately led to Kaplan and Haenlein's (2006) definition of mass customisation as "a strategy that creates value by some form of company–customer interaction at the fabrication/assembly stage of the operations level to create customized products with production cost and monetary price similar to those of mass-produced products." Note however that Kaplan and Haenlein call this a working definition; they also provide a 'visionary' definition in which "design stage" is substituted for "fabrication/assembly stage," while observing that in reality this vision is not practised.

Whilst the Kaplan and Haenlein definition accurately describes the state of mass customisation today, it is not able to include the type of consumer involvement in design which this thesis addresses. By referring explicitly to the 'operations level' this definition of collaborative customisation agrees with previous ones that customer involvement occurs before the customer takes delivery of the product. Furthermore, by stating that this happens only at the "fabrication/assembly stage" it implies the customer is engaged in configuration of pre-determined options, rather than actual design.

For these reasons, definitions so far proposed for mass customisation do not adequately encompass consumer design. Such deficiencies have been acknowledged however: in their 2012 review of the literature, Fogliatto, da Silveira and Borenstein note that major developments in MC, including the emergence of rapid manufacturing technologies, have proposed new questions and subjects for research. The possibility of definitions of MC expanding to accommodate consumer design toolkits is therefore addressed at the end of this chapter.

3.3 HISTORICAL OVERVIEW

In order to question whether consumer design and manufacture might be considered the next stage of mass customisation, it is necessary to first understand how mass customisation developed. The industrial revolution, which began in the latter half of the Eighteenth century, had helped make Britain, by the time of the Great Exhibition in 1851, the world's industrial powerhouse. Yet fifty years later Britain had been overtaken by the United States of America to become the world's largest manufacturer. This huge growth in production was primarily a result of standardisation, in what became known as the American System of Manufacture (Sparke 1987).

The leading driver at the beginning of America's embrace of standardisation was the small arms industry. The American Civil War in the mid-Nineteenth century provided a situation whereby two sides of an arms race spurred experimentation and invention, but where at the end a single country was the beneficiary of both sides' innovations. Samuel Colt is widely credited as having invented the first fully standardised revolver, 80% of which was machine manufactured, and reportedly said that "there is nothing that can't be produced by machine" (Colt Defence Weapons Systems, 2003).

The advances in weapons manufacture also influenced the industrial production of consumer goods, in particular the sewing machine, the bicycle and most importantly the automobile. As Sparke notes

> "Many firms, including the Singer Sewing Machine Company and the Ford Automobile Company, employed engineers with a background in small arms machine tooling with the specific intention of developing a system of interchangeability. Many of the same machines were in fact re-used in new contexts, given that so many of the products were made out of metal. The Remingtons, for instance, began as small arms manufacturers before they moved into typewriter production" (op. cit: p. 45).

The mass production paradigm entered its defining period immediately prior to the First

World War, when Henry Ford opened his Model T production line. Ford took the theories of standardisation and combined them with the assembly line processes which had become common in the meat-packing industries. Rather than a single worker assembling a product from standardised components, the assembly line gave one worker one job which was repeatedly endlessly. But while these efficiencies significantly reduced the cost of the final product, the de-skilling of the workforce that it entailed began to sow the seeds of the decline in Ford's dominance.

If a manufacturer can sell everything it makes, there is little need for it to listen to consumers' wishes. This was the situation in the automobile industry when Henry Ford famously proclaimed that "any customer can have a car painted any colour that he wants so long as it is black" (ibid, p.40), allegedly because black paint dried more quickly. As more players entered the market however, and as customers began to purchase their second or third car, this business model began to fall apart. In 1923 Alfred Sloan was elected president of General Motors, and as Gilmore and Pine (op. cit.) explain

> **"[Sloan] outcompeted Henry Ford by segmenting the market based on sociodemographic factors and putting in place a distinct car company - Cadillac at the high end, then Buick, Oldsmobile and so on - to achieve nearly the same economies of scale Ford had for the whole market. In industry after industry, this market segmentation led to the drawing of finer and finer distinctions between groups of customers."**

This latter system, of segmenting the market according to sociodemographic factors, and mass manufacturing according to what those mass markets demanded, served US industries well up until the 1970's. However the end of World War Two, which had seen much of Europe and Japan's manufacturing capabilities destroyed, brought about the conditions which would eventually see the weakening of the USA's dominant position. Japan in particular took the opportunity of a 'fresh start' to modernise what, prior to the war, had been a relatively low-tech country, with a largely rural and unskilled population. Japanese industry initially focussed on areas where it could gain cost advantages through low wages - industries such as textiles, shipbuilding and steel (Abegglen and Stalk, 1988). This did not last long however, as wages rose rapidly with the improving economy.

Postwar, many Japanese industries began to look to the US to understand what could be learned from the American System of Manufacture. Japanese firms did not merely seek to imitate American methods however, but instead adapted them to the realities of indigenous production (Wada and Shiba, 2004). The techniques developed by Japanese industries have since become buzzwords in modern manufacturing theory. Tseng and Jiao (op.cit.) write that

> "Competitive strategies in the 1990's include diverse and related themes such as manufacturing flexibility, timebased competition, lean production, re-engineering and continuous improvement". Of these, it is time-based competition, more commonly referred to as just-in-time manufacturing, which has played the biggest part in the development of the mass customisation paradigm."

In the old model, mass manufacturers produced for inventory which was then sold for a profit. In the new market reality, such inventory presented a risk to profit as consumers might change their minds about what they wanted to buy, leaving large amounts of investment tied up in unsold products. Reducing the time between a product's manufacture and sale would reduce the risk of unsold inventory, provided manufacturing systems were responsive enough to quickly change from one product line to another.

These responsive manufacturing systems required a number of infrastructural changes to be implemented. Shorter production runs with fast changeover times demanded more general purpose machinery and more highly skilled workers (Pine, op. cit.) - the exact opposite of the mass manufacturing paradigm which invested in specialised machines, increasingly automated production lines and fewer workers who tended to introduce unwanted variability. Predicting what consumers would buy before it was made (or even designed) required accurate feedback mechanisms from the market and a willingness to implement changes if they resulted in increased consumer satisfaction. Most importantly, in terms of mass customisation, standardisation should be applied across products, rather than just within products. This modularity would allow faster product development and manufacture as a new product would re-use existing, tried and tested modules as the basis for its new functionality.

These new manufacturing methods, developed primarily in Japan, were slow to be implemented in the US, where the old system of manufacture had served the economy so well. Nonetheless, as Japanese brands such as Toyota, Honda, Sony and Panasonic entered the US market and out-competed home brands, US manufacturers were forced to take notice. This may explain why the need for mass customisation has been more readily accepted in the US than in other countries, with many of the world's mass customisation innovators being American brands.

As market segmentations were drawn more and more finely, the logically inevitable end point was the market niche of only one consumer. At first the possibility of manufacturing for "markets of one" seemed incredible, but as Pine (ibid) explains:

> **"because the new products more closely meet consumer desires, a premium price can often be charged. This extra profit margin offsets any loss of efficiency due to their lower volumes. And, as experience is gained in mass customization processes, it is often found that products with many variations can be produced at the same or lower costs."**

So dependent was mass customisation on the new theories of production, that in some instances it was introduced without the company necessarily understanding either that it was engaged in mass customisation, or what the consequences would be. The Nokia 5110 was not the first phone with coloured covers that the company had offered, however at that early stage Nokia had not developed its expertise in spotting and understanding trends, and so colour prediction was largely based on intuition. In the past this had led to certain models which were sold out in one particular colour, whilst the same model in another colour sat unsold in warehouses. The thinking behind the 5110 was that a huge reduction in inventory costs could be achieved if it was plastic covers that went unsold, rather than complete phones (Leman, 2008). It is not certain who first realised the opportunity presented by a phone whose colour could be changed by the user, but it did not meet with company-wide approval. Many of Nokia's designers thought that offering choice in this way was a sign that the company did not really know what its customers wanted (which to a degree was correct). What no-one predicted was the way in which 'Xpress-On' covers would take off - the 5110 quickly became Nokia's best selling phone and for a while almost every phone the company

Figure 3.1. Nokia 5110 mobile phone covers. Only one of these is a legitimate Nokia cover.

offered had usable changeable covers. In addition, it spawned a massive industry of third party manufacturers (see Figure 3.1), such that at one point it seemed impossible to walk down the main street of any city in the world without noticing the opportunity to change the way your phone looked.

Today, mass customisation is the norm in some industries, but has failed to make much impression in others. While it is almost impossible to compete in the PC market without following the course set by Dell, “estimates suggest the apparel industry alone loses over $300bn every year due to erroneous forecasting, heavy inventory and lost profits as a result of necessary discounting to reduce stock levels” (Sanders, 2001, quoted by Fletcher, 2007). Increasingly however, the need to target market niches is driving mass customisation strategy:

> "There is a tendency towards an experience economy, a design orientation, and, most importantly, a new awareness of quality and functionality that demands durable and reliable products corresponding exactly to the needs of the buyer. Consumers with increasing purchasing power are increasingly attempting to express their personality by means of individual product choice." (Berger and Piller 2003).

This customer demand has led to a fundamental change in the relationship between the consumer and the manufacturer. For the first time since the mass production paradigm effectively ended the concept of craft production, the consumer is able to enter into a dialogue with the manufacturer, in effect to become involved in the product creation process. According to the mass production concept, "value creation is not only sequential, but also implies that value is 'added' along the production process, up to the moment in which the product was sold. In this framework customers were seen as destroying the value created during the production process" (Morelli and Nielsen, 2007) as the product began to devalue the moment it was purchased. In mass customisation, the customer instead creates value by giving insights as to what s/he really wants, such that "by utilising MC you are co-designing with the consumer which will allow you to always sell everything that you make" (Fletcher, op. cit.).

3.4 MODULARITY

As mentioned in the previous section, one of the key factors which allowed for both the conceptualisation and realisation of mass customisation was the notion of modularity. The increased use of modular product architectures had become necessary because the greater variety of product choice which consumers were demanding had begun to negatively impact manufacturers' profits, as Desai et al (2001) explain:

> "While product variety enables the firm to charge higher prices, there is always the risk that product design, development, and manufacturing costs may significantly escalate, thereby eroding profits. Manufacturing strategies such as modular design and delayed differentiation (Lee et al. 1998) have been deployed to mitigate the adverse impact of higher variety. Another strategy being followed is to develop common components

> across product lines. When these components are invisible to the consumer or do not affect their evaluation of product performance (for example, microprocessor-based electrical control centers in a car), achieving commonality is preferred if net savings in design and manufacturing accrue."

Modular components are like building blocks which can be assembled in different configurations to arrive at different product outcomes. Modular systems can be mechanical, such as a single gear box used in different models of car; electrical, such as a single motor used in different models of hand drill; electronic, such as a single LCD display used in different mobile phone models; and even software based, such as single 'blocks' of code re-used in different applications. The common factor is the reusability of the modules.

Modular re-use had been utilised early on in mass production - the Ford Model T chassis and engine was used in twelve variants including the roadster, coupé, towncar and tudor sedan. The innovation which Japanese companies such as Toyota introduced however, was not only to use modular components across single model variants, but also to use them across multiple models (product families), and to re-use existing modules in future products. In addition to the standard benefits of modularity (reduced R&D costs, reduced manufacturing line costs, increased economies of scale) this meant the product development time could be reduced. By re-using modular parts which had already been tested 'in the field', which had been improved, cost reduced and optimised, and whose characteristics were well understood by its designers and engineers, Toyota was able to reduce the development time for a brand new model from the industry standard of five years, to between three and four (Pine II op. cit.).

For mass customisation, which is driven by consumer demand for the fast supply of tailored products, a modular approach to product design and assembly is essential.

> "The best method for achieving mass customization - minimizing costs while maximizing individualized customization - is by creating modular components that can be configured into a wide variety of end products and services. Economies of scale are gained through components rather than the products; economies of scope are gained by using modular components over and over in different products; and customization

is gained by the myriad of products that can be configured." (Pine II, ibid).

In approaching a mass customisation strategy there are a number of ways in which products or processes can be modularised. These types of modularity were understood well before the advent of mass customisation, and detailed by Ulrich and Tung (1991) as:

- **Component-Sharing Modularity:** the same component is used across multiple products to reduce the cost of multiple product variants.
- **Component-Swapping Modularity:** the opposite of component-sharing, in that different components are paired with a single, standard product.
- **Cut-to-Fit Modularity:** one or more modules are continuously variable within pre-determined limits, such as denim cut to industry-standard sizes to create a range of jeans.
- **Mix Modularity:** components used are so mixed together that they become something different, such as two standard paint colours mixed to create a custom colour.
- **Bus Modularity:** uses a standard structure to which different kinds of components can be attached, such as halogen lighting on a track.
- **Sectional Modularity:** standard interfaces allow modules to be connected in non-predetermined ways, the classic example identified by Pine is Lego (ibid: p. 208).

Of these six modularity types, component sharing and component swapping are the most relevant to this research and are discussed further in Chapter 11.

As well as allowing the faster development of more numerous goods, modular product thinking allowed companies to ‘buy in’ modules from other companies whose expertise or capital enabled them to manufacture better quality components. This had long been the case in luxury industries which relied on highly skilled craftsmen - the Swiss watch industry for example had a history of commissioning enamellers, engravers and leatherworkers to create watch dials and straps, whilst the watch company would focus its resources on the production of its patented movements. These craftsmen would complete an order and then often begin a new order for a rival company. In the mass manufacturing mindset however, this approach was anathema - keeping all R&D and production in house created economies of scale, as well as protecting trade secrets and other sensitive information (Chesborough, 2003). However as manufacturers realised that the fastest way to develop a new product was often to buy in ready-made modules, the trend for out-sourcing the design and supply of assembled modules increased, such that today it is difficult to conceive of a complex consumer product which would not be manufactured in such a way. The original Apple iPod is a good example, as this list of its suppliers shows:

- *Portal Player* provided the design (and coordination) of the audio components.
- *Wolfson Microelectronics* provided the digital to analogue converter.
- *Sharp* provided the flash-memory;
- *Texas Instruments* provided the fire-wire controller;
- *Sony* provided the battery; and
- *Linear Technology* provided the power-system.

(Sutton 2002, quoted in Morelli and Nielsen op. cit.)

In such a case, as many fashion brands have understood, a company's core competences no longer need to include manufacturing, but can instead focus on the recognition of market trends, design and the development of a unique brand image.

Modularity has been well understood and exploited before mass customisation, but for the most part (except where modularity was a fundamental feature of the product, such as Lego) the modularity was hidden from the customer. Often it was believed that if consumers knew two different products shared components, the ability to extract a price premium on the more expensive model would be reduced (Desai et al, op. cit.). Although modularity allowed for greater variety in a brand's product offering, the essential role of the consumer was simply to choose from that variety. The crucial difference of mass customisation is that it allows the customer to manipulate the modules in order to create a customised product. This is the fundamental way in which modularity enables mass customisation, by producing discrete entities of a design and assembly which the customer can interact with and change. In other words

> "In order to produce make-to-order products at affordable cost, the product design should be separated into two phases: (1) Design of the product family architecture and modules by the manufacturer, and (2) Design of the specific, personalized product by the customer using available modules." (Koren and Barhak, 2007).

A consumer design toolkit would be conceived in the same way, and for the same reasons. Standard product architectures would be designed from modular components, tested and manufactured, in isolation (or at least removed) from the specific design of the product. Rather than re-orientate modules however, the consumer would design within parameters afforded by the product architecture and boundaries defined by the designer.

3.5 MASS CUSTOMISATION TOOLKITS

Modular product architectures combined with flexible manufacturing systems offered the theoretical possibility that products could be customised for individual consumers. However there remained the question of how a manufacturer could capture an individual consumer's needs and wishes. When goods were mass manufactured consumer demand was relatively easy to manage or predict, focus groups and surveys provided the information needed before a product was designed, and after-sales market research told a manufacturer how well it had satisfied its customers, and what to repeat or avoid in future. But as markets splintered into niches these methods became increasingly unreliable; clearly a new way was needed to understand what individual customers wanted.

This new method came about with the internet, in particular visually rich Web 2.0 technologies (Kumar, 2008) which could accurately represent the product being customised and sold. Systems to allow online consumer customisation of a product are known as customisation or configuration toolkits, and are defined by von Hippel and Katz (2002) as

> "a design interface that enables trial and error experimentation and gives simulated feedback on the outcome. In this way, users are enabled to learn their preferences

> **iteratively until the optimum product design is achieved." (Quoted by Franke and Piller, 2004).**

The vast majority of these interfaces are web-based, for the reasons described above, although notable exceptions include those of Adidas and Puma. Typically the consumer will be asked to choose from a selection of basic models, a style of shoe, a model of car, computer etc., and then customise the basic model by adding, removing or changing features (see Figure 3.2 as an example). This type of interaction immediately presents problems, in that it relies on the consumer having a certain degree of expertise in the type of product they are customising. In a conventional retail environment a customer could ask a sales assistant questions, or try on a product to ensure it functioned or fitted as expected. None of these options are possible when using a web-based toolkit:

> **"Given that the user in a consumer setting typically does not have substantial technical domain knowledge or access to analytical tools, user design bears the risk of what we call a *design defect* – a choice of design parameters that does not maximize user satisfaction. Such a design defect reflects a misfit between the product designed and the product that might have been designed, despite the fact that the user is in control of all the design decisions." (Randall et al. 2003).**

The issue of whether or not the user, in configuring a product via a toolkit interface, is acting as a designer is discussed in Chapter 6. Clearly the professional designer is not replaced as some exponents of MC have claimed (Randall et al, ibid.), since the professional designer was responsible for the standard product which is being customised, as well as, in many cases, defining the parameters within which the consumer is able to configure the standard product. Nonetheless, when using a customisation toolkit the user is partially acting as a designer in that the user is performing some of the tasks that originally were the exclusive responsibility of the designer. However, since the user is not trained as a designer, and in many instances would not have the technical knowledge to make informed decisions, the likelihood of making a mistake is high. Randall et al. (ibid) discovered that a majority of college-educated consumers could not specify the normal amount of memory in a laptop computer within a factor of 100, for example. In addition, there is inevitably a trade-off between the number of options offered, which impacts the consumer's ability to arrive at their

Figure 3.2. Fiat 500 customisation toolkit

ideal design, and the complexity of the interaction:

> "As the solution space enlarges, the accuracy with which a solution within this space matches the pre-existing ideal point of an individual consumer increases. However, the effort that needs to be made by that consumer to find such a solution also increases" (Deng and Hutchinson, 2007).

This potential for confusion amongst consumers is a major cause of concern for manufacturers involved with mass customisation, not least because of the harm a poor experience or dissatisfied customer can cause to a brand. In recent years this has led to a growing interest in the design of customisation toolkits and an understanding of the way that users experience them. The basic questions a toolkit provider must ask are:

1. How big is the solution space, i.e. how many options or possibilities are offered? (Franke and Piller, op. cit.)
2. To what extent can a module be customised, i.e. how many choices are offered within

each option? (Dellaert and Stremersch, 2005)

3. How is pricing managed - is each option of each module priced, or only the final cost of the product? Should available options increase or decrease the final cost, or both? (Dellaert and Stremersch, ibid.)
4. How is the default (i.e. non-customised) option shown - is it the most basic option, the most popular based on previous configurations etc.? (Dellaert and Stremersch, ibid.)
5. What are the design parameters by which consumers are offered configuration choices. If the weight of a laptop is dependent on the size of the battery, should the user choose between weights or battery life? (Randall et al, op. cit.)
6. Should online ordering be possible, or should the customer take the configured product specification to a physical store? What is the policy regarding returns for wrongly configured products?

The importance of these questions is addressed further in Chapter 11.

3.6 THE VALUE OF MASS CUSTOMISATION

Obviously there is a symbiotic relationship between the manufacturer and the consumer of mass customised goods. If mass customisation offers the consumer a product which more closely approaches the ‘ideal’, and if the consumer is willing to pay a premium to the manufacturer to receive such a product, then both parties to the transaction benefit. However this simplistic scenario hides the different kinds of value that each party experiences, as well as the possible negative aspects of mass customisation.

3.6.1. The Value of Mass Customisation to Consumers

Piller, Salvador and Walcher (2012) identify three areas in which MC brings value to a consumer, which they define as Fit, Form and Function:

Fit (and Comfort): refers to the ability of MC to provide goods, particularly shoes and apparel, 'tailored' to an individual's unique measurements. This is identified as one of the most attractive arguments in favour of MC, however it is also one of the most difficult to achieve and often demands face-to-face interactions with trained staff, rather than a purely web-based toolkit. As an example, miAdidas requires that customers visit a store, have their feet measured, run on a treadmill which analyses the customer's gait and running style, and work with an Adidas staff member to 'co-create' their individualised shoe (Adidas, 2007).

Form (Style and Aesthetic): relates to "modifications aiming at the sensual or the visual senses, i.e. selecting colors, styles, applications, cuts, or flavors." This is often the easiest of the three dimensions to implement, since changes in colour or material (of, for example, a running shoe) or ingredient (in, for example, muesli) are easily implemented within modern flexible manufacturing systems.

Functionality: this has traditionally been the domain of Business-to-Business (B2B) MC offerings, where machines, for instance "are adjusted to fit in with an existing manufacturing system, or components are produced according to the exact specifications of their buyers." Customisation of a computer's specification, such as that pioneered by Dell, also falls under Functional MC however, as does the increasing numbers of MC offerings within the sporting goods market (golf clubs, snow boards, bikes, etc.).

If a time arrives in any given industry where mass customisation is the normal business model rather than the exceptional one, then the benefit of mass customisation is obvious: it is necessary merely in order to compete and stay in business. This is clearly close to the case in the PC industry, where very few manufacturers are able to sell ‘off the shelf’, with no possibility of tailoring the specification to the customer’s needs. In other industries however, a growing body of research suggests that, if Fit, Form and Function are carefully considered, consumers are willing to pay significantly higher prices for products which they are able to customise.

One of the first studies which attempted to quantify this willingness to pay (WTP), conducted by Franke and Piller (op. cit.), looked at the example of an online toolkit for the customisation of watches. The website, which has since closed down, operated under the brand name of

Global Customization Ltd of Hong Kong[7]. The toolkit allowed the user to first choose the basic style of watch, and then to customise it through the choice of dial, hands, style of numeral, strap etc.

The study was divided into two experiments. In the first, users configured their own watch and were asked how much they would be willing to pay: “it was found that each user–designer’s WTP for his or her self-designed watch was [on average] 48.5 euros, more than twice the WTP for the two standard types 1 and 2 with the same technical quality (21.5/21.5 euros)” (Franke and Piller, ibid.). This was obviously a very significant finding in terms of quantifying the monetary value that a manufacturer might expect to receive by introducing a mass customisation system. Consumers were willing to pay more than twice as much for a product they had customised themselves as for a technically identical standard item. This led to a number of similar studies which Merle, Chandon and Roux (op. cit.) summarised thus:

> **"The research on consumer willingness to pay for mass-customized products is an issue of critical importance... Franke and Piller (2004) discover a 300% value increment for watches designed by users with the help of a MC toolkit. However, according to Kamali and Locker (2002), people are not willing to pay more for a mass-customized t-shirt, whatever the level of customization. On the contrary, Schreier (2006) found that 88% of respondents are willing to pay more for a mass-customized t-shirt and other products: the value increment is 113% for t-shirts, 207% for cell phone covers and 106% for scarves.″**

Merle, Chandon and Roux's own study, which used the NikeID configurator to test the WTP for customised sports shoes of 567 students, found that 73.3% of participants were willing to pay a premium of 28.49% on average, far lower than found previously in the literature. They speculated that one possibility was the high price of the standard model (€80), although it is obvious that more research is required in this area. It is also interesting to consider how this WTP might decrease as mass customisation becomes a more common method of specifying and purchasing goods.

Consumers who choose to engage in mass customisation also experience benefits of a

7. A similar configurator can be seen at http://www.121time.com.

different kind. Merle, Chandon and Roux (op. cit.), building on the previous work of Schreier (2006), found five values which consumers attach to mass customisation. Table 1 below distinguishes between two classes of value - the value of the final, customised product and the value of the experience of customising. This is an important distinction, as increasingly research has shown that the design and presentation of a manufacturer's customisation toolkit can significantly colour a user's perception of the final product (Randall et al, op. cit; Merle, Chandon and Roux, op. cit.).

Franke and Piller (op. cit.), in discussing the results of their study of consumers using a watch customisation toolkit, conclude that "the user-designed watches primarily are not designed better than standard watches but appear to be better adapted to the personal preferences of the user-designer." Interestingly, in a subsequent experiment conducted as part of the study, the watches customised by the first group of users were shown to a second group who had not been involved in the customisation task. The WTP, which valued a self-customised watch at €48.50 in the first experiment, dropped to €23.10 in the second experiment, approximately the same value as the standard, uncustomised designs. Thus it is apparent that users were not creating better watches through their customisation efforts, but rather the value of customisation stemmed from the specificity of the design to its creator.

With reference to Table 3.1 below, the first value identified is that of uniqueness. Intuition suggests that this would be the most important reason for consumers engaging in customisation. However Merle, Chandon and Roux's research concludes it is in fact the least important aspect of the value of the customised product. In addition, it is apparent that when consumers talk of exclusivity or uniqueness they do not necessarily use these terms in a strict, dictionary sense - Fletcher's (op. cit.) analysis of the Threadless online T-shirt customisation community found that 53.4% of respondents valued the 'exclusivity' of the design, even though the minimum production run is 5,000 units.

Value Components	Definitions	Statements
Mass-customization Product Value		
Uniqueness value	Value acquired from the opportunity to assert personal uniqueness with the mass-customized product	*My goal in doing this is to be the only one to have it. It's like: I got those shoes, not you.*
Utilitarian value	Value acquired from the closeness of fit between product characteristics and individual preferences	*You could find the shape of a shoe interesting but not like the color...So here you can really do what you want.*
		I often find a pair of shoes I like, except for the color, so being able to customize it means I can choose the colors I want...and I think that's a good idea.
Self-expressiveness value	Value derived from the opportunity to possess a product that is the reflection of personality	*It's a nice thing to be able to create your shoes according to your own personal taste as opposed to the pre-defined one the brand has created for you based on the wants and needs of the average consumer. It's more personal.*
Mass-customization Experience Value		
Creative and Achievement value	Value acquired from the accomplishment related to the creative task of co-designing	*You are proud...you did it yourself, you participated!...I would be happy to say that I did it.*
		The pleasure of doing it... yes... the satisfaction of doing something
Hedonic value	Value acquired from the experience capacity to "mean a need of enjoyment, fun, pleasure" (Lai, 1995).	*It's a play thing...it's fun, you do your own thing.*
		I could enjoy myself.

Table 3.1. The Value of Mass Customisation, Merle, A; Chandon, J. and Roux, E. (2007)

Utilitarian value is the second value identified in the research, which Merle, Chandon and Roux define as the degree to which the final customised product fits the consumer's 'ideal' product. Dellaert and Stremersch (op. cit.) found that the more utility displayed by the customised product, the more that consumers would view mass customisation positively. This clearly suggests that consumers who choose to customise products expect them to more closely fit their individual needs. It also implies that consumers are aware of exactly what those needs are, and are able to judge the customised product against those needs.

Self-expressiveness was the most valued quality of mass customisation in the study, defined as the ability of a product to reflect the owner's personality. Herd, Bardill and Karamanoglu (2007) write that

> **"it is a broadly held view that our possessions are both a contributor to, and reflection of, our own identities; making things a part of our 'self' by creating or altering them appears to be a universal human belief (Belk 2001). Mass customisation keys into this desire for creation as it is an approach that is fundamentally driven by an individual customers' emotional connection with the product, exemplified by their participation and engagement in the co-design experience."**

Products do not have to be unique to fulfil this role of self-expression, they may be aids to the identification and sense of belonging of the individual to a group or sub-culture (Lopiano-Misdom and de Luca, 1997). Mugge (2007) also reports that involvement in mass customisation leads to stronger feelings of attachment to the customised product, resulting in increased care in handling and postponement of replacement.

The values consumers place on the experience of mass customisation, identified in the study as creative achievement and hedonic value, are harder to differentiate. Both relate to pleasure and enjoyment, and the sense of satisfaction the consumer feels at having created the product. Franke, Schreier and Kaiser (2010) call this the "I Designed It Myself" effect, and recommend that MC toolkits should be designed to maximise the consumer's sense of having created a unique product. Franke and Piller's study of watch customisation (op. cit.) also concluded that a significant factor in consumers' willingness to pay was "pride of authorship". They also suggest that:

> "the sunk [invested] costs of time spent on designing, some notion of fairness (custom must be more difficult, so it is fair to pay more) or simple expectations (prior life experience tells us that individual products are more expensive), and other psychological explanations also might play a role."

3.6.2. The Value of Mass Customisation to Manufacturers

Mass customisation also brings additional benefits to manufacturers, in addition to an increased willingness to pay by consumers. Berger and Piller (op. cit.) introduce one of these benefits, which they term "postponement." No matter how well a manufacturer practises just-in-time production, an investment must be made in a product which is then tied up in that product until it is sold. But in a mass customisation scenario, the customer pays for the product *before* it is made. Close to 100% of goods made are sold; furthermore, "made-to-order manufacturing instead of made-to-stock largely minimises the risk of forecasting, eliminates distribution stocks, and decreases the fashion risk" (Berger and Piller, ibid.).

This change in the point at which a customer pays for goods, to before the product is actually made, is recognised as one of the fundamental characteristics of the business of mass customisation. In some respects it is an acknowledgement of its similarities to craft production, where a deposit or payment is taken in the knowledge that the product to be made is tailored to one person and therefore unsuitable for (and unsellable to) anyone else. There is a further advantage in bringing the consumer into the product creation process however: it can serve as market research:

> "Before the introduction of customization and user design, producers had to aggregate individual consumers into market segments and invest in elaborate market research techniques to hear "the voice of the customer." In contrast, user design constitutes a major step forward in industrial history, as it moves the specification decisions of a product from the producer to the user - the agent in the value chain with the most knowledge about user preferences." (Randall et al, op. cit.).

As selling to market niches has become the norm in some consumer industries, market research has increasingly come to resemble an intuitive black art. Whereas traditionally market research may have consisted of Lickert scale type questionnaires about a brand and its rivals' products, in order to ascertain which features were valued and which could be improved; nowadays trend agencies such as WGSN and Trendwatching employ thousands of 'spotters' worldwide to report on new fashions, new music, new business ideas etc. Companies and designers receive daily briefings of trends they should know about, with little indication of which are the most important or which previous ones failed to 'make it big'.

By integrating the consumer into the product creation process, many of the risks of not accurately predicting a trend can be averted. Research is still needed to spot the 'big' trends - a consumer can only customise a product within the parameters that a designer has determined - but short term trends such as colour, materials, graphic styles etc., can be accommodated provided the solution space is broad enough. In addition, since customers who seek out and use customisation toolkits tend to be in the lead user or early adopter classes of the market (von Hippel and Katz, 2002), their choices can provide valuable insights to the manufacturer who also wishes to target the wider mass market. Kotha (1996) reports the case of the National Industry Bicycle Company (NIBC) of Japan:

> "Armed with direct customer feedback regarding choices from among the numerous alternatives, the product designers, in conjunction with the process engineering group, create new product designs for the mass production factory. Based on the forecasts provided by the marketing department, the mass production factory then manufactures the new design and introduces the product ahead of NBIC's leading rivals. Thus, the mass custom factory acts as a conduit for new product ideas, as the customer chooses from the numerous combinations offered."

The final area in which mass customisation can benefit a company is that of brand building and brand loyalty. Firstly, by introducing new colour options or new materials, or by limiting the period of time a particular customisation option is available, a brand can ensure that the trend setting users of its configuration toolkit feel valued above the mass of its customers. Since early adopters, by definition, are trendsetters, whose opinion the rest of the market values, a positive feeling amongst them towards a brand is especially important. Secondly, by encouraging the building of a community around the brand's customisation initiative, particularly by web-based forums, the brand ensures it is being noticed and discussed even when consumers are not actively engaged with the toolkit. Finally, it appears that simply allowing consumers a role in the product creation process engenders brand loyalty. Kaiser and Schreier (op. cit.) write that the significantly higher levels of brand loyalty experienced by MC companies

> "is not only attributable to the increased preference fit of the self-designed products, but also to the mere fact that products are designed *by* the customer in the MC context. Irrespective of the achieved preference fit, MC customers thus reward the toolkit provider with increased emotional brand attachment in exchange for the "power to design products themselves"."

3.7 MASS CUSTOMISATION AND THE POSITION OF CONSUMER-DESIGN

This chapter has thus far considered mass customisation in its current state, and the historical precedents which led to mass customisation and the ways in which it is currently practised. It has shown that consumers who engage with mass customisation are acting creatively in a limited sense only. Within MC literature it is common to refer to the consumer as 'user-designer' or 'co-designer' (Ciccantelli and Magidson, 1993; Franke and Piller, op. cit; Koren and Barhak, op. cit; Piller, Salvador and Walcher, op. cit.). However the question of whether configuration can ever be considered design, and of MC's fit within new definitions of design, has received little attention. In 'Open Design Now' (von Abel et al, 2011), the first significant review of the new role of consumers within design, mass customisation is mentioned only as a sidenote. In 'Co-creation and the new landscapes of design', Sanders and Stappers (2008) refer to Piller's work only in passing, dismissing it as a "trend in marketing and brand development... [a way] to get new products and services into an already overcrowded marketplace." Boradkar (2010: pp. 120-121) recognises MC as sitting on a continuum between products designed entirely by a corporation and products designed entirely by the consumer, thus acting as a bridge between the established approach of mass manufacture and the potential of personalised production. However his attempt to redefine the specific consumer input to MC as mass *customerization* has attracted little attention.

It is evident therefore, that if consumers are to engage with the design possibilities which 3D printing offers, as this thesis proposes, the current definitions of mass customisation explored at the beginning of this chapter will not suffice. 'Freeform' design, by which is meant the creation and manipulation of 3D surfaces, features and details, even within pre-set boundaries, is a different task to the specification and configuration of a product from a menu of choices. This final section therefore considers whether a new definition is required for the task which consumers will, in future, undertake.

Earlier in the development of mass customisation, definitions of the visionary type described by Merle, Chandon and Roux (op. cit.) were sufficiently broad to encompass the notion of consumer design and manufacture, what Gershenfeld and others have described as fabbing. The definition of the concept by Ross (1996) as "the provision of customised products and services using stable business processes, at a cost and fulfilment time similar to standard, or mass produced, products," could be understood to include consumer design and manufacture, provided certain qualifications were included. However most recent definitions are much less ambiguous, for example Koren and Barhak's (op. cit.) insistence that mass customisation allows the customer to configure modules, but no more.

Writing in Mass Customization: Reflections on the State of the Concept, Piller (2005) defines mass customisation as a

> "*Customer co-design process* of products and services, which meet the *needs of each individual customer* with regard to *certain product features*. All operations are performed within a *fixed solution space,* characterized by stable but still flexible and responsive processes. As a result, the *costs associated with customization* allow for a price level that does *not imply a switch in an upper market segment."* [Piller's emphasis].

This at first appears to be both a constrained definition, but also one which is capable of accepting consumer created design and manufacture. However Piller goes on to explicitly state that co-design is "different than a do-it-yourself (DIY) setting," which is further defined as the "autonomous creation activities of consumers." The question is therefore: can a new definition of mass customisation be expanded to include 'autonomous creation activities', or is a new term required to explain the actions of consumers who design and manufacture their own products (or parts of products)?

Koren and Barhak (op. cit.) have described the different relationships between manufacturer and consumer, in different modes of production, thus:

- Craft Production: Sell - Design - Make
- Mass Production: Design - Make - Sell
- Mass Customisation: Design - Sell - Make

They also propose a fourth definition, personalised production, in which the relationship becomes

- Personalised Production: Design(A) - Sell - Design(P) - Make

where (A) is the product design architecture phase, and (P) is the personalised design phase. This appears to fit more closely with the product design process which this thesis investigates, whereby the manufacturer designs and makes a core architecture which will accept consumer designed modules. However a more accurate description of the proposed process would be

- Design(A) - Make(A) - Design(P) - Sell - Make(P)

Furthermore, Koren and Barhak later make clear that their new process still involves configuration rather than design:

> "The technique divides the product Design process into two phases. The first phase includes the design of the basic building blocks, or modules... and the method by which modules will be connected. Then, in the second phase the customer is selecting modules that fit his/her needs."

Kumar (op. cit.) has introduced the term mass personalization, which is defined as a limiting case of MC. Whereas both attempt to increase variation whilst retaining mass production costs and efficiencies, "mass personalization aims at a market segment of one while... mass customization [aims] at a market segment of *few*." Kumar further goes on to quote Toffler's

(1984) vision of the prosumer as a customer "so integrated into the production process that we will find it difficult to tell who the producer is." Nonetheless, Kumar fails to consider the consumer's potential to engage in the freeform design of products, and instead continues to place customer involvement in both MC and mass personalization within the existing paradigm of configuration.

Thus it seems that, despite Fogliatto, da Silveira and Borenstein's (op. cit.) recognition of the possible impact of 3D printing within the MC industry, there is little appetite to expand definitions of MC beyond the point where the manufacturer controls the product's final form. The 'Form' alluded to by Piller, Salvador and Walcher (op. cit.) in fact refers only colours and materials, and does not consider the possibility of a consumer engaging with the manipulation of a product's shape and surfaces. It is therefore apparent that mass customisation does not, in fact, bridge the gulf between mass manufacture and consumer design. Instead, on one side, proponents of MC write about 'user-design' without fully considering what 'design' actually is; whilst on the other side advocates of consumer involvement dismiss MC as no more than a development of industrial mass production.

Currently, then, it must be concluded that consumer design does not sit comfortably within the realm of mass customisation. The following chapter considers how well it fits within definitions and practices of design.

CHAPTER 4.

The Place of the Consumer in the Industrial Design Process.

4.1 INTRODUCTION

The previous chapter demonstrated that, whilst consumers who engage in mass customisation (MC) may be carrying out some of the tasks which previously would have been the responsibility of the designer, current definitions of MC are not sufficiently open to allow for the possibility of consumers moving beyond the configuration of pre-determined modules or menus. In a similar vein, this chapter explores the role of the user in the traditionally modelled industrial design (ID) process, and questions whether existing definitions admit the possibility of consumer-design enabled by additive manufacture.

Before beginning to discuss the role of the consumer within the industrial design process it is first necessary to clarify what is meant by 'industrial design'. The Industrial Designers Society of America (IDSA) defines industrial design as

> "the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems for the mutual benefit of both user and manufacturer." (IDSA, 2012).

Whilst this is a clear and sufficiently broad definition to include most of what industrial designers do, it immediately raises a number of problems with the notion that consumers might become engaged with the practise of industrial design. Firstly, and perhaps not surprisingly for a professional body, the insistence that industrial design is a professional service implies those not *employed* as designers are never able to describe what they do as industrial design. Secondly the idea of industrial design as being “for the mutual benefit of both user and manufacturer” ignores the increasingly blurred boundaries between designer, manufacturer and consumer (Stappers, Visser and Kistermaker, 2011; McGuirk, 2012).

This chapter begins by discussing ID and its sometimes synonymous interchangeability with the term 'product design'. It then defines ID in terms of process rather than service, a decision which subsequently allows non-professional designers to be judged on what they do rather than who they are. The chapter goes on to consider user-centred design - a strategy in which (ideally) the needs of the consumer drive the design of products - and shows how such approaches have become commonplace in design practice. A further strategy is co-design, in which deeper user insights are sought by actually involving users in design decision making, which is discussed together with the limitations that such a process entails. The types of user best suited to each strategy are also considered.

Despite the focus which both user-centred design and co-design demand is placed on the user of products, both approaches are limited in their impact on the conventionally modelled ID process. Neither one alters the power and decision-making relationships between designer and consumer, a situation which is explained further in the penultimate section of the chapter. Finally, the limits of the ID process with regard to the potential of AM (specifically, the ability to manufacture one-off products) is considered.

4.2 INDUSTRIAL DESIGN AND PRODUCT DESIGN

The UK Design Council exists to “bring together business decision-makers, policy-makers, educators, designers and architects to engage with the latest thinking and insight into design and innovation.” (Design Council, 2012a). In its list of design disciplines there is no mention of industrial design, instead the Design Council talks of ‘product design’, and on their website

Dick Powell of consultancy Seymour Powell describes product design (PD) as

> "an integral part of the wider process of developing new products of every type. In most cases, this will be for volume production. The product design process should ideally dovetail with every part of the wider development process, but typically it is much more involved at the beginning of the process than at the end." (Design Council, 2012b).

Powell then goes on to outline the kinds of tasks involved in a generic design project: briefing, strategic enquiry and orientation, idea generation and innovation, concept design, concept development, design development and further phases, and liaison.

Compared with the IDSA definition, whilst less elegant, it is apparent that the Design Council is describing much the same thing, i.e. it is implied that ID and PD are similar, if not identical, disciplines. Powell is also typical of practising designers in understanding industrial/product design to be the sum of the tasks that designers perform, rather than the service they offer. This apparent substituting of the term 'product design' for 'industrial design' is not an isolated instance: the Chartered Society of Designers' list of disciplines (2012) also makes no reference to ID, listing PD instead.

If there is little agreement amongst design practitioners about what to call their profession, there is an equal failure amongst academics. On a PhD Design List thread discussing the subject[8], Martyn Evans (2011) suggests that "industrial design is concerned with both smaller and larger scale objects and as such, product design is a subset of industrial design." In contrast Mark Evans (2011) concludes that "Product design can be used to describe anything from industrial design to engineering design." Love (2011) muddies the waters further by insisting that however it is termed, ID/PD cannot be considered a profession since, among other criteria, there is no single body which can authorise or prohibit membership (unlike, for example, architecture or medicine).

Whilst the situation is not consistent worldwide (the U.S. in particular favours ID over PD), in general ID and PD are virtually synonymous terms, with many designers happy to describe

8. See: https://www.jiscmail.ac.uk/cgi-bin/webadmin?A2=ind1106&L=PHD-DESIGN&D=0&P=52

themselves in either way. In ‘Becoming a Product Designer’ (Hannah, 2004) the terms industrial design and industrial designer are used by the author and those professional designers he interviews more than fifty times, with many designers using both terms to describe what they do. This interchangeability is further demonstrated in ‘Product Design Now’ (Campos, 2006), in which the author mentions ‘industrial design’ in the first sentence of the first page, and later uses both terms extensively.

It is not within the scope of this thesis to determine which term should be used in preference to the other. Nonetheless, a definition is necessary in order to understand what it is that users are beginning to engage with. In the interests of consistency therefore, the advice of Evans (op. cit.) is taken that "industrial design is a well defined term with a long history" whereas PD is not. Thus within this thesis, the work of professional designers is termed ‘industrial design’, with the understanding that those same professional industrial designers might also describe their own work as ‘product design’.

4.3 INDUSTRIAL DESIGN - A DEFINITION

The difficulty of ascertaining what industrial design actually is was recognised by Ralph Caplan in his introduction to ‘Design In America’, in what remains one of the most insightful and relevant essays on the practise of industrial design despite being written more than forty years ago:

> "What is industrial design? It was never an easy question to begin with, and it has not, through the years, become any easier. I have never seen a definition that adequately covered all of the projects that industrial design offices undertake. And even if a satisfactory definition were devised, it probably would not cover all of the activities that industrial design offices will undertake in a few years from now." (Caplan, 1969: p.1).

In reviewing the products included in the book, Caplan pre-empted and rejected some of the criteria used in later definitions of both industrial design and product design:

> "Essentially, industrial design determines the form of objects that are to be mass-produced by machines rather than crafted by hand. But while this has long been an

> *essential* definition, it is no longer sufficiently comprehensive, if indeed it ever was. Originally it served to distinguish the industrial designer from the craftsman, who made one-of-a-kind objects. That was a useful distinction, but one that is no longer necessary, adequate or even valid... First of all, the designs are not necessarily mass produced... Nor is the work necessarily done for industry." (Caplan, ibid.).

Ultimately Caplan fails, or refuses, to define exactly what industrial design is, for reasons which appear remarkably prescient of some of the issues raised by AM. In a similar way to that in which Powell defines product design in terms of what designers do, Caplan suggests that industrial design is best understood by looking at the products industrial designers create. But whilst this may indeed give a powerful sense of what industrial design is, it does not lead to an adequate definition. Despite Caplan's warnings, many definitions continue to insist on ID's relationship to mass manufacture, as exemplified by the Encyclopedia Britannica's (2012) entry which begins "industrial design: the design of mass produced products."

An alternative approach is that taken by Gemser and Leenders (2001), who instead choose to define ID in general terms, as "the activity that transforms a set of product requirements into a configuration of materials, elements and components." Whilst such a definition clearly admits the possibility of a non-professional designing and manufacturing a single product, its generality means it fails to illuminate what the designer actually does. This problem is overcome somewhat in definitions of ID which stem from an observation of process, rather than a description of the service which professional designers offer. Fiell and Fiell (2003) for example, describe industrial design as

> "the conception and planning of products for multiple reproduction – [it] is a creative and inventive process concerned with the synthesis of such instrumental factors as engineering, technology, materials and aesthetics into machine-producible solutions that balance all user needs and desires within technical and social constraints."

This definition is not without weaknesses: the term 'multiple reproduction' is problematic (though not to the same degree as "mass produced"), although it could be argued that a consumer-designed product is *potentially* reproducible, even if only one is actually made.

Importantly though, by listing the tasks typically undertaken by the industrial designer, the definition allows the possibility of quantifying the extent to which the consumer is acting as an industrial designer themselves, rather than a simple yes/no classification (the thesis explores such a possibility in Chapter 6 in order to map the degree of consumer involvement in industrial design). Throughout this thesis, therefore, the definition of ID is understood to be that given in Fiell and Fiell's statement above.

4.4 USER-CENTRED DESIGN

In one of the earliest attempts to capture and systematize the nature of the industrial design process, Archer (1965) identified six steps in a progression from 'programming' to 'communication'. Since then, numerous attempts have been made to define successive tasks of the industrial designer, from the simplistic and general (e.g. Cross, 2000: p.30) to the complex and specific (e.g. Pahl and Beitz, 1996). In studying these definitions, one of the interesting common features is the absence of any specific reference to the user. Holmes and Azam (1995) for example (see Figure 4.1), describe in detail how certain tasks should be carried out, referring to the need for sketches and 3D models, but only in very general terms about a "need" and a "statement of problem." Pahl and Beitz (op. cit.) define the clarification of the design brief as the collection of "information about the requirements to be embodied in the solution and also about the constraints", but nowhere mention the person who will use the resultant product. Furthermore, a common failing of most models has been to view the 'solution' as the end point of the design process, with no need to incorporate user feedback into either a refinement of the design, or an evaluation of whether the design was a success.

This reluctance to refer directly to the user has been, in part, responsible for the emergence of an approach to industrial design termed user-centred design. To some extent user-centred industrial design is tautologous - it is difficult to conceive of an industrial design project in which the user's imagined or expected appreciation of the final product is not a key criteria in deciding which direction the project takes, and which concepts are rejected or taken further. As Black (2006) explains however

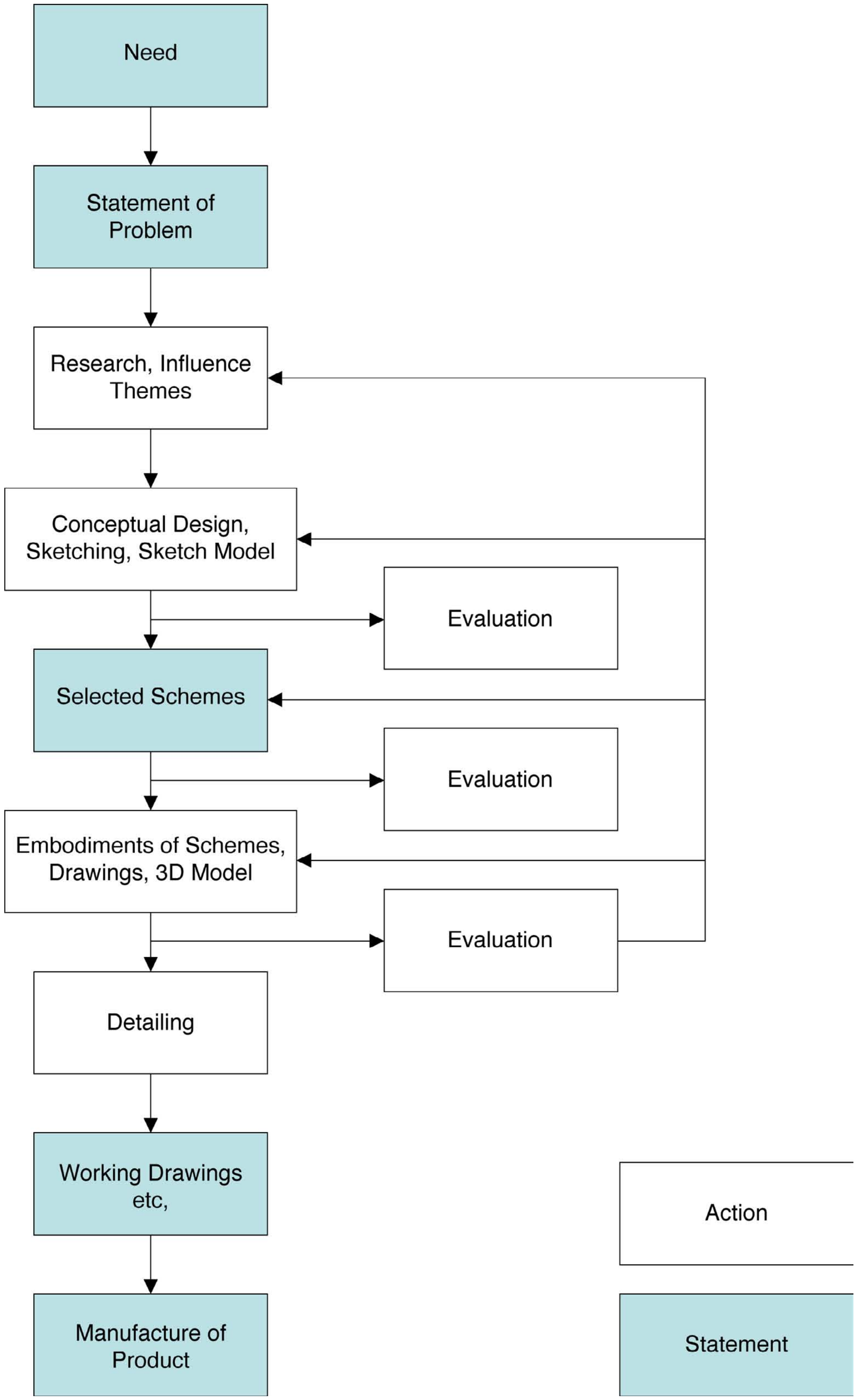


Figure 4.1. The Industrial Design Process, Holmes and Azam, 1995.

> "While most designers are conscious of the need to design for end-users, they often base their understanding of users on their own experience or on findings from market research. In contrast, user-centred designers engage with potential users directly, believing that understanding the details of individuals' experience gives greater insight than the aggregated reports of market research, and that what people tell market researchers they do doesn't always tally with what they actually do when observed in their own context.

In its most basic manifestation, user-centred design simply requires that "designers engage actively with end-users to gather insights" (Black, ibid.), which may be through conventional research methods such as interview or focus group. Many user-centred designers reject such an approach however, seeing it as inherently biased towards the designer's definition of the problem, rather than the user's experience. Furthermore, placing users in typical interview or focus group environments, which may include video cameras and one-way mirrors, with other participants who have not previously met, creates a false situation which is not best suited to eliciting information. This is particularly true when users themselves may not understand the value of the information they possess:

> "In our experience, customers are at a disadvantage when brought into a design meeting. The users' unique contribution is their real work experience. Taken out of this context, they are much less able to represent real experience." (Holtzblatt and Beyer, 1993).

To overcome these disadvantages, more developed theories of user-centred design require the designer's immersion into the user's world, spending time with the user in a work, home or other environment, using ethnographic methods to observe and uncover unexpressed needs (Black, op. cit.). This approach has hazards, as most designers are not trained in ethnographic research, nor are they interested in conducting objective, academically rigorous research while engaged in a commercial design project (Myerson, 2007). Nonetheless many designers have embraced user-centred design, with some of the best known and most prolific consultancies claiming a user-centric approach, as the examples below demonstrate:

- **IDEO:**

  "User observations are the starting point for every design program" (IDEO, 2008).

  Frog:

  "[Our work] draw[s] on a deep well of consumer understanding in every program, which is then supplemented by ongoing research - research that ranges from rapid immersions, to weeks in the field, as well as... comparative studies conducted off-site around the world." (Frog Design, 2012).

  Lunar:

  "It's all about people. Creating innovative products that satisfy the unmet - and indescribable - desires and needs of people is at the core of what we do. Our researchers employ techniques ranging from "shop-alongs" to in-home ethnography to understand people's motivations and aspirations." (Lunar Design, 2012).

4.4.1 User-Centred Design in Practice

When introducing the chapter 'The Design Process' in 'Engineering Design Methods: Strategies for Product Design', Cross (op. cit.) writes that

> "There have been many attempts to draw up maps or models of the design process. Some of these models simply describe the sequence of activities that typically occur in designing; other models attempt to prescribe a better or more appropriate pattern of activities." (p.30).

These models provide useful insights into the methodology of design, and the tasks that the industrial designer carries out in the course of a design project. However as academic attempts to describe a single process, they are increasingly at odds with the reality of how design is practised. In the past, such models have been criticised as "about as much help in navigating a designer through his task as a diagram showing how to walk would help a one year old child" (Lawson, 2005). Archer himself was aware of such criticisms when he wrote that

> "the most devastating opposition to the application of systematic methods to design problems comes from those who point out that the results of analysis are usually ponderous statements of the blindingly obvious." (Archer, op. cit.).

The point here however, is not that these models are obvious or of little use, but that they do not reflect the reality of the way industrial design is practised commercially. The design consultancies referred to above, Frog Design, IDEO and Lunar, have offices in the US, Europe and Asia, and count multi-national, household name brands as their clients. All three also have proprietary design processes.

In part these processes have evolved as a result of traditional industrial design consultancies attempting to reframe their activities as ‘innovation consultancy’ or ‘strategic consultancy’, and discovering that existing models did not adequately describe the new activity. They have also stemmed from the realisation that a unique design process can be a unique selling point, a way of differentiating one design firm from another. Frog Design for instance, use a process they refer to as *Discover Design Deliver*, which is advocated as ‘A Different Approach’ (Frog Design, op. cit.). IDEO's process, known as Design Thinking, has introduced a new way of integrating the design process into business and has spawned extensive debate, as well as adherents and imitators. In other words, these consultancies do not promote how well they follow the traditional design process, but rather seek to actively highlight the ways in which they deviate from it.

User-centred design has been one strategy by which some consultancies have sought to differentiate themselves. Although user-centred design was a term used by software designers in the early 1980’s (e.g. Eason, 1983), it was not until the mid-1990’s that the term began to appear in relation to industrial design (e.g. Eason, 1995). Even then it was a term primarily applied to ergonomics rather than the ethnographic studies of user behaviour discussed earlier. In ‘Design Process Improvement: a review of current practice’ (Clarkson and Eckert, 2005), User-Centred Design is not mentioned, and only one of the (then current) processes investigated, that of the US Food and Drug Administration, refers specifically to the needs of the user. Thus as a new approach to design, not widely understood and little practised by designers, user-centred design presented an ideal opportunity for forward-looking design groups to contrast themselves with more traditional approaches.

This is not to imply that Frog Design, IDEO or others approached user-centred design cynically. However it is undoubtedly true that in seeking to promote user-centred design as an USP for the firm's services, the result has been a somewhat opaque and esoteric understanding of how user-centred design is conducted. This lack of transparency has in part contributed to a situation in which some of the most basic considerations of user-centred design are not agreed on.

> **"Although innovation is the process of devising solutions that address unmet customer needs, there is no agreed-on standard that defines just what a "need" is, that is, what its purpose, structure, content, and format should be... Second, companies do not understand that these innovation strategies require very different types of customer inputs – in other words, they do not realize just how a "need" must be defined given the type of innovation initiative being pursued." (Ulwick and Bettencourt, 2007).**

It is therefore necessary to explain in more detail what a user-centred design process involves.

4.4.2 User-Centred Design Methods

As previously outlined, user-centred design builds on the traditional design process; users are studied in order to define the need, and in some instances to help draft a statement of the problem. They are then invited to participate in some or all of the evaluation stages. It is perhaps worth noting at this stage that despite Black's insistence on an ethnographic, observational approach detailed above, not all user-centred design advocates are so dogmatic. Krippendorff (2005: pp. 221-230) lists six ways in which user input can be integrated into a design project:

- Surveys and Structured Interviews
- Unstructured Interviews
- Focus Groups

- Observational Methods
- Protocol Analysis
- Ethnography

only two of which (observational methods and ethnography), adhere to the methodology advocated by Black. Ulwick and Betencourt (op. cit.) concur, believing that alternate strategies should be adopted depending on the type of information being sought from the user:

> "there is a misconception that the method matters most, but that's not true; it's knowing what customer inputs you are looking for that's critical for success. Any customer interaction can result in insight if you know what type of information you are looking for."

In this argument, rather than an overly proscriptive approach to the way in which research is conducted, the key to user-centred design is knowing how to extract relevant information from participants. However, as Ciccantelli and Magidson (op. cit.) caution

> "At best, the typical ways in which consumers are involved in product design - focus groups, surveys, and questionnaires - tend to elicit mostly information about what they do not want, rather than startling new insights about what they really want or need. This is due in part to the fact that people often attempt to provide answers that they think the inquirer wants, rather than probe for their own preferences."

It is also the case that many participants will find it easier to talk about what they know, rather than what might be possible. Black's enthusiasm for an ethnographic, observational approach is a response to these worries, and is why user-centred design practitioners will often simply observe users in a typical situation, asking for clarifications and explanations if necessary, rather than asking users to formulate solutions to problems. Such hurdles can also be overcome by framing questions in an appropriate manner, specifically by telling participants to focus on desirability rather than feasibility. User-centred design "starts from the ground up and ignores feasibility in the early stages of the design process. This is because it is based on the belief that the principal obstruction to creativity is a preoccupation with feasibility, a condition that is usually associated with self-imposed (rather than actual) constraints” (ibid).

Having conducted research to uncover user needs, the next stage in a user-centred design process is to evaluate the key insights and construct meaningful directions for design concepts. This is the stage at which user-centred design often breaks down, as the company or designer attempts to formulate strategies in terms of pre-existing strengths and weaknesses in knowledge or expertise (Gill, 2009). This immediately limits the range of possible solutions, often leading to only incremental changes even if ground breaking innovations were being sought. For Ulwick and Bettencourt (op.cit.) the most important requirement of any stated direction is that

> **"The statement must reflect the customer's own definition of value. It must not be an interpretation or a translation of what the customer values. It must not be the company's perception of how customers measure value or how they think customers should measure value."**

At this stage the user-centred design process reverts to the ‘traditional’ design process - concepts are generated, filtered and refined until a final solution is arrived at. Users may be invited to evaluation sessions and give feedback on design directions, but it is the designer who is assumed to be most able to interpret and translate customer needs into product solutions. Indeed this is a fundamental assumption of the user-centred design process, that

> **"the key emphasis... remains that of better understanding the needs of users as a means of informing the professional design process, rather than involving users in the process as active creative participants." (Press, 2011: p. 519)**

Co-design attempts to question this assumption.

4.5 CO-DESIGN

Co-design emerged from the Participatory Design movement in 1970's Scandinavia (Sanoff, 1970), which was led by trades unionists who believed employees could be a valuable source of ideas if permitted to engage with the engineering designers of new machinery. Identifying an agreed definition of co-design is particularly fraught, with terminology such as collaborative design and co-creation often used interchangeably (Sanders and Stappers, 2008). Outside of academic circles the situation is even more confused. A recent discussion about co-design within the LinkedIn Design Council group revealed no common understanding, with some members believing it to be the equivalent of user-centred design (e.g. Salustri, 2010), one that it meant collaboration between designers of different disciplines (Thornley, 2010), and even that co-design "does not exist" (Sa Leal, 2010), i.e. that it merely describes the way that all designers consider the user.

As mentioned in the previous chapter, co-design is also an often-used term within mass customisation literature, where it refers simply to a consumer 'designing' with a configuration toolkit. Mugge, Schoormans and Schifferstein (2009) justify this by arguing that although "there is no direct discussion between designers and end users, designers explicitly involve consumers in the design process by creating possibilities for playing an active role in this process." Within a more usually accepted model of the ID process however, co-design refers to "the creativity of designers and people not trained in design working together in the design development process" (Sanders and Stappers, op. cit.). The key requirement is that the designer and user work together, i.e. it is a collaborative process.

Although there is often confusion about the precise differences, particularly in implementation, between user-centred design and co-design, a belief held by many co-design advocates is that it offers a less pre-conceived understanding of user needs than user-centred design. Brereton and Buur for example, explain that

> "The nomenclature shift from "participatory design", which seeks sustained engagement from practitioners and stakeholders to "user-centred design" which depicts the human in the more instrumentalist terms of "user" is revealing in itself. These shifts raise considerable questions about who really stands to benefit from participation." (Quoted in Binder, Brandt and Gregory, 2008).

Within the field of ID there are very few examples of successfully implemented co-design exercises. In part this can be attributed to its roots which occurred in industrial workplace planning (as previously mentioned), and the involvement of the civil rights movement in community planning in the U.S., two areas which do not have immediate associations with ID. Sanders and Stappers (op. cit.), commenting on the time it has taken for co-design to make an impact in the professional domain, also cite a number of reasons including the challenges co-design offers to existing hierarchies and structures, as well as its antithetical stance to “passive consumerism.” As a consequence, instances of co-design most relevant to this thesis originate in research studies rather than commercially available products. Hycenek (2007) for example, reports a project by Ignition Design[9] group for Texas Instruments which involved students in the design of a projector aimed specifically at the video games market. The students were given existing projectors to use for a number of weeks, then invited to submit concepts for the new product, three of which were chosen to be developed further by the students and designers working in collaboration (this project is discussed further in Section 4.7 below). Such examples are rare, however as co-design increasingly moves from a primarily academic endeavour to one which interests practicing industrial designers, it is likely that products will begin to appear in this space.

4.6 TYPES OF USERS

Other than some very exceptional circumstances, it is impossible to identify every potential user of a product that is yet to be designed (or indeed defined), much less to invite their participation. It is therefore necessary to recruit a sample of users who can give the most valuable insights into the needs and wishes of actual users. This sample can be of two kinds: the representative user and the lead user.

A representative sample is made up of typical users of the product, with the intention that the sample reflects the whole market for the product (Seale, 2012: p. 135). It can be based on general demographic factors such as age, gender, income etc., or more specific factors such as magazine readership or monthly mobile phone bill, depending on the type of information the research is intended to uncover. In all cases however, the reasoning behind a representative sample is that participants will reveal the thoughts and attitudes of the broad

9. See http://www.qsigroup.com/clients/ignition/index.html

mass of consumers at whom the product will be targeted. A product which is designed for the small representative sample should therefore appeal to the much larger market the sample represents.

Because user-centred design advocates the participation of users at the start of the process, i.e. before the product has begun to be designed, a fundamental problem lies in communicating the nature of the proposed product to the participants. For this reason representative samples are often recruited from users who have purchased or used similar products in the past. This approach is further validated if the new product is intended to replace a previous model, and appeal to those customers who have purchased previously. However, using consumers who already have experience of existing products has an inherent drawback, which is that those consumers are often unable to think beyond their direct experience:

> "Even when consumers are aware of what they want and are willing to reveal it, their wants are likely to be conditioned by what is available. And when the product or service available is basically unsatisfying to them, they are unlikely to reveal startling new desires or concepts. (Ciccantelli and Magidson, op. cit.).

The consequences of listening too closely to existing customers are dramatically revealed by Ulwick (2002), who writes of

> "the tendency to make incremental, rather than bold, improvements that leave the field open for competitors. Kawasaki learned this lesson when it introduced its Jet Ski. At the time, the company dominated the market for recreational water craft. When it asked users what could be done to improve the Jet Ski's ride, customers requested extra padding on the vehicle's sides to make the standing position more comfortable. It never occurred to them to request a seated water craft."

Of course, not all new products are intended to be revolutionary or disruptive to the market. Representative samples in a user-centred design process can be an excellent way of incrementally improving a successful product. However in situations where genuine innovation is sought, a different type of user is needed.

The concept of the ‘lead user’ was first proposed by Eric von Hippel (1986) who defined them as “users whose present strong needs will become general to the marketplace in months or years in the future.” Prior to von Hippel, marketing theory had followed the bell-curve model of adoption (Figure 4.2) first proposed by Rogers (1962). In this model, although the innovator category was the first to adopt a new technology or product, marketers had focussed on the early adopter category as this group was identified as having the highest degree of opinion leadership, i.e. they were most likely to disseminate trends and influence the rest of the market (ibid: p. 283). However as early adopters, by definition the object being adopted must already exist, hence this group could not be inventors or innovators. Von Hippel’s new insight was to identify the innovators as lead users

> "who are ahead of an important marketplace trend and experience high benefits from innovating (von Hippel, 1986), [who] are said to come up with attractive user innovations themselves in order to meet their leading-edge needs which cannot be satisfied by commercially available products (Urban & von Hippel, 1988, von Hippel 1986). As those needs might foreshadow general demand, the problems and solutions encountered by lead users today might be highly relevant to broader parts of the market tomorrow." (Schreier, Oberhauser and Prügl, 2007).

As one example of lead user innovation, von Hippel has given the case of the development of foot straps in windsurfing. In 1978 Jürgen Honscheid from West Germany travelled to Hawaii for the windsurfing world cup, where he discovered competitors jumping by hitting a wave and using the sail to become airborne. The problem was that riders fell off in mid-air, but Honscheid had previously built an experimental board with foot straps, which he realised would solve this. When he tried it he also found the board acted like a wing, allowing a degree of controlled flight. In doing so windsurfing developed from a sport which only involved racing, to one which included aerobatics, and today the majority of windsurfing boards are sold with footstraps (von Hippel, 2005).

The idea of a particular type of user who, dissatisfied with what is commercially available, is willing to innovate and create their own solution, has been of great importance to user-centered design practitioners. There is often a certain kind of maverick mystique, which

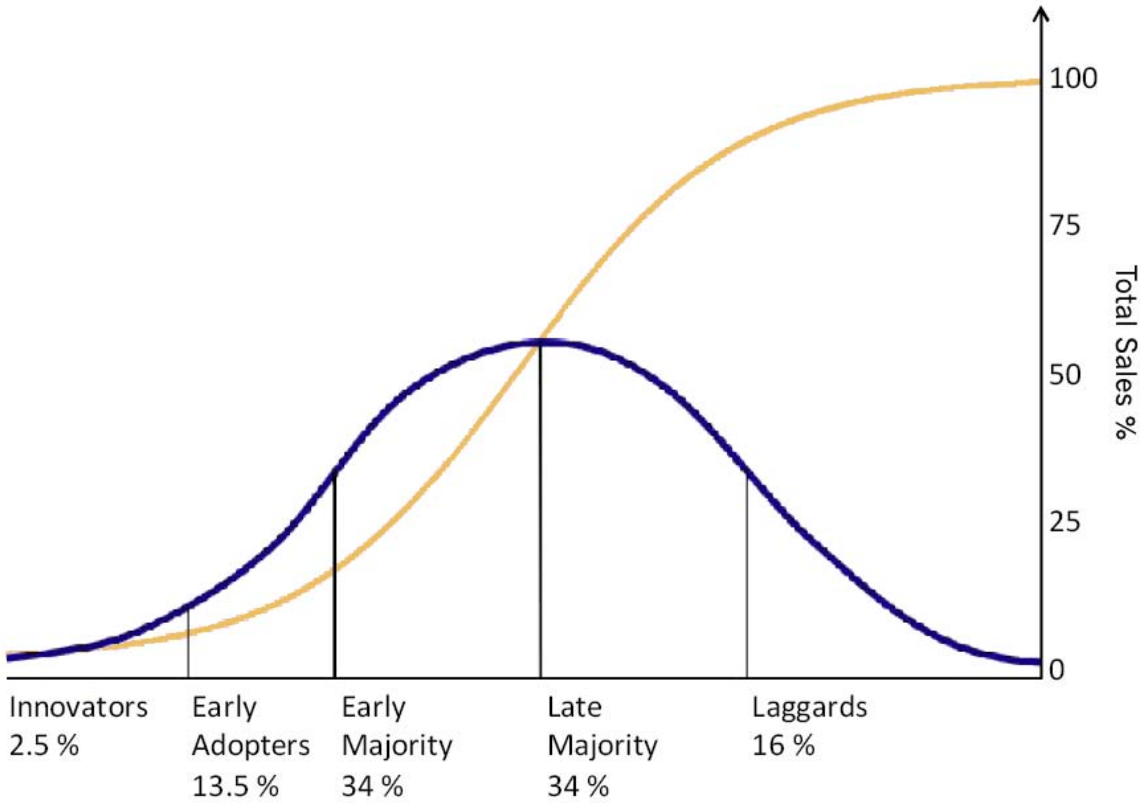


Figure 4.2. Bell-curve model of adoption, adapted from Rogers 1962.

allows consultancies such as Frog Design to describe lead users as “outliers… from freak to geek and everything in between” (Frog Design, op. cit.). It is important to understand however, that as with representative samples, there are also limitations to working with lead users, as Ulwick (op.cit.) explains:

> "Another danger arises in the common practice of listening to the recommendations of a narrow group of customers called "lead users" - customers who have an advanced understanding of a product and are experts in its use. Lead users can offer product ideas, but since they are not average users, the products that spring from their recommendations may have limited appeal."

Whilst lead users are, by definition, ahead of the market, they are also a relatively elite group (Press, op. cit: p. 521) whose understanding, usage and requirements of a product may not reflect the concerns of the rest of the market. The integration of both lead users and representative samples into a design project therefore requires careful management and an understanding of what types of product insights are being sought.

Nonetheless, it is apparent that within the context of this thesis, lead users are much more likely to embody the idea of the 'consumer as designer' than representative users. This is especially so in the case of the open source movement, a type of lead user-centred design in which the design professional is typically excluded, and which will be explored further in the final section of this chapter.

4.7 THE LIMITS OF USER-INVOLVEMENT IN INDUSTRIAL DESIGN

As a leading advocate of user-centred design, Ulwick (op.cit.) nonetheless makes clear what he feels should be the limit of consumer involvement in the design process:

> "Companies ask their customers what they want. Customers offer solutions in the form of products or services. "I'd like a picture or video phone," they say, or, "I want to buy groceries on-line." Companies then deliver these tangibles, and customers, very often and much to everyone's chagrin, just don't buy... The reason is also quite simple. *Customers should not be trusted to come up with solutions*; they aren't expert or informed enough for that part of the innovation process. That's what your R&D team is for. Rather, customers should be asked only for outcomes - that is, what they want a new product or service to do for them." [Author's emphasis in italics.]

The established view of the user within the design process, even a design process which is user-centred, is that the user represents a source of knowledge and opinion which, if accessed, can lead to the design of better products. Von Hippel (1986, 2005) proposes that within any given field, a small number of lead users are capable of designing and prototyping products more advanced than those offered by the mainstream market. However even those firms which advertise themselves as leading exponents of user-centred design, such as Frog Design and IDEO, are unwilling to accept the full implications of what von Hippel suggests, namely that users *become* designers. As such, user-centred design is essentially a sophisticated form of market research. Whilst user-centred design may propose that users are a valuable resource, and that their opinions may offer valuable guidance to the direction and outcome of a design project, it falls short of proposing that users ever become decision makers.

This at first appears to mark out co-design as a significant departure from the established ID process. Yet even within a co-design process, the designer ultimately holds the power to make the final decision, and to veto the suggestions of users if they are considered to be wrong. This “executive approach” (Oudshoorn and Pinch, 2003: p. 7) “assumes a specific type of power relations… in which designers are represented as powerful and users as disempowered relative to the experts.” The user-centred designer and co-design advocate will both attempt to address users' needs in the product’s design to a greater extent than the ‘design auteur’, but all three share the common belief that the person best suited to understand and meet users' needs is the designer.

This attitude is demonstrated in the previously mentioned exercise by Hynecek, in which end-users were invited to submit ideas for a computer game projector. The students' concepts were evaluated by a panel of gaming retailers, technology engineers and professional designers. Hynecek is revealing when he writes that “what’s interesting to note here is that many of the submissions were very pedestrian” (ibid). The underlying foundation of this statement is that the panel were not just expert suppliers and designers of gaming technology, they were also expert in knowing what users wanted, better in fact than the users themselves. ‘Pedestrian’ is a value judgement, suggesting the participants were unable to come up with solutions which the marketplace would find exciting. As such, both user-centred design and co-design fail in terms of proposing a significant shift in acknowledgement of expertise between the designer and user.

It may be noticed that, following the conclusion of this chapter, the term 'user' rarely appears in the thesis. This follows Redström’s (2008) contention that traditional ways of describing design, and its reliance on ever more sophisticated methods of understanding the user, break down in situations where users themselves participate in acts of designing. In such situations the commonly accepted necessities and practices of user-centred design and user research become confused, if not nonsensical. Redström proposes instead that there are two ways of defining a product’s use: the definition which designers do in predicting a product’s usage, and the definition which users do in actualising it. The example is given of the record player, whose redefinition by hip-hop DJ's as a musical instrument was entirely unforeseen by audio equipment designers. This research builds on that theme, but goes beyond the redefinition of existing products to consider the consumer's involvement in the design and definition of products yet to be manufactured. In such situations the term user seems paradoxical: "there must be something *to use* for actual use to happen" as Redström puts it. Thus the terms 'consumer designer' and simply 'consumer' are preferred; consequently the term consumer no longer refers simply to an assessor and purchaser of goods, but to an interested participant in the design of his or her own, unique, products.

4.8 THE LIMITS OF THE INDUSTRIAL DESIGN PROCESS

As long as designers are working towards the production of mass market products, a user-centred or co-design approach will, in many cases, remain the optimum one. The professional designer has the training and experience to look beyond the needs of the individual user, to aggregate the needs of the many, and to combine them with the numerous other constraints which shape a product's final outcome: technical constraints, cost targets, brand values etc. However mass customisation has shown that as markets divide further from niches to individual consumers, mass manufacturing paradigms struggle to supply the market with what it demands. The industrial design process, which is a consequence of the need to supply mass manufactured products, and of which user-centred design is a refined development, is unsuited to the huge variety which mass customisation promises, and which additive manufacturing may, in future, deliver. A new process, or processes, will therefore be needed to accommodate the ability of consumers to design and manufacture their own products.

The need to design objects suitable for mass production emerged in the 19^{th} Century with the development of theories of standardisation. However it was not until the 1920's that the Bauhaus, building on the principles of Modernist architecture and the pioneering work of Peter Behrens for AEG, proposed that certain products were more suited to manufacture by machine than others (Dormer, 1990). Products which were designed in this way exhibited what became known as a 'machine aesthetic', typically characterised by clean, simple shapes, smooth, unornamented surfaces, and constructed in materials such as metal, plywood and plastic. This aesthetic continues in design today, and is much in evidence in the work of design studios such as Apple.

Design for the machine production of standardised products did not just lead to a new aesthetic however, it also led to a universally accepted understanding that the purpose of the design process was to arrive at one ‘answer’; a single product design reproducible in high volume. One of the common features of mass manufacturing processes is that the means of production require substantial initial investment, however once in place the cost of manufacturing a single part or product (relative to the initial investment) is negligible. It is therefore a basic principle of mass manufacturing that as the number of parts produced increases, the cost of production of each individual part decreases. This inevitably leads to uniformity, since even small design changes require significant reinvestment in tooling.

A common feature of the design processes previously discussed is the assumption that the goal of the process is a single design (or, in some circumstances, a family of variants). The conventional industrial design process has, as its over-riding goal, the need to arrive at the smallest possible number of solutions, which can then be reproduced identically in high volume, "to converge onto a final, evaluated and detailed design proposal" (Cross, 2006: p. 186). Typically, when a brief is received, the designer (or design team) will spend a period of ‘unconstrained’ concepting in which the feasibility of solutions is less important than the recording of an idea, what Laurel (2003) describes as divergent thinking (see Figure 4.3). These ideas will then be filtered down to a number of concepts which appear to best answer the brief’s requirements, taking into account factors such as cost, technical feasibility, brand and market acceptability etc. As the project moves on these concepts will be modified, refined, combined and rejected, until one ‘final’ solution is arrived at, responsibility for which will usually then be signed off to the engineering design team whose job it is to productionise the design and ensure it can be manufactured efficiently.

Without the need for a significant investment in mass production tooling however, additive manufacturing offers the theoretical possibility that *every* concept can make it through to production. This possibility will significantly alter the long established industrial design

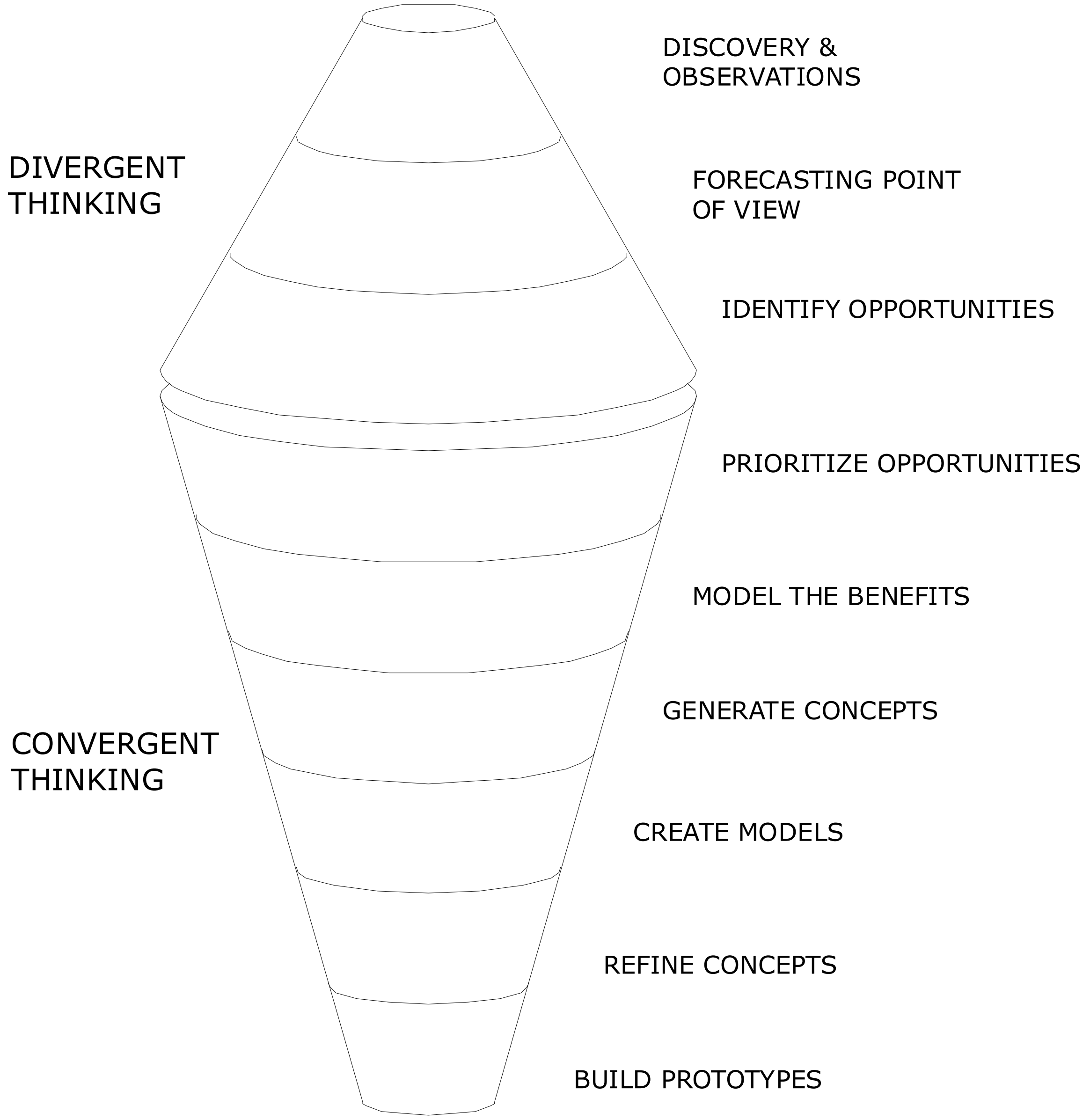


Figure 4.3. The Innovation Process in Action (Laurel, 2003: p.153)

process. Traditionally, since products must be produced in high volume, it has been inevitable that a product's aesthetics must be appealing to many, not just a few. Mass customisation has demonstrated the opportunities of allowing individual consumers to design, in a limited fashion. As additive manufacturing reaches its full potential, designers may be compelled to acknowledge the necessity of changing their design processes, of inviting individual consumers to take part as equals and even experts in what they, as an individual, want.

Mass customisation offers some clues as to how this new relationship might work. In designing a product which will be customised by the consumer, part of the job of the designer is to define which features of the product are customisable and which are not, the ‘solution space’ as Berger and Piller (2003) describe it.

> "Product architectures and range are fixed during a preliminary design stage linking overall company strategy to manufacturing capability. Here, the solution space of an MC system is set. The second design and development stage takes place in close interaction between the customer and the supplier. Here, the capabilities of the solution space from the first stage are turned through adequate configuration tools into a specific customer order."

Firstly the manufacturer and its designers must define the product architecture: which elements of that architecture are fixed, i.e. non modifiable, and which elements are customisable - what Spahi and Hosni (2007) term the ‘extent’ of customisation. Next the degree to which each element can be customised - the ‘heterogeneity of customisation' (ibid) - must be decided. Finally the customisation experience (Herd, Bardill and Karamanoglu, 2007) - the way in which the consumer will interact with the product being customised - must be considered. Only after these three stages have been deliberated, designed and developed, and the delivery systems put in place, can the consumer become involved by making choices from the elements which the designer has predefined.

It can be envisaged that the role of the designer will therefore change from that of a professional whose remit includes the design of the final appearance of a product, to one whose task is to define the parameters and boundaries within which a consumer may operate. Such a designer will have given up a significant degree of control over the way in which the product manifests itself, and will have entered the realm of what Garud, Jain and Tuertscher (2008) describes as "design for incompleteness.” The implications of such a shift in responsibilities is considered further in Chapter 6.

CHAPTER 5

Research Objectives and Methodological Framework.

5.1 INTRODUCTION

This PhD's research is primarily interested in understanding how users might best be enabled to design and manufacture their own products, using additive manufacturing as a facilitating technology. Whether design is regarded as a creative process or a problem solving activity, the result is an object or concept which is open to subjective interpretation. As Krippendorff (op.cit: p. 210) explains

> "...designers essentially are concerned with artifacts, products and practices that do not yet exist and could not come about naturally. A science for design, therefore, cannot be built on or be limited to propositional knowledge, statements of observer-independent facts, or generalizations from previous observations."

The difficulties and limitations of research into "products and practices that do not yet exist" are central to the methodological framework which supports this research, as explained further in this chapter.

The chapter begins by distilling the Literature Review into four statements which form the theoretical foundation of the subsequent research. It then explains the methodological stance of the thesis, and introduces five research questions. Particular attention is given to Design Research and the validity of conducting practice-based design activity as part of a PhD submission, together with the concept of a Design Diary as a method of recording design activity. The chapter ends with an Account of the Self by the author.

5.2 THEORETICAL FOUNDATION

In essence, this PhD is concerned with the move from mass manufacture (of which mass customisation is a highly developed form) to individualised production: manufacturing by and for ‘markets of one’. It seeks to understand how additive manufacturing technologies will redefine the industrial design process, and the future role of the consumer within product creation.

Drawing on knowledge gained from the literature review, a number of statements form the theoretical foundation of the PhD’s standpoint:

- **In time, additive manufacturing technologies will be capable of producing parts acceptable to consumers as end products.** To some extent this has already begun to happen, as examples by companies such as Freedom of Creation, and Materialize .MGX show.
- **Additive manufacturing technologies will follow a similar path as PC’s and digital printers, moving from the corporate sphere to the consumer sphere, although the internet has also enabled a new route of consumer adoption, that of the online service bureau.** Initially AM technologies were expensive and only available to large institutions. Currently these technologies are available to relatively skilled consumers through service bureaus, and hobbyist 3D printers can be bought and used in the home. In future, the skills required to access high quality 3D printed parts will fall, as will the cost of those parts.
- **As additive manufacturing technologies become cheaper and more readily**

accessible, consumers will begin to design, customise and manufacture their own products. This will happen whether designers, manufacturers and brands sanction the activity or not. Online communities such as Shapeways, Ponoko, Thingiverse and Cubify give clues as to how consumers will exploit these opportunities.

- **The traditionally modelled industrial design process is ideally suited to (and a consequence of) the requirement of manufacturers for small numbers of designs that can be reproduced identically in high volume.** It is unsuited to the possibility of high volumes of unique designs, which mass customisation hints at and which additive manufacturing may deliver. Conventional industrial design models and processes are unable to account for this development.

This final statement has driven the majority of the PhD's research, and together with the first three has generated the theory on which the remainder of this research is predicated, namely that

> **A future role of the industrial designer will be to design 'unfinished' products, whose fit, form and function will require unique decisions and inputs from consumers prior to manufacture.**

5.3 RESEARCH QUESTIONS AND OBJECTIVES

Given the statements above, the objectives of the research following the Literature Review were to answer the following questions:

- What are the new and emerging approaches to Industrial Design, and what degree of consumer involvement do they expect or advocate?
- What are the limits of what is currently achievable in the customisation of consumer electronics devices?
- How are brands' product design languages managed, and what conflicts exist

between consumers' involvement in design and the maintenance of brand equity?

- Which activities and processes are preferred by consumers engaging in the design of their own products, and how are consumers best enabled to communicate design intent?
- What can be learned from existing consumer-oriented 3D modelling software?

Having answered these questions, the final objective was to specify and prototype a toolkit capable of being used by consumer-designers, which at the same time satisfied the requirements of professional designers and brand managers.

5.4 METHODOLOGICAL STANCE OF THE THESIS

In considering the way in which professional designers are educated and subsequently work, Norman (2010) has written that

> **"We know surprisingly little about how to do design. There is no science of the practice in the same sense that there is a science to the structural analysis of buildings and bridges, or to the building of circuits. Design is still an art, taught by apprenticeship, with many myths and strong beliefs, but incredibly little evidence. "**

Given this lack of a scientific basis to design, identified both by Norman and Krippendorff above, it is understandably difficult to consider design using positivist tools of data collection or analysis, as demonstrated by Pedgley and Wormald's (2007) "A-Z criteria for design research". This is particularly so in the case of commercial consumer electronics products, whose creation and use are inextricably bound up in notions of fashion and taste, and whose 'fitness for purpose' is often determined, at least in part, by advertising and brand image. Even those researchers such as Jacob Nielsen working in the field of usability - a subject more amenable to investigation through quantitative methods - are regularly forced to confront the reality that 'well designed' products are rarely the most successful in the marketplace (BBC News, 2007).

For these reasons this research takes a predominantly qualitative, anti-positivist approach. Robson (2011: pp. 79 and 135) identifies three main approaches to qualitative research, as summarised in Table 5.1 below.

STRATEGY	TYPICAL FEATURES
CASE STUDY Development of detailed, intensive knowledge about a single 'case', or a small number of related 'cases'.	- Details of the design of the study 'emerge' during data collection and analysis. - The case is studied in context. - Information is collected via multiple methods. - 'Case' is interpreted widely to mean an individual, a group, a setting, an organisation, etc.
ETHNOGRAPHIC STUDY Seeks to capture, interpret and explain how a group, organization or community live, experience and make sense of their lives and the world.	- Tries to answer questions about specific groups, or about specific aspects of the life of a group. - The researcher is immersed in the setting. - Information is collected primarily via participant observation.
GROUNDED THEORY STUDY The central aim is to generate theory from data collected during the study	- Particularly useful in new, applied areas where there is a lack of existing theory and concepts. - Applicable to a wide variety of phenomena. - Data collection, analysis and theory development are interspersed and take place throughout the study.

Table 5.1. The Three Main Approaches to Qualitative Research

The most applicable of these, Grounded Theory, is discussed further below.

5.5 GROUNDED THEORY

The research strategy employed within this PhD places it clearly within a framework of Grounded Theory. This type of strategy was first detailed by Glaser and Strauss (1967), though subsequently it has come to encompass a variety of similar methods rather than a single rigid approach (Denscombe 2007: pp. 88-89). Essentially, Grounded Theory demands that theories should be firmly rooted in empirical research, and that they should arise through systematic analysis of data (ibid.).

Grounded Theory has become the best known approach to inductive research (Hodkinson 2008: p. 81), a process by which empirical phenomena are recorded and analysed with the anticipation that broader theories and conclusions will emerge from such study. A characteristic of Grounded Theory is that, unlike other methods, the direction of research is led by findings, rather than being pre-determined at the start of a project (Denscombe, op. cit: p. 90). This is in direct contrast to deductive modes of research more commonly associated with quantitative methods, in which a hypothesis is typically proposed and empirical research is conducted to judge the truth of falsity of that hypothesis (Hodkinson, op. cit: p. 82). Such an inductive approach corresponds well to the way in which the Literature Review has revealed the theory stated at the end of Section 5.2.

A further point which makes Grounded Theory an attractive strategy to the author is its insistence on a pragmatic standpoint with regard to conclusions and resulting theories, i.e. its relevance to the 'real world'. Grounded Theory requires that "a good theory is one that will be practically useful in the course of daily events, not only to the social scientists, but also to laymen" (Locke, 2001: p. 59). In the author's experience as a professional designer, practising designers rarely read design research, a view supported by Norman's (op.cit.) contention that too often designers find academic research to have little significance to their work. As such it is a core intention that this research will be both interesting to, and usable by, design professionals.

Grounded Theory is not without criticism however, in particular that it is too prescriptive (Andreski, 1972; Thomas and James, 2006), emphasising methodological rigour over the production of valid theories. This criticism has referred especially to Grounded Theory's expectation of complex systems of coding and re-coding of data during analysis, in order that patterns present themselves (Denscombe, op. cit: p. 98). Equally the insistence on an 'open minded' approach to data (i.e. that theories emerge from data analysis, rather than data being used to support theories) has led to criticism that Grounded Theory is too rigid in disallowing existing concepts (ibid.). Taken to an extreme it can be argued that research should be embarked upon without a literature review or indeed any prior knowledge of the subject area to be studied. However, in practise few Grounded Theory researchers operate in such a way (Hodkinson, op. cit: p. 96), instead arguing that provided such prior knowledge is treated as provisional it can provide a valuable initial focus (Strauss and Corbin, 1990; Hammersley and Atkinson, 1995).

Although Grounded Theory provides the overarching methodology of this PhD, two further methods were also incorporated. The first of these methods, Case Study, has already been introduced and forms the basis of the project reported in Chapter 8. The second method, that of Design Research, informs Chapters 9, 10 and 11, and is explained below.

5.6 DESIGN RESEARCH

One of the earliest descriptions of practice-based design research was that of Frayling (1993), who proposed such research as consisting of three strands:

- research *into* design
- research *through* design
- research *for the purpose of* design

Since then much debate has occurred regarding 'research through design' and the validity of practice-based design research (Chris Jones, 1997; Candlin, 2000; Pedgley and Wormald, op. cit.), the primary concern being whether such activity contains sufficient rigour to be classified as research (Rust, 2003). In particular, the standard required of practice-based research for the award of a PhD has been widely questioned (Durling, 2002; Friedman, 2010). However as the debate has matured, and with the increasing number of Design PhD's awarded in both the UK and worldwide (Yee, 2009), a greater understanding and consensus has arisen with regard to the standards such research demands, and the methods which are appropriate (Binder and Redström, 2006; AHRC, 2007; Evans, 2010).

Central to the viability of practice-based design as a research method is the understanding that the award of PhD is granted on the basis of the quality of research, rather than the quality of design (Rust, op. cit; Archer, 2004: p. 16). That is not to say that any design work undertaken may be of sub-standard quality, but rather that it must be undertaken, documented and analysed with the same degree of rigour employed by more conventional methods. This conscientiousness may be regarded as the fundamental difference between practice-based design research and the practice of design itself, in which intuition, tacit knowledge and undocumented approaches are common (Norman, op. cit.), not to mention the use of primarily visual, rather than written, forms of communication.

The validity of Design Research at PhD level as research through the act of designing has been argued by Pedgley and Wormald (op. cit.) as a legitimate method of advancing an identified body of knowledge. To be considered appropriate for inclusion in a PhD, the design activity must be documented, must be reflected on and must inform subsequent activity, whether that be further design or the proposal of new theories or processes (ibid.). During the course of this research these guidelines have been adhered to as follows:

In Chapter 9, the author's role was to build a number of 3D CAD models based on trial participants' sketches, such that the CAD models could later be modified, both by the participant and by an automated software system. This required considerable reflection with regard to the quality of the models, a significant amount of redesign of models built during the pilot study, a list of recommended practices, and ultimately informed the specification of the prototype toolkit described in Chapter 11. The toolkit itself was also an example of practice-based design research, demonstrating the possibility of a new type of consumer involvement in design whilst also suggesting ways in which subsequent toolkit designs might be improved. Finally in Chapter 10, which records a number of projects undertaken to analyse consumer-oriented CAD software, documentation, reflection and the informing of the prototype toolkit were again key elements of the research. The projects in Chapter 10 also made extensive use of one particular tool - the design diary - as a way of collecting data generated as part of design activities.

5.7 THE DESIGN DIARY

In planning the design phase of Chapter 10, the author drew extensively on the advice and recommendations of Pedgley (2007). In particular the keeping of a design diary, updated at the end of each day to record and reflect on the day's activities, was felt to be the best solution to the conflicting requirements of immediacy (to ensure relevant information was not forgotten) and non-interference (to avoid interruption or distraction which would hinder the work being undertaken). Clearly the use of a diary is not without problems – the importance placed on an activity or decision is naturally prejudiced, and there is an inevitable risk of editing to make oneself appear more competent or talented. However other methods of recording design activity identified by Pedgley have their own, greater limitations: interviews, surveys or questionnaires (of the designer) may easily miss important information; observation (whether 'live' or by video) can be intrusive and requires extensive transcription; reports are too far removed from the design activity (Pedgley, op cit). Furthermore, any method which utilises a third party has the risk that information will be lost through differences in communication style or the assumed expertise in each others' domains. Instead, by striving to be transparent and honest in the diary's entries, as well as retaining every design sheet, no matter how seemingly irrelevant, it was believed that the diary would afford as true an account as possible of the design activity.

Reviewing diary entries at the end of the exercise it would appear that this aim was achieved. The writing is by no means polished - it is often ungrammatical and hurried, sometimes repetitive, and interspersed with thumbnail sketches, crossings out and phrases whose meaning might not be immediately clear to anyone other than the author. A typical entry, from 10/03/2011 for example, reads

> "A third theme emerged 'by accident' when I saw something interesting develop in a sketch and went along with it. Turned into a much simpler direction of internal form

partially exposed through an external skin."

While this may not correspond fully with the instruction to 'Keep entries intelligible', there is undoubtedly an immediacy to the text; a clear intention to describe events and decision as truthfully as possible, with little consideration of how it might appear to others.

Before beginning the design activity, a list of instructions and good practices based on recommendations by Pedgley (ibid). was drawn up (see Tables 5.2 and 5.3 below). Together with a list of criteria for measurement (see Chapter 10, Section 10.2.5), these were printed and fixed to the wall above the author's desk, thus acting as a continual guide and reminder when compiling each day's diary entry. Entries were of two types: the first consisted of a one-line dated entry summarising the day's activities; at the end of the exercise these provided a chronological overview, as well as acting as a contents page for the diary. Detailed entries were filled out on A4 sheets using a pre-designed template. The diary was compiled at the end of each day when the 'flow' of activities was still fresh in the mind (on one exceptional occasion the diary was made first thing the next morning); entries typically took 15-20 minutes to complete and referred to sketch sheets and CAD models, by code, where appropriate. In addition to the diary entries, sketch sheets were scanned and annotated, where necessary, to record thought processes. During the CAD modelling phases of the projects screen-shots were also made to record significant stages in the model's progression.

Observations	Refer to the criteria for measurement. Explain how and when the criteria were encountered. If observations occur which contradict or differ from previous observations, explain the differences.
Strategy	If there is a plan for addressing modelling constraints and opportunities, explain it. If the plan changes, give details of how and why.
Outputs of Designing	Refer to sketch sheets, CAD model save points and notes as reminders of how and why decisions were taken. What has been considered regarding design decisions and CAD modelling constraints and opportunities? What knowledge has been applied and why?
Information Sources	Give details of all information sources used to address design and modelling issues. How was the information helpful?

Table 5.2. Diary Instructions

Chronology	Describe work in the same sequence that it occurred
Clarity	Keep entries intelligible, insightful and honest
Focus	Keep entries succinct
Record Images	Record still and moving images of developing and completed models
Out of Hours	Account for instances of 'out of hours' designing in the next day's diary
Diary Admin	Ensure that all diary sheets are numbered and dated
Designing Admin	Ensure that all design outputs are numbered and dated to aid cross-referencing

Table 5.3. Good Practice When Completing Diary Entries

5.8 AN ACCOUNT OF THE SELF

In addition to the criticisms of Grounded Theory described in Section 5.5, a further weakness is claimed to be that it discounts researcher bias and assumes both the theoretical and practical possibility that research can be entirely neutral of pre-suppositions. Critics claim such neutrality is simply not possible (Hodkinson, op. cit: p. 94), and that "our biases affect the subjects we choose to research, the questions we ask, the places we visit, the focus of our observations [and] the content of our interviews" (ibid.).

Ethnographic researchers have traditionally recognised the influence of the researcher on the subject, and that such influences cannot be entirely removed (Ball, 1990). It is therefore common practise to give a 'public account of the self' which allows readers to judge the degree to which the researcher may have biased the research. Denscombe (op. cit: pp. 69-70) gives guidelines as to the information which should be included in such an account of the self, which have been followed in the biography below:

Matt Sinclair, born 1969, currently living in UK

I graduated from Loughborough University in 1991 with a BA(Hons) degree in Design Technology. I subsequently graduated from the Royal College of Art in 1995 with an MA in Industrial Design Engineering. Whilst at the RCA I was profoundly influenced by Tony Dunne, who was my personal tutor, and his concept of the 'secret lives' of objects later described in his book Design Noir[10].

On graduation from the RCA I began working for Nokia Design, firstly in the UK and later in Finland. I was personally involved in the design of ten products to varying degrees, including four which were cancelled during development, primarily for the Japanese market. I was later appointed senior lead designer for the Nokia 7210 and was involved from the initial concepting phase through to the production of tooling data, as well as coordinating the design of accessories, graphics and packaging, and advertising strategy.

Whilst at Nokia I first became interested in the idea of niche marketing and the dissipation of trends from sub cultures into the mainstream market. I co-authored a six month study looking at youth trends in Japan, which involved in-depth interviews with 16 subjects in their homes, work and social venues; I also co-ordinated a questionnaire survey of 250 trendsetting teenage subjects, carried out by Gallup Japan. This study helped inform Nokia of the importance of youth trends, particularly in Asia, and influenced the setting up of a trends research unit within Nokia Design.

10 See Dunne, T. and Raby, F. (2001), *Design Noir: The Secret Life of Electronic Objects*, Berlin: Birkhäuser

As Category Design Manager for Nokia's Active category, I moved to Helsinki, Finland, where I lived for 10 years. In this role I conducted the first concepting exercise (within Nokia) to make use of lead user inputs: professional sports persons within a number of fields were recruited and interviewed regarding training routines, expectations of equipment etc. These subjects were then invited back at different stages of the project to evaluate and comment on concepts. This approach was subsequently used in a number of product programs.

After leaving Nokia in 2003 I started my own consultancy, focussing primarily in the areas of consumer and professional electronics. Often working in collaboration with CMe, an engineering design consultancy in Salo, Finland, my clients have included Benefon, EADS, Nokia, Nordic ID and Siemens.

In the past my personal views regarding the practise of industrial design have been similar to the majority of designers, namely that design is a specialism which requires both training and talent, that designers are uniquely able to envisage and answer the needs of consumers, and that design is a subjective discipline. However, whilst I continue to believe that good designers are necessary to create products for the mass market, I have increasingly come to believe that the design industry hides behind a professional 'shield' in order to avoid confronting the fact that the majority of products released to market do not function as consumers would wish, let alone inspire or delight. I am also continually fascinated by the complexity and cleverness of corporate branding, and the importance it holds for consumers. Nonetheless, I feel that established brands very rarely value innovation over their own brand image, with the result that established brands stifle, rather than stimulate, innovation.

This chapter has laid out the theoretical foundations of the PhD, and listed the objectives of the remaining research. The following chapter begins to address these objectives, by investigating a number of new and emerging approaches to industrial design, and the degree to which they advocate the involvement of the consumer.

CHAPTER 6.

The Emergence of the Consumer as Designer.

6.1 INTRODUCTION

In recent years the notion that industrial design is an activity in which anyone can take part has become increasingly common. Design has been described as everything from “the teacher arranging desks for a discussion [to] the team building a rocket” (Dubberley, 2004). As previously noted, within mass customisation literature it is common to read of the “user-designer” or “user as designer” (e.g. Ciccantelli and Magidson, 1993; Franke and Piller, 2004; Koren and Barhak, 2007), and even that “the professional designer is replaced by the user,” (Randall, Terwiesch, and Ulrich, 2003). Unsurprisingly, such assertions have caused consternation amongst design practitioners, who sense that their skills and professionalism have been misunderstood and devalued[11]. They point out that the consumer choices often presented as ‘design’ represent only a fraction of the tasks a designer will undertake in the course of a typical project (Parsons, 2009). Some have attempted to simply shut down the argument by protesting that “Consumers consume; designers design. End of Story” (Duffy and Keen, 2006).

Yet this polarisation of the argument into two extremes, summarised as either “everyone is a

11. See for example http://boards.core77.com/viewtopic.php?t=16060

designer," or "only professional designers can design," has done little to illuminate the ways in which new technologies and processes have allowed consumers to engage in the design of their own products. In chapters 3 and 4 it was seen that even in supposedly advanced concepts of mass manufacture (mass customisation) and design (user centred design and co-design), the relative positions of designer and consumer are not fundamentally challenged. Fischer (2002) notes the over-simplification of this position when suggesting that 'consumer' and 'designer' are not binary choices, but that a continuum exists between the two. To date however, little research exists to compare the extent to which new methods of design enable the consumer to engage in design activities. Olsson (2004), whose classification of degrees of user involvement defines users as co-operation partners, informants or subjects, is a notable exception. However by concentrating on the traditionally modelled design process, Olsson's classification excludes user interventions through (for example) mass customisation, 'modding' and crowdsourcing.

This chapter introduces a number of design strategies not usually considered part of the industrial design canon, and compares them to the more conventional approaches discussed in Chapter 4. It begins by defining the new product development (NPD) process, and demonstrates how the consumer's involvement at different stages is dependent on the design method being employed. From this, a classification of consumer involvement in ID is presented.

The chapter continues by examining the dependency of consumer involvement on the designer's commitment (to that involvement), and shows how a 'tipping point' exists, beyond which the designer's role is no longer that of an interpreter of consumer needs, but instead a facilitator of design by consumers. A number of incarnations of consumer design are then discussed, and the chapter concludes by asking how manufacturers and brands might engage with consumer design and what issues might arise as a result.

6.2 THE PRODUCT DEVELOPMENT PROCESS

Walton (1999) presents four models of product development (see Figure 6.1). With the exception of Ulrich and Eppinger, all feature four stages[12] which, although overlapping in places, can be broadly defined as follows:

> **Definition:** The identification of a consumer need or market opportunity, and an initial identification of a product archetype (or lack of existing archetype) which might meet that need.
>
> **Specification:** A list of the characteristics of a product which would be required to satisfy the previously identified consumer need, including modularity and customisation strategies if applicable.
>
> **Design:** The process by which an agreed solution to the specification is arrived at; it includes industrial, engineering and process design functions.
>
> **Manufacture:** Pilot production and ramp up to full production of the designed product.

Before attempting to classify the extent to which differing approaches to industrial design allow or enable the consumer's input, it is first necessary to acknowledge and define these approaches. A number of the following titles and descriptions are familiar, whereas others are less common, either because they are not typically utilised or recognised by industrial designers, or because they are attempts to describe newly emerging methods of design.

6.2.1 Conventionally Designed Products

For the purpose of this classification, conventional products are those whose definition, specification, design and manufacture occur with no consumer input. Such products are created using a process first identified by Archer (1965) in which "readily available information" on users is collected before the "Creative Phase" begins. Thus techniques such

12. The fifth stage in Anderson's process - 'Follow Up' - is discounted in this case.

Anderson (1997)	Product Definition	Architecture	Design	Ramp Up	
Wheelwright & Clark (1992)	Concept Development	Product Planning	Product / Process Engineering	Pilot Production / Ramp Up	
Ulrich & Eppinger (1995)	Concept Development	System-level Design	Detail Design	Testing & Refinement	Production Ramp Up
Clark & Fujimoto (1991)	Product Definition	Product Planning	Product Engineering	Process Engineering	
Sinclair (adapted from above)	Definition	Specification	Design	Manufacture	

Figure 6.1. Models of New Product Development, adapted from Walton (1999).

as trends analysis and consumer feedback (on existing products) may inform the creation of a conventional product, but the consumer's first engagement with the product will be during his/her decision as to whether to purchase it.

6.2.2 Bespoke Products

Bespoke products are those whose specification and/or design occur with direct input from the individual consumer, usually through personal consultation with the designer or manufacturer. The term originated in the 17th century to describe individually tailored clothing, made to the customer's specific measurements and requirements (Mahon, 2005). Nowadays bespoke is used to describe products as diverse as watches, shoes, wallpaper and computer software, though in consumer goods markets it is typically understood to signify high cost, often handmade, luxury items (see also Chapter 8).

6.2.3 Customised Products

Customised products are conventional products whose specification and/or design and/or manufacture are modified by the individual consumer after purchase. Crucially, such modification occurs without the manufacturer's express permission, and although such activity, (when carried out by individual consumers) is largely tolerated or ignored, the legality of customising products is something of a grey area (Oram, 2005). One of the best known genres of customised products are 'hot rods' - cars whose engines and bodywork are modified to improve performance or alter the appearance. Computer 'modding' (upgrading components, over-clocking processors, fabricating individual cases, etc.) is a more recent manifestation of the same activity.

6.2.4 Mass Customised Products

Mass customised products are those whose design occurs with direct consumer input, usually through online configuration tools. An extensive description has previously been given in Chapter 3.

6.2.5 User Centred Design and Co-Designed Products

User centred design and co-design are closely related, though distinct, approaches to increasing the involvement of users in the product creation process. As discussed in Chapter 4, definitions of each do not always agree, with competing explanations insisting that one or the other embodies differing techniques and philosophies. However the purpose of this classification is to determine the degree of user involvement in the design of products, rather than the methods employed, and in this the literature is in general agreement: user centred design involves observation, whereas co-design involves participation (Sanders and Stappers, 2008; Binder, Brandt and Gregory, 2008; Olsson, op. cit). User centred design products therefore refer to products whose definition and/or specification occur only with *indirect* individual consumer input – users are observed in context and may even be invited to give opinions on product concepts, but are unable to contribute directly to the creation of a product. Co-design products, in contrast, are those whose definition and/or specification and/or design occur with *direct* consumer input, by working with professional designers in a collaborative effort.

6.2.6 Crowdsourced Products

Crowdsourcing refers to products whose definition and/or specification and/or design occur with multiple direct consumer inputs. Crucially, it involves an 'open call' to any interested consumers to submit designs or help solve a problem (Howe, 2006a); potential solutions are then discussed, vetted and (in some cases) voted on by 'the crowd' with the purpose of arriving at a popular solution which then moves forward to production (Howe, 2006b). It is particularly important to stress that crowdsourcing is not the same as open source (defined below), since although solutions will have been generated openly, the intellectual property (IP) of crowdsourced products will be owned by the company or entity which first initiated the call for solutions (Brabham, 2008).

Kleeman, Voß and Rieder (2008) identify seven types of crowdsourcing, of which the first two - participation of consumers in product development and configuration, and product design - are relevant to this research. Examples of crowdsourced industrial design are relatively rare: at the time of writing CrowdSPRING[13] a popular website where clients can advertise crowdsourced projects, was advertising 142 graphic and web design projects, but none in its industrial design category (99designs[14], a similar website, does not even have an ID category).This may largely be attributed to the fact that the design of tangible, manufactured goods requires significantly greater interaction between designers and production engineers than a graphic logo or even a website. Well known examples of crowdsourced products such as Local Motors[15] and Quirky[16] therefore exhibit a number of similarities to co-design, in that the consumer will be invited to collaborate with an in-house team of product developers. Crucially however, in a crowdsourced project the design concept will have originated from the

13. See http://www.crowdspring.com/

14. See http://99designs.com/

15. See http://www.local-motors.com/

16. See http://www.quirky.com/

consumer alone, whereas in a co-design exercise it will more likely have been conceived by a designer working with the consumer.

6.2.7 Open Design Products

Open Design is an approach, closely related to Open Source, "characterised by the free revealing of information on a new design with the intention of collaborative development of a single design or a limited number of related designs for market or nonmarket exploitation'" (Raasch, Herstatt and Balka, 2009). It has recently received significant attention following the publication of Open Design Now (van Abel et al, 2011), a collection of essays documenting the history, practice and future direction of open design.

It should be made explicit at this point that open design differs significantly from the similar sounding 'open innovation'. First defined by Chesbrough (2003), open innovation is

> **"a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, ibid: p. xxiv).**

Whilst open innovation requires that manufacturers or brands open their innovation initiatives to accept input from those outside the company, it in no way requires that those 'outsiders' are given access to, or ownership of, the innovations or products that result. This is clearly different to open design, which Katz (2011: p. 63) characterises as follows:

> **"a design is an open design if it bears four freedoms. One: The freedom to use the design, including making items based on it, for any purpose. Two: The freedom to study how the design works, and change it to make it do what you wish. Three: The freedom to redistribute copies of the design so you can help your neighbour. Four: The freedom to distribute copies of your modified versions of the design to others so the whole community can benefit from your changes. Access to the design documents is a precondition for these freedoms."**

Within this classification therefore, open design products are those whose IP rights have been relaxed by the owner such that their conception and/or specification and/or design and/or manufacture may be changed with direct consumer input. Subsequent IP rights accrue to the consumer, though a condition of some open source licences is that subsequent works must be offered under the same terms (see for example the ‘Attribution-Share-Alike’ licence from Creative Commons).

6.2.8 Opened Design Products

Despite the general acceptance of Katz's definition of open design (see also, for instance, Avital, 2011: p. 55), the strict conditions of the definition means that products which allow modification but which restrict distribution (for example) cannot be classed as open design. For this reason a new term, 'Opened Design', has been conceived by the author to describe products whose IP rights have been relaxed by the owner, but not to the same degree as with open design. Opened design products are therefore those whose original specification and/or design may be changed with direct consumer input. Subsequent IP rights may accrue to either the consumer or the original owner, depending on the terms of the license.

Opened design as a recognisable genre of products can first be identified amongst video games, specifically those played on a PC. Increasing internet access amongst gamers saw the rise of fan-based websites and the sharing of knowledge needed to ‘mod’ different games (Postigo, 2003) - change the game’s code to introduce new rules, characters, scenarios, etc. Rather than attempt to stamp out this IP-infringing activity, games companies recognised the value it brought to their products in terms of increasing the longevity of sales, bug fixing, market research and prototyping of new concepts, all of which were carried out, for free, by dedicated hobbyists. Nowadays many PC games include software development kits (SDKs) which allow the game’s rules and artwork to be modified, whereas others are coded in ‘friendly’ software formats to make modification and rewriting easier, such that "the initial release of a computer game is just the starting point for an extended process of user adaptation, which makes the game richer and extends its life," (Leadbeater, 2006, p.8).

6.2.9 Consumer Design Products

Consumer design refers to products whose specification and/or design and/or manufacture may occur with direct consumer input. Although the term 'consumer design' has been used in other contexts (for example Ciccanteli and Magidson (op. cit.) use it as an alternative to consumer idealized design, itself a pre-cursor of user centred design), within the authors' research it is used to describe a consumer engaged in the process of altering a product's plastic form, for functional or aesthetic reasons. In some instances it may be seen as a development of mass customisation, one which moves beyond the configuration of features to a more 'freeform' interaction, but in other instances it represents the unauthorised modification of a product's design.

Table 6.1 below provides a summary of the points discussed above.

	Definition	Specification	Design	Manufacture
Conventional Products	No	No	No	No
Bespoke Products	No	Yes	Yes	No
Customised Products	No	Yes	Yes	Yes
User Centred Design Products	No	No	No	No
Co-Design Products	Yes	Yes	Yes	No
Mass Customised Products	No	Yes	Yes	No
Crowdsourced Products	Yes	Yes	Yes	No
Open Design Products	Yes	Yes	Yes	Yes
Opened Design Products	No	Yes	Yes	No
Consumer Design Products	No	Yes	Yes	Yes

Table 6.1. Summary of Direct Consumer Involvement in Industrial Design

6.4 A CLASSIFICATION OF CONSUMER INVOLVEMENT IN INDUSTRIAL DESIGN

Although the categorisation performed in Section 6.2 was a necessary first step, it does not provide a useful differentiation between all industrial design methods with regard to the scope or effectiveness of consumer involvement. From Table 6.1 (above) there is no difference, in terms of consumer involvement, between bespoke products, mass customised products and opened design products, for example. It was therefore necessary to map these methods in a way which would reveal which were most successful at generating genuinely unique, consumer-designed products. Figure 6.2 shows a classification of the types of consumer involvement in industrial design defined above, mapped against two axes: the degree of consumer involvement and the degree of the designer's commitment to that involvement. The reasons for choosing these two axes are examined below.

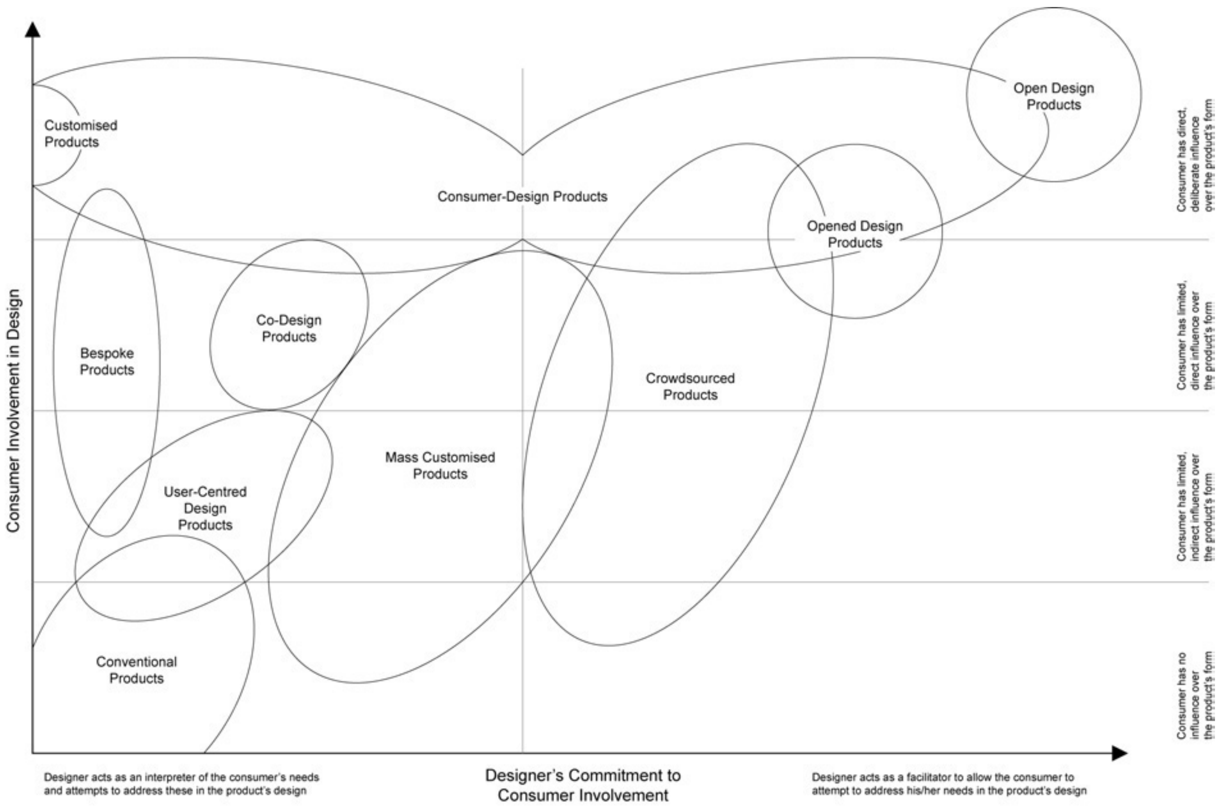


Figure 6.2. A Classification of Consumer Involvement in Industrial Design.

6.4.1 The Consumer's Involvement

An important point which should first be highlighted is that this classification considers the involvement of those consumers who actively engage in the product development process, rather than those who merely purchase the resulting product. In some instances the purchaser may be engaged in the process; this is almost always the case with mass customised products, for instance. Co-designed products illustrate the possibility of an alternative scenario however: one in which a consumer is recruited as part of a co-design exercise, is highly influential in the definition, specification and design of a product, but chooses not to buy that product when it goes on sale. Conversely the purchaser of a crowd-sourced product may have had no involvement in its creation. Accounting for the purchaser in these scenarios would therefore confuse the boundaries between the different approaches defined above, as well as significantly reducing the value of the classification.

The extent of consumer involvement is based on two factors. Firstly, as described earlier in this chapter, the product development process may be divided into four distinct phases: conception, specification, design and manufacture. The more phases that a consumer is able to influence, the higher the degree of overall involvement; thus open source products represent a high degree of involvement because the consumer has the possibility to exert influence in all four phases. Conversely a conventional product, which offers the consumer no possibility of influencing a product's development at any phase, represents a low degree of involvement. Secondly, consumer involvement is also measured by the effectiveness of the consumer's influence, i.e. the extent to which their needs and opinions affect the creation of the product. Bespoke products, for example, allow the customer to influence only two phases: specification and design. Many bespoke products reflect this limitation and are only slight variations of a standard product, perhaps made in a unique colour or material, or incorporating an engraved logo. On the other hand bespoke offerings also allow for the creation of highly individualised products, a handmade shoe or bicycle for instance, 'tailored' to the unique measurements of the customer. Thus the bespoke category spans an area ranging from a relatively low to a relatively high degree of consumer involvement.

This research is concerned primarily with the involvement of consumers in the industrial design process, as such both the degree and the effectiveness of consumer involvement are manifested in the three dimensional (3D) form of a tangible object. It is therefore possible to subdivide the vertical axis of consumer involvement into four regions corresponding to an increasing influence over the product's form. At the lowest level of involvement the consumer has no influence over a product's shape. This is the region in which most conventional products appear, offering consumers no possibility of influencing the product's design. Many mass customised items, despite giving consumers opportunities to decide the configuration or performance of their products, also appear in this category, since the type of customisation offered has no consequence for the product's external form.

At the second level of consumer involvement the consumer is able to exercise limited, indirect influence over a product's 3D form. Such influence can take two directions; in the first, particularly with regard to user-centred design products, it is exerted through interactions with the product's designer, whose expertise determines the extent to which those interactions modify the object's design. Whilst the theoretical possibility exists for the consumer to significantly influence a product's form in a user-centred design process, any such influence is mediated through the designer and therefore always applied indirectly. The second method of influence applies particularly to mass customised products, and occurs when a product's form (usually its size) can be changed to accommodate a certain fit. Thus a consumer involved in mass customising a shoe (for example) can only influence its form in a way which is both limited (to the size of the customer's foot) and indirect (if a particular size is not offered then no further opportunity for involvement is possible).

It is at the third level of involvement that the consumer begins to exert direct (albeit still limited) influence over the product's 3D form. In the majority of cases this influence will occur through the consumer's selection of parts, components or modules which, when assembled, modify or dictate the product's shape. The ability of selections to modify a product's shape may be relatively minor (for example choosing to add a sunroof or rear spoiler to a new car) or they may extend to control of the whole of the product's form (for example when determining a kitchen's layout using standardised cabinets and appliances). In both cases however, the opportunity to influence form is limited to the number and type of components available; in that sense the form is always expected, even if it cannot be precisely predicted.

Only at the fourth level of consumer involvement do opportunities for true consumer design arise. In this region of the classification, influence over the product’s 3D form is both direct and deliberate, i.e. the consumer can define form without the need for the designer’s approval and without the limitations of predetermined modules or components. This is not to say that no constraints exist - clearly the consumer-designed object will need to take account of the realities of production and operation in the same way that any professionally-designed object would. However the key determining factor for a product to appear at this level in the classification is whether its form can be freely manipulated within the constraints necessary for its manufacture, and more importantly, whether the results of this manipulation can be manufactured without the designer's explicit consent.

6.4.2 The Designer's Commitment

The commercial realities of the design and mass manufacture of products are such that the industrial designer is rarely at liberty to act as a free agent. Issues of branding and corporate strategy combined with a company’s manufacturing expertise, supply chain network and even financial status will influence the kind of product a designer is asked, or permitted, to design. That said, at the point at which a product brief is conceptualised through to the point where a final design is agreed, the designer must act as arbiter of all these influences. This chapter therefore refers to the ‘designer’s commitment’, whilst acknowledging that the designer may not have direct responsibility for all of the decisions s/he is required to implement.

The designer’s commitment to consumer involvement in product creation is partly a measure of how much autonomy the consumer has in making decisions, but also of how much autonomy the designer consciously ‘hands over’ to the consumer. Customised products allow the user considerable freedom in decision making about a product’s functionality, its appearance and the tools and methods used to customise it. Nonetheless, such decisions are taken *in spite of* the designer’s vision, rather than as a result of his/her intent. Thus customised products exhibit a high degree of consumer involvement, but a very low degree of designer's commitment. This can be contrasted with opened design products, where the designer must make a deliberate decision, not only to allow the consumer to change the product, but to help the user to do so, either by providing the tools or by supplying the product in an easy-to-modify format.

When looking at the horizontal axis of Figure 2, on the left the designer acts as an interpreter of the consumer's needs and wishes. Whether these needs are understood by acting on intuition, or reading research reports, or even talking directly to the consumer, the power to make decisions about the product's creation, its form and its ultimate usage lie with the designer and the designer's clients. As explained in Chapter 4, this establishes a relationship in which consumers are disempowered relative to designers, who are presented as experts in what consumers want. Perhaps understandably, this is a situation which many designers are keen to see perpetuated. Krippendorff (op.cit: p. 268), for example, writes that

> **"medicine could be a good model for design... [they both] are practical professions that fix things: in the case of medicine, restoring biological normalcy and in the case of design, proposing something better... Medical discourse enjoys an enormous respect by nonpractitioners. Patients are in awe of its vocabulary, and know just enough to find a doctor and pay the bills for treatment often beyond their comprehension... design discourse can acquire a comparable understanding if it adopts an easily recognizable and productive boundary."**

Leaving aside the somewhat myopic view that medicine is necessarily reactive, rather than preventative, the undisguised insinuation is that those with no formal training should not be allowed to practice design, any more than those with no training should be permitted to conduct surgery. In Krippendorff's opinion, the consumer's role is simply to pay for design without understanding how it is conducted. Similar sentiments were expressed by Marc Newson when, in a debate at the premiere of the film *Objectified*, he declared that he "lack[ed] faith in consumer's ability to know what they want," and that "democratisation ultimately pollutes design," (quoted in Pacey, 2009).

However, as the different design methods presented above demonstrate, some design professionals have begun to challenge this point of view. In moving along the horizontal axis from left to right, increasing the amount of authority the consumer has to affect decisions about a product's creation, it becomes clear that not only does the nature of the designer's relationship with the consumer change, but also the nature of the designer's own work (and, consequently, the designer's relationship to his/her profession). At a certain point, the traditionally unchallenged power relationships between designer and consumer changes: having passed this point, the designer no longer acts as an interpreter of needs, but instead as a facilitator (Siu, 2003) to allow the consumer to address his/her own requirements. Such a designer will have given up a significant degree of control over the way in which the product manifests itself, and will have entered the realm of what Tonkinwise (2005) describes as the design of "things that are not finished." Increasingly developments in manufacturing technologies which allow low volume or one-off production have been recognised as offering such potential (Campbell et al, 2003). The consumer design products which these technologies give rise to are discussed further in Section 6.5.

6.5 CONSUMER DESIGN

The realisation that some consumers are both interested and skilled enough to design and manufacture their own products has provoked considerable debate amongst practising designers, including an IDSA conference dedicated to the subject in Summer 2010[17]. Nonetheless the scope of consumer design, and the extent to which consumers are able to act as industrial designers, remains widely contested.

The primary criteria for a product or process to be considered an example of consumer design is that part of the design activity is undertaken by a non-professional, without subsequent influence by a professional designer. This lay-design may be the work of a lead user as conceived by von Hippel (1986), a so-called pro-am (professional-amateur) as described by Leadbeater and Miller (2004), or a relatively unskilled consumer who has been provided with easy-to-use tools. It is not necessary for the consumer designer to have been involved in every aspect of Fiell and Fiell's (op. cit) industrial design process, any more than a professional designer must be involved in the entire process to be considered an industrial

17. See http://idsa.org/category/tags/diy-coverage

designer. However the consumer must have been given free rein to influence the product's 3D form within the constraints of their own skill or the tools provided. Essentially, the freedom of the consumer-designer to make mistakes in determining a product's form is what defines consumer design.

Within the definition of consumer design a number of sub-sections exist as shown in Figure 6.3. These broadly relate to the level of freedom given to the consumer as the designer's commitment to consumer design increases, and are considered further below.

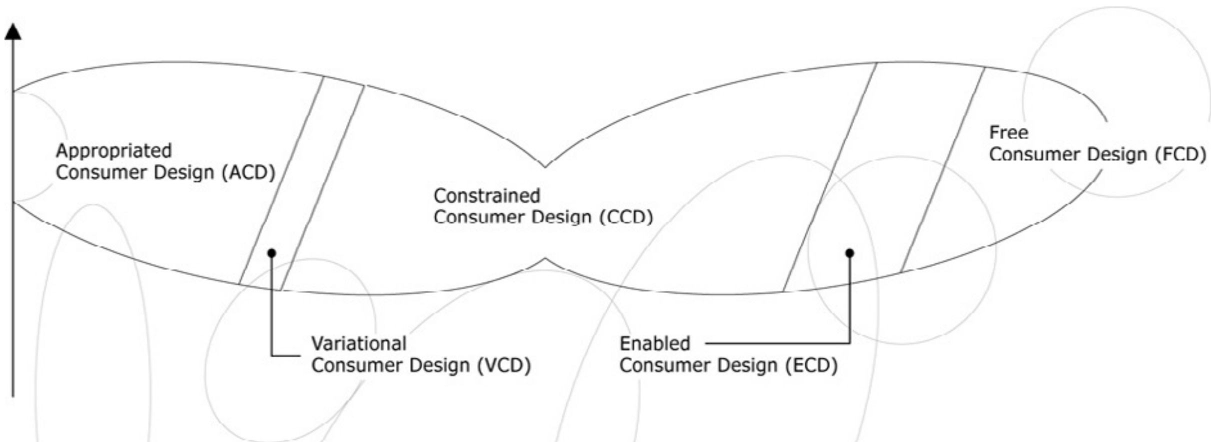


Figure 6.3. Types of Consumer Design.

6.5.1 Appropriated Consumer Design (ACD)

Appropriated consumer design refers to design activities which the owner of the product's IP rights has not sanctioned. One manifestation of ACD is the previously mentioned modification of cars to create hot rods, a subculture which nowadays is mainstream enough to have spawned a hit MTV series, Pimp My Ride[18]. ACD also emerges in situations where consumers are unable to purchase goods to satisfy their needs and are forced to recycle or reuse products in creative ways; examples include tools fabricated by prisoners as documented by Temporary Services (2003) and products fashioned from waste by residents of the former Soviet Union (Arkhiov, 2006). A similar phenomenon is apparent in the use of discarded or waste products as the basis of new items: Geekware[19], for example, reuses

18. See http://www.pimpmyride.com/

19. See http://www.geekware.ca/

electronic waste to make jewellery and household products.

Whilst the examples above rely on the skills of an expert amateur to craft a new product form, it is also possible to envisage a future where additive manufacturing technologies and the sharing of 3D CAD models make ACD much easier for the unskilled consumer. The Apple Collection[20], for example, is a website where fans upload designs of new Apple products. Were these fans to create CAD models rather than just images, it would be relatively simple for someone with no CAD modelling skills to nonetheless download the file and 3D print a new casing for their iPod. On the fringes of legality, such designs might be sold or made freely available. They would have none of the assurances (of safety or functionality) afforded by an established brand, but at the same time would likely explore design directions which no established brand would countenance.

6.5.2 Constrained Consumer Design (CCD)

One way in which brands might counter the rise of a "Pirate Bay[21] of products" (Scott, 2009) would be to provide their customers with opportunities to engage in constrained consumer design. CCD refers to the use of systems and tools, often software based, which simplify design and manufacturing tasks whilst at the same time setting limits on what such tasks can achieve. CCD systems are therefore subject to many of the same conditions and limitations as mass customisation systems, but differ by providing the opportunity for freeform manipulation of a product’s shape. The advantage to brands of CCD over ACD is obvious: it allows the retention of a degree of control over the forms, materials, colours, etc. (and thus the design language) which the consumer designer is able to work with.

CCD also offers significant advantages to the consumer: any product resulting from a commercialised CCD system would have the brand’s promise that it would function safely, that it complied with trade standards and consumer law, that it fitted and worked with other products if required to do so, and (possibly) that it came with a manufacturer’s warranty. The

20. See http://www.theapplecollection.com/design/macdesign/index.html

21. The Pirate Bay is a file-sharing website which has become infamous for facilitating the unauthorised downloading of (in particular) digital music and video files.

Lego Digital Designer (see Chapter 10) is an example of a system which offers exactly these reassurances, giving customers the opportunity to create unique products within the constraints imposed by the use of standard Lego bricks.

6.5.3 Variational Consumer Design (VCD)

Variational consumer design is a largely conceptual category which refers to a scenario in which the consumer subjects a 3D CAD model to software algorithms which generate new design variations. One example is that of the *Tuber* system by Lionel Theodore Dean (Atkinson, 2008), in which a computer script continually morphs the design of a lamp, and the consumer is able to 'freeze' the design at any point. A trial involving consumer designers in the VCD of a USB memory stick is described in Chapter 9.

VCD sits between ACD and CCD in the classification since it is able to work with either authorised or unauthorised CAD models, however in practice it is more likely to appeal to proponents of CCD due to its inherent ability to constrain (within its algorithms) the limits of variation. VCD is unlikely to interest lay designers who wish to exercise their personal creativity, however it may appeal to those who would prefer simply to choose from a library of possibilities. As such, a commercial application would likely need to limit the infinite number of possible outcomes generated by its algorithm, and present only those whose differences can be recognised by the consumer.

6.5.4 Enabled Consumer Design (ECD)

Enabled consumer design refers to scenarios in which the consumer is given access by the owner of a product's IP rights to the drawings or CAD files which describe its design; at the same time the consumer is given permission to modify the design using any tools or techniques available to him/her. One of the earliest examples of ECD was that created by Ronen Kadushin[22], whose *Open Design* series of products allowed users to download Adobe Illustrator files of designs for lamps, tableware, and furniture, amongst others, under a

22. See http://www.ronen-kadushin.com/Open_Design.asp

Creative Commons 'Attribution - Non Commercial - Share Alike' licence[23]. The files could then be modified, if required, and used to laser cut appropriate materials in order to manufacture the products. A similar scenario also exists within the Ponoko manufacturing system on occasions where a product's original designer makes the plans available, either for free or for a fee. ECD, with its requirement for expertise with certain design tools, clearly holds attractions to expert amateur designers rather than less skilled consumers; it also places considerable responsibility on the consumer by offering no assurances as to the safety or functionality of the resultant product. ECD thus allows greater design freedom than CCD, but also entails greater risk.

6.5.5 Free Consumer Design (FCD)

Free consumer design is very similar to ECD in that the consumer is given access to a product's plans as well as permission to modify them. Crucially however, ECD only allows the consumer to manufacture products for their own use. With FCD, all IP rights are given up by the original designer, allowing the consumer to then offer a modified design to others, either for sale or for free. Few examples of FCD exist, though one notable example is the Openmoko FreeRunner[24], a mobile phone whose designers made available the original CAD files (in Pro Engineer and .stp formats) such that anyone could modify, improve or redesign the product.

6.6 CONCLUSION

This chapter has developed a graphical classification of industrial design methods. By mapping these approaches against two axes - the level of consumer involvement and the level of designer commitment - it has been possible to demonstrate the power relationships between consumer and designer (i.e. the relative importance of the consumer's opinions and skills) in each method.

These power relationships have important implications for both practising designers and the

23. See http://creativecommons.org/licenses/by-nc-sa/3.0/

24. http://wiki.openmoko.org/wiki/Introduction

manufacturers and brands which employ them. Figure 6.4 shows a rising line, from conventional products through to open source products, representing the degree of control *given to* consumers. The converse of this is a falling line representing the degree of control *taken by* consumers, often without the sanction of those who own the product's IP rights. In an age of mass manufacture, where access to the means of production was largely restricted

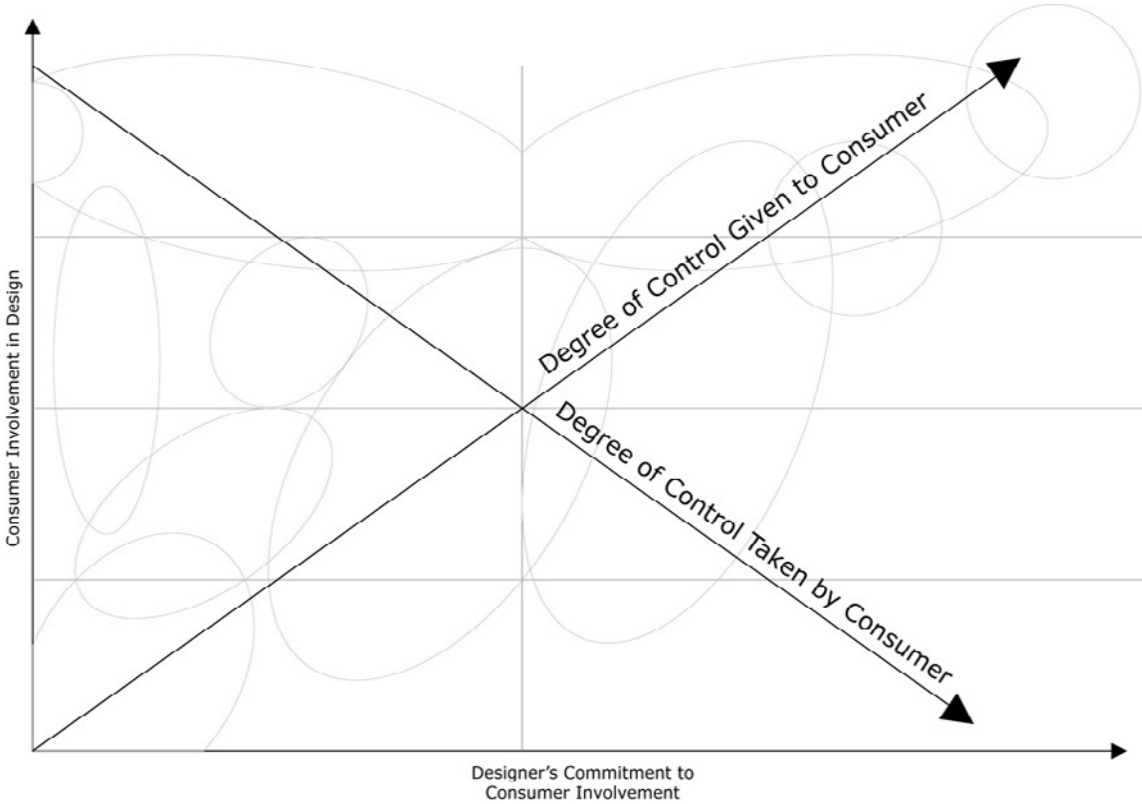


Figure 6.4. Degrees of Control in the Designer - Consumer Relationship.

to professional designers and engineers, the opportunity for consumers to design and manufacture their own products was limited. Direct digital manufacturing (technologies such as 3D printing and laser cutting), with no requirement for expensive tooling, will continue to make it increasingly easy for consumers to gain access to the means of production, through services such as Ponoko[25] and Shapeways[26]. Cheap or free CAD modelling software such as Google SketchUp[27] or 3Dvia Shape[28] (as well as pirated versions of more sophisticated

25. See http://www.ponoko.com

26. See http://www.shapeways.com

27. See http://sketchup.google.com

28. See http://www.3dvia.com/products/3dvia-shape/

packages) will allow consumer designers to create 3D models in the same formats as their professional counterparts. For those less skilled, libraries such as TurboSquid[29], GrabCAD[30], Cubify[31] and Google's 3D Warehouse[32] will give access to ready-made CAD models. At such a point, designers may find the need to answer a decisive question: should they facilitate the growing demands and skills of consumers, and help to make the consumer design of products easier, or should they continue to believe in their own abilities to design the best products to answer consumer's needs?

29. See http://www.turbosquid.com

30. See http://grabcad.com
31. See http://cubify.com
32. See http://http://sketchup.google.com/3dwarehouse/

CHAPTER 7.

Design for Bespoke Customisation - A Case Study of the Ulysse Nardin *Chairman* Phone.

7.1 INTRODUCTION

The promise of mass customisation, as exemplified by Pine II's visionary definition in Chapter 3, is that it offers consumers the opportunity to create uniquely designed products whilst incurring costs more closely associated with mass manufactured goods. However by virtue of their reliance on mass production paradigms (to reduce costs), the reality of current MC systems is that they allow the consumer to design only in a limited sense, one which might, more accurately, be termed 'configuration'. Another approach to customisation is that offered by limited editions and bespoke design, which was introduced briefly in the previous chapter. Typically bespoke products will exhibit a considerable degree of hand-made craftsmanship, which has led to their association with high cost, luxury goods. However this non- mass production approach offers a significant opportunity to learn how to design the unfinished products which will subsequently be finished with, or by, the customer.

This chapter presents a case study of the design of a luxury mobile phone (see Figure 7.1) produced by Ulysse Nardin, a traditional Swiss watchmaker. The industrial design concepting, development and detailing was undertaken as part of the author's professional design practice,

Figure 7.1. Ulysse Nardin *Chairman.*

Matt Sinclair Design, between March 2008 and October 2010, in close collaboration with Ulysse Nardin brand managers and specialist vendors which supply the Swiss watch industry. Whilst not intended to be an exclusively bespoke product, the *Chairman* (as it came to be known) was designed with the goal of serving as a platform for both 'standard' and 'limited edition' designs, as well as allowing for bespoke variants. It therefore followed a 'three-tier' approach commonly found in the luxury watch market, and demonstrates the importance of a flexible product architecture which allows for future redesigns. It also represents what might be regarded as the 'cutting edge' of customisation of high-tech products and thus offers useful insights with regard to the way brands might help enable consumer design.

[Please note that this chapter makes extensive reference to a number of technical and trade terms employed in the watch and phone manufacturing industries. Please refer to the

Glossary on pages xxi - xxiv for an explanation of terms.]

7.2 THE SWISS WATCHMAKING INDUSTRY

Watchmaking in Switzerland first appeared in the mid-19th Century, initially as a response by goldsmiths to Calvinist reforms which prohibited the wearing of jewellery (Federation of the Swiss Watch Industry FH, 2011). By the end of the century Geneva had established a reputation for its high quality timepieces and in 1601 the world's first Watchmakers Guild was established. As the city became crowded with watchmakers (by 1790 Geneva exported 60,000 watches annually) many moved to the Jura Mountains region, which remains the centre of Swiss watchmaking today.

Unlike the English watch industry, which in the 18th and 19th centuries was driven by the demands of maritime exploration and trade (Smith, 2009), in Switzerland improvements to watch design were driven largely by fashion and taste (Glasmeier, 1991). This placed the Swiss industry in a commanding position as watches became more affordable, and through the adoption of mass production technologies at the beginning of the 1900's Switzerland consolidated its domination of the world watch market (Knickerbocker, 1974).

This domination continued until the 1970's, when the introduction of quartz technology, combined with integrated circuitry, decimated the Swiss industry. Competitors from the U.S., Japan and Hong Kong were able to produce watches which were simultaneously much cheaper but also far more accurate, and in ten years Swiss exports fell from 40% of the world market to only 10% (Glasmeier, op. cit.). Factories were forced to close, and many brands consolidated or were bought out.

Throughout the 1980's and to the present day, the Swiss watch industry underwent a remarkable transformation, on two fronts. Firstly SMH (one of the conglomerates formed by the merging of previously independent companies) introduced Swatch, a precision engineered quartz analogue watch, which once again signalled Swiss dominance of the low-cost fashion market (Norman and Verganti, 2012). Partly on the back of this success (Swatch Group owns the Breguet, Blancpain and Omega brands, amongst others), Swiss watchmaking then aggressively marketed itself as the epitome of 'fine timekeeping'. The notion of Swiss-made luxury was carefully managed (in order to claim 'Swiss Made', at least 50% of components by value must be Swiss, and assembly and inspection must take place in Switzerland) and assiduously protected: the success of this strategy is demonstrated by the statistic that Switzerland manufactures only 2% of the world's watches by volume, yet accounts for 60% of the market by value (Goodman et al, 2010). An important aspect of positioning Swiss watch brands has thus been the notion of exclusivity - the idea, in the mind of the consumer, that any given model is relatively scarce.

Manufacturers have achieved this brand positioning in a number of ways, all of which rely on their products being customisable. Firstly a single model will typically be offered in a number of colours and material variants. Secondly the same model will be offered as 'limited editions' - a single production run which introduces a new product variant, which is withdrawn from sale once the production run is finished, even if demand is high. The Ulysse Nardin Maxi Marine Diver, for example (Figure 7.2), is available in 18 standard configurations and 11 titanium variants, and has been offered in 18 limited editions, six of which are no longer available. Finally a small number of highly valued (typically wealthy) clients will request a bespoke treatment of the design, which will not be offered to other customers.

Bespoke pieces are generally considered confidential and it is rare to find details of either the designs or the customers who commissioned them. An exception is Andrew Luff, a collector who has ordered a number of bespoke pieces, one of which is based on the Ulysse Nardin Diavolo model. In creating Luff's watch[33], Ulysse Nardin engaged in a typical bespoke design exercise, whereby a commissioned piece is based on a model that already exists, and the customisation will "include dials and cases with personalized designs and engraving as well as technical details such as adding functions to existing calibers... Movement parts, such as rotors and bridges, can be hand-engraved or skeletonised as the client wishes" (Doerr, 2009). In the case of Vacheron Constantin, whose 'Atelier Cabinotiers Special Order' service offers personal customisation of the brand's watches, the cost of a bespoke piece will begin at 120% of the base price, ranging from $29,900 to $49,900 (ibid.).

33. See http://ulyssenardin.watchprosite.com/show-forumpost/fi-13/pi-5106698/ti-768208/s-0/

Standard Editions.

Titanium Editions.

Limited Editions.

Figure 7.2. Ulysse Nardin Maxi Marine Diver Models

7.3 ULYSSE NARDIN

Ulysse Nardin is an independent (i.e. not part of a larger conglomerate) watchmaker, based in Le Locle in the Jura mountain region of Switzerland. Whilst it does not have the public recognition of brands such as Rolex or Patek Phillippe, amongst watch connoisseurs and collectors it is regarded as one of the most innovative (Barge, 2012), having been awarded more patents than any other watchmaking company.

Established in 1846, the company initially made marine chronometers before expanding to manufacture pocket and wrist watches. Patents and prizes awarded in the late 19th and early 20th centuries attest to Ulysse Nardin's reputation as the leading pocket chronometer maker (Jaquet et al, 1970: pp. 177-179), but after World War 2 the brand's reputation diminished and it existed only as a minor player among the Swiss manufacturers. This changed in 1983 when the company was acquired by Rolf Schnyder, with a vision of re-establishing the company's reputation as a premium watchmaker. Schnyder employed Dr. Ludwig Oechslin, who was known for having restored the Vatican museum's Farnesian clock, to design a wristwatch sized astrolabium (an instrument to measure the altitude and position of celestial bodies). Unveiled in 1985, the *Astrolabium Galileo Galilei* was a critical success[34], entering the Guinness Book of World Records as the most complex watch ever made (Paige, 1999), and presenting the brand's vision of itself once again as a leading Swiss watchmaker. Nowadays the company is known for other innovations, particularly its perpetual calenders and jaquemarts, its 'Freak' carousel tourbillon, and the use of synthetic materials such as silicium and polycrystalline diamond within its watch movements.

7.4 BRIEF AND PROJECT SCOPE

[Please note - a detailed diary of this project is provided in Appendix 7.1]

In March 2008, Matt Sinclair Design was approached by Morten Neilsen of Scientific Cellular Innovations (SCI) and invited to pitch for a project to design a luxury mobile phone for the

34. See http://www.ulysse-nardin.ch/en/swiss_watch_manufacturer/Collection/Complications/Trilogy_Set/999-70.html

Ulysse Nardin brand. Neilsen had recently signed an agreement with Rolf Schnyder to investigate the feasibility of such a product, with the understanding that Neilsen would manufacture the phone under license if the project was successful. Matt Sinclair Design worked with Neilsen, and later UN Cells (the newly-formed company set up to manufacture the phone) until October 2010, through development and production, and was responsible not just for the *Chairman* but also its accessories, packaging and numerous colour and material variants.

The brief was delivered verbally during a telephone conference 07.03.2008. As is common in such speculative, market-oriented projects, the brief remained a 'work in progress' throughout the course of the project and thus some of the initial requirements were later superseded. The author's notes reveal that the brief called for:

- A high-end luxury mobile phone, based on the brand heritage and technologies of Ulysse Nardin, a Swiss watch manufacturer.
- Price range should be comparable to watches using the same materials, based on 'simple' movements (i.e. non complications). Proposal is three tiers: $12,500, $25,000, $50,000.
- Production volume was expected to be 5,000 per annum across the three tiers.
- Other brands, notably Vertu and Goldvish, demonstrate a viable market opportunity. Neither have an established heritage, which provides an advantage for a brand such as Ulysse Nardin.
- Descriptors include conservative, classic, impeccable quality, understated, connoisseur appeal,
- Typical customer will be male, mid 30's - mid 50's. 50% of sales expected to be in Russia.
- Product should be a coupling of analogue and digital. Key to this is the incorporation of a watch rotor to provide charge to the battery.
- Modularity / Customisation is a key criteria. The product's manufacture and assembly should be flexible to allow for alternative material and design configurations, special

editions and bespoke customisation.

- A modular approach also allows for the future possibility of licensing the platform to other luxury brands.
- Integrity of materials is non-negotiable. No plastic. No ‘fake’ materials (plating, metallic painting, etc.).
- All parts will be hand finished. The product will be hand assembled. Production volumes favour machining rather than tooling wherever possible.
- Tactility is crucial to the impression of quality. This means tactile feel through keys etc, but also the weight of the product, surface finishes of materials.
- Some quotes:
    - “First, ‘I must touch’. Then ‘I must own’.”
    - “You can’t get too expensive but you can get too cheap.”

7.5 RESEARCH AND INSIGHTS

As can be seen above, the original brief contained very little information regarding either the Ulysse Nardin brand or its customers. Therefore before any design concepting could begin it was necessary to research the brand in order to gain an understanding of the qualities that customers would expect from any product which Ulysse Nardin might release.

Typically research of this kind might be carried out with focus groups of existing customers. However at this stage the project was highly confidential - Ulysse Nardin had not committed to developing the phone to production, and if customers were to know that such a project had been initiated, and then cancelled, it could be damaging to the brand. Furthermore, the luxury goods industry tends to operate outside of a 'textbook' approach to design and market research (Tynan, McKechnie and Chhuon, 2008), often utilising a counter-intuitive approach of appearing *not* to seek customer guidance, in order to create a perception of exclusivity. (In reality luxury brands do conduct market research, however it tends to be informal, at social events for example, rather than formalised focus groups, questionnaires etc. (ibid.).) Research was therefore conducted in the following ways:

1. Examination of Ulysse Nardin's products, both current and historical, through the company's website and the book 'Making of a Masterpiece' (a history of the company).
2. Reading (but not participating in) discussions and comments on internet forums used by connoisseur owners of Ulysse Nardin watches, many of whom owned a number of different models of watches, specifically:
   - Timezone (http://forums.timezone.com/index.php?t=threadt&frm_id=29) and
   - PuristsPro (http://ulyssenardin.watchprosite.com/)
3. Discussion with Bobby Yampolsky, country agent for Ulysse Nardin for North America, based in Boca Raton.

As a result of this research a number of insights were reached regarding both the brand and the ways that these findings could influence the design of the phone, which were summarised in a document entitled 'Ulysse Nardin Brand DNA'. Ulysse Nardin's watches were divided into four categories - Technical, Classic, Complex and Decorative, of which Technical and Classic were judged to be the best fit for the project. In discussion with Neilsen, the two most important drivers for the next stage were agreed to be:

1. The Technical and Classic styles should be treated individually, rather than trying to combine them into one aesthetic, which could dilute the impact of the design without remaining true to either style.

2. Compared to other brands, Ulysse Nardin watches appeared less 'severe' and less 'machined'. They were often more detailed and decorated than the plain, stark surfaces of competitors. Edges were more rounded, and metal surfaces were generally more polished (i.e. glossy). The philosophy, which should be carried over into the *Chairman*, was that although these were undoubtedly 'masculine' products, they were not being purchased by customers who felt the need to assert their masculinity.

As well as arriving at some broad guidelines which would help direct the design of the product, a list of features and details which would help the phone sit more comfortably within the Ulysse Nardin design language was also collated. The intention was not to incorporate all these details into the design, but rather to gain a sensitivity to some of the cues which would identify a particular design as a Ulysse Nardin product:

- Individually numbered products.
- Visible screws on the rear.
- A glass area to reveal the internal rotor mechanism.
- Discrete (i.e. individual) buttons rather than grouped buttons. This implied smaller buttons with space around, rather than larger buttons whose edges touch.
- Buttons should be prominent from the surface of the product, rather than flush with the surface.
- Glass should be the same as that used in the watches.
- Micro textures and patterns under the glass. Could also be replicated on the rear of the product.
- Emphasis paced on the thickness of the product, rather than the width or length.
- Analogue dials to display information such as date or time zone.
- Colours: silver, gold, black, Ulysse Nardin blue. Red for emphasis.
- Possible materials: gold, rose gold, stainless steel, titanium, rhodium, palladium, carbon fibre, zirconium dioxide (or similar ceramic), sapphire crystal, leather.

7.6 DESIGN DEVELOPMENT

The involvement of Matt Sinclair Design in the design development of the *Chairman* phone can be divided into three phases, which are detailed below.

7.6.1 Design Development (Phase 1)

The initial project plan called for CAD renderings to be ready for the BaselWorld Watch and Jewellery Show, approximately six weeks after the brief was delivered. The renderings would be shown to key Ulysse Nardin dealers and valued customers, in order to gauge reaction and judge whether the project should go ahead. Although the timescale was very tight, the non-negotiable deadline meant that making decisions quickly and emphatically was crucial.

Two weeks were spent developing initial concepts based around the two themes - Technical and Classic. This extremely compressed timescale was only feasible because of the author's previous experience working on the design of mobile phones. At the end of this phase 'exploded view' style drawings were presented to show basic architectures and how the break-down of parts would provide for customisation (Figure 7.3). Two concepts (one for each theme) were chosen to progress further.

A third week was spent developing and detailing the concepts, working over the top of engineering drawings of the proposed engine layout to ensure technical feasibility. Adobe Illustrator line drawings were created as an intermediary step before exporting the artwork into Adobe Photoshop in order to create 2D renderings (Figure 7.4). Based on these images the decision was made to go ahead with the Technical concept only. This was based on two factors - the fit with existing Ulysse Nardin products (i.e. how well did the phone concept sit in Ulysse Nardin's overall product portfolio), and the level of customisation possible. The Technical concept had an externally visible chassis, sandwiched between the front A-cover and the rear B-cover. This would provide much greater flexibility, in terms of variability of colours and materials, than the Classic concept which (in keeping with the Classic theme watches) had only A- and B- covers.

A further two and a half weeks were used to build a Solidworks CAD model prior to creating 3D renderings. In the author's professional design process CAD modelling tends to be part of the design development of a product, rather than a recreation, in 3D, of decisions already taken. This was especially true in the case in question, where the compressed timeframe meant less time had been spent checking and refining all the phone's details. Immediately prior to the BaselWorld fair, renderings were made of the front and rear of the phone, in two colour schemes.

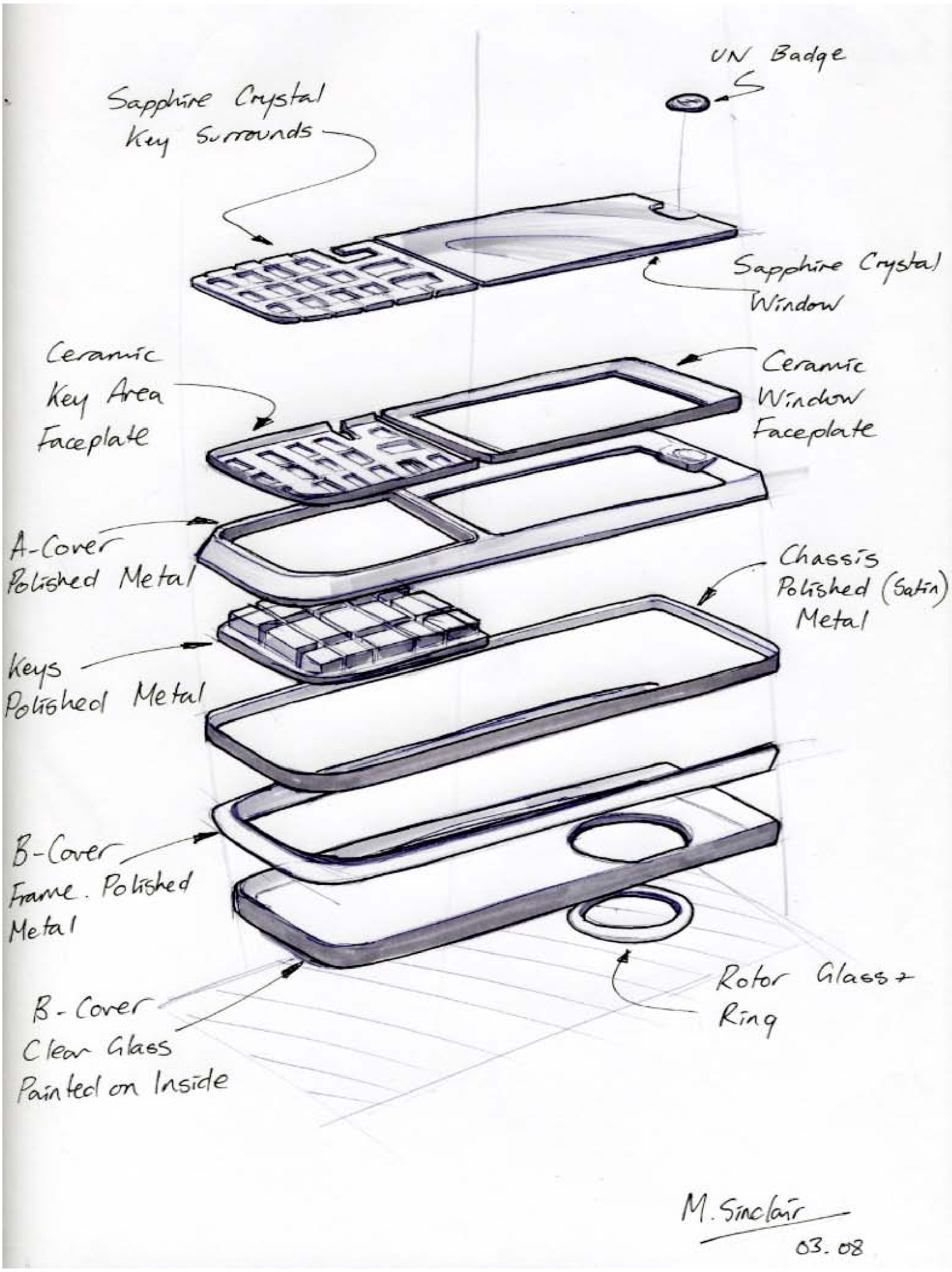


Figure 7.3. Exploded View Sketch of *Chairman* Technical Concept, presented 14.03.2008.

Figure 7.4. Classic (top) and Technical Design Proposals, presented 24.03.2008.

The key decision, based on private showings of the renderings at BaselWorld, was that the project should go ahead to the next stage: an in-depth feasibility study and the production of non-working prototypes (so called 'appearance models'). A first set of models was commissioned based on the CAD data used to create the BaselWorld renderings (Figure 7.5). Simultaneously however, these models were made out of date by developments to the design based on comments from those who had seen the renderings.

Figure 7.5. Appearance model of the Steel and Blue *Chairman* variant

Feedback from the showings led to small aesthetic changes and refinement of details, however one comment, repeated a number of times, caused the project to reassess a fundamental assumption. Until that point, the programme team's belief had been that customers would not place great importance on the phone's technical specification, so long as the performance of key tasks, primarily reception during voice calls, was excellent. The reasoning had been that Ulysse Nardin customers do not buy a watch for its performance (a $20 digital watch would keep time more accurately) but rather that purchase decisions were based on factors such as craftsmanship, reliability, status and brand heritage. However the feedback suggested that, whilst customers did not necessarily expect the highest specification product on the market, they did expect a product in the top 20%, one that would be considered a 'smart' phone. This finding would have considerable ramifications in the next phase.

7.6.2 Design Development (Phase 2)

For two months following the decision to proceed with the project, an engineering feasibility study was conducted, based on the industrial design CAD models. This study looked at both the performance of the phone together with issues regarding material selection, manufacturing processes and vendor capabilities. Based on the report from this study, in June 2008 the design was changed to reflect recommendations, particularly concerning antenna performance, together with the repositioning of some major components (namely the SIM card and battery). The B-cover was split in two, one part of which would be in ceramic fixed over the antenna, with a lower, removable cover over the battery. New CAD models were produced, and a second set of appearance models commissioned.

During the Summer of 2008, the feedback concerning the phone's specification became increasingly pressing, with doubts over whether the hardware developer could accommodate the changes being discussed. Not only had a high performance camera been added to the specification, but the inclusion of a touchscreen now appeared mandatory. At the start of the project the first Apple iPhone had only been on sale for seven months, and opinion as to its future success was divided, with many technical and investment advisors predicting failure (see for example Goldman, 2007; Haskin, 2007; Lynn, 2007; Ries, 2008). A year after its launch however, the iPhone's popularity was proving that a paradigm shift had taken place within the mobile phone market. Not including touchscreen capability increasingly seemed to be non-optional. New concepts were studied which looked at removing most of the keys in anticipation of incorporating a touchscreen, however it was decided that keeping the keys (which it was felt alluded to both professionalism and tradition), whilst also including a touchscreen could be an important Ulysse Nardin differentiator. Eventually, in October 2008

Ulysse Nardin and the hardware supplier agreed to break their contract, a new supplier was appointed, and the design concept evolved to match the new hardware specification.

At the same time as these 'high-level' discussions were occurring, the existing design was also being modified and developed based on concurrent engineering specifications. This is a common activity for any industrial designer who retains responsibility for the design as it moves closer to the reality of production, however the criteria for decision making were unlike any the author had previously experienced. Whereas, with mass manufactured products, designs will typically be revised to reduce part and assembly complexity, improve yield and reduce cycle times, or simply to reduce the bill of materials, with the *Chairman* decisions were primarily made based on whether

- A change would improve the customer's perception of the product's quality, and
- A change would increase the opportunity to customise the product.
- A change would jeopardise the inclusion of the visible rotor on the rear of the product, widely understood to be the product's most valuable USP.

Only rarely were cost issues a deciding factor (one exception being the complex inserts between keys, which were judged too expensive if manufactured in sapphire crystal) - ongoing feedback from Ulysse Nardin's authorised dealers continued to indicate a strong demand for the product, even as its estimated cost rose slightly.

The 2009 BaselWorld fair again provided a crucial deadline, and the change of hardware supplier necessitated a fast-track development plan and redesign. Fortunately there was near-unanimous approval for the existing design, and so the primary instruction was to 'change as little as possible'. Nonetheless the opportunity was taken to refresh the concept, and so, for instance, the bevel running around the A-cover was changed from a flat to a slightly convex profile, giving a more refined reflection in the part's highly polished surface. A more fundamental change was required in the design of the back covers however, due to the use of a different antenna technology, and the antenna's placement in a different position. The materials for the B-cover (ceramic) and C-cover (carbon fibre) were reversed (carbon fibre interferes with radio signals); this had a significant impact later in the project, as the C-cover was both larger and more complex than the B-cover, and produced very low manufacturing yields (less than 40%) in ceramic. This was acceptable only in the most expensive models, and so for the cheaper versions a rubberised plastic (which had previously been consistently rejected) was introduced.

Despite these changes, by the time of the BaselWorld fair five appearance models were completed, together with renderings of six other variants which were included in a sales brochure (see Figure 7.6). As this was the first time the Chairman would be on public display, Design Registration documents were pre-submitted to the UK Intellectual Property Office (see Appendix 7.2).

Figure 7.6. Renderings of the 'Stealth Black' *Chairman* variant

7.6.3 Design Development (Phase 3)

Ulysse Nardin considered the *Chairman's* unveiling at the BaselWorld fair a success, with significant pre-orders and favourable press coverage. Behind the scenes however, things were running less smoothly, and by July 2009 a third hardware supplier was appointed. This once again necessitated a redesign of the existing concept, and since contractual agreements were already in place with some customers, the instruction to change as little as possible was even more strictly enforced. Fortunately the new engine had a higher specification than previously, particularly the display which increased in size from 2.8" (240x400 pixels) to 3.2" (320x480 pixels). An executive-level decision was taken not to increase the length of the phone from its 127.75mm dimension, which caused the size of the keys to be reduced. By late August however, a new design was approved, and Matt Sinclair Design's involvement in the project gradually reduced. For the next 14 months, input consisted largely of approving minor changes and signing off on parts, and creating new colour and material variants.

As has been stressed a number of times, a central driver for the *Chairman* design had been the flexibility to create variants and limited editions. Figure 7.7 shows an exploded view of the 24 individual items whose material and/or colour could be varied, in order to create these new models. It was at this stage in the project that such flexibility proved especially valuable. The *Chairman* was originally marketed at three price points, in three main material configurations, with a total of nine standard models. By exploiting the modular nature of the design, more than 40 new variants were created and customer tested. In addition the author worked on four limited edition variants - two presented at the Monaco Yacht show (an event which Ulysse Nardin sponsors annually), one of which is shown in Figure 7.8, a maritime 'diver' variant, and an enamelled rhodium edition. Furthermore, Ulysse Nardin's own designers were able to create editions using techniques which the author had no experience of, for example the pavé diamond version shown in Figure 7.9 below.

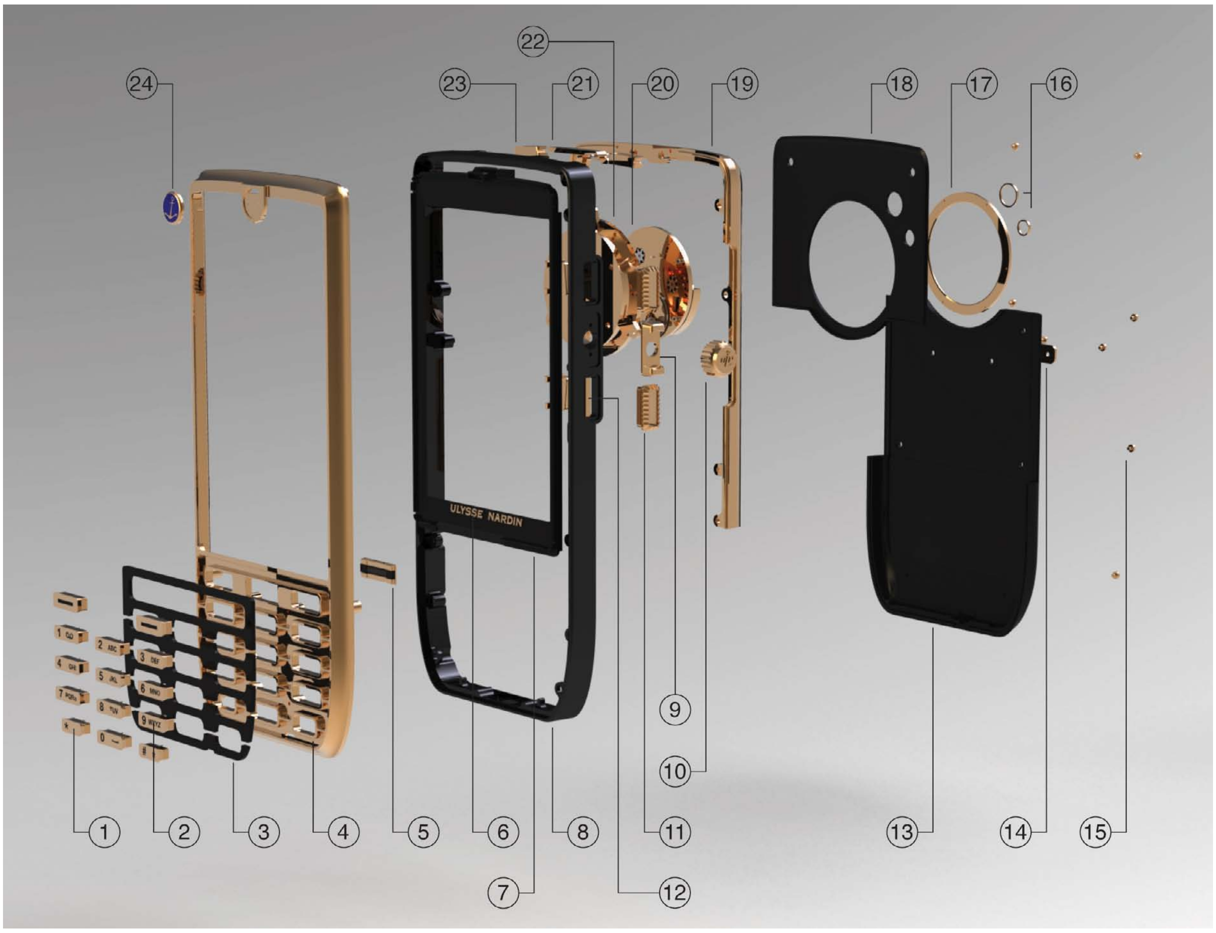


Figure 7.7. Ulysse Nardin *Chairman* Customisable Parts

1. Keys.
2. Key Graphics.
3. Key Inserts.
4. A-Cover.
5. Fingerprint Reader Surround.
6. Window Badge.
7. Window Bezel.
8. Chassis.
9. Crown Surround.
10. Crown.
11. Volume Key Surround.
12. Volume Keys.
13. C-Cover.
14. Limited Edition Badge.
15. Screws.
16. Camera & Flash Rings.
17. Rotor Glass Ring.
18. B-Cover.
19. B-Cover Surround.
20. Rotor Assembly.
21. SIM Card Door.
22. Rotor Surround.
23. Speaker Grille.
24. Earpiece Badge.

Figure 7.8. Detail of the Chairman Black Wave Limited Edition

Figure 7.9. Detail of the *Chairman* Pavé Diamond Limited Edition

7.7 CONCLUSION

The success of the *Chairman* project in design terms can be attributed to two factors. Firstly the degree to which Ulysse Nardin understood its customers meant that once the initial direction had been decided in Phase 1, there was very little equivocation at times when major decisions needed to be made. Secondly the commitment of Neilsen to the chosen design translated into a vision which was shared by the UN Cells team; this in turn led to an avoidance of the tendency to 'hedge their bets' with the concept. The degree to which this is a trait of the luxury industry in general, or Ulysse Nardin in particular, is uncertain. However in the author's experience such an approach is rare amongst clients, who will often try to 'tone down' a design in order to appeal to more customers, in turn diluting the concept which was first thought to be exciting.

Referring specifically to the customisation component of the *Chairman:* of the elements important to the design of a product whose appearance and specification will later be changed, a number of conclusions can be drawn:

1. **The need for a customisable product should be stated at the start of the project, with buy-in from all involved in the program.**

   A project in which this is not stated, or not fully embraced, will likely suffer as 'more important' issues take precedence. Designing and manufacturing a product whose final specification is 'fluid' is more difficult than one whose specification is fixed; it is also likely to be more expensive, particularly if issues of quality and reliability are properly considered. However the alternative - designing a single specification product and then attempting to make it customisable - is unlikely to prove a successful strategy.

2. **The value of customisation should be fully understood.**

   Given the points made above, the additional value that customisation brings to a project should be quantified. In Ulysse Nardin's case, particularly with their watch models, customisation brought the ability to continually refresh and update a product, as well as create limited editions which were an important factor in the customer's perception of exclusivity. A non-luxury product will have different drivers, which it should be possible to state clearly.

3. It is important to understand how the brand is perceived, by itself and by its customers.

This issue must be considered on two levels. At the higher level, how does customisation fit into the brand's image, i.e. would consumers see it as a natural fit or as something that causes friction with the brand's image? This would help determine both the degree of customisation and the way the concept is introduced and marketed to customers. At a more involved level, customisation causes problems for the management of a brand's product design language, particularly if such customisation is done by consumers rather than the brand's designers. The boundaries of customisation, the extremes of what the brand is prepared to allow, must be agreed by those involved in the brand's management.

4. Customer wishes and decisions cannot be fully predicted.

However carefully Point 3 is considered, the customer is likely to request customisations which were unexpected. In the case of the *Chairman*, a relaxed attitude was taken to colour choice - no combination was off-limits provided it proved popular amongst customers. A brand should be prepared for 'undesirable' customisations or designs and know what its response will be - whether to allow or prohibit, and how to manage customer relations in such an event.

5. Customisation is fundamentally linked to production and assembly.

In the case of Ulysse Nardin products, a significant amount of finishing and assembly is done by hand, and production runs are relatively small. Such an approach is particularly conducive to customisation and the production of special editions, as variations in material properties can be accommodated more flexibly than in, for example, a robotic assembly line. On the *Chairman* product for example, the screws used to fix the ceramic B-cover were a different size, and required different torque, than those used to fix the carbon fibre B-cover - this was easily accommodated by the process, not even requiring new jigs. The types of customisation offered should be designed with an awareness of the strengths and limitations of the manufacturing processes employed.

Whilst the case study provided some valuable insights into how the design of an 'unfinished' product should be approached, it also left a number of questions unanswered. The importance of understanding how consumers perceive the brand, and how this perception is influenced through the application of a brand design language, is highlighted in Point 3 above. However the way in which the design language itself might be managed was unclear. This gap in understanding is addressed in the following chapter.

CHAPTER 8.

The Construction, Maintenance and Value of a Brand's Product Design Language.

8.1 INTRODUCTION

From the mass customisation (MC) element of the literature review, it was revealed that previous research has focussed primarily on the higher value (both monetary and emotional) that consumers place on personalised products. There are a number of other benefits to manufacturers who engage with MC, including the elimination of warehousing of finished goods, an ability to better target niche markets, and increased brand loyalty. The literature review also revealed recommendations for the ways in which a MC offering should be conceived and delivered, particularly with regard to the design of online toolkits. However there appears to be little analysis of the consequences for a brand's image of allowing consumers to customise products, and in particular the ways that a brand's design language and its subsequent perception by consumers might be affected.

Similarly, in both popular and academic literature regarding the uptake of additive manufacturing by consumers (often regarded as part of the 'maker movement'), little account is paid to the possible adverse effects which the creation of custom parts and products might have on a brand's image. The announcement by The Pirate Bay (2012) that it would begin cataloguing and distributing 3D files provoked a short-lived reaction to questions of copyright (Duffy, 2012; Eaton, 2012; Rundle, 2012), but thus far no serious consideration has been paid to possible negative consequences of 'fan design' in products.

Yet branding is a multi-trillion dollar industry (Campbell, 2011: p.4), and increasingly the appearance of a brand's products has been recognised as part of its brand equity. It is unlikely that any successful brand would introduce a consumer-design system such as that proposed by this thesis, without careful analysis and thought being given to which features of its products might be redesigned and which should remain 'protected'. It was therefore necessary to conduct research to discover how brands approach the construction and maintenance of a design language, and which elements are considered key to its success. This would allow a more realistic assessment of the design parameters within which the proposed system might operate.

8.2 PRODUCT DESIGN LANGUAGE AND BRAND EQUITY

At its simplest,

> **"a brand is a name, term, sign, symbol, design or combination of these, which is used to identify the goods and services of one seller or group of sellers and to differentiate them from those of competitors," (Kotler et al, 1996, p. 556).**

The purpose of identification is to encourage in the customer or user perceptions of "relevant, unique, sustainable added values which match their needs most closely," (de Chernatony, 2003: p. 9). This in turn leads to customer satisfaction and 'brand loyalty', ensuring customers return to the brand to purchase again, rather than buy a competitor's product (Kapferer, op cit: pp. 164-166). Brands may operate at the level of manufacturer, product and service (among others), and a single brand's image may be the sum of factors that make up its own and its sub-brands' identities - Apple, for example, acts as an umbrella for a number of product (iPod, iPhone, MacBook, etc.), software (OSX, Safari, Quicktime, etc.) and services (iTunes, iCloud, etc.) sub-brands. Consequently, for a large manufacturer, managing a brand or brand portfolio is a complex and multi-faceted task.

One way of understanding and measuring the success of brand management is through brand equity. Brand equity is a relatively new term, having emerged in the 1980's as a way of describing a brand's intangible assets such as "awareness, image, trust and reputation, all painstakingly built up over the years," (Kotler et al. op. cit: p.16). Initially it was understood, in somewhat basic terms, as "outcomes [which] result from the marketing of a product or service because of its brand name that would not occur if the same product or service did not have that name," (Keller, 1993). This later became recognised as just one definition of brand equity, what Wood (2000) classes brand strength, the others being brand value (the total value of a brand as a separable asset) and brand description (the associations and beliefs the consumer has about the brand). Which definition is used tends to depend on a person's or organisation's profession and perspective - whether they are a corporate fund manager or an advertising consultancy for example - and brand analysts such as Interbrand and Young & Rubicam use different, proprietary, methods to measure brand equity. Nonetheless, what is true of all definitions and perspectives, is that successful brands will seek to protect and increase their brand equity.

In *On Brand*, Wally Olins (2007: pp. 201-202) describes AEG's appointment in 1907 of Peter Behrens as artistic director. What followed became the blueprint for a brand's corporate identity: products, buildings, logos, advertising and communications were all managed and required to adhere to an over-riding philosophy. By unifying elements of the AEG brand in this way, Behrens increased its recognition and reputation amongst consumers and so increased the value of AEG's brand. As the industrial design profession matured it came to recognise ways in which a brand's image could be enhanced and maintained through the development of a "repeatable language, which can be used to generate products consistent with the brand," (McCormack and Cagan, 2003), and thus product design languages (sometimes referred to as 'shape grammars') are now recognised as a contributing factor to a brand's equity. Perhaps the best known shape grammar belongs to the Coca-Cola bottle (ibid.), which has evolved over more than a century but remains recognisable when applied to both plastic and glass bottles of different sizes. In addition, Apple's filing of a lawsuit against Samsung for infringement of "trade dress" (Fried, 2011), claiming the latter's Galaxy Tab tablet computer and Galaxy i9000 phone copied the industrial design of the iPad and iPhone, is particularly relevant.

Clearly then, a carefully conceived and orchestrated product design language is not something a brand would wish to sacrifice were it to allow consumers to engage with the design of its products to create unique manifestations of those products. Such caution can be recognised in mass customisation configurators such as NikeID, detailed previously. By limiting the palette of colours and materials available to the consumer for each model of shoe, Nike's designers are able to retain a degree of control over the brand's design language. A system such as the one proposed by this thesis would similarly need to exercise control over the possible product forms which a consumer might wish to make. It was therefore judged necessary to conduct further research into the ways in which product design languages are implemented and managed, and the degree to which elements of a product (such as silhouette, detailing, colours and materials, etc.) might be 'stretched' whilst retaining a recognisable shape grammar.

8.3 SURVEY DESIGN

To better understand the commercial realities of brands' design languages, an internet-based questionnaire was devised. The questionnaire format was chosen because

a) It afforded participation by a greater number of people, in global locations, in a shorter time-frame than would be possible via interview or focus group; and

b) For the respondents targeted (see below), a survey was expected to yield higher levels of participation than other methods.

Web-based surveys are a relatively new method of conducting research, and a number of texts which were consulted regarding the design of such surveys advised little more than to treat them as mail surveys (e.g. Frazer and Lawley, 2000: pp. 48, 92). However as their use has become more widespread, their particular advantages and disadvantages have become better understood, and are summarised below:

Advantages

1. Web page surveys are extremely fast (to send out and receive).
2. There is no cost involved once the set up has been completed.
3. It is possible to integrate images, sound and video, together with colours, fonts and other formatting options
4. Web page questionnaires can use complex question skipping logic, randomisations and other features not possible with paper questionnaires or most email surveys. These features can assure better data.
5. A greater number of people will give more honest answers to questions about sensitive topics.
6. People give longer answers to open-ended questions.
7. Survey answers can be combined with pre-existing information about individuals taking a survey.

Disadvantages

8. Current use of the Internet is far from universal, therefore internet surveys do not reflect the population as a whole.
9. People can easily quit in the middle of a questionnaire.
10. No control over who replies or how often, unless the software allows password protection.

(adapted from Seale, 2012: p.190 and Creative Research Systems, 2010)

From the list above, points 1-5 and 7 were considered relevant advantages. Point 8 was disregarded, as it was considered highly unlikely that a professional in a position being sampled would not have internet access. Point 9 was deemed an acceptable risk, and point 10 was addressed by the design of the chosen survey system.

To administer and deliver the survey, a system provided by Bristol Online Surveys[35] (BOS) was used. This was the recommended online survey provider for Loughborough University,

35. Bristol Online Surveys is available at http://www.survey.bris.ac.uk

which subscribes to the system and allows free use for PhD researchers. Integral to the design of the system was an option to allow password protected access to respondents and recording of the number of responses, eliminating point 10 (above) as a cause of concern.

The BOS system provides templates for different question types, allowing the survey to be constructed and tested quickly. It also provides a number of pages regarding the design of internet questionnaires and how they should be structured; these were consulted together with other literature concerning survey design. With regard to the final draft of the survey, a number of issues are noteworthy:

Language. A number of sources recommended using language that caters for all levels of literacy and avoids jargon (e.g. Loughborough University, 200?). This was reasoned to be an inappropriate approach, as respondents were required to be experienced, senior-level professionals, working in the same industry, and so a number of 'trade terms' were used in instances where their avoidance would have proved cumbersome.

Open-ended questions. These were avoided, as it was felt they might encourage respondents to quit midway through the survey due to other demands on their time being judged more important (Salant and Dillman, 1994).

Length. Much of the literature concerning questionnaire design advises that the survey should be kept as short as possible (e.g. Loughborough University, op. cit; Seale, op. cit: p.192). However a number of sources take a more nuanced approach, advising that questions should be matched to the amount of time a respondent will spend on the survey (Fink, 2003: p.15) and how engaged the participant is with the subject matter (Barnes, 2001). In the design and testing, a guide of 30 minutes completion time was used; informal feedback from a number of respondents indicated this was a reasonably accurate estimate.

Incentive. Frazer and Lawley (op. cit: p.74) caution that "A major problem faced by a researcher is getting people to respond to questionnaires." Whilst cover letters, introductions and the general tone of the survey can increase participation rates (Seale, op. cit: pp. 192-193), often an incentive will also be offered. In this instance such a tactic was considered inappropriate, and instead respondents were asked if they wished to receive a copy of the survey results or the final Ph.D. thesis. This proved an effective incentive, with 100% of respondents asking to be sent further information when available.

Confidentiality. Particular consideration was given to the issue of anonymity and confidentiality, both as a requirement of the University's Ethical Checklist (see Appendix 8.1), but also because a number of questions were to ask about possible conflicts between the participants' opinions and those of their clients or employers. Respondents were assured, in both the email invitation and on page 1 of the survey, that although names were recorded all participants would remain anonymous unless their unambiguous written permission was given (a copy of the cover letter and data protection statement are provided in Appendix 8.2). As further reassurance, all questions in the survey were optional (with the exception of Section 1 as detailed below), allowing respondents the opportunity to veto any question they felt uncomfortable answering.

Testing. Prior to the launch of the survey, it was tested by Bill Sermon, a partner at the innovation consultancy Viadynamics. Sermon has over 30 years experience as a designer, consultant and design director at firms such as Philips, Fitch and Nokia, and was therefore considered an authoritative opinion regarding both the appropriateness of questions and the manner in which they had been presented. Following Sermon's feedback two questions were changed and a further two were re-ordered in the survey.

8.4 SURVEY STRUCTURE

The survey was presented over 11 pages, as summarised below:

1. Introduction.
2. Data Protection Statement.
3. Section 1. Personal Details.
4. Section 2. Factors Which Lead to a Well-Designed Product.
5. Section 3. Factors Which Lead to a Commercially Successful Product.
6. Section 4. Factors Which Lead to a Successful Design Language.

7. Section 5. The Consequences of a Successfully Implemented Design Language.
8. Section 6. Consumer Influence in the Design of Products.
9. Section 7. Consumer Customisation and Design.
10. Further Information.
11. Thankyou.

The primary purpose of the survey, addressed through sections 3-5, was to reveal both how a successful design language is constructed and the consequences of its implementation to a brand. As such these sections were to provide the key specific findings with regard to the scope and parameters within which the consumer-design toolkit would realistically be situated (see point 5 in the conclusions of this chapter). However a number of other questions were also asked to provide context to the commercial environment within which such a toolkit might exist. In particular, the involvement of consumers (in both direct and indirect interventions) was examined in section 6, and attitudes towards consumer customisation of products was addressed through questions in section 7. These (somewhat unexpectedly) revealed a significant degree of enthusiasm for customisation, though the extent to which consumers might be allowed to control a product's form was a highly sensitive issue (see points 2 and 3 in the conclusions).

8.5 SURVEY PARTICIPANTS

Since a product design language is applied across a brand's portfolio and may exist (and evolve) over time, it was reasoned that survey participants should be experienced in design and/or brand management, as evidenced by the participant's job title. All respondents were therefore required to be practising at a minimum level of 'senior designer' [36] or equivalent.

Survey participants were recruited from two sources. As a designer with 16 years experience, the author has worked with a large number of design professionals whose experience matches or exceeds the pre-determined requirement. The first source was therefore the author's personal contacts list. Many of these contacts were gained during the

36. Although the title of 'senior designer' varies between organisations, all survey participants referring to themselves as senior designer had a minimum of five years professional experience.

author's employment at Nokia, and have since moved to positions with other companies. This made contributions even more valuable, as they contained insights into ways that different brands manage their images.

The second source of survey participants was the membership list of the 'Post-Industrial Design' LinkedIn group, of which the author is manager. The group's aim is to provide a forum "for discussing the future of product design and development, and in particular, the Industrial Design profession," (LinkedIn, 2012), and all members are required to be design professionals or to work in professions which collaborate with designers. As of 21.02.2012 the group had 947 members, 68% of which practice at senior level or above (ibid.). The list was therefore felt to provide a rich source of experienced potential participants, who had self-identified themselves (by joining the group) as having an interest in the future of industrial design.

The survey was carried out between 01.12.2011 and 31.01.2012, and invitations were sent to 91 potential participants. 39 completed surveys (43%) were received (4 unfinished surveys were discarded from the results); this was judged to be a good response rate given the seniority of participants and that no reward was offered. An email template (see Appendix 8.2) was devised which explained the purpose of the survey and how the results would be used, and which formed the basis of all invitations (though emails to the author's own contacts were highly personalised). Invitations were sent to personal email addresses and contained a link to the survey web page together with a personal log-in name and password.

Details of respondent demographics are shown below. It should be noted that although the country of work is shown, no assumptions should be made regarding the nationality of respondents (many are living outside their home country) or the target markets for which they are designing.

Job Description:	Owner / Partner	10
	Director	13
	Design Manager / Head of Department	5
	Principal Designer	3
	Senior Designer	5
	Innovation / Strategy Consultant	3

Country of Work:	United States	15
	United Kingdom	13
	Finland	4
	China	1
	Germany	1
	Japan	1
	Netherlands	1
	New Zealand	1
	Sweden	1
	Switzerland	1

In-House or Consultant?

	In-House	18
	Consultant	21

8.6 SAMPLING BIAS

Sampling bias is defined as "the difference between the expected value of the sample estimator and the true value of the characteristic which results from the sampling procedure" (Federal Committee on Statistical Methodology, 1978: p. 9). It occurs when a surveyed sample does not represent a random sample of the population being studied. The most obvious bias within the survey presented below comes from the geographical location of respondents: 38.5% are based in the United States and 54% in Europe. This is primarily due to the author's work history, and that the LinkedIn group from which participants were contacted is an English language group. The extent to which this bias distorts the survey's findings is unclear however - it is possible to argue that Japanese, Korean and, increasingly, Chinese consumer product manufacturers (for example) operate as global brands, in which case designers working inside those corporations would record similar responses. However the authentication of such a statement is outside the scope of this research, and so the survey results should be understood as applying primarily to Western brands.

8.7 GENERALISABILITY OF RESULTS

Clearly the size of the survey sample does not allow for reliable statistical analysis (and indeed this was not the intention when the survey was proposed and designed), and the generalisability of the findings - "the extent to which they may be applied to other cases" (Neuendorf, 2002: p.12) - is therefore an issue. Generalisability within qualitative research is more commonly discussed with reference to case studies, and Silverman (2011: p.386) identifies three strategies (deductive inference, comparative inference and emblematic cases) by which small sample sizes may be argued to represent larger populations. Of these, comparative inference - the identification of "cases within a wide range of situations in order to maximise variation; that is, to have all the possible situations in order to capture the heterogeneity of a population," (Silverman, ibid.) - is the most applicable. By choosing to sample not only consumer product designers, but also those with expertise in other areas such as medical, heavy plant transportation and fashion, as well as surveying both in-house designers and design consultants, the application of design languages across many diverse situations was captured. This also allowed comparisons to be made to determine whether the views of consumer product designers differed significantly from those of designers in other sectors. For the most part little variance was discovered, which further supports arguments as to the generalisability of the findings.

8.8 SURVEY RESULTS

The full results of the survey are presented in Appendix 8.5. Results which were particularly pertinent to the specification and design of the toolkit are discussed below. In instances where differences in response between consumer product designers and those working in other fields were notable, both sets of responses have been presented and commented on.

Question 3. In which sectors do you commonly work? (Results have been summarised for clarity, please see Appendix 8.5 for a full breakdown.)

Consumer Products	50
Professional Products	29
Interior Products	32
Transportation	11
Sports & Outdoor	13
Other	15

Question 8. Thinking about the *commercial* success of products which *you* have had personal responsibility for, how important are the following:

All Respondents:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
8a. A unique aesthetic (one which differentiates from competitor's products)	48.7%	35.9%	15.4%	0.0%	0.0%
8b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	30.8%	46.2%	17.9%	5.1%	0.0%
8c. A technologically advanced specification compared to competitors	7.7%	46.2%	35.9%	7.7%	2.6%
8d. Unique functionality compared to competitors	20.5%	51.3%	23.1%	5.1%	0.0%
8e. Better considered and executed functionality compared to competitors	41.0%	46.2%	10.3%	2.6%	0.0%
8f. Colours, materials and finishes	23.1%	53.8%	20.5%	2.6%	0.0%
8g. Prominence of logo or other branding	10.3%	25.6%	41.0%	23.1%	0.0%

Respondents involved in the design of consumer products:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
8a. A unique aesthetic (one which differentiates from competitor's products)	56.0%	28.0%	16.0%	0.0%	0.0%
8b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	28.0%	44.0%	24.0%	4.0%	0.0%
8c. A technologically advanced specification compared to competitors	8.0%	52.0%	36.0%	0.0%	4.0%
8d. Unique functionality compared to competitors	20.0%	44.0%	32.0%	4.0%	0.0%
8e. Better considered and executed functionality compared to competitors	40.0%	48.0%	12.0%	0.0%	0.0%
8f. Colours, materials and finishes	32.0%	44.0%	24.0%	0.0%	0.0%
8g. Prominence of logo or other branding	8.0%	20.0%	56.0%	16.0%	0.0%

Question 10. Thinking about the *commercial* success of products which *you* have had personal responsibility for, how important are the following:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
10a. Similarity to older products in a brand's portfolio	7.7%	20.5%	46.2%	17.9%	7.7%
10b. Ability to personalise/configure the product before purchase	2.6%	7.7%	30.8%	38.5%	20.5%
10c. Ability to personalise/configure the product after purchase	2.6%	23.1%	35.9%	23.1%	15.4%
10d. Ability to upgrade the product after purchase	2.6%	21.1%	34.2%	23.7%	18.4%
10e. Low field-failure rate	41.0%	43.6%	5.1%	7.7%	2.6%
10f. Durability and long life	41.0%	53.8%	5.1%	0.0%	0.0%
10g. Ability to service and repair the product	10.3%	41.0%	38.5%	7.7%	2.6%

With regard to questions concerning factors which determine the commercial success of products (Questions 8 and 10), no significant difference was found between respondents involved in the design of consumer products and respondents as a whole. However designers who work with consumer products were more inclined to regard colours, materials and finishes as crucially important (32% vs 23.1%), and slightly more inclined to regard a unique aesthetic as crucially important (56% vs 48.7%).

Very few respondents believed the ability to personalise/configure a product before purchase was a significant factor in the commercial success of products they had worked on. This was interesting given that approximately half (20) the respondents have previously worked on mass customised products.

Question 11. Thinking about products which you have had personal responsibility for, how much emphasis do clients (or the organisation which employs you) place on the following:

	Far too much emphasis	Too much emphasis	The right amount of emphasis	Too little emphasis	Far too little emphasis
11a. A unique aesthetic (one which differentiates from competitor's products)	0.0%	10.3%	66.7%	23.1%	0.0%
11b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	2.6%	5.1%	43.6%	43.6%	5.1%
11c. A technologically advanced specification compared to competitors	5.1%	35.9%	33.3%	25.6%	0.0%
11d. Unique functionality compared to competitors	0.0%	12.8%	56.4%	30.8%	0.0%
11e. Better considered and executed functionality compared to competitors	0.0%	2.6	48.7%	46.2%	2.6%
11f. Colours, materials and finishes	0.0%	7.7%	56.4%	25.6%	10.3%
11g. Prominence of logo or other branding	5.1%	38.5%	48.7%	5.1%	2.6%
11h. Similarity to older products in a brand's portfolio	2.6%	17.9%	66.7%	10.3%	2.6%
11i. Ability to personalise/configure the he product before purchase	5.3%	7.9%	60.5%	18.4%	7.9%
11j. Ability to personalise/configure the product after purchase	5.4%	10.8%	54.1%	21.6%	8.1%
11k. Ability to upgrade the product after purchase	0.0%	8.1%	54.1%	29.7%	8.1%

In general, respondents were inclined to believe that clients and employer organisations place the right amount of emphasis on factors which might differentiate their products from those of competitors. Significantly however, almost half (48.7%) believed that not enough emphasis is placed on the development of a coherent design language. Furthermore, significant minorities believed that a greater than necessary degree of emphasis is placed on the prominence of the product's logo or branding (43.6%) and unique functionalities (as opposed to better executed functionalities) (41%).

With regard to questions concerning the requirements for a successful and coherent design language (questions 12-14, 16, below), no significant difference was found between respondents involved in the design of consumer products and respondents as a whole. Designers who work with consumer products were slightly more inclined to regard a common approach to the detailing of similar elements as the most important factor in a successful design language, and slightly less inclined to view the placement of logos or branding as important.

Question 12. Across a brand's product portfolio, a successful and coherent design language requires:

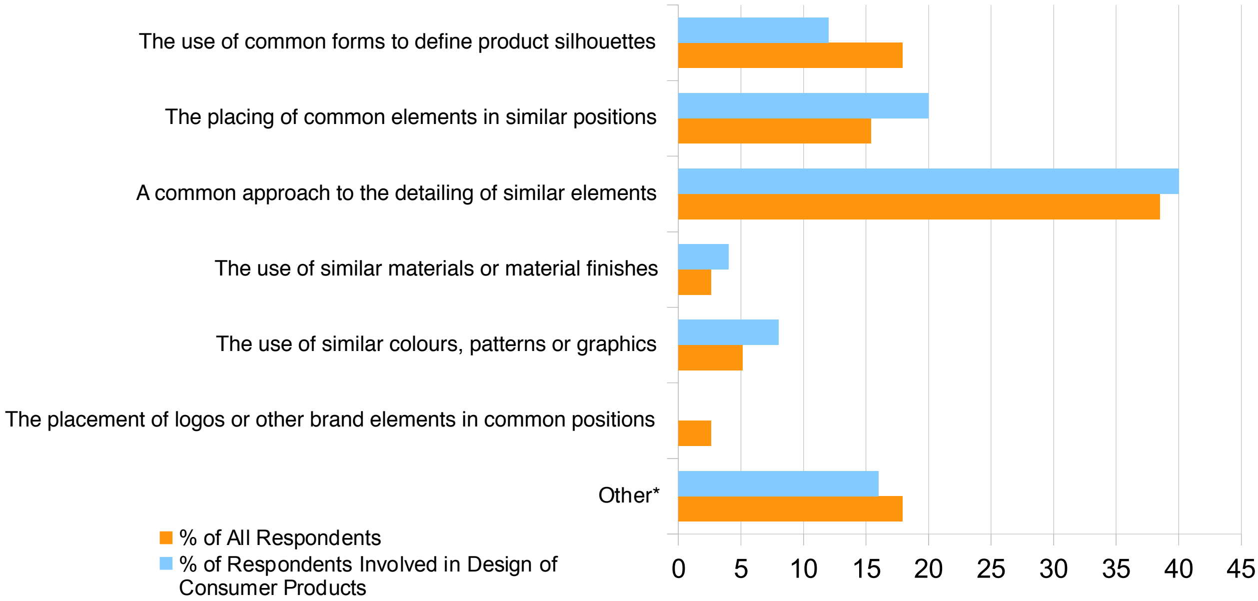
All Respondents:

	Strongly Agree	Agree	Disagree	Strongly Disagree
12a. The use of common forms to define product silhouettes	20.5%	48.7%	30.8%	0.0%
12b. The placing of common elements in similar positions	20.5%	48.7%	28.2%	2.6%
12c. A common approach to the detailing of common elements	35.9%	59.0%	5.1%	0.0%
12d. The use of similar materials or material finishes	16.2%	54.1%	27.0%	2.7%
12e. The use of similar colours, patterns or graphics	17.9%	56.4%	23.1%	2.6%
12f. The placement of logos or other brand elements in common positions	15.4%	53.8%	25.6%	5.1%

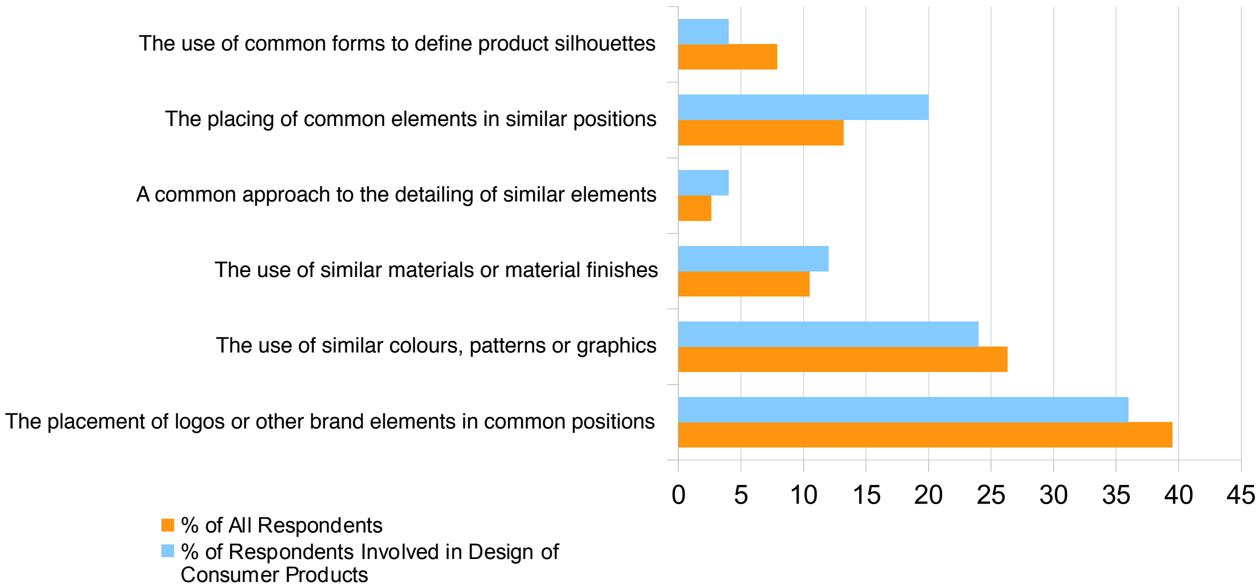
Respondents involved in the design of consumer products:

	Strongly Agree	Agree	Disagree	Strongly Disagree
12a. The use of common forms to define product silhouettes	12.0%	56.0%	32.0%	0.0%
12b. The placing of common elements in similar positions	16.0%	52.0%	28.0%	4.0%
12c. A common approach to the detailing of common elements	40.0%	56.0%	4.0%	0.0%
12d. The use of similar materials or material finishes	21.7%	43.5%	30.4%	4.3%
12e. The use of similar colours, patterns or graphics	24.0%	48.0%	28.0%	0.0%
12f. The placement of logos or other brand elements in common positions	8.0%	60.0%	28.0%	4.0%

Question 13. Across a brand's product portfolio, which of the following attributes is the *most* important to a successful and coherent design language:



Question 14. Across a brand's product portfolio, which of the following attributes is the *least* important to a successful and coherent design language:



Question 16. Across a brand's product portfolio, a successful and coherent design language requires:

All Respondents:

	Strongly Agree	Agree	Disagree	Strongly Disagree
16a. Common methods of user input to the product	24.3%	48.6%	24.3%	2.7%
16b. Common methods of product feedback to the user	26.3%	57.9%	15.8%	0.0%
16c. The use of common colours, materials and finishes	15.4%	59.0%	25.6%	0.0%
16d. Common quality standards, with regard to manufacture, finishing and durability	51.3%	46.2%	2.6%	0.0%
16e. Common marketing solutions	10.5%	44.7%	44.7%	0.0%

Respondents involved in the design of consumer products:

	Strongly Agree	Agree	Disagree	Strongly Disagree
16a. Common methods of user input to the product	20.0%	52.0%	24.0%	4.0%
16b. Common methods of product feedback to the user	24.0%	56.0%	20.0%	0.0%
16c. The use of common colours, materials and finishes	16.0%	52.0%	32.0%	0.0%
16d. Common quality standards, with regard to manufacture, finishing and durability	40.0%	60.0%	0.0%	0.0%
16e. Common marketing solutions	8.0%	48.0%	44.0%	0.0%

Question 18. Across a brand's product portfolio, a successful and coherent design language may result in:

	Strongly Agree	Agree	Disagree	Strongly Disagree
18a. Increased consumer awareness of the brand	66.7%	30.8%	2.6%	0.0%
18b. Differentiation from competitors	59.5%	40.5%	0.0%	0.0%
18.c. Increased sales to first-time customers	30.8%	53.8%	15.4%	0.0%
18d. Increased sales to returning customers	48.7%	51.3%	0.0%	0.0%
18e. Increased consumer loyalty	56.4%	38.5%	5.1%	0.0%
18f. Consumer willingness to pay a higher price	30.8%	51.3%	17.9%	0.0%

Question 19. Across a brand's product portfolio, a consequence of a successful and coherent design language may be:

	Strongly Agree	Agree	Disagree	Strongly Disagree
19a. A reluctance to experiment with new aesthetic design possibilities	25.6%	48.7%	25.6%	0.0%
19b. A reluctance to experiment with new functional design possibilities	12.8%	46.2%	38.5%	2.6%
19c. An unwillingness to expand the brand into new areas	10.3%	48.7%	30.8%	10.3%
19d. A shorter timeframe from product brief to design approval	20.5%	48.7%	25.6%	5.1%
19e. An over-reliance on consumer loyalty to maintain sales	15.8%	50.0%	31.6%	2.6%
19f. An increased appreciation/ understanding of design in the product's marketplace	15.4%	69.2%	15.4%	0.0%

Perhaps unsurprisingly, most respondents believed a successful and coherent design language would provide multiple benefits to a brand. Respondents were in unanimous agreement that a successfully implemented design language provides differentiation from competitors and increased sales to returning customers; and large majorities believed it would both increase consumer awareness of the brand (97.4% agreed) and lead to increased consumer loyalty (94.9% agreed).

However respondents also reported a number of negative consequences of a successful design language. Significant majorities believe that a successfully implemented design language results in a reluctance to experiment with aesthetic design possibilities (74.3% agreed) as well as an over-reliance on consumer loyalty to maintain sales (65.8% agreed).

With regard to questions concerning the value of consumer insights, (question 22, below), no significant difference was found between respondents involved in the design of consumer products and respondents as a whole. Both groups of respondents felt consumers had valuable insights into the strengths and weaknesses of products they own (approx 92% agreed) and a significant majority believed consumers could provide insights into improvements to new products (72% agreed); new ways of using existing features (80% agreed); and new ways of personalizing products (61.5% agreed). Very few respondents believed consumers to be capable of providing insights into a brand's future direction (23% agreed).

Question 22. In your experience, consumer's have valuable insights into:

	Strongly Agree	Agree	Disagree	Strongly Disagree
22a. The strengths and weaknesses of products they own	53.8%	38.5%	7.7%	0.0%
22b. Features that could be incorporated into new products	12.8%	46.2%	38.5%	2.6%
22c. Improvements that could be made to new products	12.8%	59.0%	25.6%	2.6%
22d. New ways of using existing features	28.2%	53.8%	17.9%	0.0%
22e. New ways of personalising products	20.5%	41.0%	38.5%	0.0%
22f. How a brand's products are perceived in the market	39.5%	55.3%	5.3%	0.0%
22g. The future direction which a brand's products might take	5.1%	17.9%	59.0%	17.9%

With regard to questions concerning the application of consumer insights (question 23, below), no significant difference was found between respondents involved in the design of consumer products and respondents as a whole. In general respondents felt consumer insights could be successfully applied across all areas, but were especially inclined to agree that such insights were valuable to the design of current products (82% agreed); the improvement of existing products (89.7% agreed); and the customisation and configuration of products they (consumers) own (83.4% agreed).

Question 23. In your experience, consumer insights can be successfully applied to:

	Strongly Agree	Agree	Disagree	Strongly Disagree
23a. A brand's future strategic direction	23.1%	46.2%	25.6%	5.1%
23b. The specification of future products	23.1%	53.8%	23.1%	0.0%
23c. The design of current products	25.6%	56.4%	15.4%	2.6%
23.d. The improvement of products already on the market	33.3%	56.4%	7.7%	2.6%
23e. The customisation and configuration of products which they own	28.9%	55.3%	15.8%	0.0%
23f. Ways of marketing new or existing products	15.4%	43.6%	41.0%	0.0%

Questions 24 and 25 referred to the Herman Miller Sayl chair and NikeID online configuration systems, respectively, accessible from:

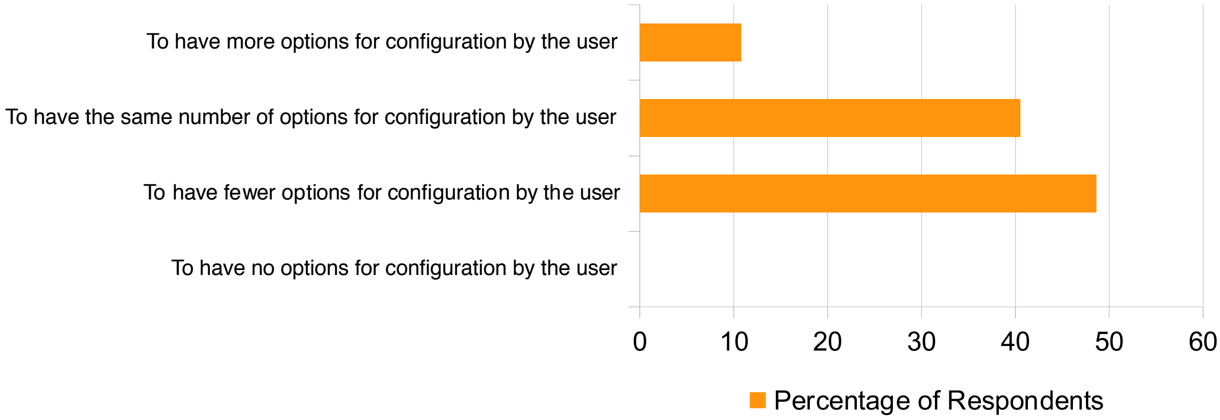
http://www.hermanmiller.com/DotCom/jsp/product/productsConfigurator.jsp?prodName=sayl

http://nikeid.nike.com/

Question 24. Referring specifically to the Herman Miller Sayl chair, the configuration options:

	Strongly Agree	Agree	Disagree	Strongly Disagree
24a. Are useful to a consumer who wants to personalise their chair	29.7%	59.5%	10.8%	0.0%
24b. Are useful to an office planner who wants to integrate the chair into an overall design	43.2%	51.4%	5.4%	0.0%
24c. Are an integral part of the design of the chair	13.5%	54.1%	32.4%	0.0%
24d. Allow the possibility of a tasteless design or colour scheme	24.3%	48.6%	21.6%	5.4%
24e. Enhance the consumer's experience of the product	18.9%	51.4%	29.7%	0.0%
24f. Detract from the purity of the design	2.7%	21.6%	70.3%	5.4%
24g. Would likely lead to increased sales	5.4%	48.6%	43.2%	2.7%
24h. Are a positive reflection of the Herman Miller brand	16.2%	67.6%	16.2%	0.0%

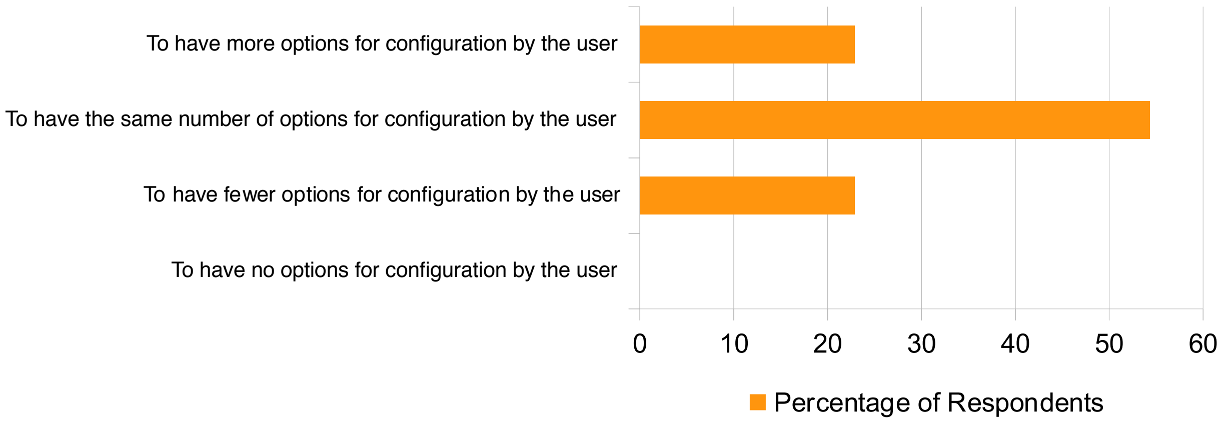
Question 25. If I had responsibility for the design or marketing of the Herman Miller Sayl chair, I would prefer:



Question 26. Referring specifically to shoes which appear in the NikeID system, the configuration options:

	Strongly Agree	Agree	Disagree	Strongly Disagree
26a. Are useful to a consumer who wants to personalise their shoe	47.4%	52.6%	0.0%	0.0%
26b. Are useful to a team who want to integrate the shoe into an overall design of kit	34.2%	63.2%	2.6%	0.0%
26c. Are an integral part of the design of the shoe	7.9%	57.9%	34.2%	0.0%
26d. Allow the possibility of a tasteless design or colour scheme	44.7%	44.7%	7.9%	2.6%
26e. Enhance the consumer's experience of the product	16.2%	75.7%	8.1%	0.0%
26f. Detract from the purity of the design	7.9%	26.3%	60.5%	5.3%
26g. Would likely lead to increased sales	7.9%	65.8%	21.1%	5.3%
26h. Are a positive reflection of the Nike brand	28.9%	68.4%	2.6%	0.0%

Question 27. If I had responsibility for the design or marketing of shoes in the NikeID system, I would prefer:



With regard to questions concerning consumer customisation of products (questions 25-28), respondents were largely positive as to the usefulness of customisation possibilities, and the effect on both sales and brand image. The NikeID system is rated slightly more highly than the Herman Miller Sayl configurator for usefulness, though it also risks a greater possibility of detracting from the original design and allowing a tasteless design or colour scheme. In addition, more respondents wished to have the same number or fewer configuration options for the Sayl configurator (91.1%) than the NikeID configurator (77.2%), though clearly in both instances a majority appear not to want the consumer's opportunity for customisation to be increased further.

The biggest difference between the two systems appears in the likelihood of increased sales: 73.7% of respondents believed this would be the case for the NikeID system, whereas only 54% believed the same to be true of the Herman Miller Sayl system (whether this is due to the intrinsic nature of the product, or the implementation of the configurator is unclear). Nonetheless, 83.8% of respondents felt the opportunity to customise the Sayl chair reflected positively on the Herman Miller brand, and 97.4% felt the same positive reflection regarding the NikeID system.

28. Thinking about products (in general), the consumer's ability to customise a product before purchase:

	Strongly Agree	Agree	Disagree	Strongly Disagree
28a. Is likely to dilute a brand's design language	5.7%	37.1%	51.4%	5.7%
28b. Is likely to enhance the consumer's perception of the brand	5.4%	64.9%	29.7%	0.0%
28c. Makes the designer's job more interesting	13.9%	50.0%	36.1%	0.0%
28d. Encourages the consumer to spend more	13.5%	51.4%	35.1%	0.0%
28e. Decreases consumer appreciation of design	0.0%	25.0%	66.7%	8.3%

A significant majority of respondents believed that opportunities for customisation enhance the consumer's perception of a brand (68.3% agreed), and that such opportunities encouraged the consumer to spend more (64.9% agreed). Unexpectedly, a majority (57.1%) also felt that customisation was unlikely to dilute a brand's design language. Correspondingly, 75% of respondents disagreed with the suggestion that customisation decreases consumer appreciation of design.

Question 29. I have previously worked on, or been responsible for, the design of mass-customisable products

Yes	20
No	18

Question 30. 3D printing systems have the ability to manufacture one-off parts. It has been suggested that in future, this may allow consumers to design or mass-customise unique products. Thinking about the *commercial* success of products which *you* have had personal responsibility for, and assuming any product would be *safe* and *functional*, if such a system were to be implemented:

	Strongly Agree	Agree	Disagree	Strongly Disagree
30a. The system should allow the maximum design freedom possible	10.5%	39.5%	36.8%	13.2%
30b. The system should set boundaries of acceptable designs	35.9%	41.0%	17.9%	5.1%
30c. It would be possible to maintain a coherent design language	23.7%	52.6%	18.4%	5.3%
30d. The system would be an addition to the brand's standard products	26.3%	57.9%	15.8%	0.0%
30e. The brand's reputation for design quality would increase	2.7%	40.5%	54.1%	2.7%

	Strongly Agree		Agree		Disagree		Strongly Disagree	
I have previously designed mass-customised products	Yes	No	Yes	No	Yes	No	Yes	No
30a. The system should allow the maximum design freedom possible	10.0%	11.8%	50.0%	29.4%	35.0%	41.2%	5.0%	17.6%
30b. The system should set boundaries of acceptable designs	40.0%	27.8%	30.0%	55.6%	20.0%	16.7%	10.0%	0.0%
30c. It would be possible to maintain a coherent design language	30.0%	17.6%	40.0%	70.6%	20.0%	11.8%	10.0%	0.0%
30d. The system would be an addition to the brand's standard products	30.0%	17.6%	55.0%	64.7%	15.0%	17.6%	0.0%	0.0%
30e. The brand's reputation for design quality would increase	5.0%	0.0%	50.0%	31.2%	40.0%	68.8%	5.0%	0.0%

Those who had previously designed mass-customisable products were more inclined to allow the user to have the maximum design freedom possible (60.0% agreed) than those who had not (41.2% agreed). However across both sets of respondents, most were inclined to set boundaries of acceptable designs within which the user might work (70.0% and 83.4% respectively). Those who had previously designed mass-customisable products were less inclined to believe that a coherent design language could be maintained (70.0% vs 88.2%) though clearly a significant majority of all respondents feel it would be possible. Approximately half of those who had previously designed mass-customisable products (55.0%) believe the brands reputation for quality would increase, compared to less than one third of those who had not.

8.9 CONCLUSIONS

With particular regard to this survey's relevance to the specification and design of a consumer design toolkit, five specific conclusions can be drawn:

1. **A successfully implemented product design language is an important factor in a brand's image and profitability.**

   More than 90% of respondents consider a coherent design language to be a critical factor in a well designed product, and more than 75% consider it to be critical to a product's commercial success. Respondents unanimously believe that a successful design language leads to differentiation from competitors and increased sales to returning customers, and a substantial majority believe it results in increased consumer awareness of the brand (98%); increased consumer loyalty (95%) and a willingness on the part of the consumer to pay more for a product (82%).

   (One caveat should be noted - approximately half of all respondents believed the companies they work for (either as employees or consultants) place too little importance on developing a coherent design language. Thus it may be argued that these organisations would be willing to sacrifice design integrity if it led to increased sales.)

2. **Consumers have insights and expertise which allow them to custom design products which meet their own needs better than non-customised products, however this may be in conflict with a brand's image.**

   72% of respondents believe that consumers have valuable insights into the design of current products and ways of customising or configuring them. Almost all believe that current mass customisation toolkits are useful to consumers and enhance the consumer's experience of both the product and the brand.

Significant majorities of respondents believe that existing mass customisation toolkits enhance the consumer's perception of the brand (84% for the Herman Miller Sayl, 97% for NikeID). However there is much less enthusiasm for AM-enabled consumer design toolkits, with a majority (57%) believing a brand's reputation for design quality would decrease.

(It is important to note that the reason for this reduced enthusiasm is unclear, i.e. whether respondents felt that a decrease in design quality would be due to the quality of consumer-designed concepts or the quality of the AM parts which resulted. Further research is therefore required to clarify this point.)

3. **The quality of a brand's product design language may be diluted by consumer customisation, therefore any consumer design toolkit should be constrained in its capabilities in order to be acceptable.**

   A significant minority (43%) of respondents felt that allowing consumers to customise products would dilute a brand's design language. Most respondents preferred to reduce the number of options for customisation that a design toolkit offers, suggesting they would seek to retain control over a brand's design language by restricting the consumer's ability to customise a product. This is confirmed by 77% of respondents who suggested a consumer design toolkit should set boundaries of acceptable designs.

4. **There are few differences between the opinions of those who specialise in the design of consumer products and those who specialise in other areas of industrial/product design.**

   In most cases there is no significant difference between the views of respondents who specialise in the design of consumer products, and the views of designers in general. The exception is with regard to the development of briefs and scenarios, where consumer product designers were more likely (60% vs 46% and 80% vs 64% respectively) to place value on indirect consumer involvement.

5. In order of degree of influence, a consumer design toolkit should allow:

- Changes to the position of logos and brand identifiers
- The use of non-standard colours, patterns and graphics
- The use of non-standard materials or material finishes
- Changes to the position of common elements
- Changes to the product silhouette
- Changes to the way in which common elements are detailed

CHAPTER 9.

A Trial to Assess Consumer Preferences and Abilities in Methods of Self-Design.

9.1 INTRODUCTION

This thesis has thus far argued that additive manufacturing has the potential to enable the design and manufacture of unique products, optimised for individual consumers. It has further argued that in future, one of the tasks of the professional industrial designer will be to facilitate consumer engagement in the design of those products, by designing incomplete objects together with the tools necessary to individualise their design. Such proposals have raised a number of research questions however, in particular

- What methods do consumers prefer to use when engaging in industrial design?
- How well are consumers able to communicate design intent through sketching?
- To what degree of completeness should a product be designed, before a consumer is able to optimise it?

In addition a supplementary question was also investigated, namely how a variational consumer design approach (as identified in Chapter 6) might be integrated into the process.

The chapter begins by laying out the theoretical foundations of the trial which sought to answer these questions by investigating the ability of consumers to design and modify a USB memory stick. This product was chosen as a relatively simple consumer electronics device whose function would be well understood by those who took part. It then introduces two crucial concepts: the concept of the 'Safe Model' and the use of Genoform, an iterative design software tool. The chapter analyses participants' use of sketches and compares this to their modification of CAD models of the memory stick.

The chapter concludes by discussing findings from the trial, in particular the apparent conflict between the preferred design process and the preferred design outcome. It also recommends a conceptual approach to the specification of an industrial design toolkit, together with features which should be implemented.

9.2 FOUNDATIONS OF THE TRIAL

The foundations of the trial built on the observations of (for example) Tovey (1989) Yi-Luen Do (2005) and Purcell and Gero (2006) with regard to the way designers and architects use drawing as a way to generate and evaluate design solutions, but sought to place such observations more specifically within a mass customisation scenario. It also sought to understand the practical difficulties of expecting consumer designers to use drawing in the same way that trained designers do. The intended outcome was to better understand, in general terms, what future tools might best enable consumer-design; these issues are addressed in the Conclusions of this chapter and inform the later part of the thesis in which the specification of an industrial design toolkit is proposed.

It should be made clear at this point that within the user trial, neither modelling exercise (in Part 1 and Part 2 of the trial) was intended to test or replicate a co-design exercise. Although the design of the trial (see Section 9.5) necessitated the consumer designer sitting alongside a CAD operator, the purpose of the trial was to investigate a situation in which the participant had the ultimate power of decision over his or her design. In all instances where the participant worked with the computer aided design (CAD) operator, described below, care was taken to ensure the CAD operator did not offer opinions as to the value of any design or decision. Advice was given only on the capability of the CAD software to achieve a desired outcome, rather than the value of that outcome. Thus the role of the CAD operator was that of a facilitator between the participant as designer and the requirement to create a 3D CAD model.

9.3 CONCEPT OF THE SAFE MODEL

A Safe Model, sometimes also called a ‘keep away’ model, is a concept used by industrial designers to understand and visualise the minimum possible size of a product, whilst taking account of internal mechanisms and electronics, thickness of materials, tolerances, etc. A safe model of an MP3 player for example, would be created by ‘expanding’ the dimensions of the internal electronics by an amount equal to the thickness of the materials used in the outer casing, plus the distance required between the electronic components and the inside of the casing. It can also incorporate considerations of safety, ergonomics, marketing, etc; thus the safe model for a family car would be affected by the need for crash crumple zones, headroom in the passenger compartment and size of boot. A safe model does not dictate (though it does influence) the final design of the product, rather it indicates the absolute minimum volume a product can be when all other requirements are met.

The concept of the safe model was used in two ways in the user trials. Firstly, having calculated a safe model for the USB memory stick, images of this safe model were given to participants during briefing of the drawing exercise. Participants were shown how to use these images as underlays which acted as guides during design. Provided the participant’s drawings were not smaller than the images of the safe model, their design would be realistically manufacturable.

The safe model was also used in the two modelling exercises. By modelling the safe model inside Solidworks, any design could be superimposed to check if it satisfied the minimum volume requirements (see Figure 9.1). Furthermore, when setting up the parameters for the operation of the Genoform software, the safe model placed lower limits on the extent to

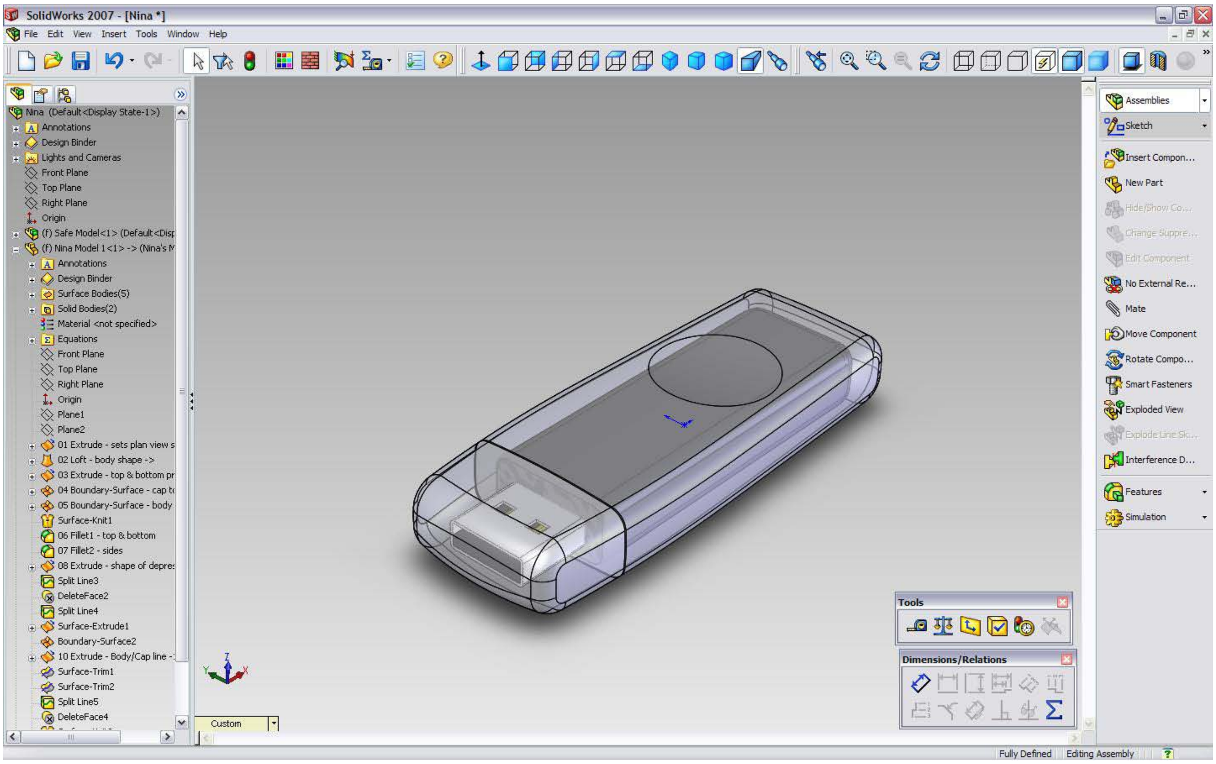


Figure 9.1. Participant's model superimposed over the USB memory stick safe model, in the Solidworks CAD modelling environment

which Genoform could modify the design. Provided the participant's drawings were not smaller than the images of the safe model, their design would be realistically manufacturable.

9.4 GENOFORM

Genoform is an iterative design exploration tool which operates as a plug-in module to Solidworks. It is produced by Genometri[37], a design technology company which develops specialised software, which was created as a spin-out company from the National University of Singapore. Genoform was used in the trial because, at the time of the trial, it was gaining attention within the industrial design community as a possible tool for use by professional designers. In addition, a personal contact within the University of Singapore was able to provide a copy of the software for evaluation.

37. See www.genometri.com

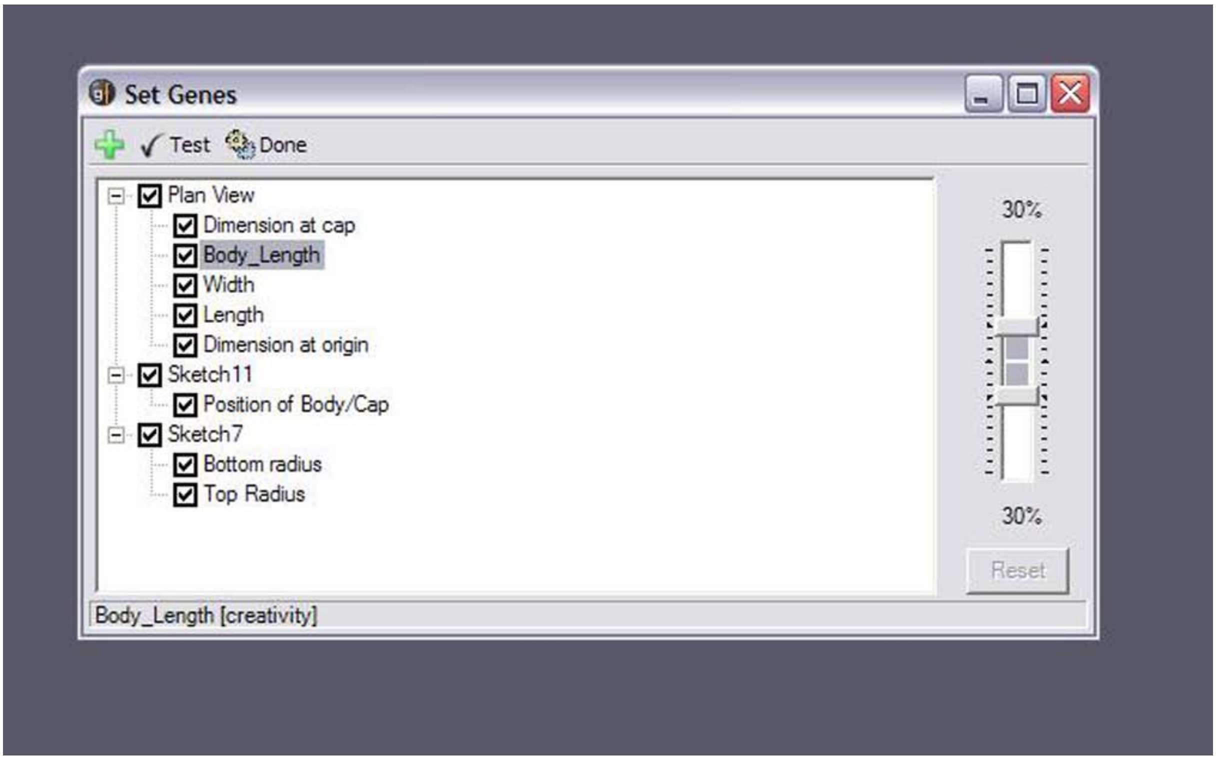


Figure 9.2. Genoform user interface, showing the dimensions which will be varied

Genoform works by varying the dimensions of a Solidworks sketch; the designer can assign which sketches Genoform can manipulate, which dimensions within those sketches, and the degree to which the dimension can be varied (see Figure 9.2). Thus it is possible (for example) to instruct Genoform to vary a dimension of 10mm by plus or minus 25% (i.e. a range of 7.5mm - 12.5mm). It is also possible to set maximum or minimum values, thus the designer may decide that the 10mm dimension can never be reduced, but can be increased by 45% (i.e. a range of 10mm - 14.5mm). In this way Genoform will run through the structure of a Solidworks CAD model, altering dimensions by a random factor within limits decided by the designer, and creating new iterations of the original CAD model. Genoform will create between one and one thousand variants, as the designer decides. Figure 9.3 shows variants of a single design created by Genoform.

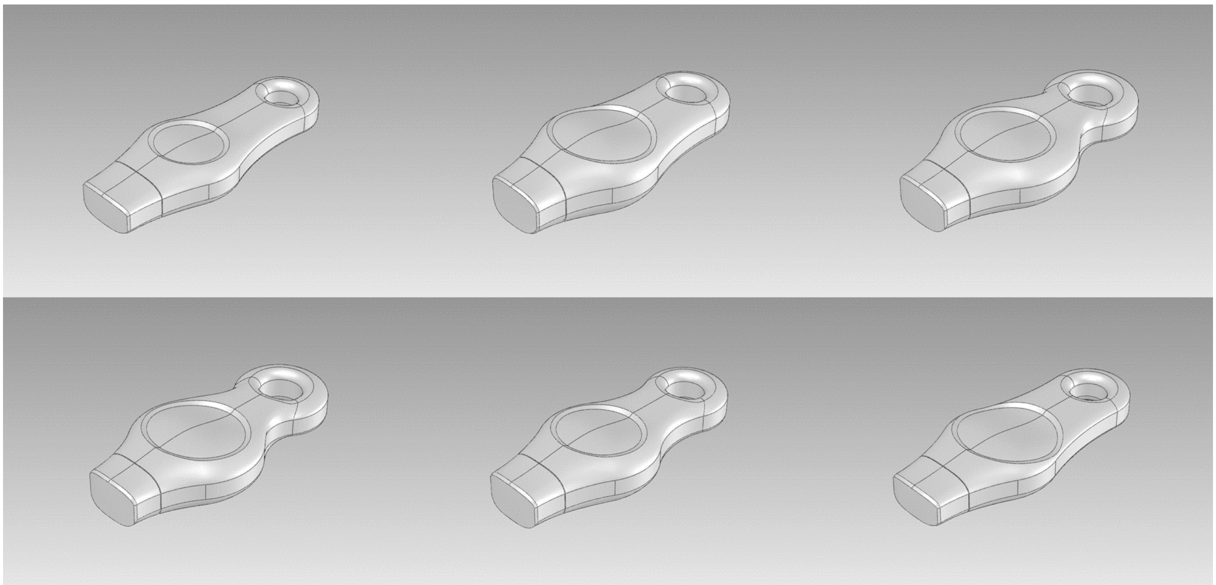


Figure 9.3. Variants of a design created by Genoform. The original design is in the top left.

9.5 DESIGN OF THE TRIAL

As mentioned above, the task of the study was for participants to design a USB memory stick. The trial was divided into two parts; in Part 1, the participant was first required to undertake an unobserved drawing exercise, followed by a design modelling exercise with the assistance of a trained CAD software operator. In Part 2, participants were asked to choose one of six pre-existing designs which was then modified with the assistance of the CAD operator. Participants were placed in one of two groups; group one conducted Part 1 of the trial followed by Part 2, whilst group two conducted the trial in reverse order. Figure 9.4 below shows how the trial was structured.

The first method of design exploration, addressed in Part 1 of the study, may be classified as unconstrained concepting. Participants were free to explore issues of functionality and aesthetics with no constraint other than that the design should be bigger than a minimum volume (the minimum size required for the electronics to fit inside). This first method was therefore close in scope to the design process of a trained industrial designer. The second method of design exploration, addressed in Part 2 of the study, may be classified as constrained concepting. Participants were able only to modify a pre-existing design within the

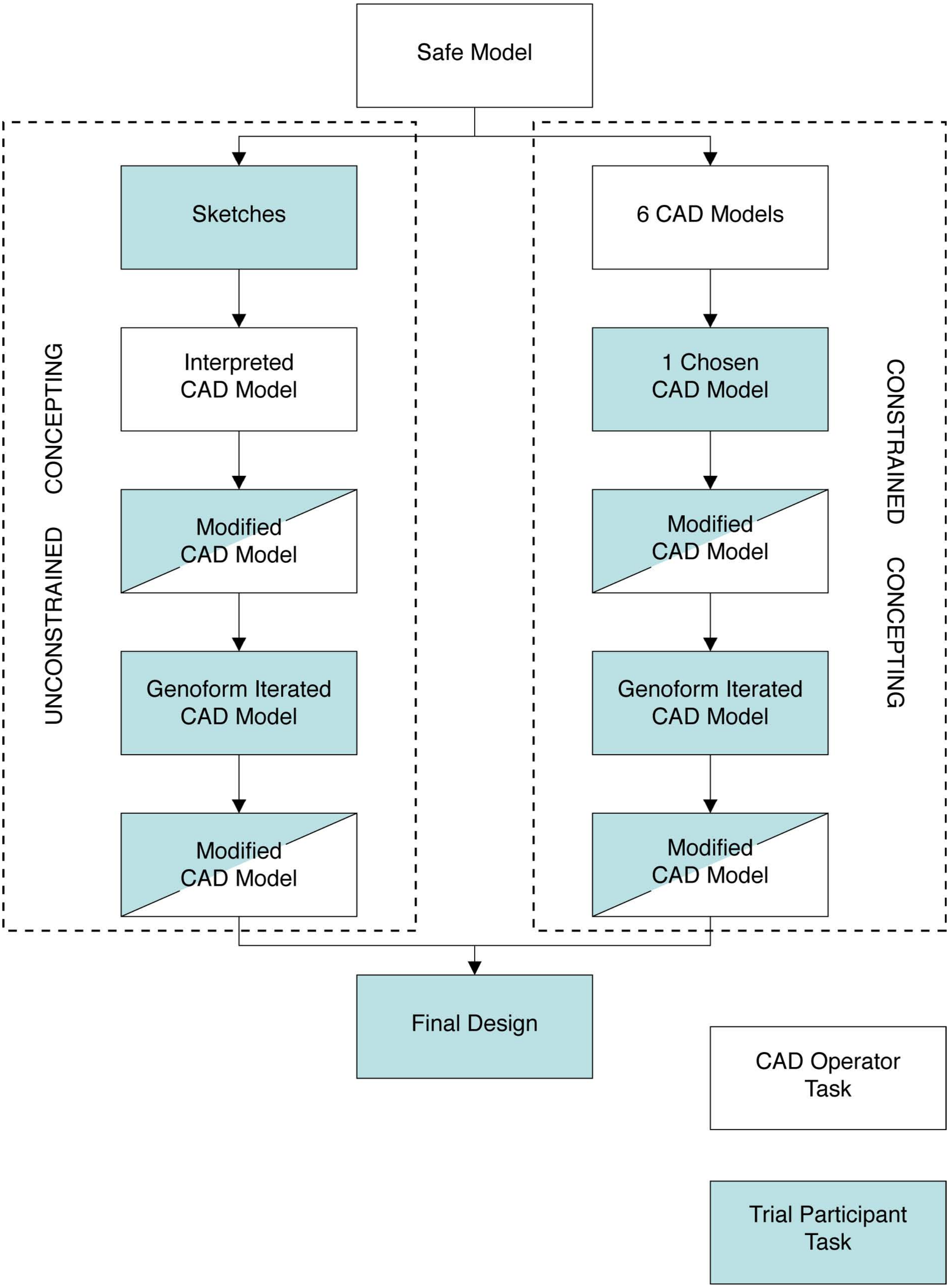


Figure 9.4. Structure of the trial

constraints allowed by the CAD model. Consequently the second method was closer in scope to a MC toolkit experience.

9.5.1 Part 1a - Sketching Exercise

Participants were briefed verbally as to the task and requirements of the exercise, but conducted the exercise unobserved such that they were in a more natural environment and worked in a less time-constrained manner. Participants reported spending one-and-a-half hours on average on the task, though most reported thinking about the task over a period of days before beginning. Participants were required to complete the sketching exercise within one week of having been briefed.

In the briefing participants were asked to create drawings on an A4 marker pad supplied to them. A number of images were supplied of a 'minimum volume' Safe Model of the USB memory stick, and participants were shown how to use these images as underlays over which their own designs could be drawn. Participants were instructed only to use the drawings pads and pens, pencils, markers etc, and specifically not to create designs using a computer. They were told that the purpose of the study was not to judge drawing skill.

Participants were instructed to design the body and the cap of the memory stick, and to imagine they were designing a personal product, i.e. not to consider the needs of other consumers. It was stated that participants should not copy an existing design, and that the more personal the design (in terms of either function or aesthetic) the more useful it would be to the research. Participants were also supplied with a sealed envelope containing photographic images of existing USB memory sticks (see Appendix 9.2), and told they could open the envelope at any time during the exercise. This was in order to understand how participants might use or refer to existing designs whilst creating their own concept.

Finally, participants were told that whilst they could work on any number of designs, at the end of the exercise they should have one final, favourite design. Participants were instructed to return all drawings, even those of discarded ideas. It was also made clear that when submitting the final design, participants should consider how well it could be understood by someone looking only at their drawings.

A written summary of the instructions above (see Appendix 9.1) was also provided to participants after they had been briefed, which could be referred to whilst conducting this part of the exercise.

9.5.2 Part 1b - Modelling Exercise

Participants were required to return their drawings by mail such that no verbal explanation could be given about the design. This ensured that their ability to communicate through sketching and annotation only was tested. Drawings were then used as the basis for construction of a 3D CAD model by a CAD software operator experienced in making industrial design models. The CAD operator was thus required to 'read' the drawings, 'interpret' the participant's design intent, and develop the 2D drawings into a 3D model (Figure 9.5).

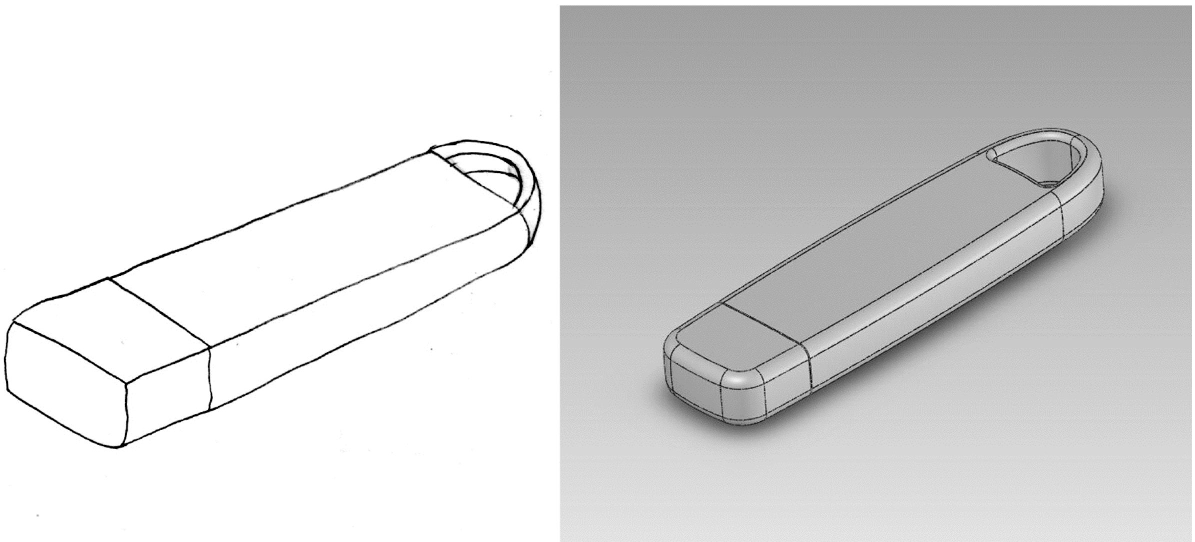


Figure 9.5. Sketch with Interpreted CAD Model

In a number of instances what was drawn by the participant was not physically realisable in 3D - the participant had failed to 'reinterpret' the drawing and perceive the physical attributes it implied (Purcell and Gero, op. cit.). Figure 9.6 shows such a failure of reinterpretation: the indentation in the top surface is shown as breaking the side surface in orthographic views but not in the perspective views. In such cases the task of the 3D modeller was to intuitively judge the participant's intent.

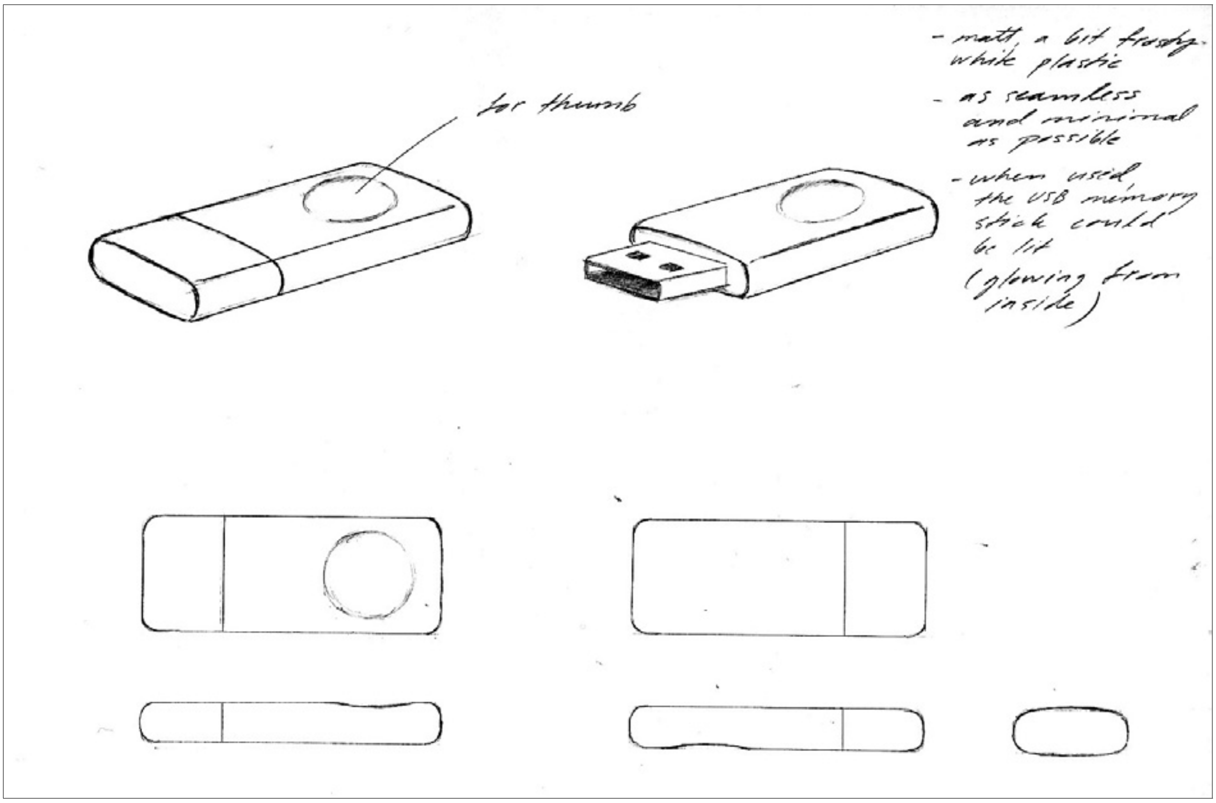


Figure 9.6. An example of a failure of reinterpretation in a participant's design sketch

3D models were built using Solidworks 2007 (Service Pack 2.0) CAD software. The software and version were determined specifically by the use of Genoform, which at the time of the exercise was not compatible with later versions of Solidworks. Solidworks itself is a hybrid parametric CAD modeller (it allows the use of both solid and surface modelling techniques), in which features are primarily created from constrained, dimensioned sketches (see Figure 9.7). One of the skills of the CAD operator therefore lies in understanding how to constrain sketches such that the model will update smoothly when a sketch's dimensions are altered. Sketches which are not appropriately constrained will cause the update to fail, which can then result in significant time spent 'debugging' the problems.

Participants were invited back to conduct the modelling exercise approximately one week after having submitted their design. They were asked to review the model and to comment specifically on how well it captured their design intent (i.e. did it look the way they expected).

Attention was drawn to specific aspects of the model, particularly where the CAD operator had interpreted a difficult-to-understand drawing or feature. Participants were then asked whether there was anything they would wish to change about the model either to improve the design or to correct mistakes in the interpretation of their drawings.

When the CAD model had been modified to a state which the participant felt reflected their aspirations for the design, the Genoform software program was used to generate alternative design options. Initially ten options were generated but participants were free to generate more if they wished. Options which were liked or perceived as interesting were imported back into Solidworks; these reimported options were then compared to the originator model.

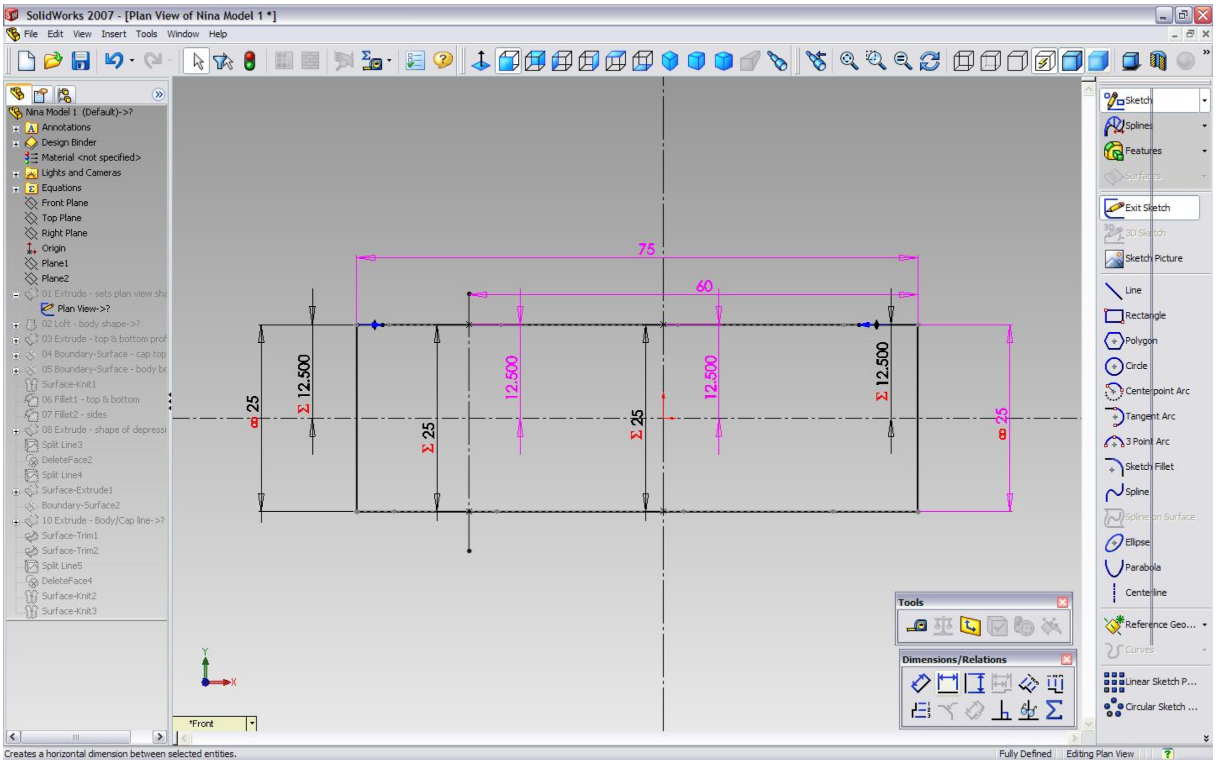


Figure 9.7. A typical Solidworks sketch. Black line work indicates the sketch is fully constrained.

In a majority of cases the participant requested changes to the originator model, based on ideas stimulated by the Genoform options, however in no instance was a Genoform option chosen as a 'most favoured' design.

9.5.3 Part 2 - Modelling Exercise

In this part of the study, participants were shown six pre-designed CAD models (Figure 9.8). The reasoning behind each design, e.g. why it was a certain size or contained certain features, was explained; the extent to which it might be modified was also made clear. Participants were then asked to choose one of the six models as the basis for the rest of the exercise.

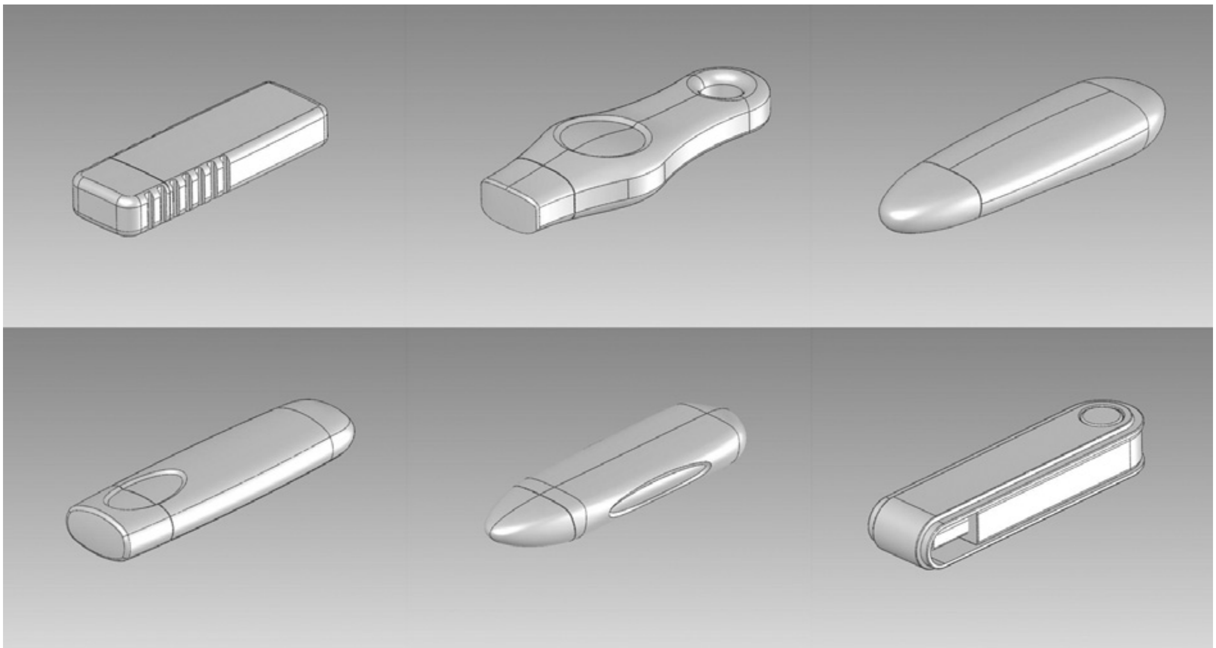


Figure 9.8. Six pre-designed memory stick CAD models

Having chosen a model, participants were asked which aspects of its design they wished to change. Where it was possible to modify the model by changing a feature's dimensions or parameters this change was accepted. However any request which involved adding new features was not accepted. For example: with the 'grip' feature on model 1 of the six pre-designed memory sticks, the number of grip details could be modified, however a similar grip feature could not be transferred to any other model. In such a way participants were deliberately constrained in their ability to influence a given design. The CAD model was again modified by the CAD operator in front of the participant according to his/her instructions.

When the chosen model had been modified to reflect the participant's intent, the Genoform program was again used to generate alternative designs. Ten options were generated initially but participants were able to request more options. Those felt to be interesting were imported back into Solidworks and compared to the participant’s own modified model. In this part of the exercise Genoform was less able to suggest new ideas or directions, and a majority of participants preferred their own modified model to the Genoform derived options.

9.6 PILOT STUDY

The pilot study had two main objectives: firstly to ensure that the main study would run smoothly and as expected, and secondly to identify any flaws or weaknesses in the design of the pilot study that might affect the usefulness or validity of the main research results. In particular, the pilot study was used to investigate the usefulness of Genoform to suggest possible designs to consumers. It was therefore important to understand how Genoform worked in relation to Solidworks (the CAD software used to model the memory stick designs) and how to design ‘Genoform-friendly’ CAD models.

The pilot study was conducted with two participants, both of whom met the study's criteria for participation (see Section 9.7 below). The pilot was conducted in full with the first participant; the exercise was then modified according to the findings from this first test-run before being tested once again with the second participant.

The pilot study highlighted a number of important aspects with regard to the instructions given to participants. Most notably, the first participant discarded some sketch sheets, returning only the one which showed their final design. This was despite having been told during the briefing that all sheets should be returned. In addition the second participant returned a sheet showing two, slightly different versions of a final design. The instructions given to participants in both the briefing and the written notes were therefore made more explicit for the full trial. It was also realised that the length of time that each participant spent making design drawings should be recorded, and that participants should be questioned in more detail in order to gain a better understanding of their design processes.

The study also highlighted the necessity of creating CAD models which were capable of being quickly updated according to 'unexpected' instructions. For example, the CAD operator interpreted and built the first participant's design using an arc profile, however when conducting Part 1b of the exercise the participant asked for the design to be modified in a way which was only possible by using a more complex spline profile. This required that the original sketch was recreated, which in turn caused subsequent operations to fail. A more flexible solution in the CAD model interpretation of the original sketch would have been to use a spline, constrained to the profile of an arc - this would have allowed the sketch to be updated more easily, preventing subsequent failures in the CAD model's history.

The final benefit of the pilot study was to demonstrate how Genoform-compatible CAD models should be constructed. When building both participant's CAD models, sketches were labelled and constrained with a preconceived notion of which features should be manipulated by Genoform. This 'preconceived notion' may be thought of as the designer placing restrictions on the consumer as to which elements of a product might be changed and which are fixed. However when Genoform was first run, it was obvious that the model had not been built in a sufficiently robust way. In attempting to generate new iterations, Genoform failed to rebuild the model in approximately 80% of attempts (figure 9.9). On analysing the model, it became apparent that the problem lay in not fully appreciating the nature of Genoform's operation.

Usually when building a CAD model, the designer will have an appreciation of the overall scale of the product, and how much different elements and surfaces might be required to change in relation to each other. Thus a sketch or model can be successfully constrained in the knowledge that an element will not change by more than a certain amount, since that would alter the designers intent. However the usefulness of Genoform is precisely that it *does* generate designs which are different to the designers original intent, since this is where new avenues of exploration are opened up. In order for this to happen however, sketches and models must be constrained to allow for unexpected occurrences. Thus there is an inherent paradox in the use of Genoform, in that it is impossible to create a model which always updates, since such a model would yield only iterations which had previously been considered by the designer. Nonetheless, having understood the problem it did prove possible to build more robust models, significantly reducing the rate of failure.

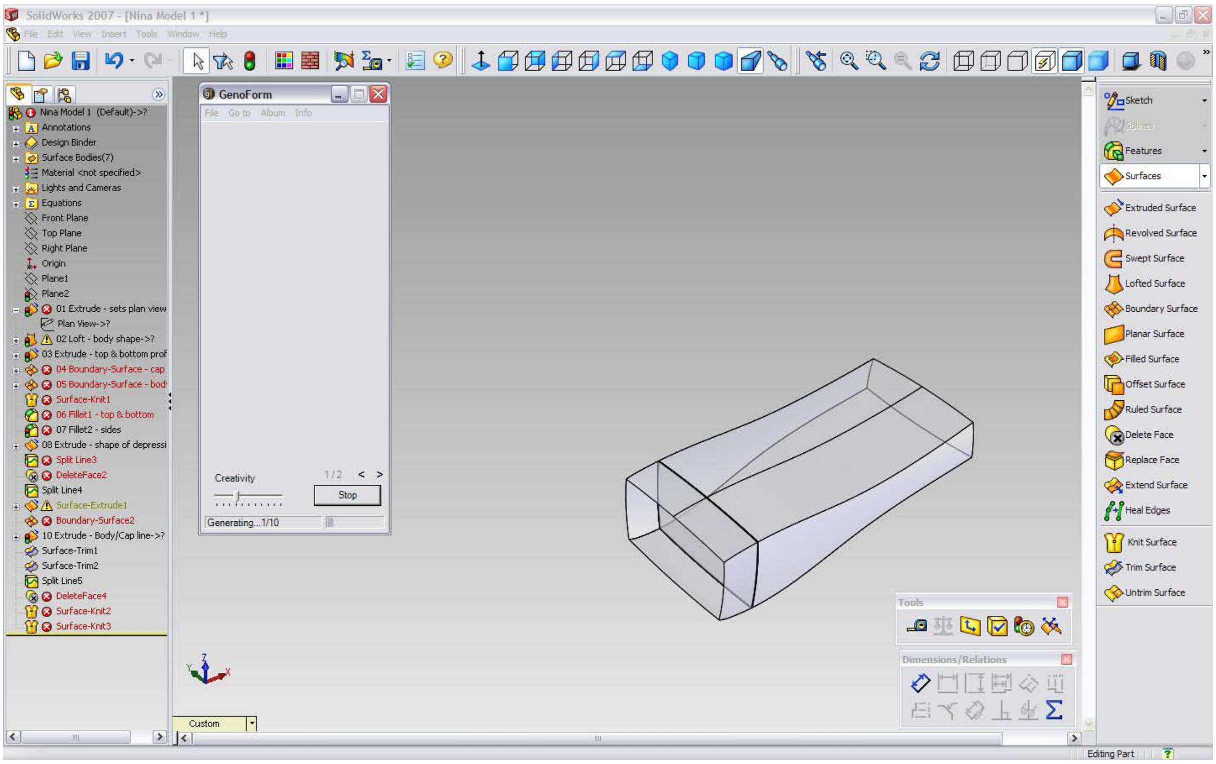


Figure 9.9. Solidworks model update. The red text on the left indicates features which have failed.

Following the pilot study, a list of recommended modelling practices for Genoform was drawn up to act as a reminder when conducting the main exercise:

a) Dimensions which Genoform is to modify should be descriptively named, whilst default names should be retained for dimensions which are not to be modified. Genoform differentiates between dimensions which have been renamed and those which have not, thus identification of specific dimensions is made easier.

b) Where one surface is used to trim another, the trimming surface should be excessively large, such that the operation is successful even if the surface to be trimmed grows in size.

c) Surfaces should be stitched together at every opportunity - unstitched surfaces appear to be a major source of update failure, whereas stitched surfaces behave more reliably.

d) Surface offset operations should be avoided wherever possible (for a reason which was not identified, the direction of offset would sometimes flip, creating an unsolvable loop in which the model would never update successfully.

By building models to these rules in the main exercise, it was possible to arrive at solutions which, when modified by Genoform, failed on average only 10-15% of times, rather than the 80% failure rate of the first model.

9.7 TRIAL PARTICIPANTS

Ten participants were recruited from within the postgraduate student body of Loughborough University in the age ranges as shown in Table 9.1. Participants were required to be computer literate as defined by daily engagement with five out of seven of the following activities: web browsing, e-mail, social networking, chat, VOIP (e.g. Skype), Microsoft Office software, other software. Participants were also required to self identify as “being interested in design and new technology.” As such, the profile of participants fitted with the findings of e.g. Bauer et al. (2007) and Füller and Bartl (2007) regarding the types of consumer most likely to engage in mass customisation. Furthermore, the trial excluded participants who had trained or were working as industrial designers.

	16-18	19-25	26-35	36-45	56-65	65+
Male	0	2	3	1	0	0
Female	0	0	3	0	1	0

Table 9.1. Trial Participants

9.8 RESULTS OF THE STUDY

The findings of the study can be divided into two main areas: the results of the drawing exercise together with the success of developing the drawings into a 3D CAD model, and the results of the two CAD modelling exercises. In both cases the objective was not to judge or analyse the quality of the design, but rather to gain subjective feedback from participants about which activities they enjoyed or disliked, and which approach resulted in the most favoured product .

9.8.1 Drawing Exercise and 3D CAD Model Development

		A	B	C	D	E	F	G	H	I	J
I	Number of sheets returned	6	3	3	1	2	5	5	1	2	1
	Total number of drawings	5	6	6	6	7	12	21	5	7	2
II	Understanding of safe model concept	Y	Y	Y	N	Y	Y	Y	Y	Y	Y
	Consistency between drawings	N	Y	Y	N	Y	Y	N	N	N	Y
	Understanding of orthographic projection	Y	N	Y	N	N	Y	Y	Y	Y	N
	Use of annotation	Y	Y	Y	Y	N	Y	Y	N	Y	N
III	Evidence of design iteration	N	N	N	Y	N	Y	Y	N	N	N
	Number of designs drawn	1	1	1	3	1	2	2	1	1	2
	Final design identified?	Y	N	Y	N	Y	N	Y	Y	Y	N
IV	Functionality (Attach/Grip/Retain/Other)	A	GR	R	O	O	AO	RO	R	G	R
	Functional detailing	N	N	N	N	N	N	N	N	N	N
	Cosmetic detailing	N	N	N	N	Y	N	Y	N	Y	N
	Colour & texture	N	Y	N	N	Y	N	N	Y	Y	N
	Manufacturing constraints	N	N	N	N	N	N	Y	N	N	N
V	Existing designs (Before/During/After)	A	B	A	A	B	A	A	D	D	B
VI	Degree of Interpretation	2	2	1	5	1	1	2	2	1	3

Table 9.2. Analysis of Participants' Design Sketches

Table 9.2 shows the results of analysis of the drawings returned by the participants. All drawings were analysed and coded according to the following criteria:

I (i). Number of sheets - How many sheets of paper were used in the exercise?

(ii). Number of drawings - The total number of sketches made during the exercise, including sketches of ideas which were rejected.

II (i). Understanding of Safe Model concept - Did the participant understand and follow the instructions regarding the images of the safe model?

(ii). Consistency between drawings - Did sketches exhibit inconsistent or contradictory information?

(iii). Understanding of orthographic projection.

(iv). Use of annotation

III (i). Evidence of design iteration - Did the participant develop and test the validity of a design through sketches?

(ii). Number of different designs drawn.

(iii). Final design identified - Did the participant make obvious which was the final design?

IV (i). Functionality - Did the participant design a functional element in addition to the basic functionality of the USB memory stick?

Attach (A) - A method of attaching the product

Grip (G) - A feature which allows the product to be held more easily

Retain (R) - A method of keeping the cap in place

Other (O) - Any other form of functionality

(ii). Functional detailing - Did the participant include functional details such as screws or split lines in the design.

(iii). Cosmetic detailing - Did the participant include cosmetic details such as fillets or chamfers in the design?

(iv). Colour and Texture - Did the participant include details whose colour or texture were specified?

(v). Manufacturing constraints - Did the participant consider details imposed by manufacturing such as draft angles or material wall thicknesses?

V (i). Existing Designs - Did the participants look at the envelope of existing designs before, during or after the exercise?

VI (i). Degree of interpretation - a measure of the degree to which the CAD operator had to interpret the participant's drawings in order to build the CAD model. Measured on a scale of 0-5, where:

0 = no interpretation needed, the drawings were accurate and fully resolved;

2 = some interpretation needed, the drawings were accurate but some details were unresolved

5 = significant interpretation needed, the basic idea was communicated but details were unconsidered or unresolved

9.8.2 3D CAD Model Modification

		Agree	Disagree
		(no. of participants)	
Part I - Drawing exercise then modification of own design	The CAD model was an accurate representation of my drawings	10	0
	After the model was modified according to my instructions, the design was improved	10	0
	After modification using the Genoform software, the design was improved	7	3
	After modification using the Genoform software, I was able to improve my design	9	1
Part II - Modification of pre-existing design	I felt limited by the six choices I was shown	8	2
	After the model was modified according to my instructions, the design was improved	10	0
	After modification using the Genoform software, the design was improved	1	9
	After modification using the Genoform software, I was able to improve my design	4	6
Comparison of Part I and Part II	I enjoyed the process of design in Part I more than Part II	1	9
	The final design from Part I was better than the final design from Part II	10	0

Table 9.3. Participant responses to the two alternative design processes

Results in this area refer to the tasks in both Part I and Part II of the trial which involved modifying the CAD model. The results largely consist of a comparison between the design process of Part I and Part II, and which process yielded the most favoured design. Participants' opinions were recorded during and immediately after the trial, and are summarised in Table 9.3 above.

9.8.3 Examples of Sketches and Final CAD Models

Table 9.4 below shows examples from four participants of sketches and final CAD models (i.e. CAD models at the end of Part 1b of the exercise).

9.9 DISCUSSION OF RESULTS

The following discussion first considers two of the three questions posed earlier in the thesis, namely:

> What methods do consumers prefer to use when engaging in industrial design? and
>
> How well are consumers able to communicate design intent?

It then considers the use of Genoform, and goes on to consider a number of further findings relevant to the specification and design of an industrial design toolkit. The final research question, namely to what degree of completeness should a product be designed, before a consumer is able to optimise it? is addressed in the chapter's Conclusions.

The two methods of design exploration available to participants in the trial were ‘unconstrained concepting’ (the sketching exercise in Part I) and ‘constrained concepting’ (the modification of an existing design in Part II). Within the unconstrained concepting exercise, participants were free to explore any number of designs and to develop those designs in any direction. However the sketches showed that only four participants drew more than one design option. Even fewer (three) engaged in any form of design iteration, i.e. a process in which a design idea was modified. The most common form in which drawings were returned was a single idea, drawn from multiple viewpoints. As such, the ability of the participants to

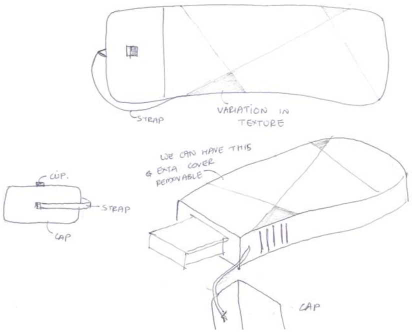
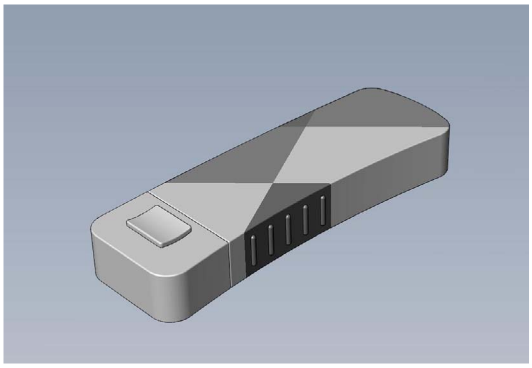
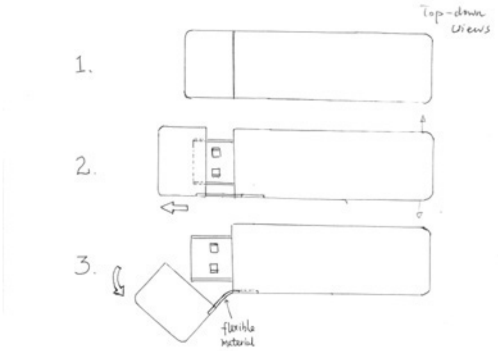
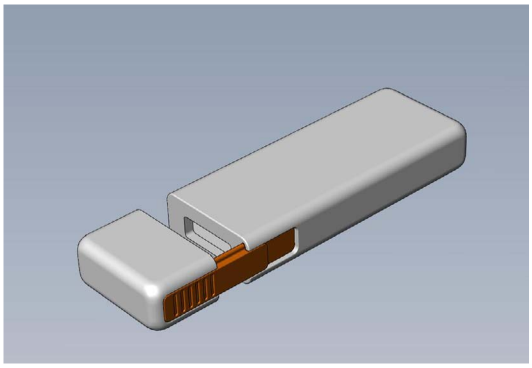
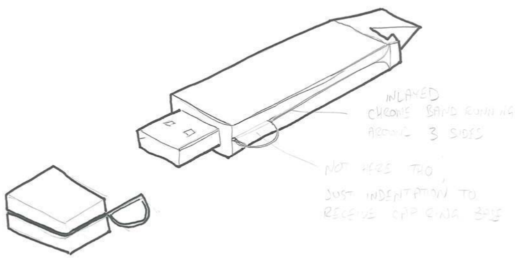
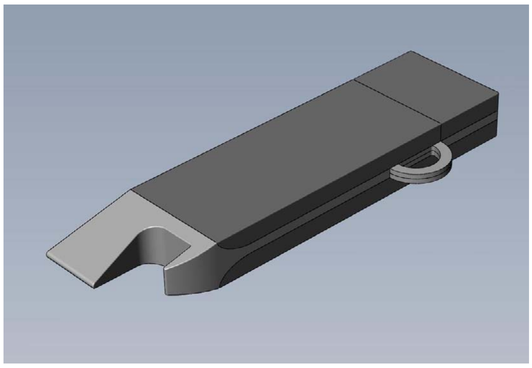
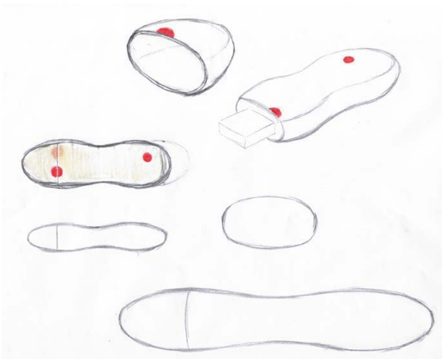
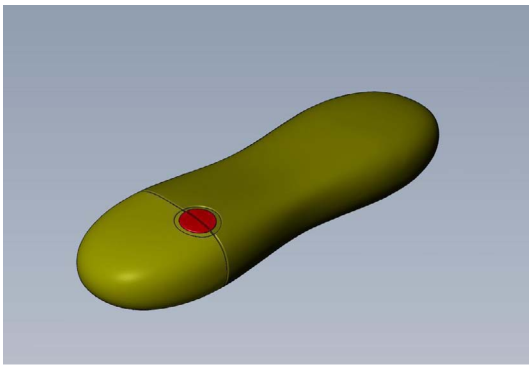
	 Example C
	 Example E
	 Example G
	 Example I

Table 9.4. Examples of sketches and final CAD models

engage in design exploration through sketching was extremely limited.

This finding is supported by existing research into the manner in which designers use the activity of drawing. Garner (1990) for example, suggests that designers use drawing in two ways: firstly as a means of “exploration and manipulation,” and secondly as a means of communication. The first is a creative activity, a way of “conversing with yourself” (ibid.) in which multiple sketches are used to develop a design from the first idea to the ‘best’ idea. Such sketches do not need to be accurate or even realistic provided they offer an insight into the problem or possible solution. A communicative sketch, by contrast, is a method of explaining a (partial or full) design solution (Purcell and Gero, op. cit.).

Drawings returned by participants appear to show an inability to utilise sketching as a method of exploration. Instead most participants attempted to draw the ‘correct’ design immediately, i.e. they tried to communicate a final design without testing whether it was, in fact, the best solution (see Example I in Table 9.4). Garner (op. cit.) identifies a “randomness” within design exploration, and attributes it to a “lack of inhibition” among trained designers to the act of drawing. Designers are often taught that mistakes when drawing have value and can lead a design in new directions; in contrast a number of participants’ drawings showed evidence of the use of an eraser to remove ‘wrong’ sketches. This inhibition or discomfort with drawing was further borne out by responses from participants, nine out of ten of whom preferred the process in Part II where drawing was not involved.

Although their sketches showed a lack of design exploration, the need for design iterations was implicitly recognised by all participants in their reactions to the CAD model representation of their design. Initially all participants believed the CAD model to be an accurate interpretation of their drawings. However, all participants subsequently accepted the invitation to modify the CAD model, and all believed that the design was improved by this process of modification. Participants perceived the CAD model as a ‘sketch’ or work-in-progress which required development, and recognised that design iteration was necessary to arrive at a better design.

This recognition of the need for design iterations was also demonstrated in Part II of the trial, in which participants were required to modify one of six pre-existing designs. A majority of participants felt constrained by the choice of designs, however all were able to improve the design (in their own judgement) by modifying it. Again participants were able to perceive the CAD model as a work-in-progress rather than a final solution.

Figure 9.10. An example of a sketch design without design iteration

The use of Genoform as an aid to design appeared to have variable success. In Part I, seven participants felt that Genoform was useful in improving their designs, however none felt that the software was able to provide the 'best' design. Instead it proved useful as a tool for generating ideas or suggestions for how the design might be improved. Nine participants used these suggestions to arrive at a final design. In Part II however, only one participant believed Genoform improved on their own modifications of the pre-existing design. A minority (four) were able to identify new ideas within the Genoform variations and improve their designs. The reasons for this discrepancy are unclear, however it may be the pre-existing designs were perceived as initially more resolved by participants than their own designs.

The most significant finding from the trial comes from comparing both the processes (constrained vs. unconstrained concepting) and the outcomes of those processes. As previously mentioned, nine out of ten participants felt uncomfortable with the drawing exercise, preferring to modify a CAD model representation of a design. However every participant believed the drawing exercise ultimately led to the best design. When questioned, the main reason given was, as might be expected, that the design more closely matched their needs and wishes than the pre-existing model. Three participants stated that they would like to imagine their design was unique, and did not feel certain a pre-existing model would not be modified in similar ways by others. One participant said he would be proud to show the product to friends and explain to them why he had designed it in the way that he had.

These results clearly demonstrate the value which participants attached to their self-designed products. Looking more closely, a further reason which emerged was the ability to introduce additional functionality to the product, which the modification of pre-existing designs did not allow. All ten participants added additional functional elements to the USB memory stick, for example, details which enhanced grip, or methods for ensuring the cap was not lost. One participant shaped the device such that it could act as a bottle opener, whilst another attempted to decrease the possibility of the product being knocked and broken when plugged into a computer. This value placed on functionality rather than just aesthetics, together with a preference for a design which more closely fits the consumer's needs, also coincides with findings from mass customisation literature (e.g. Schreier, 2006; Merle et al. 2007).

Half the participants looked at the images of existing memory stick designs after completing their own design, however four of these reported their reason for doing this as an attempt to keep the design 'pure' for the purpose of the trial. Thus it appears their behaviour was modified as a result of the research conditions. On further questioning, these participants suggested that in other circumstances they may have looked at the images to gain inspiration; it was also suggested that looking at images after the design was complete was valuable, as their design was 'validated' as being as good as other designs. The five remaining participants reported looking at the images for inspiration, and one stated that some of the images gave her "permission" to design a more personal, less conventional product.

9.10 CONCLUSION

The trial demonstrated that participants placed significant value on the ability to design their own USB memory stick. Products which were self designed were valued more highly than those which were customised from pre-existing designs, despite the fact that most participants felt uncomfortable with the process of self design and preferred the process of customisation. Participants were generally unable to engage in design iteration through sketching, and used drawing as a method of recording and communicating a design rather than exploring it. However, when presented with a CAD model representation of their own design, participants recognised the value of developing that design through iteration in order to arrive at a better solution. Participants also placed a high priority on the ability to incorporate additional functionality into the basic usage of the memory stick (see Table 9.4

previously referred to.

The trial raised a number of issues of importance to the design of an ID toolkit as proposed by this thesis. Firstly, the question of how to resolve the apparent paradox between the preferred design process and the preferred outcome must be addressed. Participants unanimously favoured self-designed products over modified or customised pre-designed products, however a clear majority did not enjoy the drawing task required to initiate the self design process. In a setting outside of a user trial it might therefore be expected that consumers would not engage in self design at all, and thus never arrive at a point where they were able to assess the value of their self-designed product.

It is outside of the scope of this research to investigate a system which would allow and encourage consumers to sketch designs, which would subsequently, through an automated process, be transformed into 3D CAD models suitable for manufacture. Therefore the recommendation should be to allow consumers the maximum freedom possible to modify an existing design. Rather than presenting consumers with a 'blank canvas', this incomplete design should instead be thought of as a generic offering which would become individualised as the consumer designed within the boundaries it encapsulated. Such a system, whilst inevitably limiting creative freedom to some extent, would also give the consumer confidence that the self designed product would always be manufacturable.

With regard to the use of Genoform, an iterative design tool appears to have most value when applied to a consumer's own design. When Genoform was used on the six CAD models of pre-existing designs, a majority felt it to be of little use. Thus it would appear that within the type of tool investigated by this research there is low demand for such functionality.

A number of specific recommendations for the toolkit can also be drawn from the trial:

- The use of orthographic projection should be avoided. A majority of participants were not able to understand this convention correctly, thus a more visually realistic representation should be used. This would imply a three dimensional, rendered view.
- No participants considered the functional detailing of their design (i.e. details

such as screw bosses or snap features necessary for the product's assembly), and most ignored the constraints imposed by manufacturing processes (draft angles etc.). This was not unexpected, and indeed it is a feature of MC toolkits that such considerations can be ignored by the consumer. It is unreasonable to expect an untrained consumer-designer to have the expertise needed to design such details, and therefore an incomplete design should include functional detailing, although it should be largely invisible to the consumer using an ID toolkit.

- In addition, few participants considered cosmetic detailing such as edge fillets or chamfers. This implies that such details should also be included in the incomplete design presented to consumers.
- A majority of participants gave no consideration to the colour or texture of their design. This was surprising as colour would seem to be one of the most obvious ways to personalise a product. An ID toolkit might therefore need to guide the consumer through the process of colour selection, perhaps making complementary suggestions.
- All participants saw value in looking at examples of pre-existing designs, whether for inspiration or validation of the value of their own designs. A gallery of designs created by other users would therefore be valuable; it might also be that consumers could start with another consumer's design, rather than the incomplete design provided by the designer.

This chapter has shown some of the strengths and weaknesses in consumers' abilities to design their own products. It has also listed some broad concepts, together with a number of recommended features, for the specification of an ID toolkit. The following chapter considers the specific tools and approaches that such a toolkit might implement by testing a number of consumer-oriented software packages, together with mass customisation toolkits, in order to develop that specification.

CHAPTER 10.

An Analysis of Consumer-Oriented 3D Modelling Software.

10.1 INTRODUCTION

Chapter 9 investigated two scenarios in which consumers might have direct involvement in the design of their own products. In the first, consumers were able to engage in 'unconstrained' concepting, and sketched designs which were then modelled by an experienced CAD operator. In the second, a CAD model was presented which consumers were able to modify, within constraints predetermined by the designer. This chapter examines a third scenario, namely the use of CAD software by consumers themselves.

Consumer-oriented 3D modelling software is a relatively new phenomenon, and is characterised by two criteria:

1. It is cheap, and often free.
2. It is easy to learn.

Unsurprisingly, in comparison to professional-level CAD software such as Solidworks or ProEngineer, consumer-oriented modelling software is extremely limited, both in terms of the modelling tools available and its ability to construct a part which might subsequently be manufactured. In recent years however, consumers interested in modelling parts for their own use, which are subsequently manufactured by an AM process, have seen a number of appropriately featured software packages introduced. It was therefore necessary to understand the capabilities of such software, in order to judge the degree to which the specification of a consumer-design toolkit might involve CAD-type functionality.

This chapter compares four consumer-oriented 3D modelling packages: Google SketchUp, Moments of Inspiration (MoI), Sculptris and Cosmic Blobs. It begins by describing the objectives of the testing and a scenario developed to ensure that the software was judged using comparable criteria. It then details a process of Reverse Engineering of an existing product (in this case a computer mouse) in order to model a number of critical features which were subsequently imported into the software being tested. The learning of the software and the design of a new mouse concept appropriate to that software is then discussed. Finally the features and performance of each software package is coded and compared, and recommendations of features which might transfer to the consumer-design toolkit are given.

This phase of the PhD research took place over a period of approximately ten months, and generated significant amounts of material in terms of design diary entries, design sketches, CAD models, screen shots, renderings and manufactured parts. Detailing this for all five modelling packages would be both lengthy and repetitive. An in-depth description of the process is therefore given for Google SketchUp; the remaining software is then described more succinctly, highlighting only significant features. Copies of diary entries and all other material is provided in Appendices 10.1 - 10.4.

10.2 SOFTWARE TESTING METHOD

Having decided to analyse and compare a number of consumer-oriented modelling systems, a number of issues were immediately raised with regard to the design of the test:

1. How should consumers be involved in the testing of the software?
2. How could consistency in testing and reporting be ensured?

3. Which software should be tested?

These issues are considered further below.

10.2.1 Participation in Testing

A significant problem with regard to the recruitment of test participants was that it could take a number of weeks to become proficient in even supposedly easy-to-learn software; this was especially true given that it was unlikely to be a full-time activity for any participants recruited. Furthermore, the varying complexities, learning curves and conceptual approaches (NURBS or sub-division modelling, for example), suggested that comparisons of software would only be valid if all participants had learned all the modelling packages being tested. The long term commitment that would be required of test participants to learn and analyse all the software being tested meant that such an approach was judged unfeasible.

An alternative approach may have been to set participants a modelling task and ask that they learn each modelling package to a level where the task could be completed. However this strategy was also rejected, as it was felt that such a task would necessarily have to be relatively simple (in order to avoid a lengthy learning phase) and was therefore unlikely to yield useful results. Consequently it was decided that consumer testing of the software should be discounted, and that the different modelling systems should be learned and compared by the author.

This approach raised a further significant issue however. As a professional designer it was likely that the author would have difficulty discounting his prior knowledge when learning and using the software. However in considering this issue further, it was reasoned that the purpose of the testing was not to judge how well the software could be used by a non-professional designer. Instead the testing should consider whether the modelling systems demonstrated similarities or differences (in concept and implementation), and identify features that might be integrated into a consumer design toolkit. This was a task which could be considered from a neutral perspective, provided there was a standard framework under which each piece of software would be assessed. Thus the role of the author was that of an expert evaluator.

10.2.2 Scenario Development

The standard framework mentioned above consisted of two parts. A list of specific criteria for measurement is given in Section 10.2.5. More fundamentally however, it was felt that learning the software via tutorials etc. would not provide a stringent test, and would instead play to the strengths of each modelling system (tutorials are, understandably, designed to teach what the software *can* do, rather than what it cannot). A more valuable assessment would be provided by envisaging a 'real world' task which should be attempted using each modelling package, thus providing insights as to how the software might perform during realistic usage. In keeping with the overall theme of this PhD, the following scenario was therefore developed:

In the short-term future, a person with relatively well developed skills in a ‘professional’ CAD software package would be able to reverse engineer an existing product and create a digital 3D model of that product. This 3D file could then be placed in a library and made available for download (either for a fee or for free) to others. Consumers with less skill than the person making the file available could nonetheless download it and use the file to create (via additive manufacturing) a copy of the original product. Consumers could also use a more readily available (i.e. less expensive and easier to learn), non-professional CAD package to modify or redesign the original, and thus create a unique product (again via AM).

This scenario then provided a procedure to be followed for each modelling package being tested, as follows:

1. Import the critical features of the original mouse model (see Section 10.2.3 below) as the basis for the new design.
2. Learn the software.
3. Create a new design based on the capabilities of the software. Since these were not well understood at the start of each exercise, stages 2 and 3 inevitably became concurrent activities.

4. Model the new design of mouse.
5. Output the design and manufacture using an AM process.

10.2.3 The Computer Mouse

A computer mouse was chosen as the subject of the exercise for a number of reasons. Firstly the form of the mouse - those parts which would be measured, reverse engineered and redesigned - was complex, consisting of 'freeform' surfaces and blended transitions between surfaces, and therefore presented a considerable challenge in the reverse engineering phase of the exercise (Section 10.3). Secondly, it was felt that a mouse might be a product which consumers would indeed be interested in redesigning, whether for functional or aesthetic reasons, if given the opportunity. Finally the model chosen, a Microsoft Comfort Optical 1000, was reasonably cheap and the electronics hardware was relatively simple (the model was a wired USB, rather than wireless, design), making its accidental damage or destruction less of a concern.

10.2.4 Software Considered for Testing

Research into low-cost 3D modelling software provided a number candidates for testing (see Table 10.1). Each package was judged according to ease of use (defined as software whose promotional material claimed "easy to learn/use" or similar); low cost (defined as costing less than $100); as well as other factors including similarity to other candidates. Software selected for testing is highlighted in orange in the table below.

NAME	DESCRIPTION	PRICE	OTHER INFO.
3D Tin	Solid polygonal modeller	Free web application	Tested on a number of browsers, but unable to run.
3Dvia Shape	Hybrid solid / surface polygonal modeller	Free download	Similar to Google SketchUp in concept and execution
Alibre Design	Parametric NURBS modeller	$199	Close to conventional CAD software in terms of functionality.
Autodesk 123D	Hybrid solid / surface polygonal modeller	Free download	Performed poorly: numerous graphic glitches and frequent crashes.
Autodesk 123D Sculpt	Sub-division modeller	Free download	Available as iPad app only.
Blender	Hybrid solid / surface polygonal modeller	Free download, open source	Very complex to learn
Cosmic Blobs	Solid polygonal modeller	$99.00, but no longer available for purchase	Aimed specifically at children.
DAZ3D Hexagon	Sub-division modeller	Free download	Primarily intended as (non-character) modeller for use in conjunction with DAZ Studio.
Moments of Inspiration (MoI)	NURBS modeller	$99.95	Close in feel to Rhino though simpler to use, with less functionality.
Sculptris	Sub-division modeller	Free download	Primarily intended as entry-level character modelling software.
Google SketchUp	Hybrid solid / surface polygonal modeller	Free download	Used extensively by architects, but becoming popular amongst hobbyist designers.
TinkerCAD	Solid polygonal modeller	Free web application	Not available at time of testing.

Table 10.1. Software Comparison

10.2.5 Criteria for Measurement

During testing the modelling software was assessed in three main areas, according to the criteria listed below.

Quality of User Experience

- Cost
- Platform (PC / Mac / Unix / Other)
- Ease of Installation
- Documentation
- Tutorials
- Bugs
- Support (Company)
- Support (Community)

Ease of Use

- UI Structure (icons, menus, hidden items etc.)
- Presentation (shaded or wireframe, single view or multi view etc.)
- Follows existing paradigms (is similar to other software)
- Ease of View (zoom, rotate etc.)
- Repetition of function (different tools achieve the same result)
- Redundancy (tools are not used)
- Creates modifiable models

Communication with External Environment

- Tools required (mouse, tablet etc.)
- Inputs existing file formats
- Outputs existing file formats

- Outputs RM data formats

This list was continually referred to when compiling the design diary (see Section 5.7 above) at the end of each day. It also provided the format for comparing each software package at the end of the exercise, as discussed in Section 10.7.

10.3 REVERSE ENGINEERING

The reverse engineering component of the exercise can be divided into two main sections - firstly the measuring of the original mouse, and secondly the creation of a 3D CAD model representation. In reality the workflow could more accurately be described as one of taking initial measurements, beginning the modelling task, and then taking additional measurements as required by the developing model. For the sake of clarity however, the two operations are described separately below.

10.3.1 Measurement

The tools used for disassembling and measuring the mouse were as follows:

- Vernier Calipers - the most used item, this set were analogue and therefore required a degree of familiarity (compared to digital) to use accurately.
- Mini screwdriver set.
- Torx screwdriver set - not actually used, but would be essential if the exercise were repeated on a different class of product (e.g. mobile phone).
- Scalpel - for cutting through and removing adhesive labels.
- Anti-static bag - once removed the pcb was placed inside.

These tools were sufficient to begin taking accurate internal and external measurements, however they were far from adequate at providing all the dimensions required to accurately model the mouse. As explained previously, one of the reasons for choosing a computer mouse (and this model in particular) was that the split lines between parts describe a number of complex curves (i.e. splines, rather than arcs), which lay on more than one plane and would therefore prove challenging to measure and model. Attempting to measure such curves using the equipment described above would have proved fruitless, and so instead the mouse was photographed using a Nikon D40X (digital) SLR camera, mounted on a tripod, with a 28mm lens. (Although this lens allowed the product to be photographed at close range, it introduced distortion to the subsequent images, as discussed in Section 10.3.3 below.) The images were then opened in Adobe Photoshop and resized where required, such that when overlaid the features of the mouse aligned.

NOTE: In the time since this exercise was conducted, a number of consumer-oriented 3D scanning solutions have appeared on the market, for example Autodesk 123D Catch (which uses multiple digital photographs) and Reconstruct Me (which utilises the Microsoft Kinect device). At the time of the exercise, 3D scanning as a method of Reverse Engineering was discounted as being too complex and expensive to align with the scenario. However in future it may be a viable method for consumer designers to capture 3D data from existing products.

10.3.2 Modelling

In order to accurately recreate the critical features (see Section 10.4) which would be used later in the exercise, it was first necessary to create a 3D CAD model of the original mouse. This was carried out using Solidworks 2009 (service pack 2.1), which was used primarily because it is a system with which the author has extensive experience and skill. As a 'professional level' CAD package it is of course extremely unlikely that a consumer would have access to such software. However it was felt reasonable, within the bounds of the scenario, to suppose that the skilled amateur (who would be making the reverse engineered model available to other, less-skilled amateurs) would have access to software of a similar type (whether legitimate or pirated), as well as experience of its use.

The procedure for creation of the CAD model was as follows: images of the mouse were imported to Solidworks and sketches drawn to replicate the product's form (Figure 10.1). Initially working purely with surfaces, and on one half of the model only, the overall shape was developed. The surfaces were then mirrored and knitted to form a solid. Thereafter the solid was split into its (three) constituent parts and a hybrid solid and surfacing process was

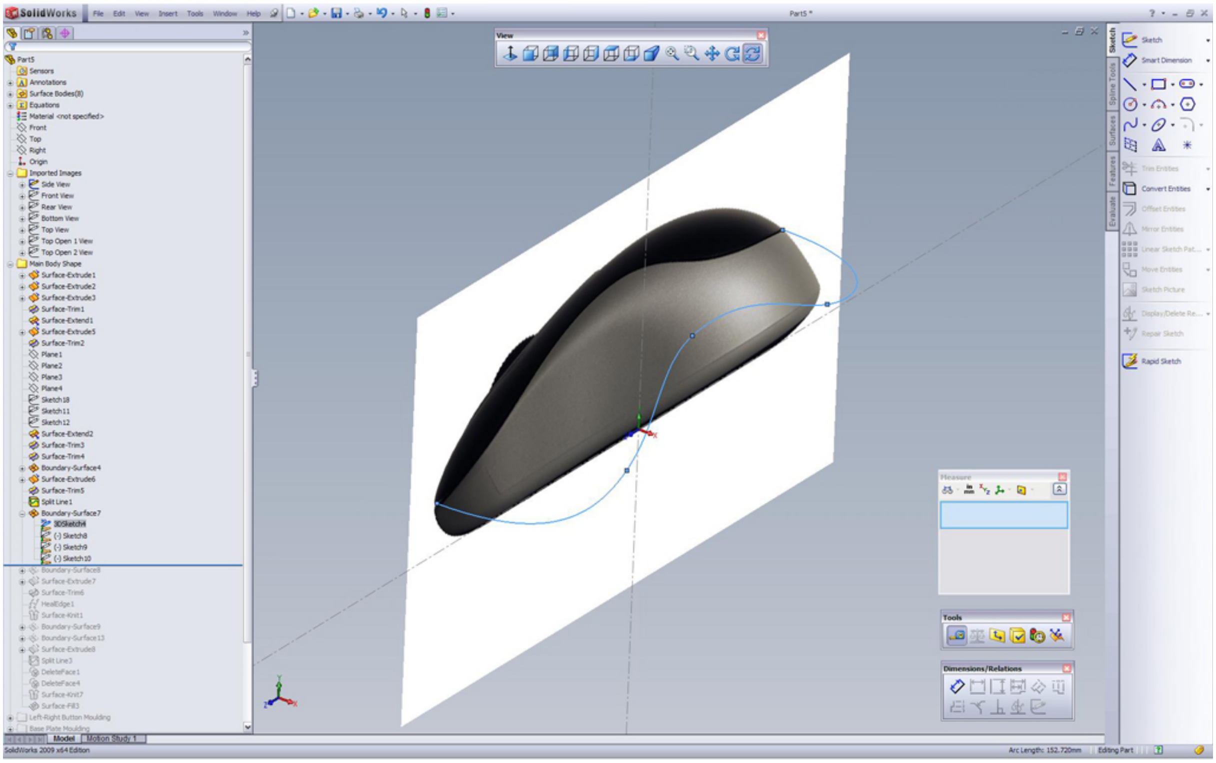


Figure 10.1. A 3D curve drawn to match the split line profile between parts

used as appropriate. Figure 10.2 shows the completed CAD model.

10.3.3 Errors and Corrections

As mentioned above, a number of errors were introduced by the use of the digital camera. Firstly, despite shooting the images at the camera's maximum resolution (10Mb), when zoomed in the graininess of the image meant any measurements were only accurate to approximately 0.4mm. Furthermore the part with the most features, the base of the mouse, was moulded in a translucent plastic, which made reading the photographic image even harder as it was not always clear which edges were which. The main source of photographic error, however, was undoubtedly the distortion introduced by the use of the 28mm lens. Whilst the centre of each image was relatively accurate, towards its edges the image was foreshortened, with the result that dimensions taken from the image in these areas were unreliable. This necessitated significant measurement and re-modelling to ensure the CAD model was accurate.

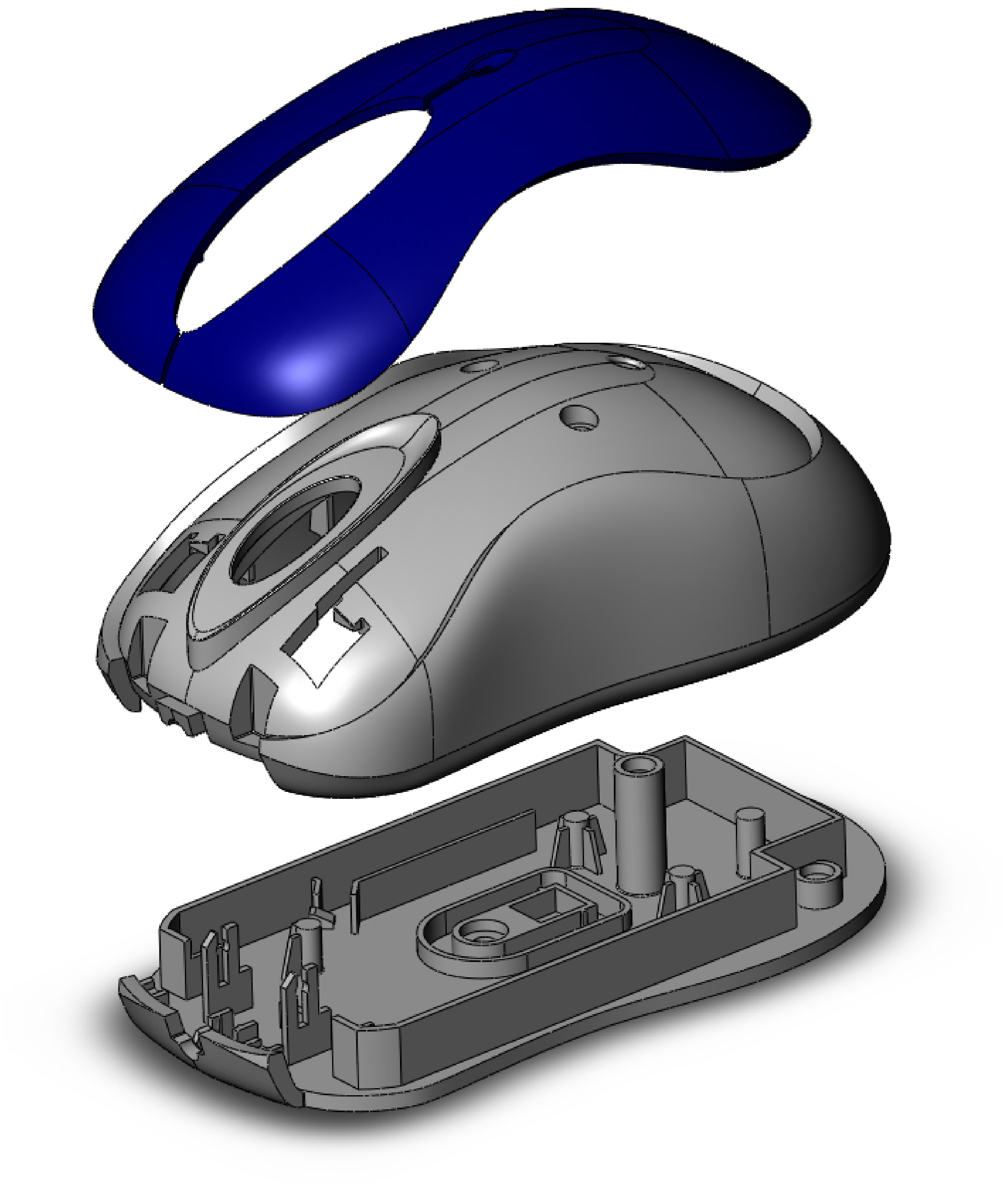


Figure 10.2. Exploded view of the completed Solidworks CAD model.

10.4 CRITICAL FEATURE MODELLING

After rebuilding the Solidworks CAD model to correct the errors above, an exported .stl file would be sufficient to allow a consumer to download and manufacture their own copy. However the true benefit of such a model would be realised if it allowed a consumer to modify or redesign it to meet their own requirements. A ‘hands-off’ approach to allowing such consumer modification would simply be to make the model available and let the consumer’s level of enthusiasm or skill decide the extent to which the model could be redesigned. A more helpful approach however, was to ‘strip out’ all the extraneous features and surfaces, and leave only the critical features, defined as:

Functional features: features which are necessary for the redesigned mouse to interface with the internal parts and electronics, this includes the struts which hold the scroll wheel in place, and the pushers which operate the left and right button switches.

Assembly features: features which are necessary for the redesigned mouse to fit together robustly, this includes snap features and a screw tower. It also takes account of material wall thicknesses and tolerances.

Functional surfaces: less prescriptive than functional features, functional surfaces define the position of a surface but not necessarily its shape or size. An example is the external surface surrounding the scroll wheel, which could not be moved up or down (i.e. in the Z-axis) without compromising the scroll wheel’s functionality.

Fit features: features which ensure that the internal parts and electronics fit inside the redesigned mouse. Together with the assembly features, fit features were used to generate a safe model of the type previously described in Chapter 9 (Figure 10.3).

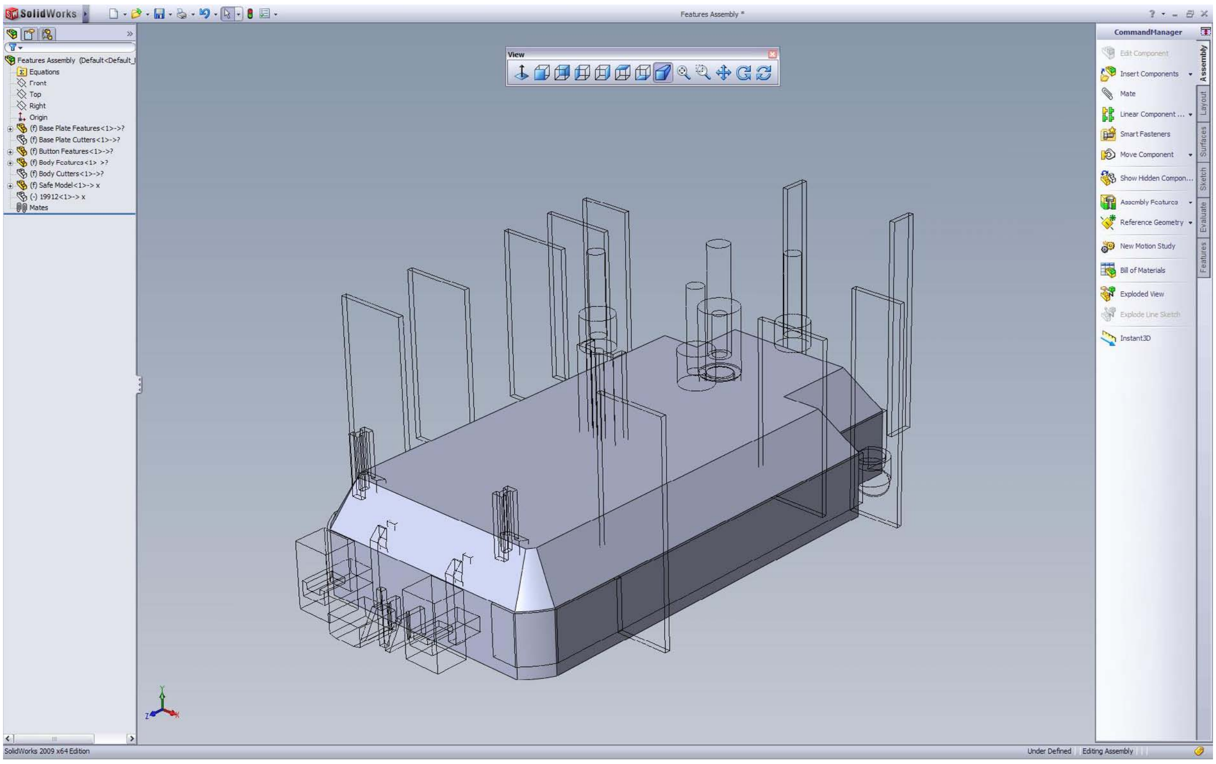


Figure 10.3. The mouse safe model, with critical features (in wireframe).

10.5 DESIGN PROCESS

As mentioned in the introduction to this chapter, this section explains in detail the part of the exercise that involved learning and testing Google SketchUp. The three other modelling packages - Cosmic Blobs, MoI, and Sculptris - were tested in the same manner, and are explained in less detail in Sections 10.7, highlighting important features and weaknesses. Broadly speaking, the design process whilst testing each modelling package followed that shown in Figure 10.4 below.

The first task was to learn the basics of the software, using both official and user-generated tutorials, where appropriate. To gain a more in-depth understanding, self generated tutorials were devised; these usually consisted either of copying another user's model or attempting to model an existing product. The concepting phase involved both designing the new mouse concept and checking that it could be modelled. When a final concept was decided upon, this was detailed and integrated with the critical features previously mentioned. The final stages were to check the model for integrity and export in a file format suitable for AM.

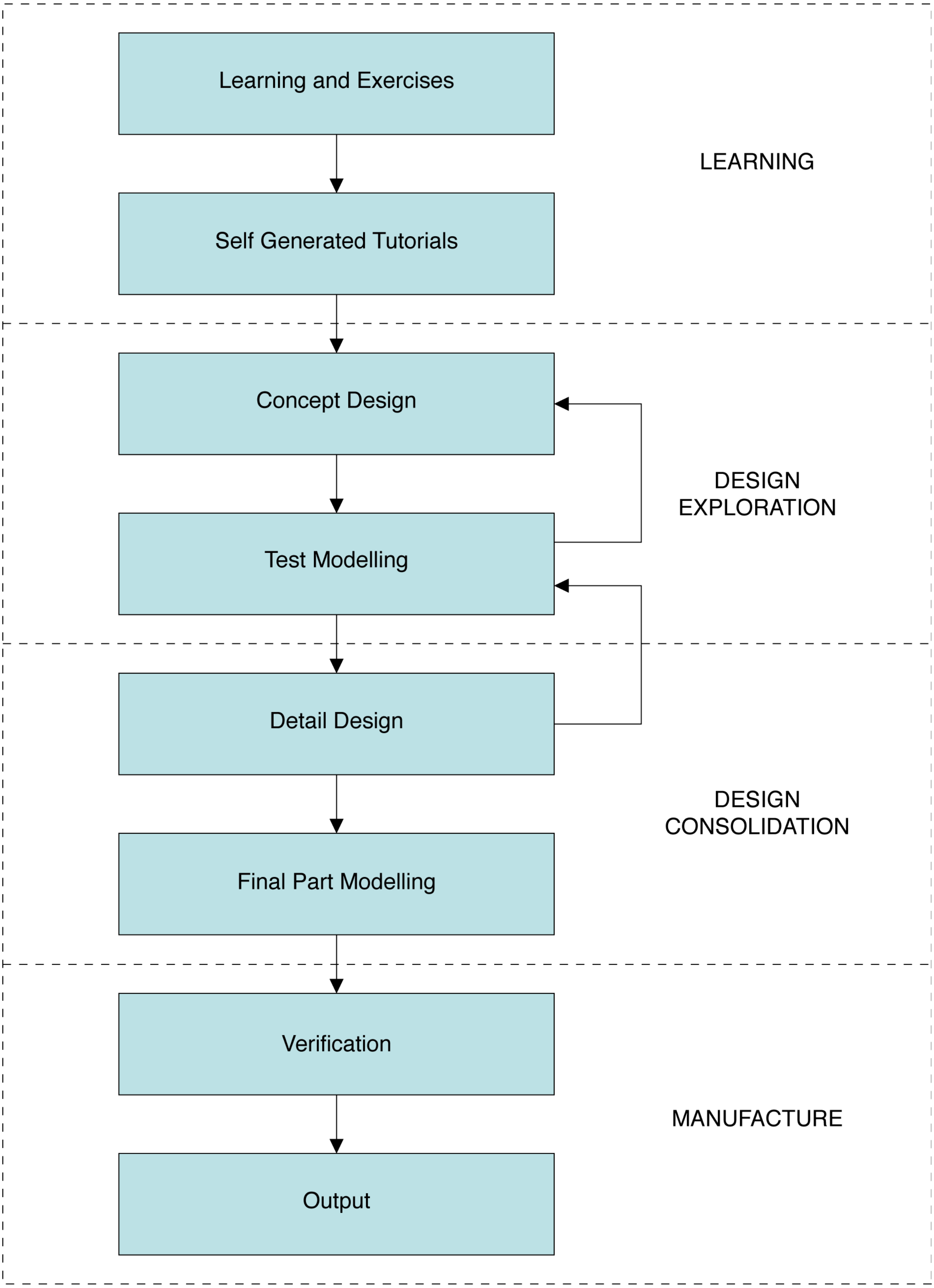


Figure 10.4. Design process during software testing

10.5.1 Google SketchUp

Google SketchUp is a 3D modeller which runs on both Apple OSX and Windows operating systems. Originally intended primarily as a tool for modelling buildings which could be placed into Google Earth, the software continues to display its heritage by the concentration (of its tools and tutorials) on architectural modelling. However it has increasingly been used by designers (in particular games designers).

SketchUp was chosen to be tested for two reasons. Firstly it met the criteria of being both cheap (it is free to download) and described as easy to use:

> **"To build models in SketchUp, you draw edges and faces using a few simple tools that you can learn in a small amount of time. It's as simple as that."** (Google, 2011)

The software is also free to download and use (a ‘premium,’ paid for version also exists, although the differences are primarily related to the creation of 2D drawings, and presentation), an important consideration for consumers with little or no CAD modelling experience. Furthermore, it was known that SketchUp had a number of limitations with regard to its toolset, this would therefore make the exercise valuable in understanding the challenges faced when using ‘simple’ software.

The software was downloaded and installed via a standard automated process with no issues. The computer used for the exercise (and all other software except Cosmic Blobs) was an Apple MacBook Pro (3.06 GHz Intel Core2 Duo, 8Gb RAM), running Windows Vista (Business Edition) via Boot Camp.

The SketchUp installation includes no manual although an online reference guide exists. Tutorials were also provided online as YouTube videos, but these are primarily ‘watch and learn’ rather than directed lessons (Google, 2011b), and so act as encouragement to simply experiment with the tools. It is often the case that initial tutorials are limited, covering only the basics of usage; a good way to learn more sophisticated techniques can therefore be to study models made by more expert users - this is particularly the case with parametric CAD software, in which a user can move back through the ‘history’ of the model, thus learning not only the individual methods used but also the strategy employed. SketchUp provides an extensive library of models which can be freely downloaded, known as the Google 3D Warehouse (Google, 2011c), however a substantial number of models contained therein have not actually been modelled in SketchUp but rather exported from another CAD program. This causes a lot of confusion amongst users (as demonstrated by many of the comments that some models receive, see for example Google, 2011d), and gives little indication of SketchUp's true capabilities. A number of user-created tutorials also exist, but the majority of those tested were of poor quality – either hard to understand, or simply resulting in a poor model. In order to overcome these limitations it was decided to download an appropriate model which had been created in SketchUp - in this case a digital camera - and attempt to recreate it (see Figure 10.5). This proved to be a considerable challenge and was therefore useful in understanding both the capabilities and the limits of the software. Recreating the camera took approximately two days, which, combined with the official video tutorials, added up to approximately four days 'training', after which the author felt proficient enough to begin the design phase of the exercise.

SketchUp's approach to the creation of 3D objects is indeed simple. A 2D shape is drawn on a plane, when this shape is closed (i.e. the lines defining it contain no gaps) a face is formed, which can be extruded, moved or swept along another line or edge. Shapes can be drawn on the faces of objects to add or subtract from the original. Particularly noticeable by their absence are tools commonly found in other software to create lofts, blends and fillets.

Modelling the camera also highlighted another very important aspect of SketchUp - its user-developed tools. On a number of occasions the software reported that the model was not 'solid,' an essential requirement if it were to be manufactured via an AM process. However, within SketchUp, there is no way to discover what is actually causing such problems, which by their nature tend to be hard to find (the easy-to-find problems having usually been fixed). A solution was found within a resource library provided by Google which contains Ruby scripts - plugins for SketchUp which have been developed by users. These plugins are unsupported by Google, who provide no guarantee as to their quality, nonetheless a significant number of such plugins are well written (many have been updated numerous

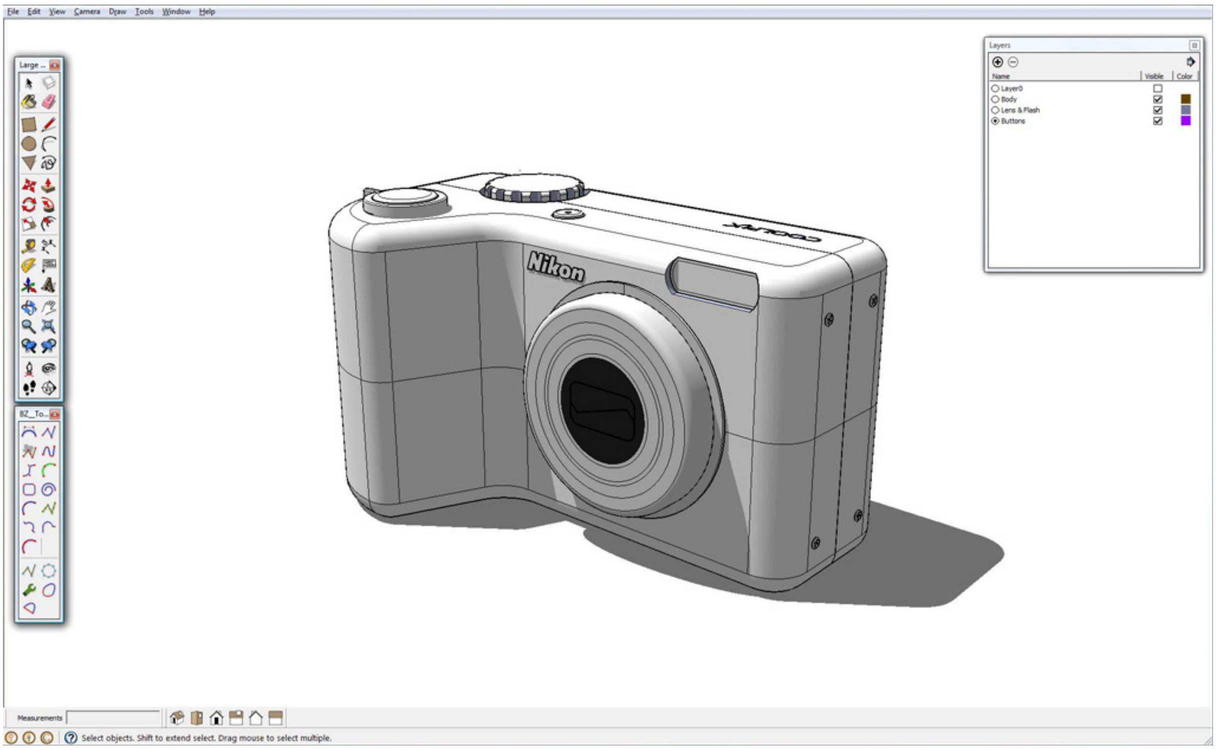


Figure 10.5. The author's copy of a previously modelled digital camera.

times) and extend SketchUp's capabilities dramatically. One such plugin[38] was found which analysed a model and showed any problems preventing it from becoming solid; other particularly useful plugins included those for drawing splines[39], and those for importing and exporting file formats not included in the original software[40].

10.5.2 Google SketchUp Concepting and Development

The design process within this exercise may be considered as four discrete entities as shown previously in Figure 10.4 - the learning of the SketchUp software previously described, the design of the new mouse concept, the modelling of the concept in SketchUp, and the manufacture of the new design. In reality however, the four entities were intricately intertwined. In particular, learning the software was an ongoing process right up to the end of the exercise, when trials had to be made to determine the best method of exporting the

38. See: SketchUp Solid Inspector: http://forums.sketchucation.com/viewtopic.php?f=323&t=30504

39. See: SketchUp Bezierspline: http://rhin.crai.archi.fr/rld/plugin_details.php?id=34

40. See: SketchUp STL Importer: http://sketchuptips.blogspot.com/2010/03/sketchup-stl-importer-redo.html

model in order to produce the part. The limitations of the software also had a profound effect on the actual design concept, which changed and developed as the capabilities of SketchUp were better understood. For a significant part of the design phase there was also a continuous back-and-forth ‘conversation’ between the paper-based sketch designs and the computer-based CAD model designs, as concepts were tested to determine whether their modelling within SketchUp was actually possible. The diary entries reflect and comment on the somewhat messy nature of this process, but at the same time give an insight into the difficulties faced by a consumer designer still learning the limits and potentials of the software tools being used.

Sketching was carried out on A4 marker paper; this allowed images of the safe model to be used as underlays, and also permitted the sketches to be easily scanned. Since SketchUp is a non-parametric modeller, and has no history tree, the developing CAD model was saved at critical points. This ensured the model could be returned to its previous state if an attempt to construct a certain feature was unsuccessful, it also provided a record of the progress of the 3D design investigation (in the earlier stages) and the creation of the final model (in the latter stages).

At the end of days where sketching had occurred, design sheets were scanned, analysed and notes made over the top of drawings (via a layer in Photoshop) to give a commentary on the way the work had progressed. It should be admitted at this point that the style of the commentary evolved during the course of the exercise and so is not entirely consistent. In his professional practice, the author’s way of working is to annotate sketches infrequently - the sketches are rarely shown to others, and when this does occur it is with the author present to explain them. For this reason explanatory annotations tend to be superfluous. The situation is very different when one of the purposes of the design sheets is to allow analysis by a third party, as is the case in the inclusion of a PhD submission. Thus at the beginning of the sketching phase, some of the notes added at the end of the day were identified as explaining details of the drawings, rather than providing an analysis of process. However, this was recognised as an issue and resolved by a conscious effort to annotate design sketches as the exercise progressed. Where there may be confusion in the commentary of the earlier design sheets, notes more appropriate to annotation have been highlighted in a different colour text.

Figure 10.6. SketchUp inspirational images

A very early, and fundamental, decision was to create a concept which played to the strengths of SketchUp (this was continued during testing of all the software), rather than attempt to force the software to create forms it was ill-suited to model. The lack of ‘loft’ or ‘blend’ tools in SketchUp meant that the construction of complex surfaces - a fairly mundane task within most modern CAD software – was extremely problematic. However the ability to ‘pull’ one surface out from another meant it was easy to very quickly build a multiply faceted model. This capability suggested a design made up of deliberately planar surfaces with hard, non-tangential intersections, and an image search was conducted in order to build a mood-board of inspirational images (Figure 10.6).

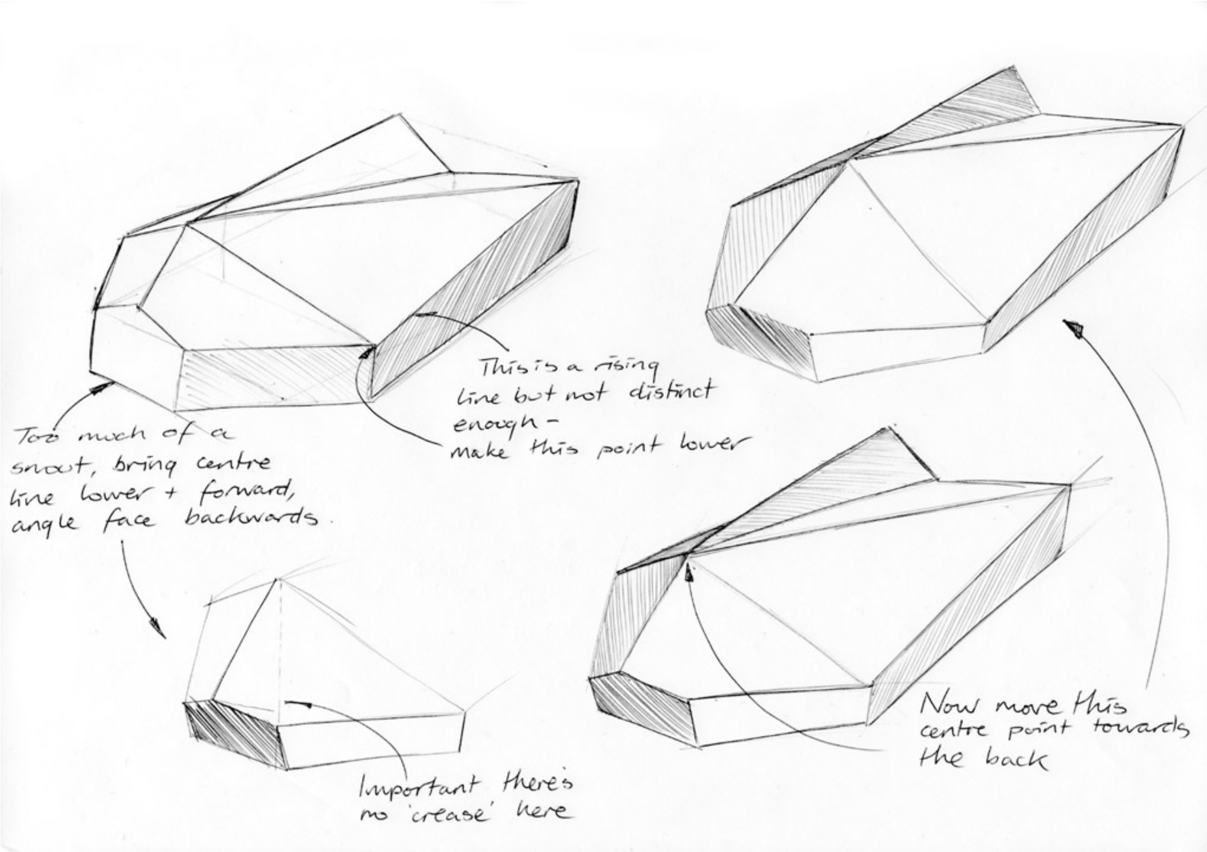


Figure 10.7. An early sketch design sheet.

Reviewing the design sheets with hindsight, the earlier sketches show a preoccupation with caricaturing the mood-board images, rather than allowing the new concept to find its own aesthetic (see Figure 10.7). However this inhibition recedes as the sketches develop and a confidence in the design direction emerges. The first sheets show little consideration of functionality, but instead concentrate on an exploration of sculptural form. The intention at this point was to identify a number of directions to explore within one over-arching theme, and to introduce constraints of functionality, ergonomics, production etc. as the concepts developed. Whilst this may not conform to a text-book approach to design, in a situation where the product's functionality was so rigidly predetermined (by using the original product's pcb), it seemed to be a reasonable approach.

Due to the author's unfamiliarity with the software, during the design phase many sketches were 'tested' to see if they could actually be modelled. A number of concepts which, on paper, had appeared promising were discarded because of their unsuitability for modelling in

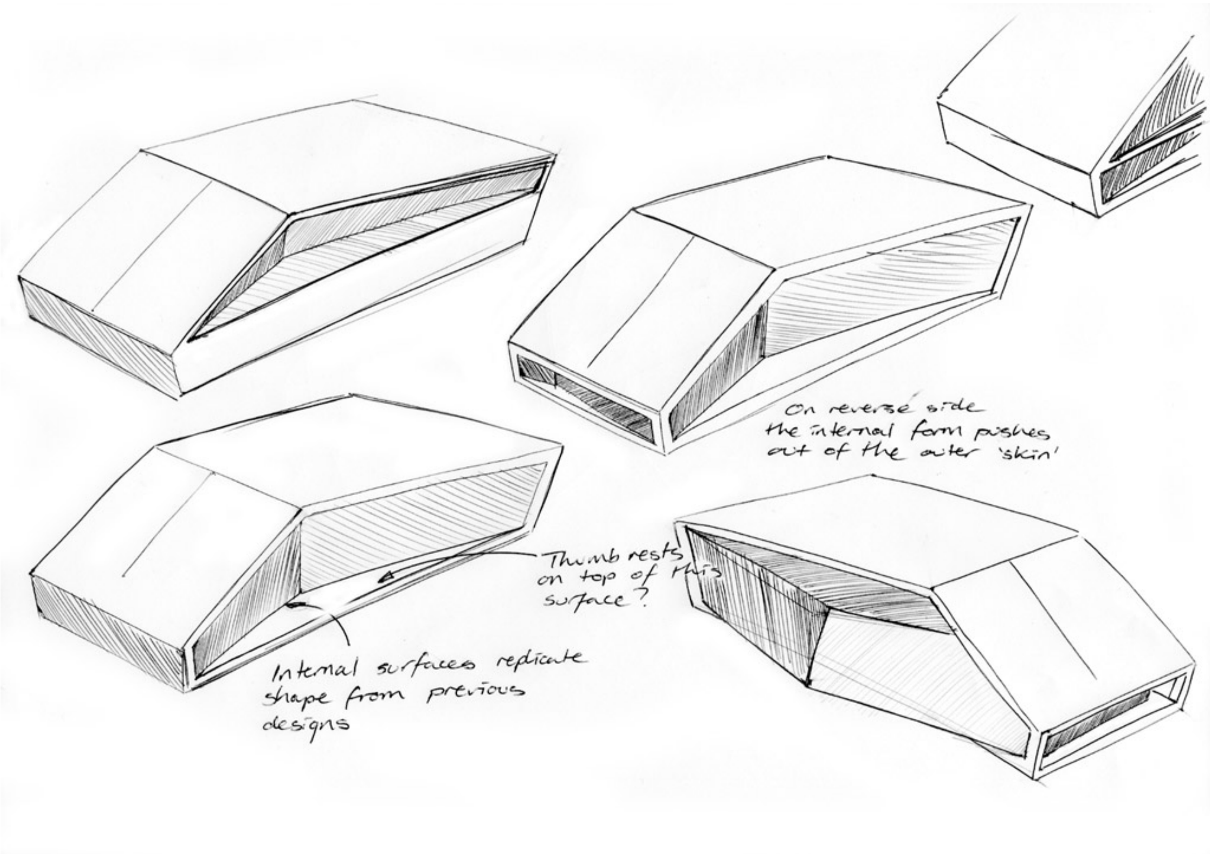


Figure 10.8. Detail design of the new mouse concept.

SketchUp. Thus the limitations of the software became an integral feature of the decision making process regarding which concepts to reject and which to pursue.

As the design phase progressed the sketches show a shift from an exploration of concepts and an identification of a preferred solution (what is often termed 'design concepting') to a concentration on that solution and its modification (see Figure 10.8) to take account of the realisms of production, assembly and use (often termed 'design detailing'). The diary reveals that the design concepting phase lasted five days, whereas the detailing phase was completed after a further 15 days. However it would be misleading to assume that this 1:3 ratio indicates the relative importance given to each phase; the reality was that the detailing phase was extended whilst discovering, and overcoming, the many limitations of the software. Had these limitations not existed the length of the detailing phase would likely have taken approximately 10 days.

Having created accurate sketches based on the safe models, these were scanned and imported to SketchUp to act as templates for initial sketches. The critical feature parts previously described were also imported, oriented and placed in position (see Figure 10.9). The external and visible surfaces were created relatively easily, in part because of the number of test models (21) that had been made during the concepting phase. However it was when the internal features and details came to be modelled that SketchUp's limitations became most apparent.

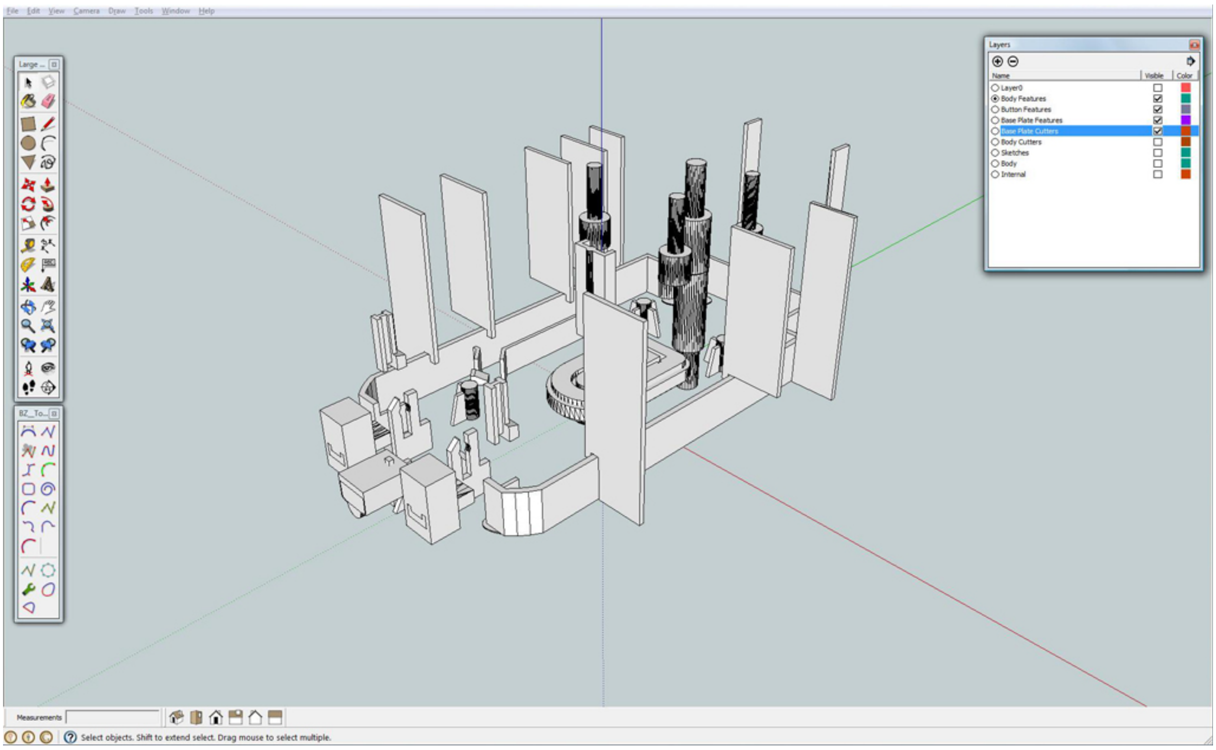


Figure 10.9. Critical features, imported and positioned in SketchUp.

In a professional CAD system such as Solidworks or similar, numerous dedicated tools exist to aid the task of modelling a product's internal details. Considering the design was relatively simple (in terms of surface complexity) and contained no draft angles (not needed for AM), the design would likely have presented few problems to a simple 'Shell' operation (to create wall thicknesses), followed by 'Combine' or 'Cut' operations as appropriate, to integrate the critical features. SketchUp however, has neither 'Shell' nor any boolean commands, and thus all these operations were carried out by intersecting and trimming surfaces. Not only was this laborious and time-consuming, it also presented numerous opportunities to make mistakes. These were further compounded by SketchUp (unlike a parametric modeller) having no 'history tree'; this meant that when a mistake was spotted there was no clue as to when it had been made. The only solution in such an event was to go through the previously saved files until one was found which did not contain the error; the irritation this caused is evident in one diary entry which describes "three hours work wasted" through not having saved at the right point.

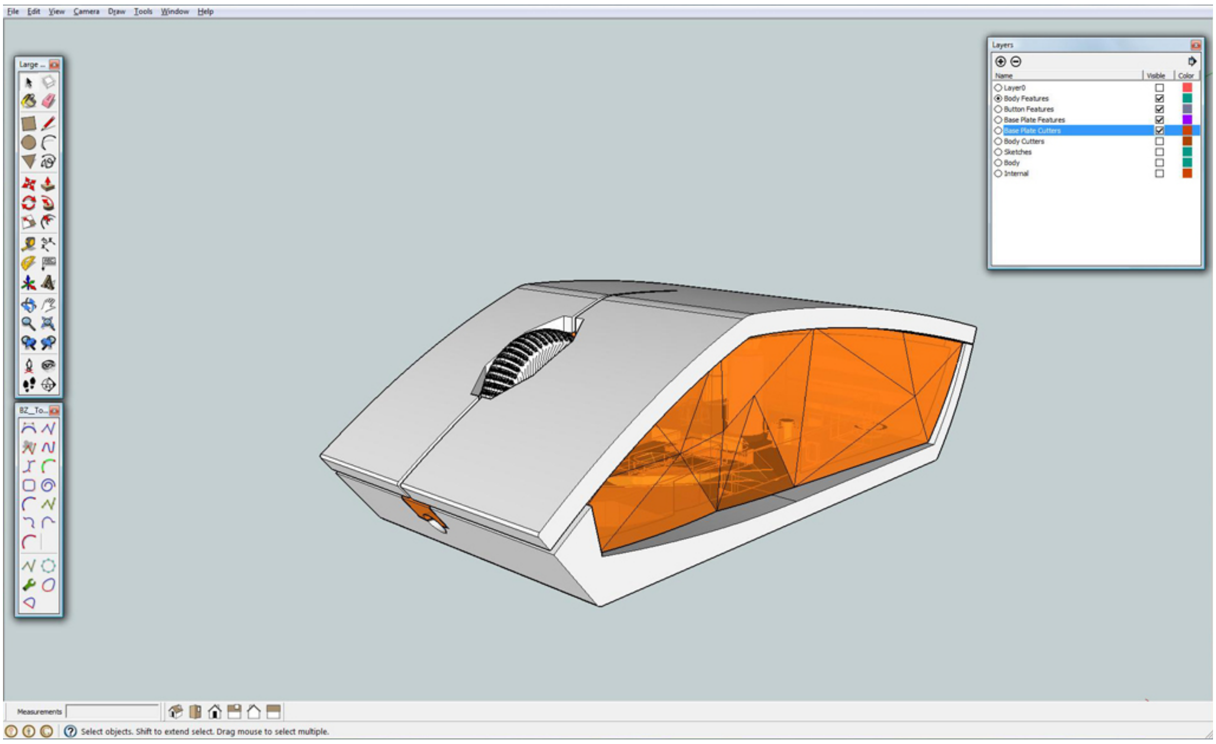


Figure 10.10. The finished SketchUp CAD model, ready for export.

A further task was that of identifying reasons why a surface model would not 'knit' to become a solid. Despite the previously mentioned Rubyscript plug-in which was found to help with this issue, it still proved a time-consuming task. The last few pages of the diary record a growing frustration at the time taken to identify and resolve simple problems, and this is certainly a limitation of the Google SketchUp software. Nonetheless, it eventually proved possible to create a model comprised only of fully enclosed volumes (Figure 10.10), suitable for manufacture as described in the following section.

10.6 MANUFACTURE OF THE DESIGNS

In order to manufacture a 3D part via additive manufacturing it is first necessary to create a file of the correct format, usually .stl or .wrl. All the parts contained within such a file must be fully enclosed volumes (or more colloquially, 'watertight'), with no overlapping, redundant or unstitched surfaces. The final SketchUp design contained three parts, as in the original mouse design.

SketchUp provides a number of export options as standard, one of which (.wrl) had the potential to be used directly, and another (.obj) which might be taken into an intermediary program and the re-exported. However when experimenting with the options a number of problems became apparent, as shown in Table 10.2 below. For this reason a Rubyscript plug-in was identified[41] which would allow the export of files in .stl format. Files in all three formats were imported into three CAD software packages (Rhino, Solidworks and ProE) in order to check their integrity; three programs were used so that, in case of problems, it could be ascertained whether the issue lay with the SketchUp exported file or the importing CAD program.

Exported File Format	CAD SOFTWARE			File is usable for AM?
	Rhino	Solidworks	ProEngineer	
.wrl	Can be opened but all parts centred and combined to one part.	Can be opened but no parts present (i.e. file is empty).	Can be opened but all parts centred and combined to one part.	No
.obj	Can be opened but only one of three parts is a closed volume.	Cannot be opened (no .obj import).	Can be opened but no parts present (i.e. file is empty).	No
.stl	Can be opened as 3 discrete parts, all closed volumes in correct positions.	Can be opened as 3 discrete parts, all closed volumes in correct positions.	Can be opened as 3 discrete parts, all closed volumes in correct positions.	Yes

Table 10.2. Results of file export and import.

Files exported in the .stl format were first used to manufacture parts using the Loughborough Design School's Objet Connex 500 polyjet machine (Figure 10.11). These parts fitted together reasonably well, however two problems which required addressing were that:

41. See: SketchUp Export Toolbar: http://rhin.crai.archi.fr/rld/plugin_details.php?id=133

1. The fit of the PCB was extremely tight across the Y-axis (width).
2. The fit of the bottom and middle parts of the mouse was also very tight.

To solve these issues, the CAD model was modified in SketchUp in the following ways:

1. The overall width was increased by 1mm to accommodate the PCB.
2. The snap locators between the two parts were reduced in size.

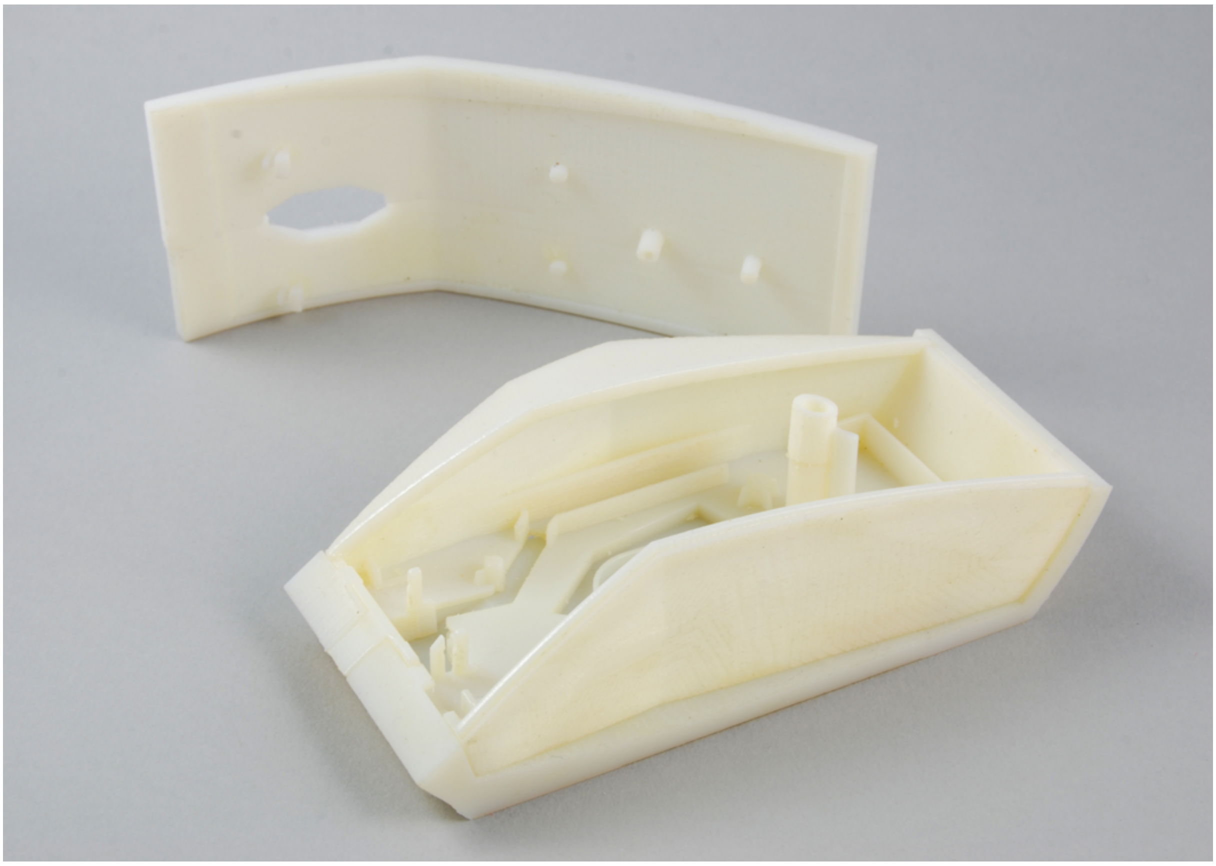


Figure 10.11. Model parts produced from Objet Connex 500.

For manufacture of the final parts, the model was uploaded to the Shapeways online service. This had the advantage of both allowing greater choice in material selection, but also better fitting with the original scenario, in which the consumer-designer would be unlikely to have access to an AM machine or the expertise needed to optimise part orientation etc. Manufactured parts were delivered approximately 3 weeks after ordering,[42] and the final

42. Costs for the manufacture of parts from Shapeways are provided in Appendix 10.8

product was assembled easily (Figure 10.12).

Figure 10.12. Model parts produced by Shapeways in two material choices.

10.7 SUMMARY OF TESTING OF ADDITIONAL MODELLING SOFTWARE

This section provides a summary of testing of the three remaining modelling packages - Moments of Inspiration, Sculptris and Cosmic Blobs.

10.7.1 Moments of Inspiration (MoI)

Moments of Inspiration is a NURBS modeller developed by Michael Gibson, one of the chief developers of Rhino. It is available for both Mac OSX and Windows operating systems, and is the most CAD-like package (in terms of tools and capabilities) tested in this exercise. It is intended as a tool for artists and amateur designers (Folini, 2008), though actually contains a number of sophisticated features (G1, G2 and G3 options for fillets, for example).

Learning: MoI has three official (video) tutorials, although the online help also links to a number of user-created ones. The official tutorials are very basic and cover only a fraction of the software's features, but two user-created tutorials were followed, the first of these (modelling a lamp[43]) was relatively unsophisticated, but the second, (modelling a SpacePilot[44]) was very useful, utilising a wide range of tools and techniques and demonstrating MoI's freeform surfacing abilities.

Design Exploration: The concept direction quickly began to look at flowing, 3D curves and complex surfaces, to take advantage of the software's capabilities (loft, sweep, blend, etc.). Inspiration images were collected and concepts developed through sketching and then recreating in the software. Unlike SketchUp, almost every concept could be built, which pushed the design concept to a more 'extreme' position.

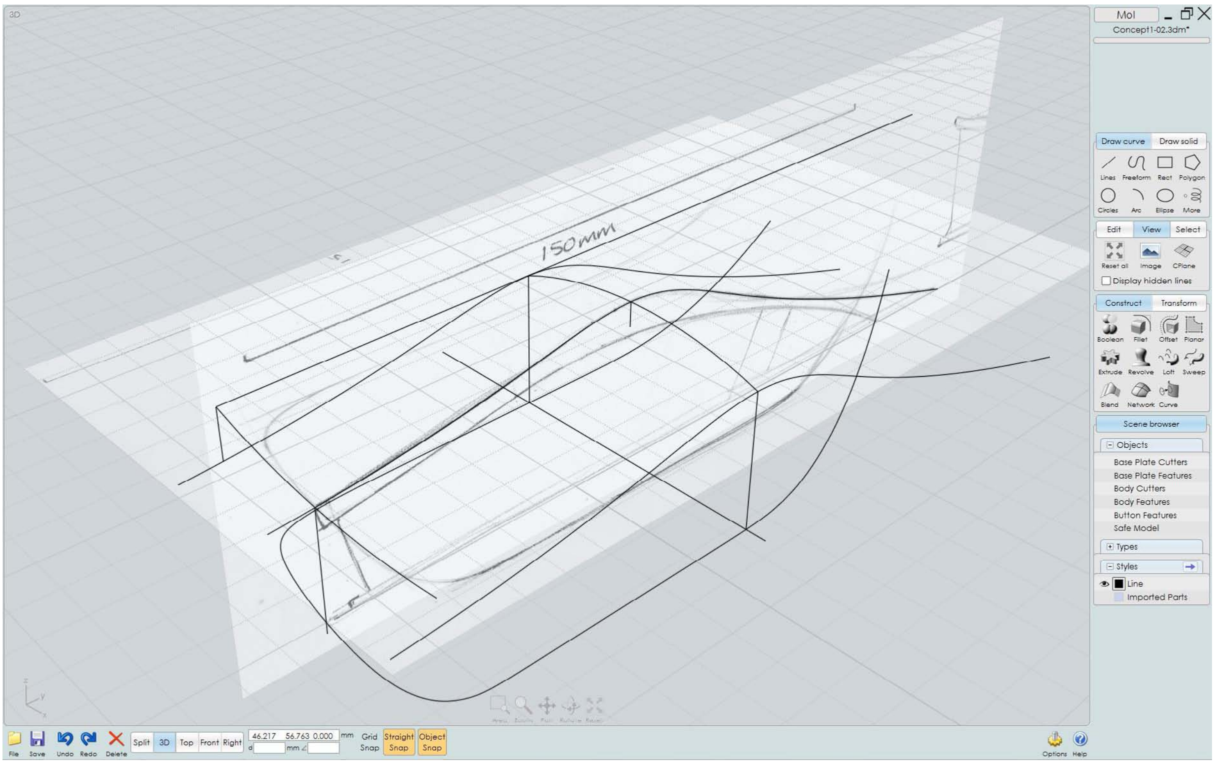


Figure 10.13. Curves drawn using imported sketches as underlays.

Design Consolidation: Sketches were scanned and imported as underlays (Figure 10.13). Critical features were imported as .step files (MoI has no .stl importer). Although MoI is

43. See: http://www.divshare.com/download/2726439-dba

44. See: http://moi3d.com/forum/index.php?webtag=MOI&msg=3842.1

primarily a surface modeller, it allows boolean solids operations, and so integration of the critical features with the newly designed parts to create a finished CAD model (Figure 10.14) was very simple. The biggest limitation of the software was a lack of constraints in sketches.

Figure 10.14. MoI mouse concept.

Manufacture: MoI has very fine .stl export controls, and all parts converted without problem. However when uploaded to the Shapeways site, one part was identified as having a too thin wall section; this required repair but took only a few hours. When delivered parts were assembled after minor adjustments (Figure 10.15).

Figure 10.15. MoI model parts produced by Shapeways

10.7.2 Sculptris

Sculptris is a free-to-download sub-division modeller produced by Pixologic, who also make ZBrush. It is intended as an entry-level digital sculpting tool for those interested in character modelling for games or animation. It is available for both Mac OSX and Windows operating systems, and includes both modelling and painting tools (the latter were not used in this exercise).

Learning: Sculptris has a number of official videos, but most are relatively superficial and more suited to advertising than tutorials. A number of 'demonstrator' videos created by users were also found, including a very good introduction[45] to the tools. However it proved necessary to create a number of self-generated tutorials in order to fully learn the capabilities of the software (see Figure 10.16). The user interface (UI) consists of 9 'brushes' whose size and strength can be adjusted. The modelling process involves starting with a sphere, then

45. See: http://vimeo.com/12186535

distorting and sculpting the shape. There are no boolean operations, and in many ways the software has greater similarity to Photoshop than to other CAD software.

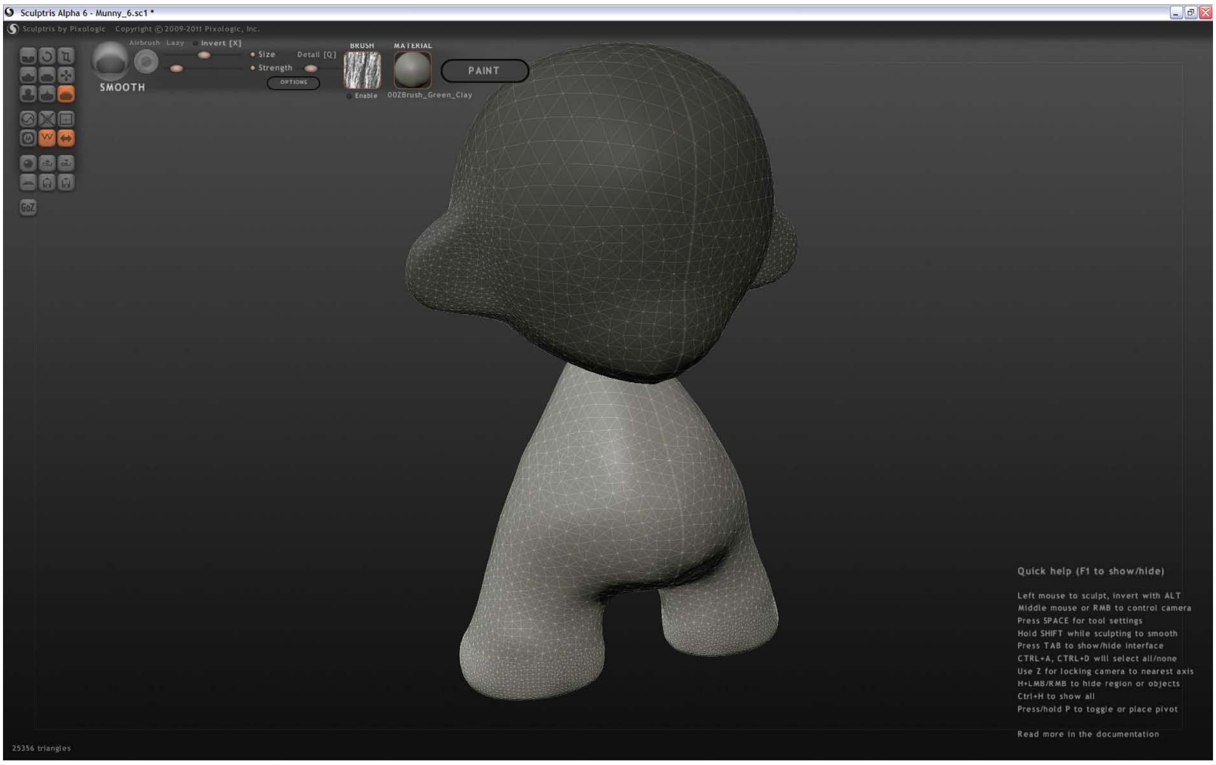


Figure 10.16 The Sculptris user interface, with a model by the author showing sub-division surfaces.

Design Exploration: It was quickly discovered that it is very difficult to create symmetrical, hard edged objects (such as a cube). The first concept directions explored a very organic, natural form, however it was felt this did not translate well to a usable product. A different idea was to start with a very unnatural shape (a cuboid), then sculpt into it but leave evidence of the original shape; this eventually became the final concept.

Design Consolidation: The nature of the software meant that most design happened on screen, rather than on paper. A solution to the difficulty of creating a cuboid shape was to import the object via .obj format, then increase the polygon count. This was not possible for the critical features, and in any case the lack of boolean functions meant it was not possible to create an integrated part.

Manufacture: Sculptris exports only in .obj format, which then required conversion to .stl. The resulting shape was extremely faceted, and although not intended it was felt to be an interesting aesthetic (see Figure 10.17). Critical features were integrated after export, in Solidworks. Files were uploaded to the Shapeways site and when the parts were delivered they were assembled after minor adjustments. As can be seen, the faceting shown in Figure 10.17 was largely removed in production of the final parts (Figure 10.18).

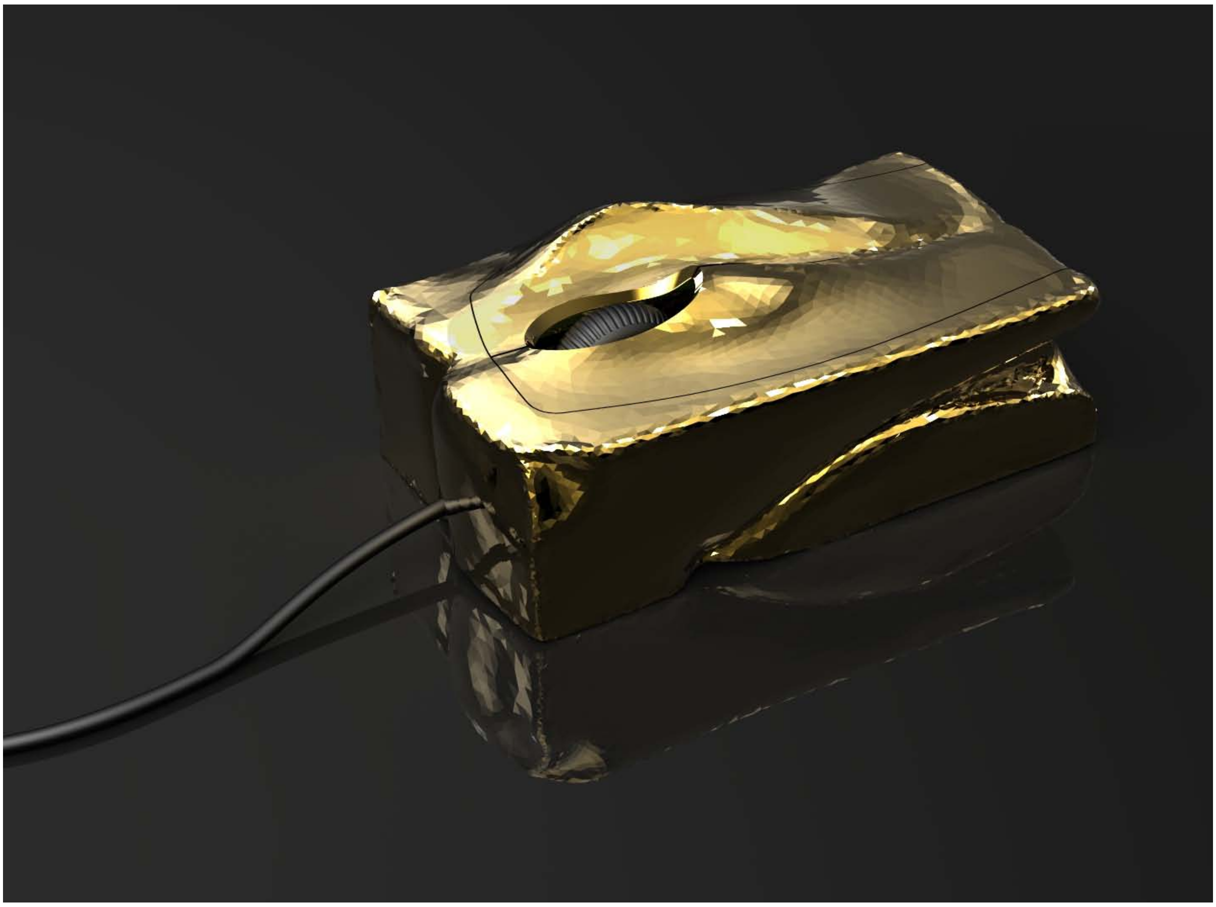


Figure 10.17. Sculptris mouse concept.

Figure 10.18. Sculptris model parts produced by Shapeways

10.7.3 Cosmic Blobs

Cosmic Blobs was a 3D modelling package, produced by Dassault Systemes and aimed specifically at children. It was discontinued in 2007 though copies are sometimes available on Ebay. Cosmic Blobs was available for PC's only, and was tested on a machine running Windows XP as it would not install correctly on Windows Vista.

Learning: The installation CD contained no tutorials or Help files, and links to online tutorials were no longer functioning. The only useful learning resource was a number of user created videos by Tom Meeks[46], although many of these referred to the software's rendering and animation capabilities. The UI follows very few standard conventions, either of CAD software or computing software in general (see Figure 10.19), which makes it difficult to learn and frustrating to use. The basic modelling procedure is to begin with a primitive volume which is distorted using the various modelling tools. Although individual functions are easy to

46. See: http://s101.photobucket.com/albums/m47/TMeeks/CosmicBlobs%20Tutorials/

understand, there are no possibilities for dimensional accuracy, and as a whole the software feels very much like a toy, rather than a useful modeller.

Design Exploration: With little idea of how to model a functioning part, the first design explorations were simply to try to recreate existing designs (in this case, a number of chairs by Ron Arad). These were chosen because their aesthetic seemed similar to some of the shapes created during the tutorials. However on trying to model the chairs, the limitations of the software became ever more apparent: no boolean solids operations, no way to mirror parts, no way to check the model's integrity etc. Eventually it was understood that the task of redesigning the mouse would not be possible using Cosmic Blobs, and so the Design Consolidation and Manufacturing phases were abandoned.

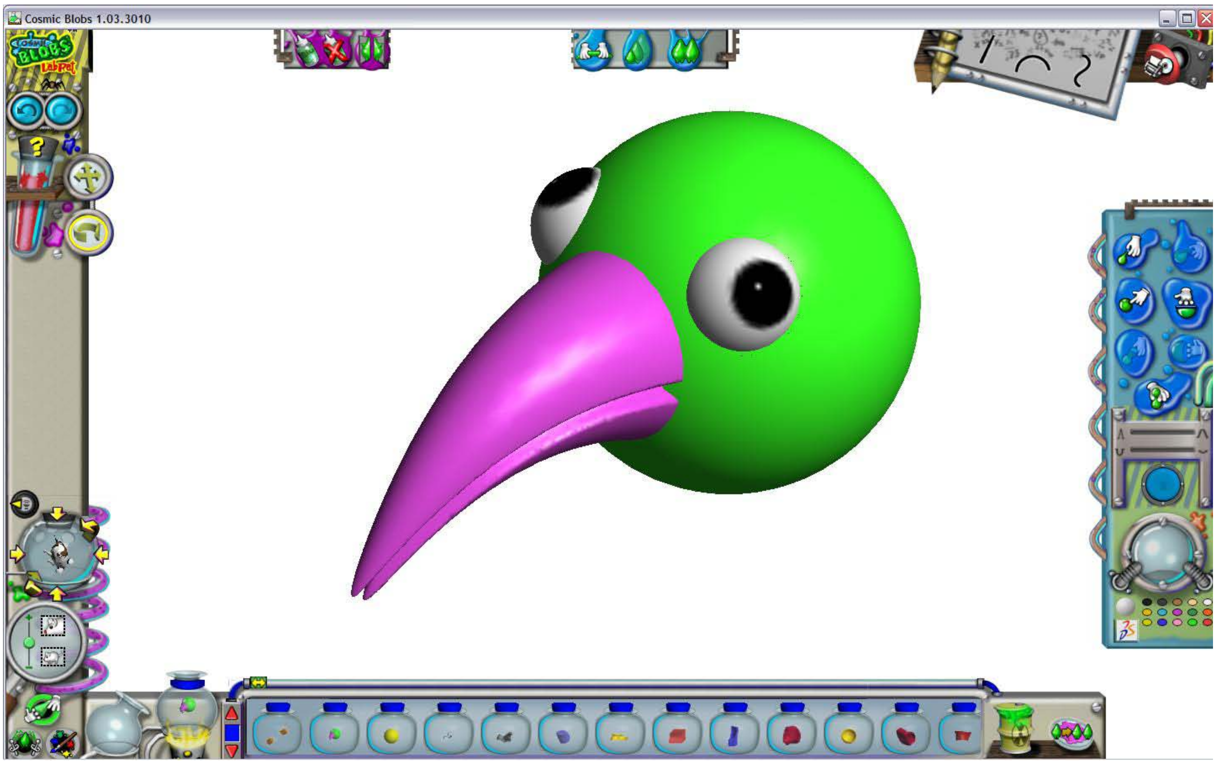


Figure 10.19 The Cosmic Blobs user interface, having modelled a Meeks tutorial part.

10.8 CODING AND COMPARISON

On completion of each individual testing exercise a report was generated, these were written with reference to the criteria for testing established in Section 10.2.5 and by re-reading the design diaries to understand issues which had seemed especially important. The report for Google SketchUp is shown below in Table 10.4, other reports are provided in Appendices 10.2 - 10.4.

Google SketchUp	
Quality of User Experience	
	Details
Cost	Free
Platform	PC (Windows XP/Vista/7), Mac (OSX 10.5+)
Ease of Installation	38.9Mb, 23 secs to download, requires Google account. Standard Windows installation wizard. Approx 3 minutes total installation time.
Documentation	Online (Youtube) demos (primarily undirected). In-application 'Instructor'. Online user guide and reference manual (accessed through application Help).
Tutorials	Official: 28 Introductory videos, 10 'expert' videos, generally 3-5 minutes, easy to follow. Community generated: downloadable (example model) tutorials from Google 3D Warehouse, most of poor quality. Numerous Youtube tutorials/demos of varying quality. Websites (e.g. www.SketchUcation.com). Books (e.g. SketchUp for Dummies) not tested.
Bugs	Changing a part's layer does not always update
Support (Company)	Hosted forums with Google employee interaction on some topics.

Support (Community)	Forum for problems, tips & discussions. Ruby Script library of 3rd party plugins greatly extends basic functionality.
Comments	Easy to download and set up. Official tutorials only cover basics as do most free learning resources. Difficult to find good examples of complex models. Forum is often full of chatter. Ruby Script library is invaluable.
Ease of Use	
Presentation	Pale grey background, various display modes (wireframe, hidden line etc.). Icons are appropriate ('sketch-like'). As Ruby Script plugins are added they appear in different places and menu structure becomes confused.
UI Structure	Standard File-Edit-etc menu structure. Floating toolbox (non-customisable) repeats menu commands. Some palettes. Dialogue gives instructions for use for each tool
Adherence to Existing Conventions	Click-drag L-R & R-L selection. Right-click shows sub-menu related to selected part. Undo/Red
Divergence from Existing Conventions (minus score)	Shift does not constrain e.g. rectangle to square. Invisible layers are editable. Circles/arcs are a series of lines, need to set number when drawn. Dimensions are editable but do not update model.
Notable Features and Methods	Push/Pull surface to extrude or extrude-cut. Automatic surface division from sketch on surface. Automatic plane or face selection for sketching. Copy-Paste places parts, surfaces, etc. exactly. Simple to use rotate tool.
Ease of View	MM-scroll to zoom, MM-click to rotate, MM-click+Shift to pan. Menu and shortcuts to orthographic views, menu to perspective on/off.

	Bad graphic clipping in some instances.
Repetition	All Tool palette operations are repeated in the File-Edit-etc menu structure, other palettes have unique functions. Right click palettes have repeated and unique functions. Ruby Script plugins are user generated and therefore often repeat functionality.
Redundancy	Architectural tools and lighting options. Animation. Materials palettes
Learning Curve	Basic skills: shallow Advanced skills: moderate
Model Accuracy and Integrity	No measure command, but can use dimension values. No 'Shell', 'Offset Surface' or boolean commands mean internal surfaces must all be manually modelled. Modelling process tends to leave v. small surfaces & unstitched edges. Rubyscript (Solid Inspector) identifies but doesn't show precisely.
Comments, Total Score	No fillets reduces ID capabilities. No loft dictates 'planar' aesthetic. Difficult to scale imported drawings
Communication with External Environment	
Tools Required	One button mouse, two button with scroll wheel preferred.
Imports non-native file formats?	Vanilla: 3ds, bmp, jpg, png, psd, tif, tga, pdf With Ruby Script Plug-ins: obj, stl
Exports non-native file formats?	Vanilla: No With Ruby Script Plug-ins: obj, dxf, stl
Exports AM data formats?	Vanilla: No With Ruby Script Plug-ins: stl (but no option to set no. of triangles).
Comments	Plug-ins are generally good and extend the functionality greatly. No native formats (sldprt, 3dm, prt, etc.) though.

Table 10.4. Report on Google SketchUp.

Within the report, significant points such as those which showed adherence or divergence to existing conventions, or tools which were felt to be well implemented, were highlighted. This then allowed a system of coding to be developed, which revealed common features or concepts across all the software tested, and highlighted instances where one modeller had performed particularly well. Table 10.5 shows this comparison.

Google SketchUp (green) · Cosmic Blobs (magenta) · MoI (blue) · Sculptris (grey)		
Quality of User Experience		
	Details	Software
Cost	Free	Google SketchUp, Sculptris
Platform	PC (Windows XP/Vista/7), Mac (OSX 10.5+)	Google SketchUp
Ease of Installation	Standard Windows installation wizard.	Google SketchUp, Cosmic Blobs, MoI, Sculptris
Documentation	In-application 'Instructor'. Online user guide and reference manual (accessed through application Help).	Google SketchUp, Cosmic Blobs Google SketchUp, MoI
Tutorials	Introductory videos, 3-5 minutes. Advanced videos, 5-8 minutes.	Google SketchUp, MoI, Sculptris Google SketchUp
Support (Company)	Hosted forums with developer interaction. Email contact to support desk.	Google SketchUp, MoI Sculptris
Support (Community)	Forum for problems, tips & discussions.	Google SketchUp, MoI, Sculptris
Ease of Use		
Presentation	Various display modes (wireframe, hidden line etc.). Icons are appropriate to brand/product. Icons animate/highlight on roll-over/selection. Background can be changed.	Google SketchUp, MoI, Sculptris Google SketchUp, Cosmic Blobs, Sculptris Cosmic Blobs, MoI, Sculptris MoI, Sculptris
UI Structure	Floating toolbox (non-customisable by user) Some palettes. Tools divided into meta-function sections (Construct, Transform, Colour, etc.).	Google SketchUp, MoI Google SketchUp Google SketchUp, Cosmic Blobs, MoI, Sculptris

Google SketchUp (green) | Cosmic Blobs (magenta) | MoI (cyan) | Sculptris (grey)

	Icons expand to show increased options/complexity	MoI
	Each Tool has options for size, strength, detail etc, operated by sliders.	Cosmic Blobs, Sculptris
Adherence to Existing Conventions	Click-drag L-R & R-L selection.	Google SketchUp, MoI
	Right-click shows sub-menu related to selected part.	Google SketchUp, Sculptris
	Undo	Google SketchUp, Cosmic Blobs, MoI, Sculptris
	Redo	Google SketchUp, Cosmic Blobs, MoI
Notable Features and Methods	Push/Pull surface to extrude or extrude-cut.	Google SketchUp
	Automatic plane or face selection for feature insertion	Google SketchUp, MoI, Sculptris
	Copy-Paste places parts, surfaces, etc. exactly.	Google SketchUp, MoI
	Can use 'Undo' on saved and closed models	Cosmic Blobs
	Pick tool - modify - adjust (with slider) with direct visual feedback..	Cosmic Blobs
	Tools work in both 2D and 3D.	MoI
	'Incremental Save' to give model 'history'.	MoI
	'How to use' dialogue for each tool	Google SketchUp, Cosmic Blobs, MoI
	'Hidden' commands extend functionality	Google SketchUp, MoI
	'Reduce' (Triangles) and 'Reduce Region' to lower file size.	Sculptris
Ease of View	MM-scroll to zoom, MM-click to rotate, MM-click+Shift to pan.	Google SketchUp, Sculptris
	RMB+shift snaps to closest orthographic view.	Sculptris
	Parts/features can be hidden	Google SketchUp, MoI
Learning Curve	Basic skills: shallow	Google SketchUp, Cosmic Blobs
	Advanced skills: moderate	Google SketchUp, MoI, Sculptris
Model Accuracy and Integrity	Bricks will not place if software detects 'overlap'.	
	Sketches can be dimensioned and measured.	Google SketchUp, MoI
	Most models are fully enclosed volumes.	Sculptris

Google SketchUp ▌ Cosmic Blobs ▌ MoI ▌ Sculptris ▌		
Communication with External Environment		
Tools Required	One button mouse, two button with scroll wheel preferred.	▌▌▌▌
Imports non-native file formats?	ai, png, tif, jpg, gif, bmp	▌ ▌
Exports non-native file formats?	obj, stl	▌ ▌
Exports AM data formats?	stl	▌ ▌

Table 10.5. Comparison of notable features.

10.9 RECOMMENDED IDEAS FOR IMPLEMENTATION

Working from the colour coded comparison, concepts or features which might be suitable for inclusion in a consumer design toolkit were identified. These are listed below in Table 10.6, and again correspond to the original criteria for comparison, effectively forming a compilation of "best practice" from the modelling packages evaluated. At the time of comparison, no decision had been made as to whether the toolkit should be an online or downloaded application. Some features are therefore denoted as more suitable to an online (and most likely, simpler) version, whereas others are more applicable to a more advanced modeller.

Quality of User Experience	
	Details
Cost	Free
Platform Basic Version	Runs as web-based application and is platform-independent, but should operate on both mouse-based and touch-screen (iOS, Android) interfaces. Possibility of stand-alone app for touch devices should also be considered.
	Requires download, should run on PC (Windows XP/Vista/7), Mac

Advanced Version	(OSX 10.5+) as minimum. More functionality, faster (processing and rendering). Can work offline.
Ease of Installation Basic Version	Should run on all major browsers (Internet Explorer, Firefox, Chrome, Safari). Should run without new software download (though may require update of Java, Adobe AIR, Flash). Should avoid Flash if possible to allow iOS implementation. Environment should open immediately (although model may render more slowly).
Advanced Version	Standard Windows or Mac installation wizard.
Documentation Basic Version	Ideal would be no need for documentation, i.e. self explanatory. But this may not be possible given complexity of interaction.
Advanced Version	Online user guide and reference manual (accessed through application Help). In-application 'Instructor'. Function to create building guide for model.
Tutorials (Web-based)	Introductory videos, 3-5 minutes. Advanced videos, 5-8 minutes.
Support (Company)	Hosted forums with developer interaction. Email contact to support desk.
Support (Community)	Forum for problems, tips & discussions. Previously customised designs (by other users) can be used at start points for design/modification.
Ease of Use	
Presentation	Icons customisable by customer/manufacturer and should be appropriate to brand/product. Background can be changed by customer. Option to make background changeable by user (decided by customer). Icons animate/highlight on roll-over/selection.

Basic Version	2 display modes (rendered, hidden line). New configuration animates (objects slide into place, rather than just appear). Background changeable by user (if customer-enabled)
Advanced Version	Multiple display modes (rendered, hidden line, wireframe, etc.). 2 analysis display modes (zebra stripes, curvature) Background changeable by user (if customer-enabled)
UI Structure Basic Version	Floating toolbox (non-customisable by user) Tools divided into meta-function sections (Construct, Transform, Colour, etc.). Each Tool has options for size, strength, detail etc, operated by sliders. All options continuously visible, can be changed in any order. Choosing an option opens sub-menu of further options (if applicable). Tool Tips on mouse-over.
Advanced Version	Icons expand to show increased options/complexity. Tool Tips can be turned off.
Adherence to Existing Conventions	Click-drag L-R & R-L selection. Right-click shows sub-menu related to selected part. Undo (Ctrl-Z) Redo (Shift+Ctrl-Z) Copy (Ctrl-C) Paste (Ctrl-P)
Ease of View Basic Version	MM-scroll to zoom, MM-click to rotate, MM-click+Shift to pan. RMB+shift snaps to closest orthographic view. Parts/features can be hidden. Perspective view. Rotation between fixed views (if processing requirements of full rotate are too great).
Advanced Version	Perspective can be changed to isometric. 'Snap' to nearest orthographic view.

Notable Features and Methods	Basic Version	Can choose to start from either minimum volume block or suggested design. Push/Pull surface to extrude or extrude-cut. Automatic plane or face selection for feature insertion. Pick tool - modify - adjust (with slider) with direct visual feedback. Copy-Paste places parts, surfaces, etc. exactly. Circular Fillets. 'Tighten' and 'Relax' command applies to all fillets in model. Parts and features snap into position. Auto insertion of features to finish product if required. Automated variant generation at any stage (Genoform) Filters (similar to Photoshop) apply effects to parts (e.g. 'Liquify', 'Crystallize', 'Texturize', etc.). 'Compare to Original' button shows default design in position of new design. Full list of modifications provided at end of task, with option to return (directly) to each one. Price of configured product is shown and continuously updated. Software contains in-built pricing/shopping tool. Links provided for users to share designs (Twitter, Facebook, etc.).
	Advanced Version	'Hidden' commands (beta testing?) extend functionality. Can use 'Undo' on saved and closed models. G2, G3 and conic fillets 'Incremental Save' to give model 'history'. 'Reduce' (Triangles) and 'Reduce Region' to lower file size.
Learning Curve	Basic Version	Shallow
	Advanced Version	Moderate
Model Accuracy and Integrity	Basic Version	Surfaces will not update inside or outside pre-determined limits. Features will not place if software detects 'overlap' or bad placement. All models are fully enclosed volumes (software will not allow bad surfaces).

Advanced Version	Parts can be dimensioned and measured.
Communication with External Environment	
Tools Required	One button mouse, two button with scroll wheel preferred.
Imports non-native file formats?	ai, png, tif, jpg, gif, bmp. Software allows image files to be used as underlays.
Exports non-native file formats?	jpg, obj, stl, skp. Software allows model files to be exported to other CAD systems, but no way to re-import.
Exports AM data formats?	stl, Slider control determines stl accuracy.

Table 10.6. Recommended ideas for inclusion in a consumer-design toolkit.

When reading the points above, it should be understood that the ideas were generated solely from the analysis of the consumer-oriented modelling software discussed in this chapter. Some of the above recommendations therefore conflict with findings in other parts of this research (for example, the ability to specify and modify fillets is not fully supported by the results of the trial to design a USB memory stick, in which few of the participants considered fillets as part of their design). Solving such conflicts, and providing a specification of consumer design toolkit which marries the wishes and concerns of both consumers and professional designers or brand managers, is the subject of the following chapter.

CHAPTER 11

The Specification and Design of a Consumer-Design Toolkit

11.1 INTRODUCTION

This chapter focusses on the final objective listed in Chapter 5, namely the specification and design of a prototype consumer-design toolkit. It utilises findings from Chapter 10 regarding features and tools which should be included, grounded in conclusions drawn from previous chapters regarding its architecture and scope.

The toolkit was based around the design of a mobile phone concept, which was chosen for a number of reasons:

1. It had sufficient complexity in terms of product design, i.e. the number of parts which make up a product assembly.
2. It had sufficient complexity in terms of limitations imposed by functional requirements. For example, the toolkit would have to take account of the need to plug in a USB charger, and thus prevent designs which might inhibit this action; similarly the toolkit would need to recognise parts where material choice might affect antenna performance.

3. Users of mobile phones have widely varying requirements; consumers would therefore place different levels of importance on different elements of the product.
4. The mobile phone is a product archetype whose design attracts significant interest from both consumers and designers; it was hoped that this would make the research more interesting and thus more widely disseminated.
5. The mobile phone is a product with which the author had an in-depth understanding, in terms of both product design and engineering.

It should be stressed at this point that the purpose of the toolkit was not to test the functionality of specific tools, but rather to provide a first instantiation of how a consumer-design toolkit might appear and operate. Within user interface design such prototypes are referred to as wireframes, and are intended

> "primarily [to] demonstrate functionality, features content and user flow without explicitly specifying the visual design," (Angeles, 2011).

As such, wireframe prototypes are usually created without consideration of colour or graphics, and can be as 'low-fidelity' as a flow chart made from Post-It notes. However this is at odds with recommendations from mass customisation literature, which stresses the need for the realistic visualisation of products (Walcher and Piller, 2012). Thus the toolkit attempts to portray a neutral outlook (for example by using muted colours and sans-serif typefaces), whilst providing as realistic as possible images of the mobile phone as the product is re-designed and completed.

This chapter begins by presenting the framework definition of the toolkit. Questions regarding the size of the solution space, the type of modularity underlying the phone's architecture, and the manufacturing solution, are addressed. The definition of details is then considered, including issues such as how to display and update the price, tools for manipulating the product's design, and options for sharing the design with other consumers. In both these sections, specification decisions are supported by reference to previous findings in the research.

The chapter continues by presenting the design of the prototype toolkit, and provides a 'visual walk-through' of the process a consumer-designer would undertake. It then discusses initial feedback from users (both consumers and designers) who were introduced to the toolkit as a *chauffeured prototype* (Usability First, 2012). The chapter concludes by reflecting on the design of the prototype and proposing ways it may be improved.

11.2 FRAMEWORK DEFINITION

The framework definition of the toolkit refers to decisions required before the detail design could commence. A framework definition involves the specification of "the supporting structures and underlying concepts upon which every detail depends," (Goodwin, 2009: p. 377), and in a commercial context would typically involve inputs from product and brand managers as well as designers (ibid). The framework definition in this case also provides supporting evidence from previous chapters as justification for the decisions made.

11.2.1 Design Method Type

The consumer design toolkit should be an example of Constrained Consumer Design (CCD), as defined in Chapter 6 and supported by findings in Chapter 8.

Whilst much of the implementation of the toolkit has drawn on mass customisation (MC) literature, the toolkit's framework definition should clearly place it within the CCD category identified in the Industrial Design methods classification (see Section 6.5.2). 77% of respondents to the design language survey believed a consumer-design toolkit should set boundaries of acceptable designs in order to retain control over a brand's design language (Section 8.9). CCD allows for such control by placing constraints on the degree to which software tools can change a product's form. The toolkit should also provide the consumer with the reassurance that any product resulting from its use would be safe, functional and sold under warranty.

11.2.2 Value of Customisation and Design

The toolkit should enable consumers to add value to a generic, incomplete design through customisation of form and function, as defined in Chapter 3.

The toolkit should allow consumers to choose from products whose specification would target particular usage scenarios, for example a business phone or a sports phone. It should then be possible to change the specification to better meet the consumer's needs (Section 3.5). Interaction with the form of the product should allow the consumer to determine whether design decisions are made for functional or aesthetic (fit) reasons (Section 3.6.1), and should allow the freedom of both (within the boundaries determined by designer and brand).

11.2.3 Type of Modularity

The product architecture of the phone used as the basis of the toolkit should utilise component-sharing and component-swapping modularity, as theorised in Chapter 3 and demonstrated in Chapters 7 and 10.

A basic phone module of engine and internal (non-visible) chassis should provide the foundation of all consumer-design variants, i.e. the same module should be used in all phones (component-sharing modularity). Consumer-designed parts should then fix to the chassis using standard features such as screw bosses and snap details (component-swapping modularity) (Section 3.4). This strategy was key to Ulysse Nardin's ability to produce customised and limited edition products, for example swapping a carbon fibre part for a ceramic one (Section 7.4). A similar approach was also used in the re-design of the computer mouse, where the PCB and critical features were shared by all designs (Section 10.4).

11.2.4 Extent of Customisation and Design

The extent of customisation (i.e. the number of choices of a particular option) should be *relatively small, whereas the extent of design (within the pre-determined boundaries) should be large, as demonstrated in Chapters 7, 8 and 9.*

The question of the extent of customisation was raised in Chapter 3. However the findings from subsequent research suggested the potential for conflict between what the consumers might want and what designers or brands might be prepared to allow. The extent of customisation of the specification of the phone (screen size, memory, etc.) should be small, to ensure the project remained manageable and since, in any case, such customisation is not commonly possible in the mobile phone marketplace. A key concern of respondents in the design language survey was the degree to which consumers might damage a brand's design language (Section 8.9); the boundaries within which a consumer might design would therefore also likely be constrained. However within those boundaries design freedom should be unlimited (Section 9.9).

In Chapter 9 it was also shown that consumers had little knowledge of functional detailing (wall thicknesses, draft angles, etc.) or cosmetic detailing (fillets, chamfers, etc.) (Section 9.9). In common with mass customisation toolkits, the application of such details should therefore be automated and invisible to the consumer.

11.2.5 Parameter-based Definition

The toolkit should employ parameter-based questioning to determine the best product specification for the consumer, as implied in Chapter 3.

Within MC literature, toolkits are defined as either 'parameter-based' or 'needs-based' (Section 3.5). Weinmann, Hibbeln and Robra Bissantz (2011) demonstrate the difference by comparing two customisation toolkits for the Volkswagen Golf. The first (needs-based) configurator requires customers to indicate the degree to which they support certain assertions, such as "My car needs to be eco-friendly" or "My car can get me from A to B in superior comfort". The second (parameter-based) configurator asks customers to choose from a list of engine sizes, CO_2 emissions, etc. Parameter-based systems are better suited to expert users who understand the technical details of the product being customised, whereas needs-based systems appeal to consumers with less technical knowledge (Randall, Terwiesch and Ulrich, op. cit.).

Walcher and Piller (2012) recommend needs-based systems in most business-to-consumer (B2C) configuration systems, however they also admit that such systems are more complex to implement due to the algorithms needed to translate consumers' needs into module choices. Developing these algorithms for the prototype was felt to be impractical and non-essential, given that the specification of the phone was not the main focus of the prototype toolkit. In addition, those who would engage with a consumer-design toolkit were likely to be lead users or early adopters, and thus have a higher-than-average understanding of technical details (Section 4.6). Therefore a more conventional parameter-based system should be used.

11.2.6 Design Interaction Type

The toolkit should present a generic, incomplete design which consumers could then manipulate directly to change the product's form, as supported by findings in Chapters 9 and 10.

In contemplating the type of design interaction used by the toolkit, two dissimilar approaches were considered. In the first, a user interface would consist of tools such as slider bars or similar, to morph the design of a feature between two extremes as determined by the designer of the original product. Different slider bars would affect different parameters of the phone, for example height, thickness, fillet radii etc. This type of interface is utilised by (for instance) Nervous Systems[47] to create consumer-designed jewellery, and Digital Forming to create lamps for Tom Dixon[48].

Whilst interactions of the kind described above can allow for the creation of intricate and complex products, it might be described as a 'hands-off' approach, in that the consumer's interaction with the product is mediated through the interface. Such a system would allow a

47. See: http://n-e-r-v-o-u-s.com/cellCycle/

48. See: http://www.digitalforming.com/2/post/2012/05/a-look-back-at-a-great-show-with-tom-dixon-at-milan-design-week.html

surface to be deformed at a point for example, but allowing the consumer to determine where that point was placed on a surface or profile would become extremely difficult. Furthermore, this type of design interaction generates designs in a manner similar to that employed by Genoform (albeit controlled by the consumer rather than randomly generated). Participants in the trial reported in Chapter 9 felt this to be a limiting method of design.

For these reasons, a second type of design interaction was chosen, closer in scope to CAD software but simplified and dedicated to the toolkit's product. This was very much influenced by the use of SketchUp (Section 10.5.1), which demonstrated the complexity of design that could be achieved by the use of a reduced number of tools, allowing surfaces or surface edges to be moved. However the weakness of SketchUp was its lack of tools for creating complex surfaces (Section 10.5.2), thus the toolkit should also allow for such geometries (Section 10.5.4).

11.2.7 Manufacturing Scenario

The unique parts designed by the consumer should be produced and assembled by the phone manufacturer or authorised vendor, as supported by findings in Chapters 2, and 10.

Consumer-oriented additive manufacturing systems are not currently capable of producing parts to a standard which would be acceptable to most consumers or brands. Part quality is also highly dependent on the consumer's knowledge and skill in operating and maintaining their machine (Section 2.4.2). Consumer-oriented AM systems are also very limited in terms of materials compared to vendors such as Shapeways (Section 10.6).

11.3 DETAIL DEFINITION

The detail definition of the toolkit refers to decisions governing the implementation of features with which the consumer would interact directly. The detail definition again provides evidence from previous chapters to support the decisions which were made. As a point of reference when reading the components of the Detail Definition, figure 11.1 below shows the final screen of the toolkit, prior to purchase.

Figure 11.1. The final screen of the consumer-design toolkit.

11.3.1 Platform and Installation

The toolkit should run as an in-browser application and be platform independent, as suggested in Chapters 3 and 10.

MC toolkits are almost exclusively implemented as in-browser applications, requiring no download or installation (Section 3.5). This ensures platform independence (they will work on Mac OSX, Windows and Linux operating systems) though updates to the browser or extensions such as Flash or Java may be required. A touchscreen version of the toolkit may represent a further option though this has not been developed.

It is unlikely that the toolkit could be successfully implemented exactly as prototyped, as limitations of bandwidth and connections speeds would preclude the use of fully rendered, photo-realistic models. However systems such as Tinkercad and 3DTin[49] demonstrate that

49. At the time of the software testing reported in Chapter 10, Tinkercad was not available and 3DTin would not run successfully. However subsequent experiments have proven both to be functional.

'low-end' CAD software can be developed to work as in-browser applications (Section 10.2.4). It is anticipated that future improvements to web infrastructure would increasingly allow the use of highly rendered models.

11.3.2 Adherence to Existing Conventions

Wherever possible the toolkit should adhere to existing conventions of usage, both general and CAD related, as recommended in Chapter 10.

Commonly understood conventions including keyboard shortcuts (e.g. Ctrl-c, Ctrl-v, etc.), selection (left-right drag, Shift-click, etc.), and right-mouse-button menus should follow standard conventions. When viewing/rotating the model the mouse wheel (scroll) should zoom, the mouse wheel (click) should pan, and Shift + mouse wheel (click) should rotate.

11.3.3 Visualisation

The phone should be presented as realistically as possible, as supported by findings in Chapters 3, 9 and 10.

MC literature stresses the importance of realistic visualisation (Walcher and Piller, op. cit.) to increase consumer confidence in the product they are purchasing. It is also important when working on fine details or making only small changes. In the context of the prototype toolkit realistic visualisation has two implications: firstly the representation of colours and materials should be accurate; secondly the phone should be shown in 3D perspective (Section 9.9) and should rotate as required to allow viewing from different angles (Section 10.8).

11.3.4 Documentation and Tutorials

Tutorials should be provided as short videos, documentation should also be available online or as a PDF download, as recommended in Chapter 10.

11.3.5 Price

The price of the product should continually update to reflect changes made, both to the specification and design, as theorised in Chapter 3.

Consumers prefer systems in which they are able to see the final price of the product update (Dellaert and Stremersch, op. cit.), rather than systems in which the price of individual modules is given and the total revealed at the end of the process. Consumers also prefer systems in which choices add functionality (and therefore cost) rather than remove it (ibid.); this implies that a default product presented to the consumer should be the lowest specification (and hence lowest price) that is possible using the system.

11.3.6 Default Option

The system should allow the consumer a choice from a number of basic models, which would then act as a start point for subsequent design work, as theorised in Chapter 3 and supported in Chapter 9.

As mentioned above, Dellaert and Stremersch suggest presenting the consumer with the most basic version of a product, i.e the version which allows the maximum degree and extent of customisation. This appears to be supported by findings from the USB memory stick trial, in which participants preferred solutions where the maximum design freedom was offered (Section 9.8). However, the same trial highlighted the usefulness of images of existing designs, and many MC configurators allow the browsing of previous designs, either to copy or to modify. A pragmatic solution would therefore be to offer both options as start points for new designs, such that the consumer could choose to begin either with a basic version, or one which had previously been designed by another consumer.

11.3.7 Order and Degree of Design Interaction

The order of interaction should be suggested but not rigorously enforced. It should begin with the specification of the product; the design phase should then take place in the order of *importance of decisions as revealed in Chapter 9.*

As previous chapters have shown, the importance of different design elements is not always shared by consumers and designers. For example, the design professionals that responded to the survey in Chapter 8 felt the way in which common elements are detailed was the most important factor in a product design language. However participants in the USB memory stick exercise in Chapter 9 paid very little attention to such details. The toolkit should therefore present options in order of importance to the consumer, but the degree of influence should be determined by recommendations from Chapter 8. A progression through the process should be suggested, but it should be possible to carry out tasks in any order, or to repeat or miss out tasks as the consumer wishes.

11.3.8 Design Tools

The toolkit should provide a number of tools to allow the phone to be manipulated and re-designed. These tools are suggested by the findings of the software comparison in Chapter 10.

Scale: The model should scale as required. Features such as the display window should remain fixed in size and position during this operation.

Shape (Silhouette): The silhouette of the phone should be modifiable as required. As the shape is changed features such as fllets or buttons should update automatically.

Shape (Move Surfaces): The model should allow individual surfaces to be moved; connected surfaces and features should again update to reflect these changes.

Shape (Modify Surfaces): The model should also allow individual surfaces or connected surfaces to be modified and re-shaped.

Colours, Materials and Finishes: Colours, materials and finishes (CMF) should be applied at the part level. It should also be possible for designers/brands to link the CMF of parts (for example the volume keys and on-screen Android keys might be linked so they are always the same colour).

Detailing: The detailing of the product (however defined by the designer and brand) should be 'protected' and non-changeable by the consumer. A menu of alternative choices might be provided.

Logo: The consumer should have the opportunity to upload a logo or type a message which would appear on the phone's cover.

In addition, the toolkit should aid in the creation of models which fit with commonly accepted norms of designed products. For example changes to the shape of one side of the product should be symmetrically mirrored on the opposite side (though it should also be possible to disable this feature, if required). Similarly when surfaces are changed, their boundary conditions with adjoining surfaces (primarily tangency or curvature continuity) should remain. This lack of appreciation for 'designerly' conventions was the over-riding factor in determining that Cosmic Blobs provided an unsuitable model for a consumer-design toolkit (Section 10.5.5), whereas Sculptris (the most similar modeller to Cosmic Blobs that was tested) was much more suitable.

11.3.9 Model Integrity

The toolkit should ensure that any resulting consumer-design should be manufacturable by a suitable AM system, and comply with all necessary standards, as implied in Chapters 2 and 3 and recommended in Chapter 10.

A basic function of any MC toolkit is to guarantee the integrity of the product in terms of safety, functionality, consumer law, etc. The toolkit's parameters should therefore prevent the consumer from designing a product which compromises these requirements, for example it should not be possible to shape the body in a way that prevents the USB charger from connecting, or to specify a metallic part close to the antenna.

The toolkit should also ensure the geometric integrity of the model, such that it can be converted to files suitable for additive manufacture without requiring manual repair.

11.3.10 In-Application Help

An in-application Help function should give guidance to consumers using the toolkit, as recommended in Chapter 10.

11.3.11 Community

Opportunities should be provided to share designs with friends or other consumers, as demonstrated in Chapter 6 and recommended in Chapters 3 and 10.

Creating a community of interested participants would have a number of benefits (Berger and Piller, op. cit; Fletcher, op. cit):

- It acts as promotion
- it generates new starting points for other consumers to begin designing
- it bug tests and solves problems
- it can act as a source of trends research

It may also be the case that consumers have an expectation of opportunities to share designs; a lack of options to do so would therefore be perceived negatively.

11.4 DESIGN OF THE PROTOTYPE TOOLKIT

The design of the toolkit had two major components - the design of the toolkit itself, and the design of the phone model which is the subject of the toolkit.

11.4.1 Phone Design

The purpose of the phone concept used to demonstrate the potential of the toolkit was to provide an architecture which could be used as the basis of a number of models, and which could then be modified within fixed parameters. To create an example which was as realistic as possible, an assembly of major components was created using Solidworks CAD software. This assembly contained digital models of three LCD displays (see below), manufactured by Truly Semiconductors[50], whose data sheets could be downloaded freely:

1. 2.8" 240 x 320 pixels
2. 3.2" 320 x 480 pixels (½VGA)
3. 3.7" 480 x 800 pixels

Digital models of additional components (which the author had access to from previous projects), were also added, as follows:

4. Battery, in three sizes (1020mAh, 1250mAh and 1550mAh)
5. USB (mini) connector
6. Loudspeakers
7. Earpiece speaker
8. Switches for power and volume keys
9. Camera
10. Representative PCB Engine

These components were then used in a number of assembly configurations (Figure 11.2), corresponding to five different usage scenarios:

- Movies and Music
- Gaming
- Business
- Sports and Outdoor
- Basic Usage

In this way, the Solidworks assembly simulated the component-swapping and component-sharing modularities that would be required by the phone architecture.

50. See: http://www.trulydisplays.com/tft/index.html

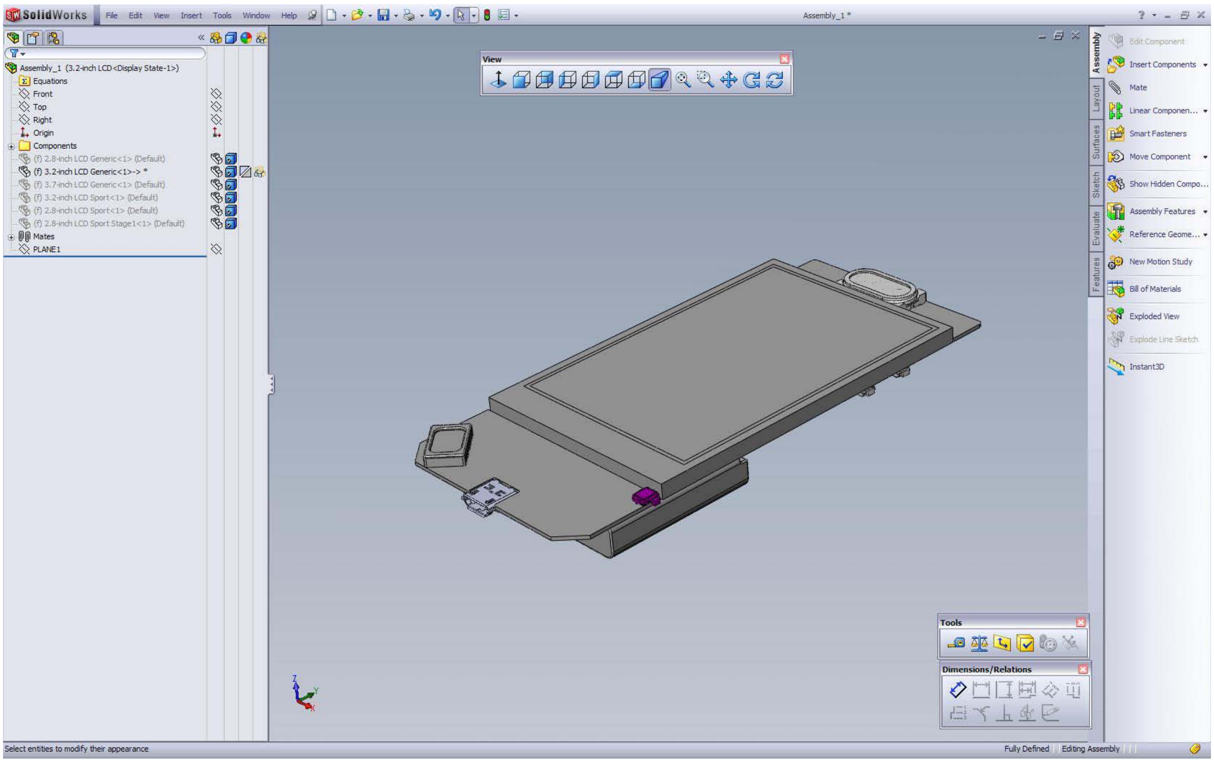


Figure 11.2. Solidworks configuration using Truly 3.2" ½VGA LCD and 1550mAh battery

Drawings of the assemblies were then printed and used as underlays during sketching of the phone concepts. Here the purpose was not to create fully resolved design solutions, but instead it was to develop designs of unfinished products as proposed in Chapter 6. These would then form the basis of the consumer design enabled by the toolkit. Thus the designs might be described as 'generic' and possessing little personality. CAD models of each design were created, again using the Solidworks CAD system; these were to form the basis of the prototype toolkit simulation.

11.4.2 Toolkit Design

As mentioned earlier in this chapter, the intention of the prototype toolkit was not to demonstrate how such a system might appear if implemented, but rather to simulate its structure and functionality. Thus the graphic design of the toolkit was functional and low key. In contrast the phone was realistically rendered and animations used to simulate the use of design tools.

The layout of the user interface followed a simple grid template and was replicated on every page to ensure consistency. Similar functionalities were grouped together and a hierarchy of importance was established by the size and position of these functionalities; a left-to-right flow through the pages was used to increase intuitive understanding. Thus the toolkit layout followed basic principles of user interface design (Tidwell, 2005: pp. 89-95), with the exception of using only one font and type-size, in keeping with previously noted recommendations for the design of wireframe prototypes.

The finished toolkit was to work as a chauffeured prototype, a concept in which "the designer walks through with the user and manually demonstrates how the interface would respond to user actions" (Usability First, op. cit.). As such, none of the tools were required to actually function, but instead to clearly demonstrate how such a tool should work. Those features directly related to the design of the phone were simulated fully; more peripheral functionality (such as the sharing of designs via Facebook or Twitter) were indicated but not simulated.

The CAD models from Solidworks were imported to Keyshot, an HDRI (high dynamic range imaging) renderer with which the author had extensive experience. Turntable renderings were created by rotating the model in 15 degree increments to create 24 images for a 360 degree rotation. In cases where the simulation was to show the phone's design changing (a surface being moved, for example) a series of models were created in Solidworks which showed the surface in incrementally increasing positions. These models were also imported to Keyshot for rendering. Once renderings had been created for a particular stage in the toolkit, they were imported to Adobe Photoshop for correction (where required) and post-production. This was necessary in instances where particular surfaces were required to highlight (see for example Figure 11.8).

The toolkit itself was built using Freeway Pro, an HTML editor used primarily for website design. This was chosen primarily because of the author's familiarity with the software, but also because the functionality of more commonly used rapid application development software such as Visual Basic was not required. Animation of the rendered images and simulation of interactions was achieved using Adobe Flash, with coding in Actionscript where required. The Flash Player files were then embedded in the Freeway-created web pages, thus presenting a prototype, step-by-step toolkit.

11.4.3 A Visual Walk-through of the Prototype Toolkit

Figure 11.3 shows the opening screen of the toolkit, which allowed the consumer to choose from five basic models. Throughout all stages of the toolkit, the user interface was divided into four regions. The top of the screen showed the consumer's progression through the Choose - Specify - Design - Checkout stages of the toolkit. The left hand side of the screen allowed the consumer to look at and choose from the five, generic, starting designs at any time. The bottom of the screen contained options for sharing or looking at other user's designs, as well as the online Help and Price indicator. The main stage displayed the model of the phone, which was updated in real-time as the phone was modified.

Figures 11.3 - 11.15 provide a visual walk-through of the toolkit.

Figure 11.3. The opening screen, with choices of model on the left hand side.

Figure 11.4. The Specify screen, displaying consumer-configurable options.

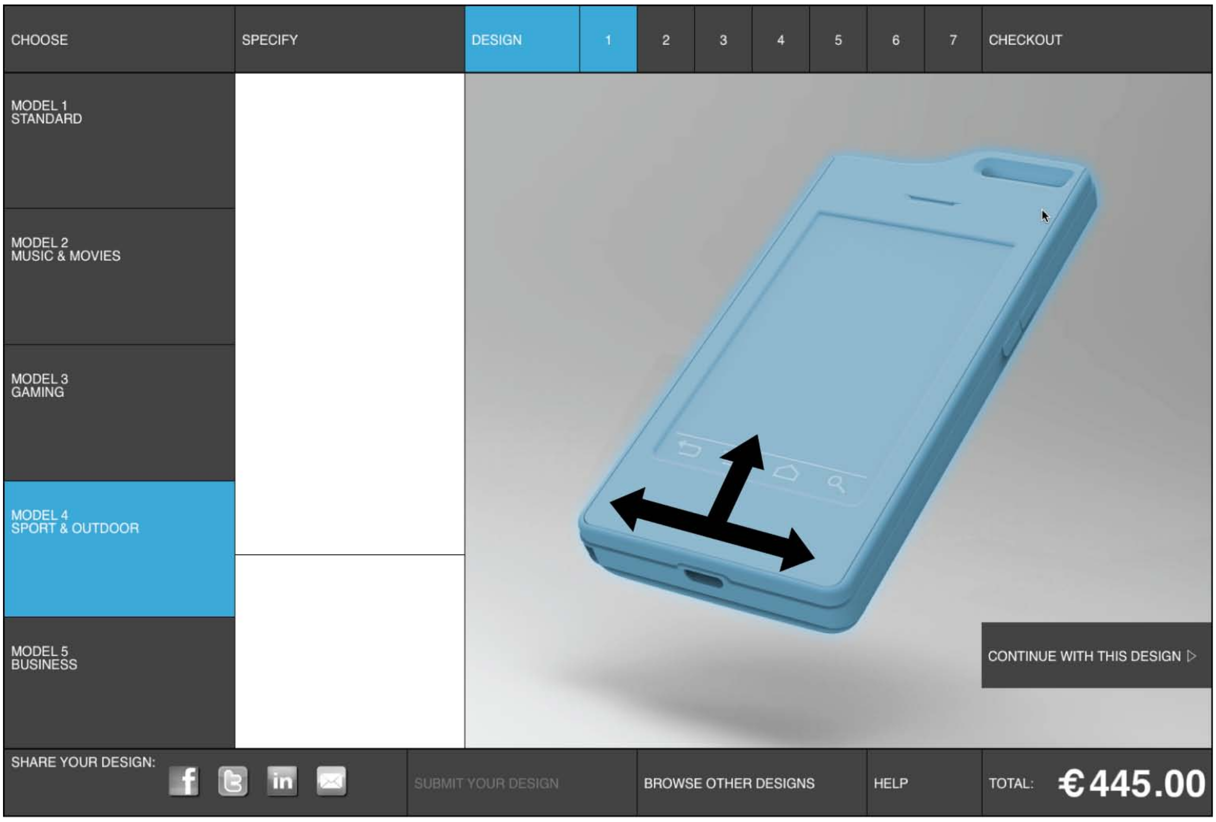


Figure 11.5. Design Stage 1: Scale

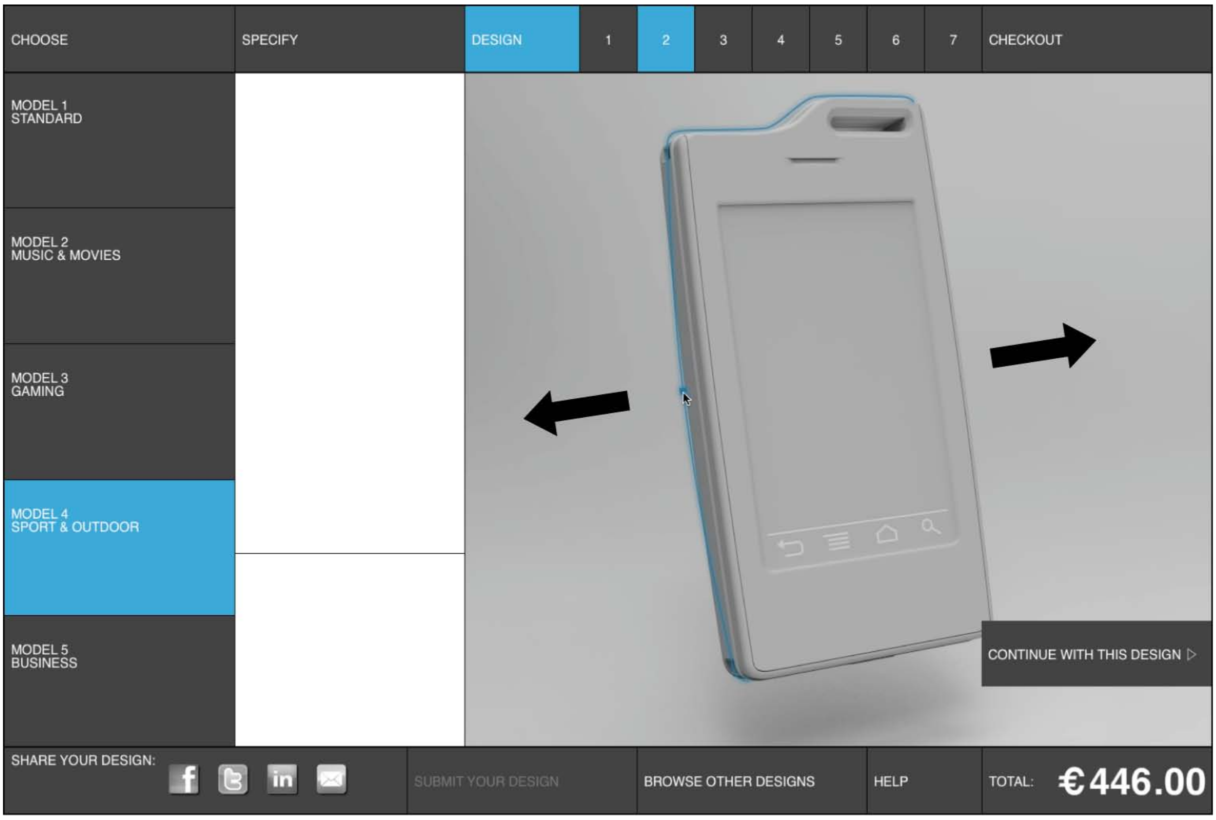


Figure 11.6. Design Stage 2: Shape (Silhouette).

Figure 11.7. Design Stage 3: Shape (Move Surfaces).

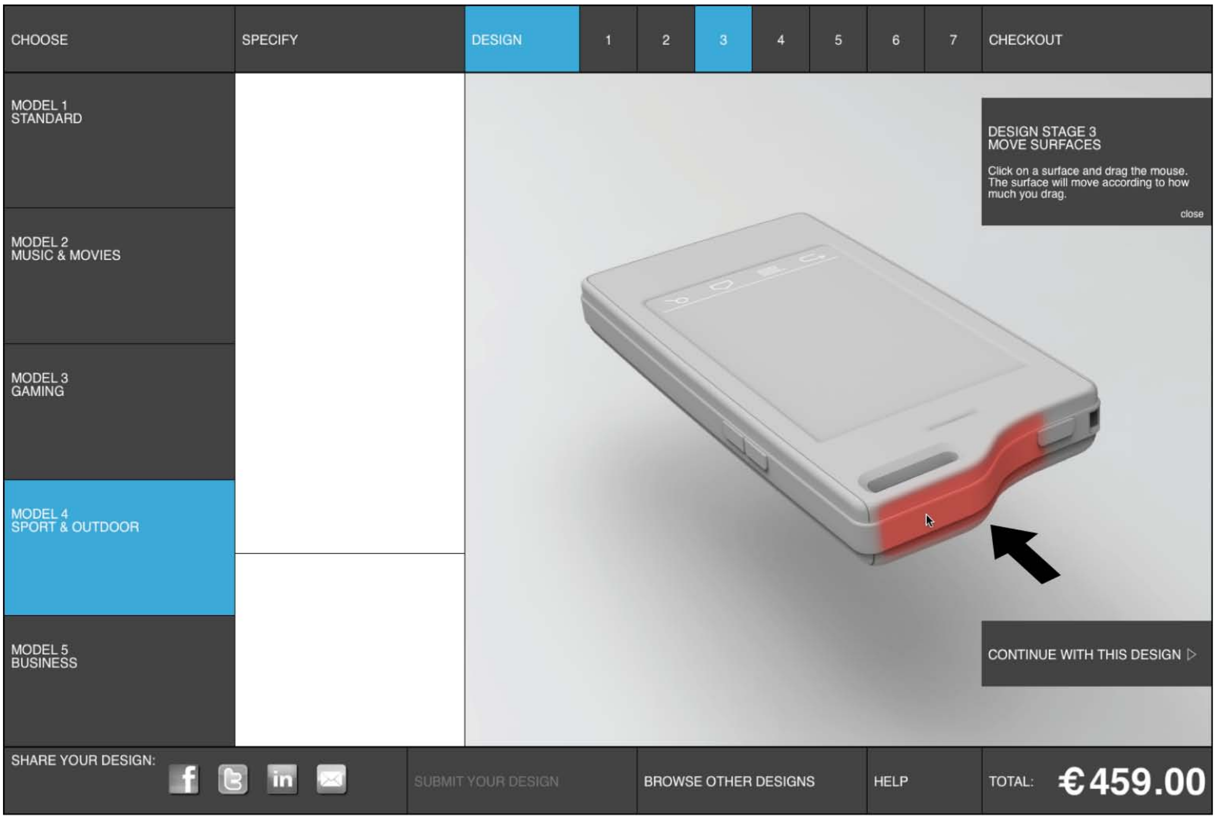


Figure 11.8. In all stages, the toolkit highlighted and prevented non-manufacturable modifications.

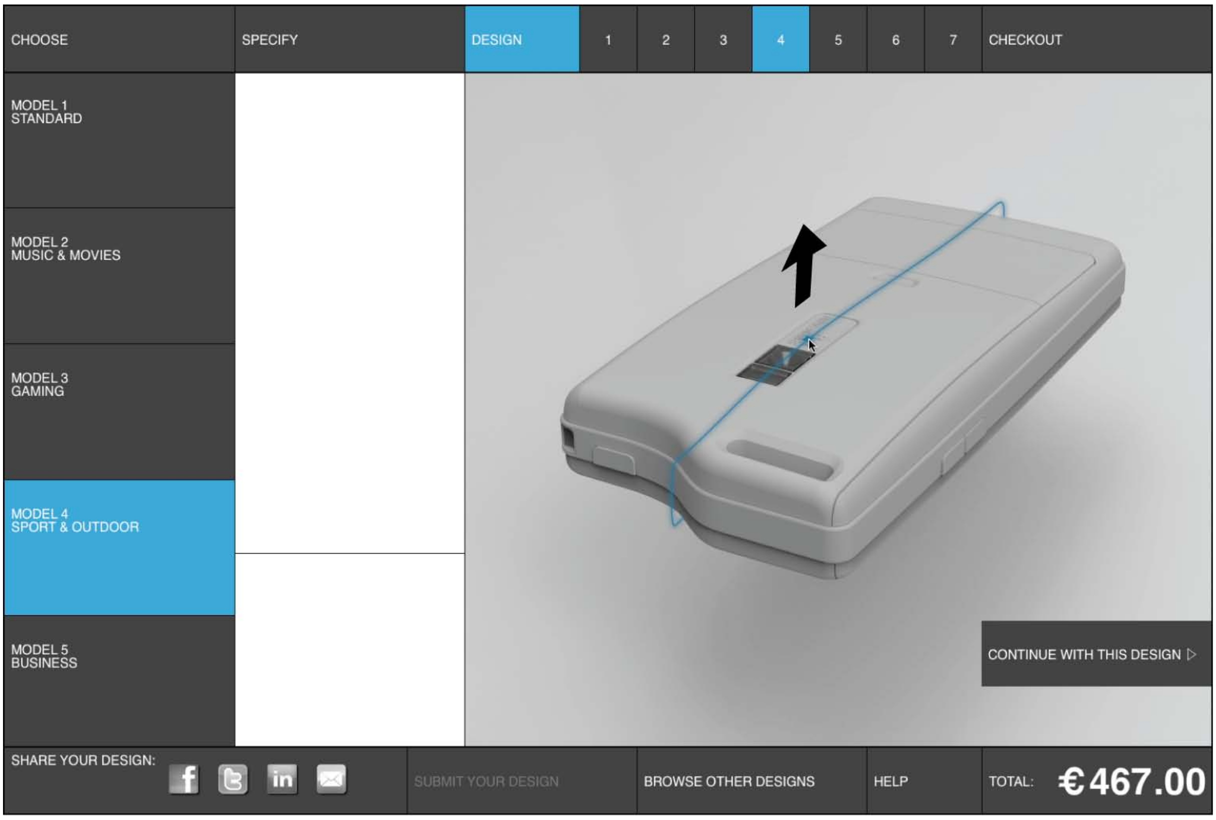


Figure 11.9. Design Stage 4: Shape (Modify Surfaces).

Figure 11.10. Design Stage 5: Colours and Materials, showing a number of pre-designed options.

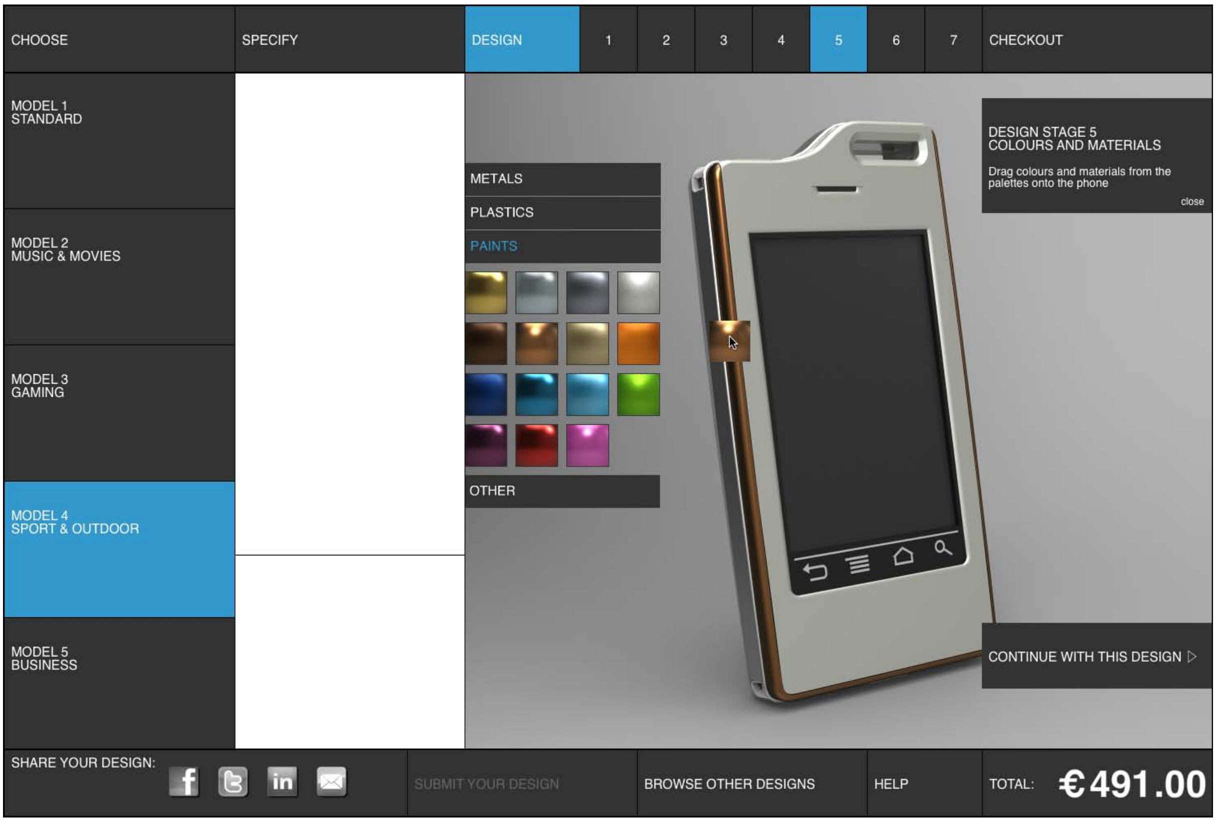


Figure 11.11. Colours and Materials, showing drag-and-drop assignment of finishes to parts.

Figure 11.12. Design Stage 6: Selection of feature details.

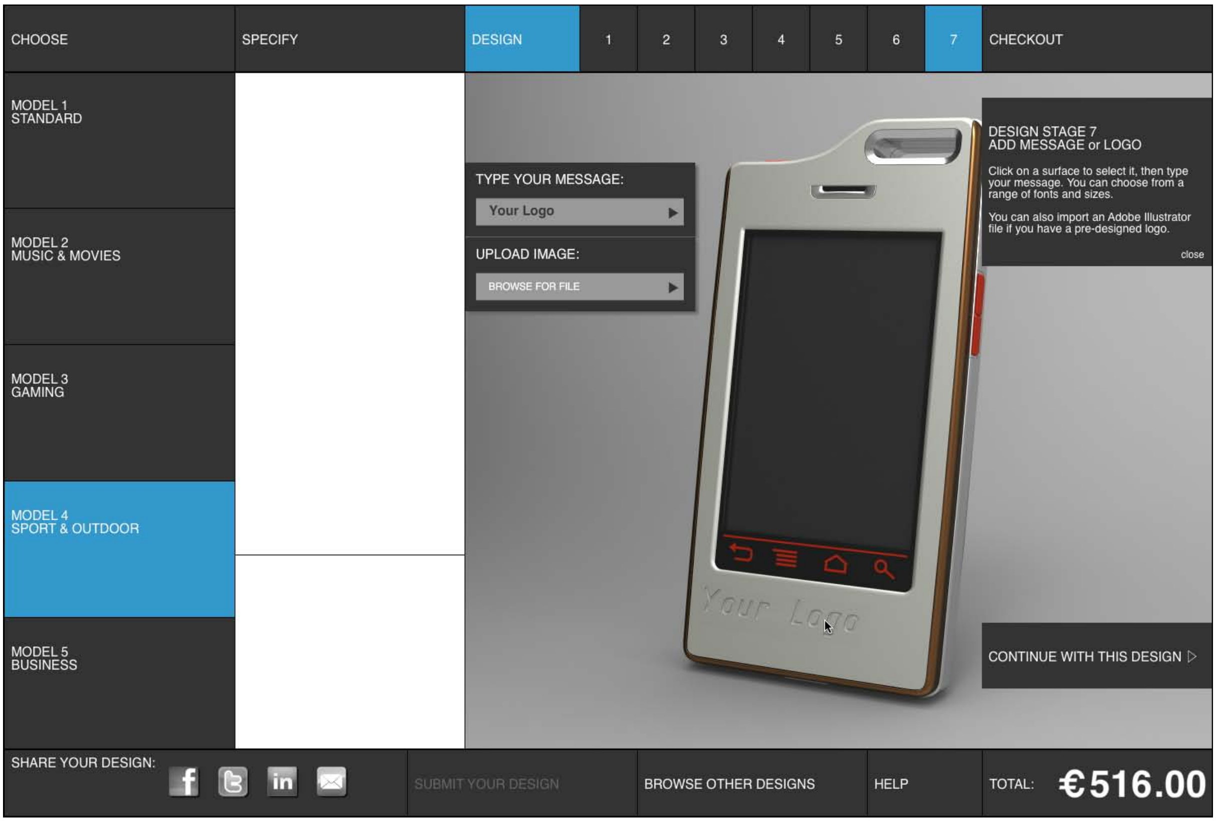


Figure 11.13. Design Stage 7: Add Message or Logo.

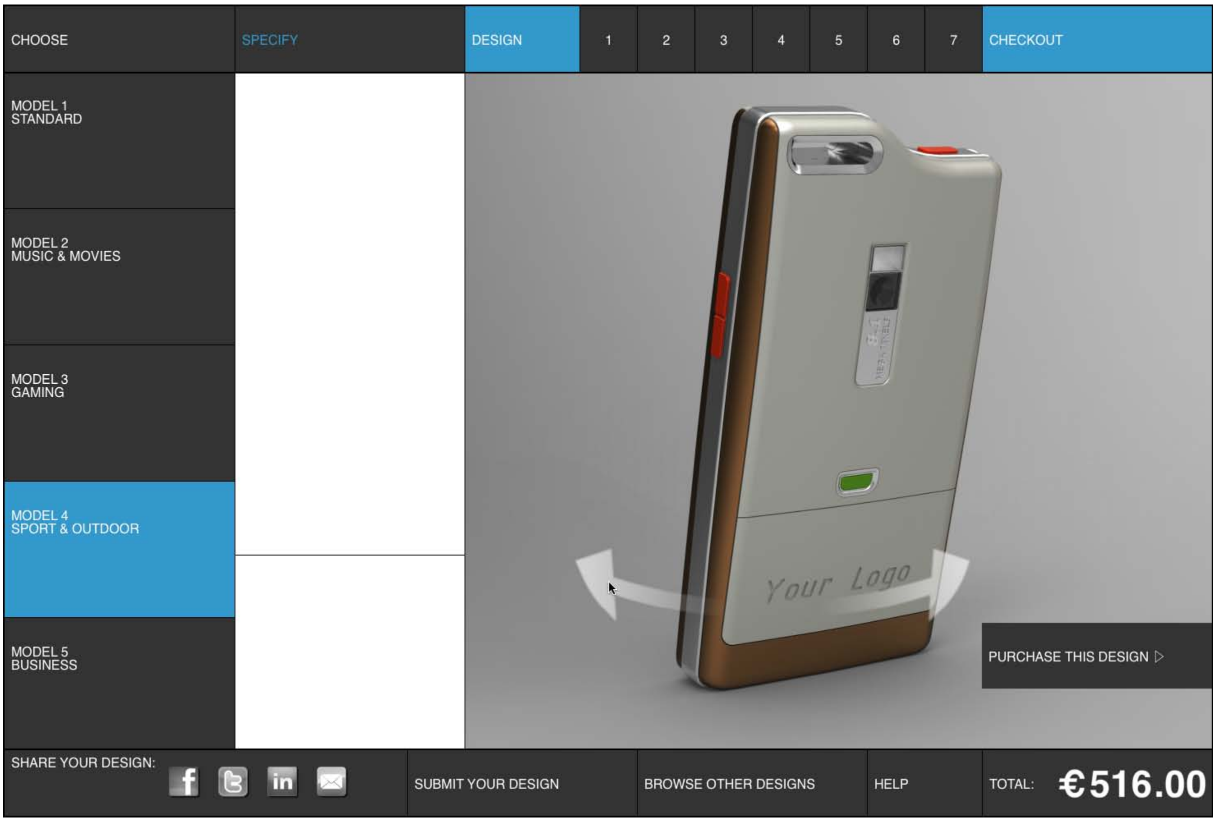


Figure 11.14. The Purchase screen, showing a rotatable view of the phone.

11.5 DEMONSTRATION AND TESTING BY SEMI-STRUCTURED INTERVIEW

In order to gain preliminary feedback on the prototype and to provide a richer reflection on its design, the toolkit was demonstrated to four subjects, who were interviewed about their opinions and reactions. The purpose of these interviews was not to gain experimental data or to prove the success of the toolkit, both of which would be inappropriate to its nature as a wireframe prototype. Instead the interviews were intended to confirm the value of a consumer-design toolkit by showing how it would work and what kind of products would result - what Krippendorff (op. cit: p. 263) describes as Demonstrative validity.

Demonstrations via chauffeured prototypes can affirm whether the framework definition is sound and whether the detail definition is well resolved. However as Krippendorff (ibid) warns, "demonstrative validity can speak only to the sensory modality on which the demonstration relies." Thus it is important to note the areas in which the prototype deviates from the way in which it would exist, if implemented. For example, as a simulation running directly on the author's laptop, no feedback could be given on how the toolkit might operate as a browser-based application. Issues regarding internet connection stability, download speeds, graphical capability - all of which could significantly influence a consumer's experience of the toolkit - were therefore not addressed. Similarly questions regarding the purchase of the consumer-designed product (for example how long would the order take and what would be the quality of the parts) could not be asked.

11.5.1 Interview Participants

Four participants were recruited to gain feedback from two distinct standpoints: that of the professional designer and that of the consumer designer. Both professional designers were practitioners at senior managerial level and thus met all of the criteria previously stipulated in Chapter 8. In addition both had previously worked as in-house designers for Nokia, and therefore had an extensive understanding of the technical realities of mobile phone design and production. The consumer designers were computer literate and self-identified as being interested in the design of products, though neither had studied industrial design, and thus met all of the criteria previously stipulated in Chapter 9. In addition both were familiar with some form of consumer-oriented CAD software (Google SketchUp and Daz3D), and had knowledge (though not direct experience) of 3D printing.

Professional Designers

PD1	Co-Founder and Creative Director of own consultancy
PD2	Design Strategy Consultant

Consumer Designers

CD1	Architectural Assistant
CD2	Artist

11.5.2 Interview Procedure

Interviews were conducted on a semi-structured basis and an audio record was saved digitally. Interviews lasted 50 minutes on average, with the initial demonstration taking approximately 15 minutes. An explanation and brief introduction to the research was made, before demonstrating the prototype toolkit, with the author controlling the on-screen actions. Participants were invited to ask questions at any stage of the demonstration. Once concluded, participants were asked for their immediate reactions to the toolkit's functionality and value.

The demonstration was then repeated, but at each stage in the toolkit design process participants were asked to comment regarding functionality and specification. Finally participants were asked to give their thoughts regarding who might use the toolkit, what other products it might be most useful for, and which brands might offer such opportunities to consumers.

11.6 INTERVIEW FEEDBACK

For clarity, the feedback from interviews is presented with reference to the framework and detail specifications discussed previously.

11.6.1 Feedback Regarding the Framework Specification

Although not explained explicitly, the framework definition was outlined in the introduction to the demonstration and referred to as the demonstration progressed. For example component-swapping and component-sharing modularity were not explained, but were understood intuitively by participants when viewing the Specify page of the toolkit. As might be expected, both professional designers understood the parameter-based customisation system. However both consumer designers also understood its functionality, the terms used and the value of such a system. This appears to validate the assumption that interested lead-users would understand technical terms, and that a needs-based system would therefore have less value.

All participants understood the value of a Constrained Consumer Design (CCD) method of design, and responded positively to it. Both PD1 and PD2 suggested that such a scenario was the most likely one that brands would accept, at least in the short to medium term future, and that established brands were unlikely to allow consumers to engage in either Enabled Consumer Design (ECD) or Free Consumer Design (FCD).[51] However both also expressed doubts as to whether CCD would be accepted by all brands, and both Nokia and Apple were mentioned as examples of brands which were unlikely to allow consumers to engage with all of the toolkit's functionalities. Both consumer-designers also understood the reluctance that brands would have to allowing consumers to freely modify their products, and both were interested in discussing the implications of such a scenario. However, whereas CD2 wished to have greater freedom to create more personalised and "unusual" designs, CD1 felt the freedom offered by the toolkit would likely lead to "ugly" concepts which brands might not allow.

This leads on to questions regarding the extent of design and customisation. To some degree, all participants felt that the demonstration of the toolkit's possibilities was too conservative, i.e. the 'finished' design did not look different enough from the original, unfinished one. This is due in part to the choice of a mobile phone as the subject of the toolkit, which is addressed further in Section 11.7. However this conservatism is primarily a result of the wish to convey what a brand might realistically permit, as well as the technical constraints of manufacturing a functioning product. Thus, in more accurately reflecting commercial and technical realities, the toolkit has failed to express the full potential such a system might have.

The design interaction type raised no significant issues or questions. All participants understood the Design stage functionalities and none questioned whether an alternative might be more appropriate. CD2 in particular was positive about both the ability to pull surfaces, and the method of warning of and preventing non-manufacturable designs. As

51. These terms were not introduced to the participants, and so CCD, ECD and FCD were not referred to explicitly. However, in discussing possible scenarios of consumer-design activity, participants mentioned traits and features which allow their explanations to be classified as such.

expected, all interviewees understood the concepts of clicking on profiles to place points, and then dragging profiles to influence surface shapes. PD2 raised the question of how a designer might control curvature continuity across surfaces, and whether designers would ever accept the possibility of 'bad' designs. However PD1 became interested in a "new way of designing," in which the designer created forms that pre-empted consumer interventions, and whether it would be possible to create designs which looked good no matter how they were subsequently modified.

Finally the manufacturing scenario, in which the phone would be pre-ordered then manufactured by an external vendor (rather than by the consumer at home) was accepted by all participants.

11.6.2 Feedback Regarding the Detail Specification

In a similar way to the framework specification, most of the detail specification was referred to during the demonstration, rather than formally explained. However it was felt important to make clear that the toolkit would work as an online, in-browser application, rather than run directly on the consumer's computer (as was the case with the prototype). Both CD1 and CD2 believed this was more likely to attract consumers than a system which required download and installation. However CD2 also wondered whether an advanced system might be available for download by those consumers who were particularly interested.

The visualisation of the phone model was appreciated and attracted comments from both CD1 and CD2. Similarly the updating of the price of the phone at every stage was felt to be important as it demonstrated honesty, as well as allowing consumers to easily understand which options incurred most costs.

The question of how to present a default phone model generated a number of differing opinions. CD2 was happy with the five generic, unfinished designs, and felt they offered the best starting point as they were closer to a blank canvas. In contrast, whilst CD1 appreciated being able to choose from five pre-determined specifications, he also wanted the ability to look through designs by other consumers and be able to use someone else's design as a start point. Both CD1 and PD2 suggested the ability to filter (by colour, material, etc.), as well as community voting such that consumers could look at the most popular designs.

The order of interaction also attracted considerable discussion. All participants expressed confusion as to why 'Scale' was the first operation, and in some cases wondered if it was even necessary. CD2 reasoned that a person with disabilities might want a larger phone, but CD1 believed most consumers would want the phone to be as small as possible. PD2 suggested the Scale tool might have more value for a different product, for example a bath. CD2 and PD2 also had strong opinions regarding the importance of the 'Colours and Materials' stage; CD2 believed it should be Design Stage 1, and PD2 that consumers should be able to complete the stages in the order that they felt was important. Whilst this was in fact the intention of the prototype, PD2 felt that the linear numbering of stages was too prescriptive, and proposed it should be presented more like a spider diagram, with no implied start point. In contrast though, PD1 felt the linear progression was important, as it made it easy to understand which stages had been completed.

CD1 and CD2 believed the tools supplied would allow them to do everything they wanted, and PD1 was reluctant to allow consumers any more freedom to change the design. Both PD1 and PD2 agreed that the 'Detailing' stage of the toolkit was well implemented, and that it was important that consumers should not be able to change the way that detailed features were treated. However PD2 was surprised that there was no tool to 'Texturise' surfaces, and that this was a significant omission. Since AM technologies are able to create highly intricate textures which would be impossible in parts produced by (for example) injection moulding, PD2 believed such an option would be popular amongst consumers whilst also highlighting the uniqueness of the system.

PD1 and PD2 expressed no strong opinion on the 'Logo' stage of the toolkit, except to wonder how it would be policed (i.e. how trademark infringement or obscene messages would be prevented). CD2 was very enthusiastic, claiming that it would work as "personal branding" and would be "a fantastic benefit." However CD1 disagreed, and did not expect anyone he knew to take advantage of such a tool.

The integrity of the model, and the understanding that whatever design was created could be manufactured, was assumed by all participants. CD1 deduced the concept of a safe model without it being explained, commenting "so there's a box inside that contains the electronics and you cant infringe on it." Both he and CD2 understood the warning given by the model (a blue surface which changed to red) and felt it was well implemented. All participants understood the concept of, and the need for, a constrained model that could not be changed outside of pre-determined parameters, and neither PD1 or PD2 raised concerns about the ability of designers to determine where such parameters should be set. However CD2 was disappointed that the model stopped changing at the outer limit of the set parameters, and would have preferred to be able to stretch the model to "outrageous" limits, before watching it "spring back" to its acceptable form.

The 'Help' system generated considerable discussion by all participants. Whilst it was generally felt to explain the tools' functionalities adequately, all believed it should also have a role in explaining and aiding 'good design'. CD2 and PD2 in particular advocated on-screen messages to explain why an action was not possible (for instance, a message explaining "You cannot select metal for this part, as it would affect the antenna performance,"). PD2 suggested "Designer Tips" might also be displayed, so that if, for instance, a consumer selected a painted finish for the central, protective chassis of the product, a message would inform the consumer that "We recommend you use another finish for this part, as paint will rub off easily." CD2 also thought messages might make visual suggestions, based on what the toolkit believed the consumer was trying to achieve, proposing "if there were five little screens popped up related to what you were doing, you could click on one" and the model would update.

The community elements of the toolkit, whilst not actually functioning, nonetheless raised considerable comment. All participants perceived benefits to consumers, though CD2 believed he would not look at many designs by other people. In contrast CD1 expected to look through many designs, especially if his friends were using the toolkit, and would probably use someone else's design as a start point, if possible. He also speculated that companies might be set up, which would use the toolkit to design for other people who could not use it as well. PD2 believed community voting and discussion would enhance the perceived value of the system amongst consumers, and suggested a prize whereby the creators of popular designs would work with the (professional) designer of the original product. In this way a brand could use the toolkit as a market research tool, as well as a possible recruitment aid.

11.7 REFLECTION ON THE TOOLKIT PROTOTYPE

With regard to the framework definition of the toolkit, the fundamental foundations appear to be sound. Most importantly, amongst those to whom the prototype was demonstrated, there was no question as to whether it was useful to consumers or whether it was a system with which (some) consumers would want to engage. Similarly the placing of the toolkit within the category of Constrained Consumer Design (CCD) raised no disagreement, and appears to partially resolve the conflict between the degree of design which consumers might wish to undertake, and the degree of freedom which designers and brands would be prepared to allow. Consumers understand and accept that brands would wish to impose restrictions on the extent to which a product could be modified, and in fact appreciate that such restrictions might enable them to design better products. Nonetheless, it is likely that a brand's desire to control its image will, in some cases, conflict with a consumer's desire to exercise design freedom, and in such cases resolving the conflict in a way which maximises brand equity will be a complex operation.

The biggest limitation in the implementation of the prototype toolkit was the decision to use a mobile phone as its basis. Whilst the phone was chosen for a number of valid reasons (see Section 11.1 previously), it proved to be a constraining factor in demonstrating the toolkit's potential. The large, flat, front face of the phone, imposed by its LCD touch screen, significantly limited the extent to which the newly designed concept appeared different to the original, unfinished design. This did not appear to affect the understanding of the tools amongst those to whom the toolkit was demonstrated, but it may have had the effect of reassuring the designers that a consumer-design toolkit was not a significant 'threat' to their way of working. PD2 suggested that a mobile phone manufacturer might choose to restrict customisation on the front of the phone (which is seen in advertising and sales catalogues) but permit greater freedom on the rear of the product. If the opportunity existed to repeat the building of a prototype toolkit, the author would recommend using a product more amenable to significant transformation, for example a watch.

The type of design interaction, using CAD-like tools to modify the model, was perceived as appropriate and the tools included were easily understood. This was a significant finding, since other types of design toolkit (see Section 11.2.6) have differed by using slider bars or similar to set values, which then influence a product's design. Clearly CAD-like tools require a level of expertise greater than that required for more basic interactions, however the degree of control over individual surfaces (for example) is considerably increased.

The order in which the tools were accessed is an aspect of the prototype which should be re-addressed. In the detail definition of the toolkit, Section 11.3.7 required that "a progression through the process should be suggested, but it should be possible to carry out tasks in any order." Whilst this requirement was implemented, the guiding of the consumer through the process was nonetheless applied too rigidly. Options for ways in which a more non-linear process could be integrated should therefore be investigated. In addition, the possibility of a palette of tools which could be individually activated or removed (by the brand provider of the toolkit) would address the redundancy of tools (such as the Scale tool in the demonstration) whilst also allowing additional functionalities.

Options for colours and materials should have a greater emphasis within the toolkit, with the Colours and Materials stage possibly appearing as Design Stage 1 (rather than Design Stage 5, as in the prototype). Whilst it may have been expected that consumers would wish to choose the product's CMF specification at the beginning of the process, this was not supported by the earlier research: in the USB memory stick trial, most participants paid no attention to colours or materials. Within the demonstration however, participants believed the ability to choose colours and materials was one of the most important aspects. An improved Help system - one which gave design hints and suggestions - would also have a role here, advising on the best materials for different parts or which colours complement each other, for instance.

Finally, an issue which did not inform the prototype toolkit's design but which was nonetheless raised during the demonstrations, was that of IP protection. PD2 raised the question of how one brand would protect itself from consumers who changed their product to look like that of another brand, for example changing a Samsung product to look like a Sony. If the manufacturing model was for the brand to ship the final product, this could probably be policed: NikeID, for example, faces a similar issue in disallowing other brand names to be used by consumers who choose the customised message option in its toolkit. On a related note, CD1 asked whether it would be possible to protect a design, such that other consumers could not view or copy it, or else to receive a 'royalty' whenever his design was used. Whilst at first this appears to run counter to the spirit of sharing, it could prove to be an important issue - consumers who use the toolkit from a desire to create a unique product would not appreciate others buying the same product, thus rendering it no longer unique. A brand would therefore need to consider whether complete openness, or optional openness, is the best strategy.

11.8 LIMITATIONS OF THE RESEARCH

In assessing the validity of the findings from the prototype toolkit, a number of limitations should be acknowledged.

The first limitation lies in the nature of a wireframe prototype as a relatively undeveloped design solution. The purpose of the wireframe was to test general principles and methods, such as

1. Is a toolkit an appropriate means of enabling consumer design?
2. Are CAD-like tools appropriate for a consumer-design toolkit?
3. Is it possible to create a toolkit whose functionality is acceptable to both consumers and designers / brand managers?

In order to answer these questions, a number of design tools were created for the toolkit. However, the purpose of these tools was only to suggest a CAD-type environment, and to ascertain whether such tools are appropriate. Feedback regarding the specific use of these design tools is therefore premature. Further improvements to the interaction architecture of the toolkit (for example, the implementation of a non-linear design tool menu) should therefore be made before attempting to develop the design tools further.

A second limitation is that, even though the purpose of the toolkit was not to test the design tools themselves, the use of animations to simulate interaction may influence perception of the toolkit. An animation which makes a particular tool look easy to use may hide difficulties which are revealed when the tool is developed further. This in turn may have a bearing on the previously tested general principles. Thus, whilst the research appears to answer questions 1 - 3 (above) positively, it should be qualified by the understanding that the design tools, when developed, may be more difficult to use than the animations suggested.

Finally, a further limitation of the toolkit was that it did not test a product manufactured by a real, recognisable brand. This had been a deliberate decision, as it was felt to be inappropriate to a wireframe prototype, and the choice of brand may have affected participants' responses to the toolkit. However it should be acknowledged that changes to a design which appear acceptable (to both consumers and designers) on an unbranded product, may not be acceptable on a recognisably branded on.

11.9 CONCLUSION

This chapter has explained the reasoning behind the format in which the toolkit was developed and presented. It has also justified the framework definition (i.e. the underlying concepts) and the detail definition (i.e. the tools and features) of the toolkit using supporting evidence from previous chapters. Finally it has reported initial feedback from interviews with professional and consumer designers, and reflected on the toolkit's specification and design. The following chapter, which concludes this thesis, uses this reflection to inform some of the recommendations for future work.

CHAPTER 12

Conclusions and Future Work

12.1 INTRODUCTION

This PhD research has attempted to understand how additive manufacturing technologies might impact the profession of industrial design. In particular, it has investigated the implications of changes to a fundamental basis of industrial design: that it involves design for the multiple reproduction of identical objects. The research has not suggested that AM will supplant mass manufacturing, nor that a "third industrial revolution" (Economist, 2012) is imminent. Instead it has assumed a future in which mass manufacturing and additive manufacturing combine to create hybrid production processes, utilising the particular advantages of each system.

In Chapter 5 it was proposed that "a future role of the industrial designer will be to design 'unfinished' products, whose fit, form and function will require unique decisions and inputs from consumers prior to manufacture." The specification and design of a prototype consumer-design toolkit has provided an embodiment of this statement. However this embodiment is by no means a finished design concept, nor is it the only conceivable concept that might result from the statement. This final chapter therefore begins by considering the PhD research as a whole, identifying the research objectives that have been achieved and the research questions answered. The original contribution to knowledge is summarised, and some of the limitations of the research are discussed. The chapter concludes by recommending future directions for research, including ways in which the consumer-design toolkit might be developed further.

12.2 ACHIEVEMENT OF RESEARCH OBJECTIVES

Chapter 5 listed five research questions, based on the six objectives identified in the Introduction to this thesis. The extent to which these questions and objectives have been addressed is now considered.

Research Objective 1. To review the literature and critically analyse the role of the consumer in design processes outside of those traditionally employed by professional industrial designers.

Research Question 1. What are the new and emerging approaches to Industrial Design, and what degree of consumer involvement do they expect or advocate?

Chapter 6 identified 10 methods of conducting industrial design. Commonly accepted methods involve:

- Conventional Design
- User-Centred Design
- Co-Design
- Bespoke Design
- Customisable Design
- Mass-customisable Design

New and Emerging methods include

- Crowdsourcing
- Open Design

- Opened Design
- Consumer Design

A classification of consumer involvement in Industrial Design was developed, which showed how new methods of ID differ in the degree of consumer involvement they expect. However, all require that the professional designer relinquishes a degree of control over a product's final design, thus changing from an interpreter of consumer needs, to a facilitator of consumer involvement.

Research Objective 2. To explore the process and outcomes of bespoke design and customisation, and understand how these might be applied within a design toolkit.

Research Question 2. What are the limits of what is currently achievable in the customisation of consumer electronics devices?

Chapter 7 presented a case study of a mobile phone, whose design and development were specifically intended to provide flexible opportunities for bespoke design and customisation. The case study showed how the ability to offer customised and limited edition designs was fundamentally tied to the modular product architecture. It also demonstrated that although customisation can exploit exotic materials such as ceramics, precious metals and gem stones, it is largely limited to changes of materials, rather than changes of form. In this respect, bespoke design and customisation reflect the same limitations demonstrated by mass customisation in Chapter 3.

Research Objective 3. To understand how a product design language affects brand equity, how design languages are developed and maintained, and what conflicts might arise from consumers' interventions in design.

Research Question 3. How are brands' product design languages managed, and what conflicts exist between consumers' involvement in design and the maintenance of brand equity?

Little information was discovered in the literature regarding the construction, maintenance and value of a brand's product design language. A survey was therefore conducted amongst senior design professionals and brand managers, the results of which were reported in Chapter 8. The survey results revealed that a product design language involves the common application of features, details and shape grammars across a brand's product portfolio. In order of importance, the design language is constructed through:

- A common approach to the detailing of similar elements
- The use of common forms to define product silhouettes
- The placing of common elements in similar positions
- The use of similar colours and materials
- The placement of logos or other brand elements in common positions

Survey respondents believed that the quality of a brand's design language may be diluted by consumer design and customisation, therefore any consumer design toolkit should be constrained in its capabilities in order to be acceptable.

Research Objective 4. To investigate, through user trials, non-designers' abilities and preferences with regard to a number of design methods.

Research Question 4. Which activities and processes are preferred by consumers engaging in the design of their own products, and how are consumers best enabled to communicate design intent?

A trial was conducted, as detailed in Chapter 9, to investigate non-designers' abilities and preferences when asked to undertake the design of a USB memory stick. Participants were asked to create an original design of memory stick, and their satisfaction (with process and outcome) was compared to a task in which they were required to modify a pre-existing design. The trial found that participants preferred the process of modification, but were more satisfied with the outcome of the original design task. This paradox lead to the specification of a consumer-design toolkit which allowed the freedom to conduct freeform modification of pre-existing designs, within limits determined by the designer. The trial also found that the majority of participants were unable to communicate accurate designs, typically disregarding functional and cosmetic detailing. The specification of the consumer-design toolkit therefore required that such details should be included in the unfinished design of the product to be modified.

Research Objective 5. To further investigate consumer-oriented product design and development software.

Research Question 5. What can be learned from existing consumer-oriented 3D modelling software?

To answer this question, 14 consumer-oriented 3D modelling packages were considered, and four were tested in order to ascertain what tools and features might be transferable to a consumer design toolkit, as described in Chapter 10. In order to fully explore the software's features, a common task - to design a computer mouse based around an existing design - was conducted. A report was compiled for each software package (Google SketchUp, Moments of Inspiration, Sculptris and Cosmic Blobs) which measured performance across a number of criteria. This allowed a set of recommendations to be gathered, which informed the design and specification of the consumer-design toolkit.

Research Objective 6. To develop a specification for a toolkit capable of being used by consumer-designers, which at the same time satisfies the requirements of professional designers and brand managers.

The final objective was to develop a prototype to demonstrate the feasibility of a consumer-design toolkit, and to gain feedback on its design and specification. A wireframe prototype was created, whose framework and detail definitions were guided by findings from previous chapters. Semi-structured interviews were conducted with both consumer-designers and senior design professionals, in which the toolkit was demonstrated. Feedback from these interviews has led to proposals of ways in which the toolkit's specification and implementation could be improved.

12.3 CONTRIBUTION TO KNOWLEDGE

This research has made a number of original contributions to knowledge, as listed below:

1. The research investigated the tripartite relationship between additive manufacturing (AM), mass customisation (MC) and industrial design (ID). It found that traditional definitions of ID are unable to accommodate scenarios in which non-professionals design or modify products which are manufactured via AM for personal use. Similarly, definitions of MC fail to consider the possibility of a consumer engaging directly with the design of a product's shape. The identification of the need for new definitions was an important contribution to knowledge, providing a foundation for the remainder of the research.

2. A Classification of Consumer Involvement in Industrial Design was developed. This showed how traditional methods of ID reinforce power relationships between designer and consumer, in which the professional designer is assumed to be the person best suited to understand and meet consumer needs. It also showed how new methods of industrial design challenge this assumption, requiring the designer to engage with the consumer as a facilitator of involvement, rather than a translator of needs.

   Five new terms have been defined under the umbrella term of Consumer Design

   - Appropriated Consumer Design (ACD)
   - Variational Consumer Design (VCD)
   - Constrained Consumer Design (CCD)
   - Enabled Consumer Design (ECD)
   - Free Consumer Design (FCD)

   In addition a sixth term, 'Opened Design', has been defined to distinguish products which allow modification but restrict distribution, from those in which distribution is unrestricted (Open Design products).

3. The research found that, in a trial to design a simple electronic product (a USB memory

stick), participants' most preferred solutions resulted from a less preferred design process. Participants preferred a process in which they modified a pre-existing 3D CAD model design; however participants unanimously agreed that the best design was achieved through a sketching / modelling process. Identifying this paradox was essential to an understanding of how consumer-design should be accommodated, and led to the specification of a toolkit which utilised CAD-like tools, rather than one which relied on less direct interactions.

4. A survey of senior design and brand professionals found that consumer-design toolkits have the potential to dilute a brand's product design language, and thus damage brand equity. The prototype toolkit that was developed demonstrated the principle of boundaries of acceptable designs, as suggested by the survey: these boundaries would be determined by the designer, outside of which a product's form could not be changed. Nonetheless, consumer-designers found value in the design opportunities within these boundaries. The prototype therefore demonstrates the possibility of a toolkit which:

    a). Enables untrained users to change the form of a product.

    b). Protects brand equity in a way that is acceptable to designers.

    c). Ensures the product's functionality and manufacturability.

5. A specification and embodiment (prototype) of a consumer-design toolkit for ‘unfinished’ objects was developed. This prototype utilised CAD-like tools to manipulate the form of a generic product design, and differed from previous examples of consumer design toolkits, which rely on the input of numerical values (either directly, or via UI tools such as slider bars) to influence the shape of a product.

12.4 LIMITATIONS OF THE RESEARCH

As with any research work, the research undertaken for this PhD has been limited in a number of ways, which should be acknowledged.

The most important limitation has been in the degree of input from experienced designers and brand managers. The author is fortunate in having a network of contacts within the design industry, and these have been called on where appropriate. The design language survey reported in Chapter 8 received 39 completed responses, which was considered good given the seniority of those questioned. However, a larger number of respondents would have allowed a more sophisticated statistical analysis of the results, which in turn may have revealed new insights. In addition the majority of respondents were from the U.S. and Northern Europe; a similar survey of respondents from (in particular) China and India may have provided different results.

Throughout the research, emphasis was placed on the appropriateness and quality of test subjects, rather then the quantity. This was in accordance with Grounded Theory, which emphasises purposive sampling in order to gain richness of data, rather than volume. Such a strategy appears to have been successful, in both the USB memory stick trial and especially the consumer-design toolkit demonstrations, in which the quality of feedback led to a number of clear recommendations for improvement and further research. However, demonstrations to a greater number of professional and consumer designers may have led to further recommendations for improvement. Limitations on time, and the difficulty of recruiting senior level designers with the experience of mobile phone design necessary to provide useful feed-back, therefore precluded further research.

12.5 RECOMMENDATIONS FOR FUTURE WORK

Whilst this research has achieved the objectives listed at the beginning of this thesis, there are a number of recommendations which might be implemented in order to develop the research further.

Chapter 6 presented a classification of consumer involvement in Industrial Design. An obvious question which arises is whether the classification also applies to disciplines other than industrial design, and indeed whether it is possible to create a general classification which applies to all disciplines. One issue is that the methods of industrial design identified in this research have different degrees of prominence in other fields: within fashion design for example, bespoke (or couture) design is significantly more important than within industrial design, whilst co-design receives little attention. Further research would therefore be required to establish the generalisability of the classification.

With regard to the development of the consumer-design toolkit, feedback from the demonstrations and reflection on the prototype have identified a number of areas in which the design could be improved. Consideration should be given to the product used as a basis for a new prototype, in order to ensure the toolkit's potential is fully communicated. Attention should also be paid to the interaction architecture of the toolkit, in particular the possibility of a non-linear process structure.

This thesis has argued that theories developed within mass customisation literature are applicable to consumer design enabled by additive manufacturing, in particular that involvement in the customisation of unique products leads to increased consumer satisfaction and willingness to pay. Nonetheless the extent to which consumer design via AM might be driven by market demand (rather than by the possibilities of the technology) was not a focus of this research, and so warrants further attention. In addition, the degree to which the cost of a product (and its resultant value to the customer) might inhibit consumers' willingness to engage in consumer-design was not addressed by the research. Within the toolkit, the price of the phone was displayed as the total cost of the product (rather than just the cost of the AM parts), and so was relatively high (€516.00 in the toolkit example). Whilst this figure was not raised as an issue by any of the participants, it is reasonable to question whether consumers might be wary of engaging in the design of a high value item rather than a lower value one, and the issue would therefore benefit from further research.

Finally, this research has investigated a direct, 3D CAD-type approach to the toolkit, rather than the indirect approaches of toolkits such as those by Nervous System and Digital Forming. To ascertain which type of toolkit is preferred by consumers, comparison testing should be carried out. This would inform decisions regarding the future direction such a toolkit might take, or even whether a hybrid approach might be appropriate.

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APPENDIX 3.1 Dell Precision T1600 Configuration Options

Feature	No. of customisation options
Processor	5
One Intel® Xeon® E3-1225 (Quad Core, 3.1GHz, 6MB, 2GT)	
One Intel® Xeon® E3-1245 (Quad Core, 3.3GHz, 8MB, 2GT)	
One Intel® Xeon® E3-1270 (Quad Core, 3.4GHz, 8MB, 0GT)	
One Intel® Xeon® E3-1280 (Quad Core, 3.5GHz, 8MB, 0GT)	
One Intel® Xeon® E3-1290 (Quad Core, 3.6GHz, 8MB, 0GT)	
Operating System	4
English Genuine Windows® 7 Professional (32Bit OS)	
English Genuine Windows® 7 Professional (64Bit OS)	
English Genuine Windows® 7 Ultimate (32Bit OS)	
English Genuine Windows® 7 Ultimate (64Bit OS)	
Monitor	9
Display Not Included	
Dell E-series E2211H 54.5cm(21.5") LED monitor VGA,DVI-D (1920x1080) Black UK	
Dell Professional P2210 56cm(22") monitor VGA,DVI-D,DP (1680x1050) Black UK	
Dell Professional P1911 48cm(19") NO STAND/CABLE monitor VGA,DVI-D (1440x900) Black UK	
Dell Professional P1911 48cm(19") monitor VGA,DVI-D (1440x900) Black UK	
Dell Professional P190S 48cm(19") Std monitor VGA,DVI-D (1280x1024) Black UK	
Dell Professional P170S 43cm(17") Std monitor VGA,DVI-D (1280x1024) Black UK	
Dell Professional P2210 56cm(22") monitor VGA,DVI-D,DP (1680x1050) Silver UK	
Dell UltraSharp U2410 61cm(24") PremierColor monitor VGA,2DVI,DP,HDMI,Cs,Cn (1920x1200) Black UK	
Hard Drive	4
250GB 3.5inch Serial ATA (7.200 Rpm)	
500GB 3.5inch Serial ATA (7.200 Rpm)	
1TB 3.5inch Serial ATA (7.200 Rpm)	
2TB 3.5inch Serial ATA (7.200 Rpm)	
Memory (RAM)	14
4GB (2x2GB) 1333MHz DDR3 Non-ECC	
8GB (2x4GB) 1333MHz DDR3 Non-ECC	
16GB (4x4GB) 1333MHz DDR3 Non-ECC	
8GB (1x8GB) 1333MHz DDR3 Non-ECC	
16GB (2x8GB) 1333MHz DDR3 Non-ECC	
32GB (4x8GB) 1333MHz DDR3 Non-ECC	
4GB (2x2GB) 1333MHz DDR3 ECC UDIMM	

8GB (4x2GB) 1333MHz DDR3 ECC UDIMM

8GB (2x4GB) 1333MHz DDR3 ECC

16GB (4x4GB) 1333MHz DDR3 ECC

8GB (1x8GB) 1333MHz DDR3 ECC

16GB (2x8GB) 1333MHz DDR3 ECC

32GB (4x8GB) 1333MHz DDR3 ECC

4096MB 667MHz Dual Channel DDR2 SDRAM [4x1024]

Graphics Card 15

512MB AMD FirePro 2270 (DMS59) (DMS59 to 2DVI adapter)

512MB NVIDIA Quadro NVS 300 (DMS59) (DMS59 to 2DVI adapter)

1 GB ATI FirePro V4800 (2DP & 1DVI-I) (1DP-DVI & 1DVI-VGA adapter)

512 MB NVIDIA Quadro 400 (1DP & 1DVI-I)

1 GB NVIDIA Quadro 600 (1DP & 1DVI-I) (1DP-DVI & 1DVI-VGA adapter)

1 GB NVIDIA Quadro 2000 (2DP & 1DVI-I) (1DP-DVI & 1DVI-VGA adapter)

512MB NVIDIA Quadro NVS 420 (VHDCI) (VHDCI to 4DVI adapter)

512MB NVIDIA Quadro NVS 420 (VHDCI) (VHDCI to 4DP adapter)

Matrox M9140 Half Height PCIe x16 Quad Port Graphics Card

NVIDIA Quadro NVS450 512MB Quad DisplayPort PCIe x16 Graphics Card

Dual 512MB AMD FirePro 2270 (2cards w/ DMS59) (2DMS59 to 2DVI adapter)

Dual 512MB NVIDIA Quadro NVS 300 (2cards w/ DMS59) (2DMS59 to 2DVI adapter)

256MB ATI® Radeon™ HD 2600 XT graphics card

SINGLE 512MB NVIDIA GeForce 8800GT card

512MB ATI® Radeon® 3870 Graphics card

Optical Drive 5

16x DVD+/-RW Drive

6x Blu-ray Writer for Windows 7

16x DVD-ROM Drive and 16x DVD+/-RW Drive

16x DVD+/-RW Drive and 16x DVD+/-RW Drive

16x DVD+/-RW Drive and 6x Blu-Ray Writer for Windows 7

Style

Standard Mini-Tower (Vertical orientation) 2

E-Star Standard Mini-Tower (Vertical orientation)

Keyboard 5

UK/Irish (QWERTY) Dell KB212-B QuietKey USB Keyboard Black

UK/Irish (QWERTY) Dell KB212-PL QuietKey USB Keyboard Dualtone/Grey

UK/Irish (QWERTY) Dell KB-522 Wired Business Multimedia USB Keyboard Black

UK/Irish (QWERTY) Smartcard Reader USB Keyboard Black

UK/Irish (QWERTY) Dell KB212-B QuietKey USB Keyboard Black With Palmrest

Mouse 2

Dell Optical (Not Wireless), Scroll USB (3 buttons scroll) Black Mouse

Dell Laser Scroll USB (6 Buttons) Silver and Black Mouse

Speakers 3

No Speakers

Internal Dell Business Audio Speaker

External Dell AX210 CR Black USB

APPENDIX 2 RbK Custom Ventilator Configuration Options

Feature		No. of customisation options
Overlay		46
Leather	17	
Suede	17	
Special Materials	10	
Patent Leather	2	
Side Logo		17
Eyestay		34
Leather	17	
Suede	17	
Base		34
Leather	17	
Nylon	17	
Quarter Panel		34
Leather	17	
Suede	17	
Side Stripe		36
Leather	17	
Suede	17	
Patent Leather	2	
Mesh	2	
Midsole (Sole Component)		17
Base (Sole Component)		17
Arch Accent (Sole Component)		17
Centre Accent (Sole Component)		17
Accent (Sole Component)		17
Tongue		34
Leather	17	
Nylon	17	
Tongue Lining		17
Tongue Logo		17
Tongue Accent		17
Laces		17
Eyelet		17
Lining		17
Heel Text (Colour)		17

APPENDIX 7.1 Ulysse Nardin Project Diary

March 2008

- I am approached to pitch for the project. The contact comes through CMe, a Finnish engineering design consultancy that I have collaborated with on a number of projects.
- The pitch is in competition with another (unknown) Danish design consultancy, paid at full rates, to the production of initial sketch concepts.
- A brief is supplied.
- Consumer research is conducted in two ways: by reading internet forums used by owners of Ulysse Nardin watches, and by speaking with authorised dealers from the North American country agent.
- Brand research is conducted from analysis of the Ulysse Nardin online catalogue.
- First Round Concepting (sketches) of initial ideas. Two concept directions are selected to take forward. I am chosen to continue with the contract.
- Second Round Concepting (sketches, Illustrator layouts, Photoshop Renderings) of the two selected concepts. One solution is selected to move forward.
- Third Round Concepting (detailing, refinement of concept, 3D CAD modelling in Solidworks) of the chosen concept.

April 2008

- First Round CAD model is completed
- Colour schemes and material breakdowns are agreed with the client.
- 3D renderings are produced by an external agency.
- The renderings are shown to selected Ulysse Nardin dealers at the Basel Watch and Jewellery Fair. Feedback and opinions are collected and analysed.
- Based on this feedback a revised specification is drawn up.

- I visit Ulysse Nardin's factory and R&D facility.
- Ulysse Nardin confirm they wish to proceed with the project and agree to the production of physical, non-working models.
- I contact a number of model makers and choose Solve3D.

May 2008

- Instruction document produced for model maker
- Artworks for keys, window and badges.
- Three physical models based on First Round CAD are produced by model maker.
- Detailing is refined based on feedback from the Basel fair.
- Second Round CAD modelling incorporates these refinements.

June 2008

- Engineering design team produce first detailed feedback based on First Round CAD model, with suggestions / requirements for design changes.
- Design is refined based on these technical requirements. Main changes are due to antenna performance, together with positioning of some major components (SIM card, battery, display flexi).
- Back cover is split. A fixed, ceramic part covers the antenna, carbon fibre is chosen as a material for the removable battery cover.
- Third Round CAD modelling incorporates these design changes.
- Ulysse Nardin commission a new set of models based on the latest CAD model.

July 2008

- Three physical models based on Third Round CAD are produced by model maker

August 2008

- Ongoing customer feedback suggests a camera and touch-screen capability are necessary for the product.
- Hardware developers express concerns that these requirements can be met. Primary concern is the software development necessary to support these features.

September 2008

- Cost issues mean the proposal for sapphire crystal inserts between keys cannot be continued. New design proposals for the front cover are drawn up.
- Fourth Round CAD modelling incorporates these design changes.
- Doubts continue as to the possibility of incorporating camera and touch-screen functionality.
- Client begins to look for new hardware supplier.

October 2008

- Client and hardware supplier agree to break contract.
- Client's and supplier's legal teams negotiate ownership of IPR, including industrial design.

November 2008

- New hardware supplier is chosen. Supplier has an existing platform with camera and touch-screen functionality, suitable for migration to the proposed design concept.
- Kick-off meeting with new supplier. Fast-track development plan initiated.
- Feasibility study for platform migration begins.

December 2008

- Revised product specification is agreed.
- Design concept is revised to take account of new platform. The main changes are:
    - Display size increases from 2.7" QVGA (240x320 pixels) to 2.8" WQVGA (240x400 pixels).
    - Scroll key and 'soft' keys are made redundant by touch-screen, and therefore removed.
    - A fingerprint recognition sensor is incorporated.
    - Antenna technology changes, and position of antenna moves from top to bottom of phone. This requires major redesign of the back cover.

January 2009

- Design proposals (sketches) based on extrapolation from existing phone platform.
- Second meeting with supplier
- Decisions taken regarding screen position, UI and key layout.
- Detailing (Illustrator layouts)
- Fifth Round CAD modelling based on revised design begins.

February 2009

- Design proposals for materials and colour variants created
- CAD Modelling completed.
- Production of Renderings in chosen colour/material variants.
- CAD models and material specs sent to model maker
- Appearance models based on third round CAD used for PR shots

March 2009

- Appearance models completed and shipped to BaselWorld fair.
- Renderings completed and incorporated into sales brochure.
- Design Registration documents prepared and submitted to UK Patent Office.
- Attend BaselWorld fair to get first-hand feedback from customers.

April 2009

- Begin work on concepts for packaging and accessories.

May 2009

- Continue work on packaging/desk charging system
- Begin work on identity for user guide, DVD etc.
- Design continues to be revised based on concurrent engineering recommendations.

June 2009

- Disagreements between hardware supplier and UN Cells regarding how to proceed with project cause tensions and work slows down. UN Cells begins to look for new vendors.
- CAD model produced of packaging/desk charging system.

July 2009

- New supplier is chosen, and work begins rapidly to migrate design to new engine platform. Main change is that display size increases from 2.8" 240x400 pixels to 3.2" 320x480 pixels.
- Increase in size of display reduces size allowed for keys. Decision that maximum length of phone cannot be greater than 127.75 mm, this causes key area to reduce

by 6.8 mm.

- Thickness of the phone set to increase by 1.8mm, there is a lot of pressure to change display detailing to reduce depth to LCD. I strongly resist, insisting bezel is key link to brand DNA from watches. Eventually win, though depth of bezel is reduced from 1.0mm to 0.72mm.

August 2009

- CAD model produced of new design.
- Renderings created of new design.
- Concept work on leather case accessory begins.

September 2009

- Design of leather case continues, working closely with leatherwork supplier.

October 2009

- Artworks created for all language variants: Arabic, Cyrillic, Latin, Stroke.
- Designs and renderings for a number of new colour and material variants created. Includes special edition for Monaco Yacht Show.
- Briefing documents written for UI designer.

November 2009

- I have a new baby. Work slows down.

December 2009

- Design of leather case completed.

January 2010

- Begin design on another limited edition, enamel version.
- Refinements of material variants.

March 2010

- Design created for new hallmark, required to be visible on all gold variants of the phone.
- Hallmark artworks submitted to Swiss Assay Office.

April 2010

- Prototypes of enamel and diamond pavé variants are finished.

May - October 2010

- A number of other colour/material variants are created. Approval and sign-off given to designs of leather case and desk charging system.

APPENDIX 7.2 Ulysse Nardin Chairman Design Registration Application

Concept House
Cardiff Road
Newport
South Wales
NP10 8QQ

INTELLECTUAL PROPERTY OFFICE

Designs Form DF2A

Official fee due with this form

Application to register one or more designs

This is the 1st (for example, first) design out of a total of 1 designs

You must answer these questions for each design in a multiple application, so copy this sheet as many times as you need.

A.	**Name of the applicant.**	Matthew Sinclair
B.	**Which product or products is the design for?**	Ulysse Nardin Chairman mobile phone
C.	**How many illustration sheets are there for this design?**	3
D.	Write "RSP" if this is the design of a pattern which repeats across the surface of a product, for example, wallpaper.	
E.	If you wish, you may give a brief description of the design shown in the illustration or sample.	
F.	List any limitations or disclaimers you want to record.	No claim or restriction is made for colours or materials
G.	**Do you agree that we should publish this design as soon as possible? Please state yes or no.**	Yes
H.	If you are claiming priority from an earlier application to register this design, give these details.	Priority date / Country / Application number
I.	If the earlier application was made in a different name, say how the current applicant has a right to apply. If, for example, by assignment of the earlier application, give the date of the transaction.	

Notes: **You MUST answer all of the questions above which are shown in BOLD print.**

Please phone us on 0300 300 2000 if you need help to fill in this form.

Checklist Tick the box if you have included priority documents with this application ☐

Illustration sheet 1

This is the first design out of a total of one designs

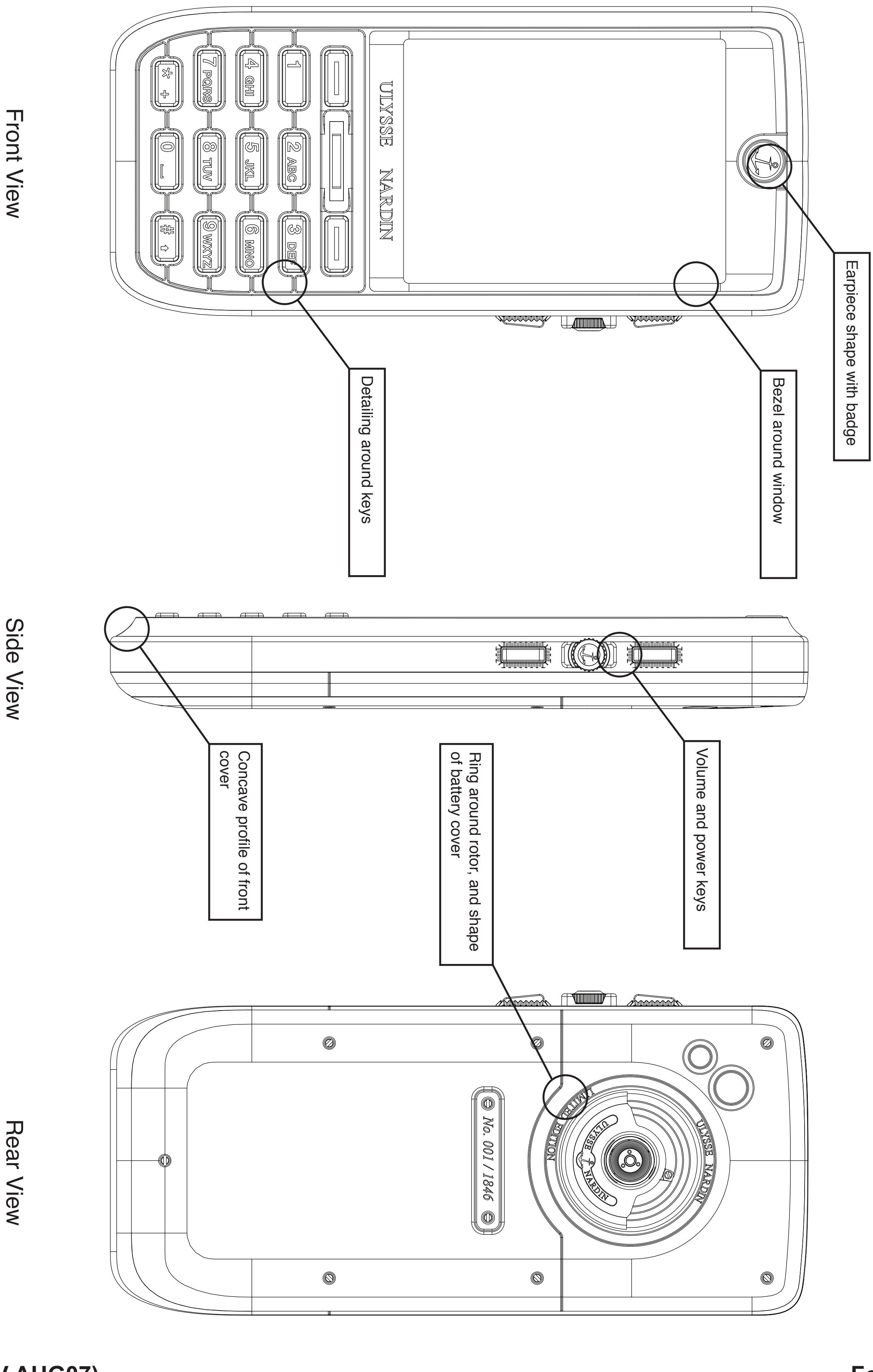

Illustration sheet 2

This is the first design out of a total of one designs

Illustration sheet 3

This is the first design out of a total of one designs

APPENDIX 8.1 Loughborough University Ethical Checklist

APPENDIX 8.2 Design Language Survey Cover Letter

APPENDIX 8.2 Design Language Survey Cover Letter

Dear XXXX,

I am writing to ask whether you would be willing to take part in a survey/questionnaire I'm conducting as part of my PhD research at Loughborough University in the UK. I am the manager of the LinkedIn Post-Industrial Design group, and I found your contact details after looking at your LinkedIn profile. However it is absolutely not my intention to spam you or to give the impression I have taken advantage of my position, therefore if you would prefer not to take part in this survey please ignore this mail and I assure you I will not contact you further.

Participation in the survey is by invitation only, and all participants are required to be practicing at a senior level (design or brand managers, creative directors, principal designers etc) with knowledge and experience of the ways in which brands' product portfolios are managed. The survey asks about the elements which make up a brand's design language, and I'm specifically interested to find out how consumer participation in the design process (through mass customisation or co-design for example) affect this. It should take around 20 minutes to complete, and all results will be anonymised.

If you are interested in taking part in this survey, please click on the link below, and enter the following details:

https://www.survey.lboro.ac.uk/design_language

user name: AperG

password: OZbrZw

Your time in completing this survey is very much appreciated, and I would like to thank you for the contribution to my research.

All the best,

Matt Sinclair

APPENDIX 8.3 Design Language Survey Introduction

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Welcome to this survey, and thankyou for agreeing to take part. The survey forms an important part of my PhD research, which is looking at the growing phenomenon of the "consumer designer" and the ways in which additive manufacturing (commonly known as 3D printing) might enable highly customised products. The survey's specific aim is to gain an understanding of the consequences of such products for the management of a brand's corporate design language.

The survey records respondents' names, but all data will be anonymised for inclusion in the PhD thesis. No respondent's name will be mentioned publicly (either in the thesis or elsewhere) without their express, written permission. Information regarding data protection is given on the following page, but if you have any questions please e-mail me at m.sinclair@lboro.ac.uk.

Invitations to complete this survey have been sent to a limited number of experienced, practicing designers, design managers and brand managers. Your contribution is therefore extremely valuable. The survey recognises that some respondents may not wish to answer all questions, therefore any question (with the exception of those in Section 1) may be left blank.

The survey can be saved part way through and should take around 20 minutes to complete.

APPENDIX 8.4 Design Language Survey Data Protection Statement

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This survey is conducted over a secure, encrypted connection. No cookies are used or stored on your computer. Data collected in this survey will be held anonymously and securely. Data collected in this survey will be held for a period of six years (in compliance with Loughborough University guidelines) after which time it will be permanently deleted.

Your name will be recorded with your survey submission, this is to allow respondents to be contacted at a later date, if agreed. All responses will be anonymised for inclusion in the PhD thesis. On completion of the survey you will be given the opportunity to print your submission, for your own records. At any time after submission you may request that your response is excluded from the survey and that your personal details are permanently deleted by emailing the survey author at the address below.

Analysis of the data collected in this survey will be used in the survey author's PhD thesis submission; it may also be used in submissions to academic journals or conferences. Analysis of the data will not be used for commercial purposes.

Approval for this survey has been granted by Loughborough University's Ethics Committee. If you have questions or complaints about the conduct of this survey you should contact the survey author in the first instance at the email address below. If you are unsatisfied with the response you should contact the Director of the School of Design Research, Dr. Ian Campbell, at r.i.campbell@lboro.ac.uk

Matt Sinclair (survey author), November 2011.

m.sinclair@lboro.ac.uk

APPENDIX 8.5 Design Language Survey Results

SECTION 1.

Question 3. In which sectors do you commonly work? Summary:

Consumer Products	50
Professional Products	29
Interior Products	32
Transportation	11
Sports & Outdoor	13
Other	15

Consumer Products includes Consumer Electronics (including 'white' goods), Hand Tools (including electrical), Telecoms & Mobile Computing, Toys, Watches, Jewellery & Eyewear and Other (4).
Professional Products includes Medical, Military, Professional Electronics and Other (2).
Interior Products includes Furniture, Lighting, Tableware, Textiles (Interiors) and Other (6).
Transportation includes Personal (including automotive), Public and Plant/Heavy Machinery
Sports & Outdoor includes Sports Products, Textiles (Fashion) and Other (3).
Other includes FMCG and Other (11).

Question 3. In which sectors do you commonly work? Full Results:

Consumer Electronics (including 'white' goods)	22
FMCG	6
Furniture	8
Hand Tools (including electrical)	6
Lighting	8
Medical	12
Military	5
Professional Electronics	10
Sports Products (including sports footwear)	8
Tableware	8
Telecoms and Mobile Computing	10
Textiles (Fashion)	2
Textiles (Interiors)	2
Toys	5
Transportation - Personal (including automotive)	7
Transportation - Public	2
Transportation - Plant/Heavy Machinery	2
Watches, Jewellery and Eyewear	3
Other[1] *(please specify)*	14

[1] Responses given under 'Other':

Baby products
Bathroom products, Industrial Safety products, POS
Consumer products for the kitchen
Cookware, Homeware

Design eduction (PG)
Innovation Consultants
Interior Design Marketing
Lifestyle Products, Consumer Goods (Wearable Technology,) Branding & Packager Design
Luggage
Open Design, DIY, Digital fabrication, Home wares, Spatial
Outdoor Gear
Retail Display Systems
Soft Goods - Bags
Telecoms

Question 4. Which of the following best describes the field(s) in which you work?

Industrial/Product design	34
Graphic design	5
User Interaction design	11
Packaging design	5
Fashion design	1
Advertising	3
Innovation and Strategy	22
Branding	9
Research	9
Mechanical Engineering[2]	3
Other[3]	2

[2] Mechanical Engineering was not specified as an option in the original survey, but was mentioned three times under 'Other'

[3] Also mentioned under 'Other' were Architecture and 'Service Design

Question 5. What is your primary relationship to consumers and product users?

I design products	20	(51.3%)
I specialise in the design of certain elements of products	0	
I manage others who design products	6	(15.4%)
I develop insights or strategies which influence the design of products	8	(20.5%)
I develop guidelines or rules which steer the design of products	2	(5.1%)
I have no direct input into the design of products	0	
Other[3]	3	(7.7%)

[3] Relationships mentioned under 'Other':

I design experiences through my leadership and influence
I develop insights, I design products, I also specialise in certain elements depending on my role in a certain project
I develop products to production

SECTION 2.

Question 6. Thinking about products (in general) which you admire and/or consider to be well designed, how important are the following:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
6a. A unique aesthetic (one which differentiates from competitor's products)	41.0%	48.7%	10.3%	0.0%	0.0%
6b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	53.8%	38.5%	7.7%	0.0%	0.0%
6c. A technologically advanced specification compared to competitors	12.8%	28.2%	51.3%	7.7%	0.0%
6d. Unique functionality compared to competitors	17.9%	25.6%	48.7%	7.7%	0.0%
6e. Better considered and executed functionality compared to competitors	56.4%	35.9%	7.7%	0.0%	0.0%
6f. Colours, materials and finishes	35.9%	48.7%	15.4%	0.0%	0.0%
6g. Prominence of logo or other branding	2.6%	15.4%	35.9%	35.9%	10.3%

Question 7. Thinking about products (in general) which you admire and/or consider to be well designed, how important are the following:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
7a. Similarity to previously owned products by the same brand	5.3%	26.3%	31.6%	31.6%	5.3%
7b. Ability to personalise/configure the product before purchase	2.7%	8.1%	48.6%	32.4%	8.1%
7c. Ability to personalise/configure the product after purchase	7.9%	23.7%	39.5%	23.7%	5.3%
7d. Ability to upgrade the product after purchase	10.3%	25.6%	51.3%	5.1%	7.7%
7e. Durability and long life	51.3%	43.6%	2.6%	2.6%	0.0%
7f. Ability to service and repair the product	23.1%	53.8%	20.5%	2.6%	0.0%
7g. Brand's reputation for quality	38.5%	53.8%	7.7%	0.0%	0.0%
7.h. Brand's reputation for innovation	30.8%	48.7%	20.5%	0.0%	0.0%

SECTION 3.

Question 8. Thinking about the *commercial* success of products which *you* have had personal responsibility for, how important are the following:

All Respondents:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
8a. A unique aesthetic (one which differentiates from competitor's products)	48.7%	35.9%	15.4%	0.0%	0.0%
8b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	30.8%	46.2%	17.9%	5.1%	0.0%
8c. A technologically advanced specification compared to competitors	7.7%	46.2%	35.9%	7.7%	2.6%
8d. Unique functionality compared to competitors	20.5%	51.3%	23.1%	5.1%	0.0%
8e. Better considered and executed functionality compared to competitors	41.0%	46.2%	10.3%	2.6%	0.0%
8f. Colours, materials and finishes	23.1%	53.8%	20.5%	2.6%	0.0%
8g. Prominence of logo or other branding	10.3%	25.6%	41.0%	23.1%	0.0%

Respondents involved in the design of consumer products:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
8a. A unique aesthetic (one which differentiates from competitor's products)	56.0%	28.0%	16.0%	0.0%	0.0%
8b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	28.0%	44.0%	24.0%	4.0%	0.0%
8c. A technologically advanced specification compared to competitors	8.0%	52.0%	36.0%	0.0%	4.0%
8d. Unique functionality compared to competitors	20.0%	44.0%	32.0%	4.0%	0.0%
8e. Better considered and executed functionality compared to competitors	40.0%	48.0%	12.0%	0.0%	0.0%
8f. Colours, materials and finishes	32.0%	44.0%	24.0%	0.0%	0.0%
8g. Prominence of logo or other branding	8.0%	20.0%	56.0%	16.0%	0.0%

Question 9. Thinking about the *commercial* success of products which *you* have had personal responsibility for, how important are the following:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
9a. A competitive price point	35.9%	30.8%	33.3%	0.0%	0.0%
9b. Marketing and advertising	25.6%	56.4%	15.4%	2.6%	0.0%
9c. Consumer recommendation (eg on websites such as Amazon)	10.3%	35.9%	35.9%	7.7%	10.3%
9d. Brand's reputation for quality	48.7%	41.0%	10.3%	0.0%	0.0%
9e. Brand's reputation for innovation	38.5%	43.6%	15.4%	0.0%	2.6%
9f. Packaging	5.1%	30.8%	43.6%	10.3%	10.3%
9g. After-sales support	20.5%	28.2%	33.3%	10.3%	7.7%

Question 10. Thinking about the *commercial* success of products which *you* have had personal responsibility for, how important are the following:

All Respondents:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
10a. Similarity to older products in a brand's portfolio	7.7%	20.5%	46.2%	17.9%	7.7%
10b. Ability to personalise/configure the product before purchase	2.6%	7.7%	30.8%	38.5%	20.5%
10c. Ability to personalise/configure the product after purchase	2.6%	23.1%	35.9%	23.1%	15.4%
10d. Ability to upgrade the product after purchase	2.6%	21.1%	34.2%	23.7%	18.4%
10e. Low field-failure rate	41.0%	43.6%	5.1%	7.7%	2.6%
10f. Durability and long life	41.0%	53.8%	5.1%	0.0%	0.0%
10g. Ability to service and repair the product	10.3%	41.0%	38.5%	7.7%	2.6%

Respondents involved in the design of consumer products:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
10a. Similarity to older products in a brand's portfolio	8.0%	20.0%	48.0%	16.0%	8.0%
10b. Ability to personalise/configure the product before purchase	0.0%	12.0%	28.0%	48.0%	12.0%
10c. Ability to personalise/configure the product after purchase	0.0%	20.0%	48.0%	28.0%	4.0%
10d. Ability to upgrade the product after purchase	4.2%	12.5%	45.8%	29.2%	8.3%
10e. Low field-failure rate	36.0%	44.0%	8.0%	8.0%	4.0%
10f. Durability and long life	40.0%	52.0%	8.0%	0.0%	0.0%
10g. Ability to service and repair the product	8.0%	36.0%	48.0%	8.0%	0.0%

Question 11. Thinking about products which you have had personal responsibility for, how much emphasis do clients (or the organisation which employs you) place on the following:

	Far too much emphasis	Too much emphasis	The right amount of emphasis	Too little emphasis	Far too little emphasis
11a. A unique aesthetic (one which differentiates from competitor's products)	0.0%	10.3%	66.7%	23.1%	0.0%
11b. A coherent design language (an aesthetic or philosophy which unites a brand's products)	2.6%	5.1%	43.6%	43.6%	5.1%
11c. A technologically advanced specification compared to competitors	5.1%	35.9%	33.3%	25.6%	0.0%
11d. Unique functionality compared to competitors	0.0%	12.8%	56.4%	30.8%	0.0%
11e. Better considered and executed functionality compared to competitors	0.0%	2.6	48.7%	46.2%	2.6%
11f. Colours, materials and finishes	0.0%	7.7%	56.4%	25.6%	10.3%
11g. Prominence of logo or other branding	5.1%	38.5%	48.7%	5.1%	2.6%
11h. Similarity to older products in a brand's portfolio	2.6%	17.9%	66.7%	10.3%	2.6%
11i. Ability to personalise/configure the he product before purchase	5.3%	7.9%	60.5%	18.4%	7.9%
11j. Ability to personalise/configure the product after purchase	5.4%	10.8%	54.1%	21.6%	8.1%
11k. Ability to upgrade the product after purchase	0.0%	8.1%	54.1%	29.7%	8.1%

SECTION 4.

Question 12. Across a brand's product portfolio, a successful and coherent design language requires:

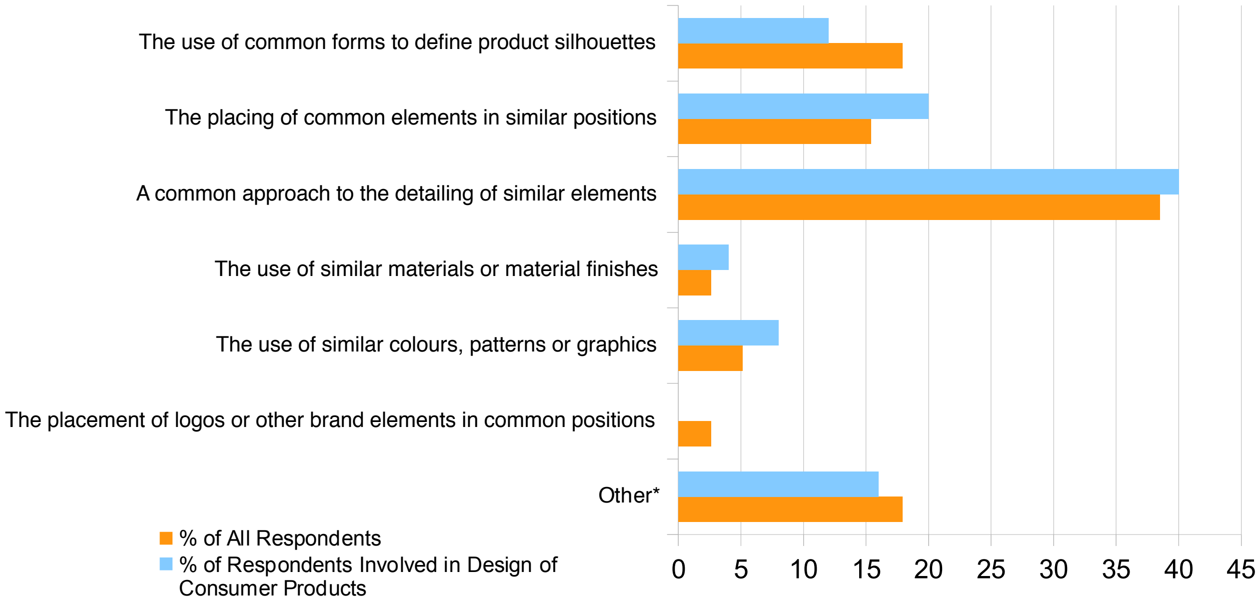
All Respondents:

	Strongly Agree	Agree	Disagree	Strongly Disagree
12a. The use of common forms to define product silhouettes	20.5%	48.7%	30.8%	0.0%
12b. The placing of common elements in similar positions	20.5%	48.7%	28.2%	2.6%
12c. A common approach to the detailing of common elements	35.9%	59.0%	5.1%	0.0%
12d. The use of similar materials or material finishes	16.2%	54.1%	27.0%	2.7%
12e. The use of similar colours, patterns or graphics	17.9%	56.4%	23.1%	2.6%
12f. The placement of logos or other brand elements in common positions	15.4%	53.8%	25.6%	5.1%

Respondents involved in the design of consumer products:

	Strongly Agree	Agree	Disagree	Strongly Disagree
12a. The use of common forms to define product silhouettes	12.0%	56.0%	32.0%	0.0%
12b. The placing of common elements in similar positions	16.0%	52.0%	28.0%	4.0%
12c. A common approach to the detailing of common elements	40.0%	56.0%	4.0%	0.0%
12d. The use of similar materials or material finishes	21.7%	43.5%	30.4%	4.3%
12e. The use of similar colours, patterns or graphics	24.0%	48.0%	28.0%	0.0%
12f. The placement of logos or other brand elements in common positions	8.0%	60.0%	28.0%	4.0%

Question 13. Across a brand's product portfolio, which of the following attributes is the *most* important to a successful and coherent design language:



* Responses categorised as 'Other':

A combination of the above.

A common approach to forms, details and CMF without BEING the same.

A unique and positive experience which can be identified as being from the company/brand.

All listed above...a brand product portfolio revolves around the look and feel of the line..consistency is what builds a unique brand.

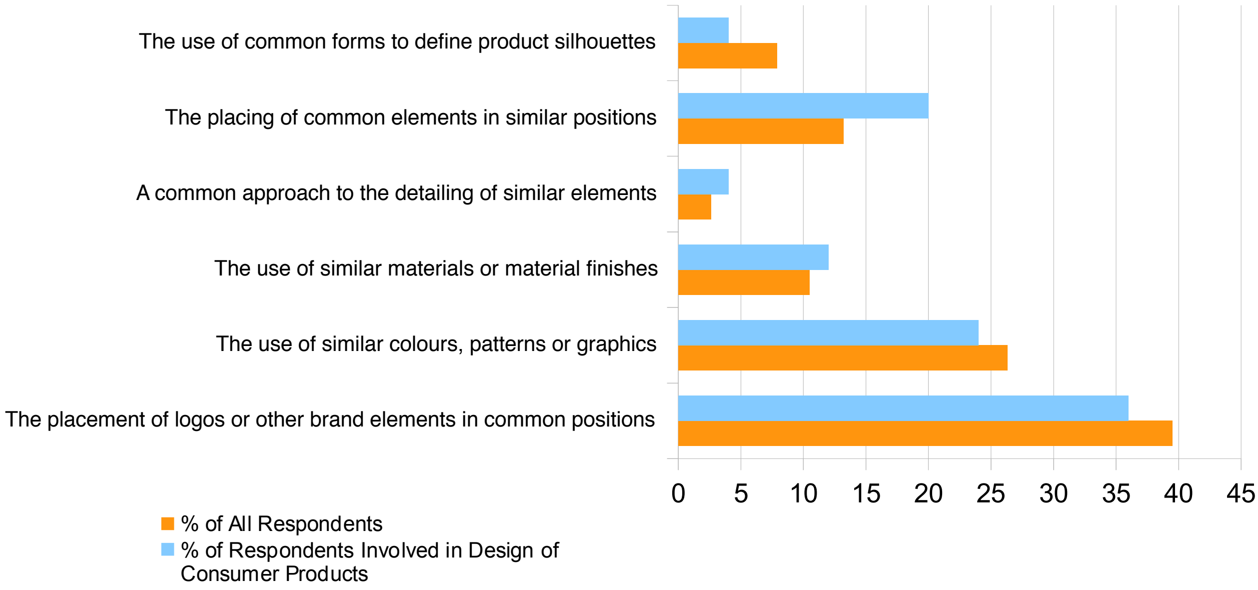
One that keeps customers coming back.

It´s not always the same type of attribute that are the most important, Sometimes one attribute overpower the others depending on the rhetorical situation.(Brand ethos, purpose, audience, context).

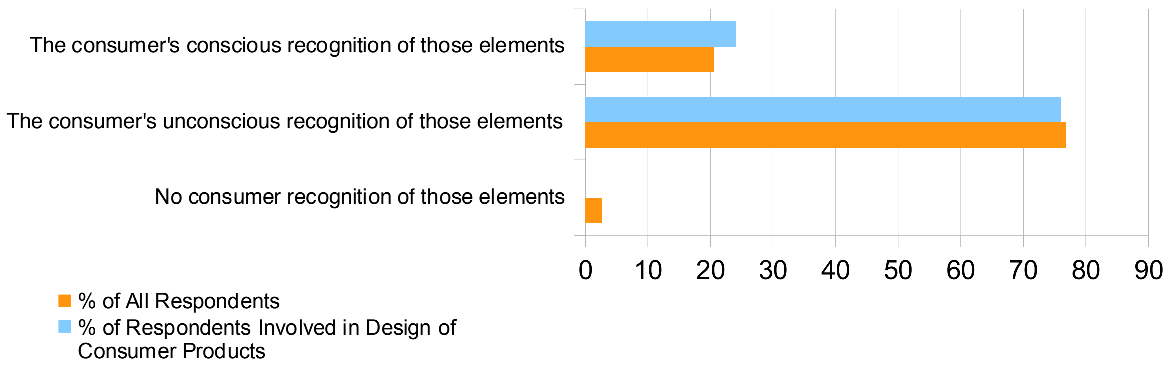
The collective portfolio coherence of relevant attributes.

The company's design strategy.

Question 14. Across a brand's product portfolio, which of the following attributes is the *least* important to a successful and coherent design language:



Question 15. With regard to the elements identified in Question 12 above, a successful and coherent design language requires:



Question 16. Across a brand's product portfolio, a successful and coherent design language requires:

All Respondents:

	Strongly Agree	Agree	Disagree	Strongly Disagree
16a. Common methods of user input to the product	24.3%	48.6%	24.3%	2.7%
16b. Common methods of product feedback to the user	26.3%	57.9%	15.8%	0.0%
16c. The use of common colours, materials and finishes	15.4%	59.0%	25.6%	0.0%
16d. Common quality standards, with regard to manufacture, finishing and durability	51.3%	46.2%	2.6%	0.0%
16e. Common marketing solutions	10.5%	44.7%	44.7%	0.0%

Respondents involved in the design of consumer products:

	Strongly Agree	Agree	Disagree	Strongly Disagree
16a. Common methods of user input to the product	20.0%	52.0%	24.0%	4.0%
16b. Common methods of product feedback to the user	24.0%	56.0%	20.0%	0.0%
16c. The use of common colours, materials and finishes	16.0%	52.0%	32.0%	0.0%
16d. Common quality standards, with regard to manufacture, finishing and durability	40.0%	60.0%	0.0%	0.0%
16e. Common marketing solutions	8.0%	48.0%	44.0%	0.0%

Question 17. Across a brand's product portfolio, a successful and coherent design language requires:

	Strongly Agree	Agree	Disagree	Strongly Disagree
17a. No explicit communication with customers in order to be recognised	10.5%	31.6%	44.7%	13.2%
17b. Some explicit communication with customers, such that they are 'educated' about the subtleties	15.8%	52.6%	28.9%	2.6%
17c. Consistency and evolution, to remain recognisable	43.6%	51.3%	5.1%	0.0%
17d. Occasional revolution, to remain relevant	42.1%	50.0%	7.9%	0.0%
17e. A willingness on the part of consumers to pay a premium for good design	13.2%	39.5%	44.7%	2.6%

SECTION 5.

Question 18. Across a brand's product portfolio, a successful and coherent design language may result in:

	Strongly Agree	Agree	Disagree	Strongly Disagree
18a. Increased consumer awareness of the brand	66.7%	30.8%	2.6%	0.0%
18b. Differentiation from competitors	59.5%	40.5%	0.0%	0.0%
18.c. Increased sales to first-time customers	30.8%	53.8%	15.4%	0.0%
18d. Increased sales to returning customers	48.7%	51.3%	0.0%	0.0%
18e. Increased consumer loyalty	56.4%	38.5%	5.1%	0.0%
18f. Consumer willingness to pay a higher price	30.8%	51.3%	17.9%	0.0%

Question 19. Across a brand's product portfolio, a consequence of a successful and coherent design language may be:

	Strongly Agree	Agree	Disagree	Strongly Disagree
19a. A reluctance to experiment with new aesthetic design possibilities	25.6%	48.7%	25.6%	0.0%
19b. A reluctance to experiment with new functional design possibilities	12.8%	46.2%	38.5%	2.6%
19c. An unwillingness to expand the brand into new areas	10.3%	48.7%	30.8%	10.3%
19d. A shorter timeframe from product brief to design approval	20.5%	48.7%	25.6%	5.1%
19e. An over-reliance on consumer loyalty to maintain sales	15.8%	50.0%	31.6%	2.6%
19f. An increased appreciation/understanding of design in the product's marketplace	15.4%	69.2%	15.4%	0.0%

SECTION 6.

Question 20. In your experience, and thinking about the *commercial* success of products which you have worked on, how important is the consumer's direct involvement in the following:

Note: In the survey an explanatory note defined 'direct involvement' as "involvement by consumers (either existing or potential) in the development and decision making process, through workshops, interviews, focus groups etc."

All Respondents:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
20a. Development of the brief	7.7%	20.5%	25.6%	28.2%	17.9%
20b. Development of scenarios	12.8%	28.2%	25.6%	17.9%	15.4%
20c. Development of product concepts	0.0%	15.4%	20.5%	35.9%	28.2%
20d. Filtering of concepts and design directions	7.7%	12.8%	30.8%	35.9%	12.8%
20e. Approval for final product concept	7.7%	15.4%	25.6%	23.1%	28.2%
20f. Testing of the product prior to launch	28.2%	30.8%	28.2%	10.3%	2.6%

Respondents involved in the design of consumer products:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
20a. Development of the brief	12.0%	20.0%	20.0%	28.0%	20.0%
20b. Development of scenarios	12.0%	28.0%	28.0%	16.0%	16.0%
20c. Development of product concepts	0.0%	20.0%	20.0%	40.0%	20.0%
20d. Filtering of concepts and design directions	4.0%	12.0%	40.0%	36.0%	8.0%
20e. Approval for final product concept	4.0%	16.0%	20.0%	32.0%	28.0%
20f. Testing of the product prior to launch	36.0%	24.0%	24.0%	16.0%	0.0%

Question 21. In your experience, and thinking about the *commercial* success of products which you have worked on, how important is the consumer's indirect involvement in the following:

Note: In the survey an explanatory note defined 'indirect involvement' as "the use of previously conducted consumer research to direct the development and decision making process."

All Respondents:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
21a. Development of the brief	20.5%	25.6%	43.6%	7.7%	2.6%
21b. Development of scenarios	20.5%	43.6%	25.6%	5.1%	5.1%
21c. Development of product concepts	12.8%	28.2%	23.1%	20.5%	15.4%
21d. Filtering of concepts and design directions	7.7%	15.4%	38.5%	33.3%	5.1%
21e. Approval for final product concept	10.5%	13.2%	26.3%	26.3%	23.7%
21f. Testing of the product prior to launch	23.7%	15.8%	26.3%	18.4%	15.8%

Respondents involved in the design of consumer products:

	Crucially important	Very important	Somewhat important	Of little importance	Of no importance
21a. Development of the brief	28.0%	32.0%	36.0%	4.0%	0.0%
21b. Development of scenarios	24.0%	56.0%	12.0%	8.0%	0.0%
21c. Development of product concepts	12.0%	36.0%	24.0%	20.0%	8.0%
21d. Filtering of concepts and design directions	8.0%	20.0%	44.0%	28.0%	0.0%
21e. Approval for final product concept	8.0%	20.0%	24.0%	28.0%	20.0%
21f. Testing of the product prior to launch	28.0%	16.0%	32.0%	12.0%	12.0%

Question 22. In your experience, consumer's have valuable insights into:

All Respondents:

	Strongly Agree	Agree	Disagree	Strongly Disagree
22a. The strengths and weaknesses of products they own	53.8%	38.5%	7.7%	0.0%
22b. Features that could be incorporated into new products	12.8%	46.2%	38.5%	2.6%
22c. Improvements that could be made to new products	12.8%	59.0%	25.6%	2.6%
22d. New ways of using existing features	28.2%	53.8%	17.9%	0.0%
22e. New ways of personalising products	20.5%	41.0%	38.5%	0.0%
22f. How a brand's products are perceived in the market	39.5%	55.3%	5.3%	0.0%
22g. The future direction which a brand's products might take	5.1%	17.9%	59.0%	17.9%

Respondents involved in the design of consumer products:

	Strongly Agree	Agree	Disagree	Strongly Disagree
22a. The strengths and weaknesses of products they own	56.0%	36.0%	8.0%	0.0%
22b. Features that could be incorporated into new products	16.0%	40.0%	40.0%	4.0%
22c. Improvements that could be made to new products	16.0%	56.0%	24.0%	4.0%
22d. New ways of using existing features	32.0%	48.0%	20.0%	0.0%
22e. New ways of personalising products	28.0%	32.0%	40.0%	0.0%
22f. How a brand's products are perceived in the market	37.5%	58.3%	4.2%	0.0%
22g. The future direction which a brand's products might take	8.0%	12.0%	60.0%	20.0%

Question 23. In your experience, consumer insights can be successfully applied to:

All Respondents:

	Strongly Agree	Agree	Disagree	Strongly Disagree
23a. A brand's future strategic direction	23.1%	46.2%	25.6%	5.1%
23b. The specification of future products	23.1%	53.8%	23.1%	0.0%
23c. The design of current products	25.6%	56.4%	15.4%	2.6%
23.d. The improvement of products already on the market	33.3%	56.4%	7.7%	2.6%
23e. The customisation and configuration of products which they own	28.9%	55.3%	15.8%	0.0%
23f. Ways of marketing new or existing products	15.4%	43.6%	41.0%	0.0%

Respondents involved in the design of consumer products:

	Strongly Agree	Agree	Disagree	Strongly Disagree
23a. A brand's future strategic direction	24.0%	48.0%	28.0%	0.0%
23b. The specification of future products	28.0%	48.0%	24.0%	0.0%
23c. The design of current products	20.0%	64.0%	16.0%	0.0%
23.d. The improvement of products already on the market	36.0%	56.0%	4.0%	4.0%
23e. The customisation and configuration of products which they own	29.2%	54.2%	16.7%	0.0%
23f. Ways of marketing new or existing products	16.0%	52.0%	32.0%	0.0%

SECTION 7

Note: Questions in Section 7 referred to the Herman Miller Sayl chair and NikeID online configuration systems, accessible from:

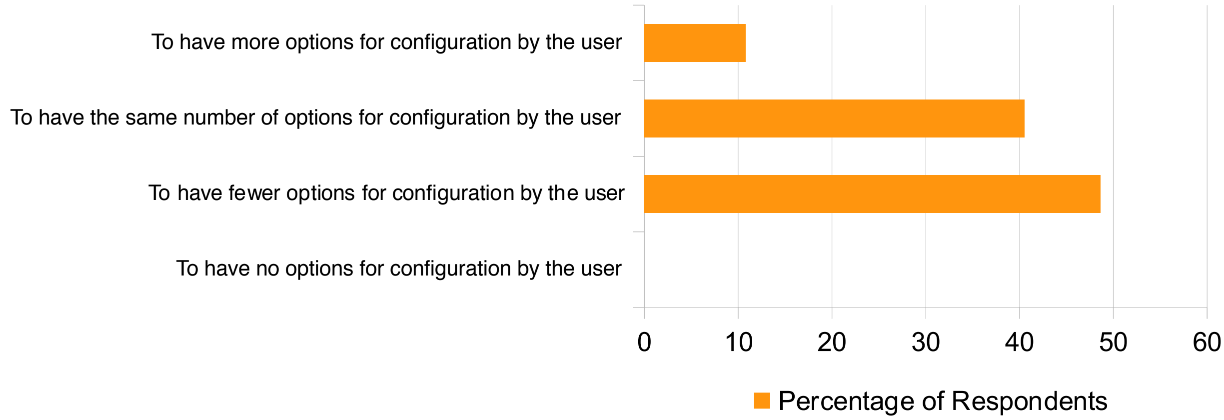
http://www.hermanmiller.com/DotCom/jsp/product/productsConfigurator.jsp?prodName=sayl

http://nikeid.nike.com/

Question 24. Referring specifically to the Herman Miller Sayl chair, the configuration options:

	Strongly Agree	Agree	Disagree	Strongly Disagree
24a. Are useful to a consumer who wants to personalise their chair	29.7%	59.5%	10.8%	0.0%
24b. Are useful to an office planner who wants to integrate the chair into an overall design	43.2%	51.4%	5.4%	0.0%
24c. Are an integral part of the design of the chair	13.5%	54.1%	32.4%	0.0%
24d. Allow the possibility of a tasteless design or colour scheme	24.3%	48.6%	21.6%	5.4%
24e. Enhance the consumer's experience of the product	18.9%	51.4%	29.7%	0.0%
24f. Detract from the purity of the design	2.7%	21.6%	70.3%	5.4%
24g. Would likely lead to increased sales	5.4%	48.6%	43.2%	2.7%
24h. Are a positive reflection of the Herman Miller brand	16.2%	67.6%	16.2%	0.0%

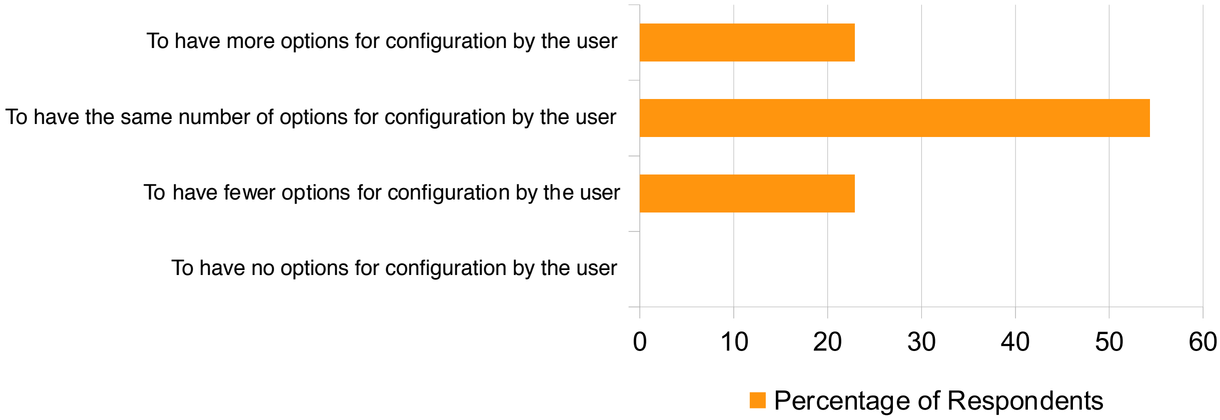
Question 25. If I had responsibility for the design or marketing of the Herman Miller Sayl chair, I would prefer:



Question 26. Referring specifically to shoes which appear in the NikeID system, the configuration options:

	Strongly Agree	Agree	Disagree	Strongly Disagree
26a. Are useful to a consumer who wants to personalise their shoe	47.4%	52.6%	0.0%	0.0%
26b. Are useful to a team who want to integrate the shoe into an overall design of kit	34.2%	63.2%	2.6%	0.0%
26c. Are an integral part of the design of the shoe	7.9%	57.9%	34.2%	0.0%
26d. Allow the possibility of a tasteless design or colour scheme	44.7%	44.7%	7.9%	2.6%
26e. Enhance the consumer's experience of the product	16.2%	75.7%	8.1%	0.0%
26f. Detract from the purity of the design	7.9%	26.3%	60.5%	5.3%
26g. Would likely lead to increased sales	7.9%	65.8%	21.1%	5.3%
26h. Are a positive reflection of the Nike brand	28.9%	68.4%	2.6%	0.0%

Question 27. If I had responsibility for the design or marketing of the shoes which appear in the NikeID system, I would prefer:



28. Thinking about products (in general), the consumer's ability to customise a product before purchase:

	Strongly Agree	Agree	Disagree	Strongly Disagree
28a. Is likely to dilute a brand's design language	5.7%	37.1%	51.4%	5.7%
28b. Is likely to enhance the consumer's perception of the brand	5.4%	64.9%	29.7%	0.0%
28c. Makes the designer's job more interesting	13.9%	50.0%	36.1%	0.0%
28d. Encourages the consumer to spend more	13.5%	51.4%	35.1%	0.0%
28e. Decreases consumer appreciation of design	0.0%	25.0%	66.7%	8.3%

Question 29. I have previously worked on, or been responsible for, the design of mass-customisable products

Yes	20
No	18

Question 30. 3D printing systems have the ability to manufacture one-off parts. It has been suggested that in future, this may allow consumers to design or mass-customise unique products. Thinking about the *commercial* success of products which *you* have had personal responsibility for, and assuming any product would be *safe* and *functional*, if such a system were to be implemented:

	Strongly Agree	Agree	Disagree	Strongly Disagree
30a. The system should allow the maximum design freedom possible	10.5%	39.5%	36.8%	13.2%
30b. The system should set boundaries of acceptable designs	35.9%	41.0%	17.9%	5.1%
30c. It would be possible to maintain a coherent design language	23.7%	52.6%	18.4%	5.3%
30d. The system would be an addition to the brand's standard products	26.3%	57.9%	15.8%	0.0%
30e. The brand's reputation for design quality would increase	2.7%	40.5%	54.1%	2.7%

	Strongly Agree		Agree		Disagree		Strongly Disagree	
I have previously designed mass-customised products	Yes	No	Yes	No	Yes	No	Yes	No
30a. The system should allow the maximum design freedom possible	10.0%	11.8%	50.0%	29.4%	35.0%	41.2%	5.0%	17.6%
30b. The system should set boundaries of acceptable designs	40.0%	27.8%	30.0%	55.6%	20.0%	16.7%	10.0%	0.0%
30c. It would be possible to maintain a coherent design language	30.0%	17.6%	40.0%	70.6%	20.0%	11.8%	10.0%	0.0%
30d. The system would be an addition to the brand's standard products	30.0%	17.6%	55.0%	64.7%	15.0%	17.6%	0.0%	0.0%
30e. The brand's reputation for design quality would increase	5.0%	0.0%	50.0%	31.2%	40.0%	68.8%	5.0%	0.0%

Question 31.With regard to question 30, and thinking about the *commercial* success of products which *you* have had personal responsibility for:

I have previously designed mass-customised products	Yes	No
I believe this will be a realistic scenario in future	61.1%	70.6%
I do not believe this will be a realistic scenario in future	38.9%	29.4%

APPENDIX 9.1 Instructions for Participants in USB Memory Stick Trial

The aim of this research is to understand how people who are not industrial designers are able to communicate design intent. The first stage is to design, by drawing, a USB memory stick.

There is no right or wrong answer, and you will not be judged on your drawing skills.

You can ask for advice from friends, family, colleagues etc, as long as they are not industrial designers.

You can use any medium (pen, pencil, coloured marker etc) as long as it is ‘paper based’. Please do not create your designs on computer.

You have been supplied with a number of drawings of a basic USB memory stick. Use these drawings to judge the size and scale of your designs. Your design can be any size, but cannot be SMALLER than the basic USB memory stick (the electronics will not fit inside).

You should design the body and the cap of the memory stick. The join between the body and the cap must be a flat, straight line.

Think about what is important FOR YOU about your design. This might be functional or it might be aesthetic. Do not think you have to copy an existing design: the more personal your ideas the more helpful it is for my research.

I have included some images of existing USB memory stick designs (in the envelope): You can look at these before, during or after the exercise. I will ask you about this during the second stage.

There is no limit to the number of ideas you can have at the beginning. You may want to draw the same idea a number of times to get it just right. However at the end of the exercise you should have one favourite, final design.

When submitting your design, think about how it will be understood by someone who is only looking at your drawings. Make as many drawings as you feel are necessary to make your final design understood.

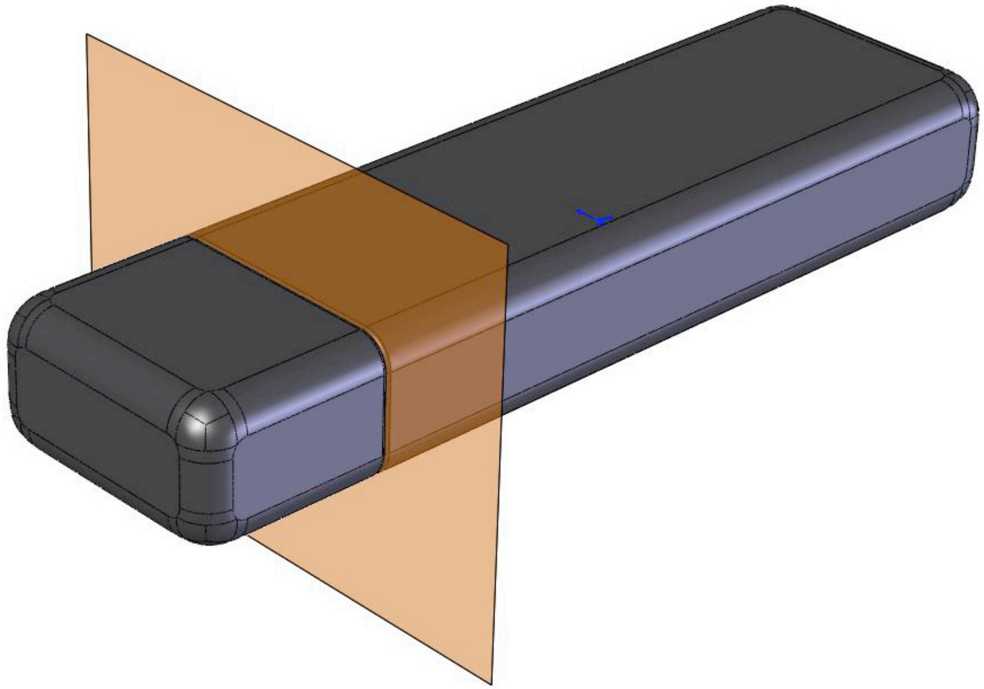
Name: ....
Age (will not be disclosed): ....
Occupation: ....

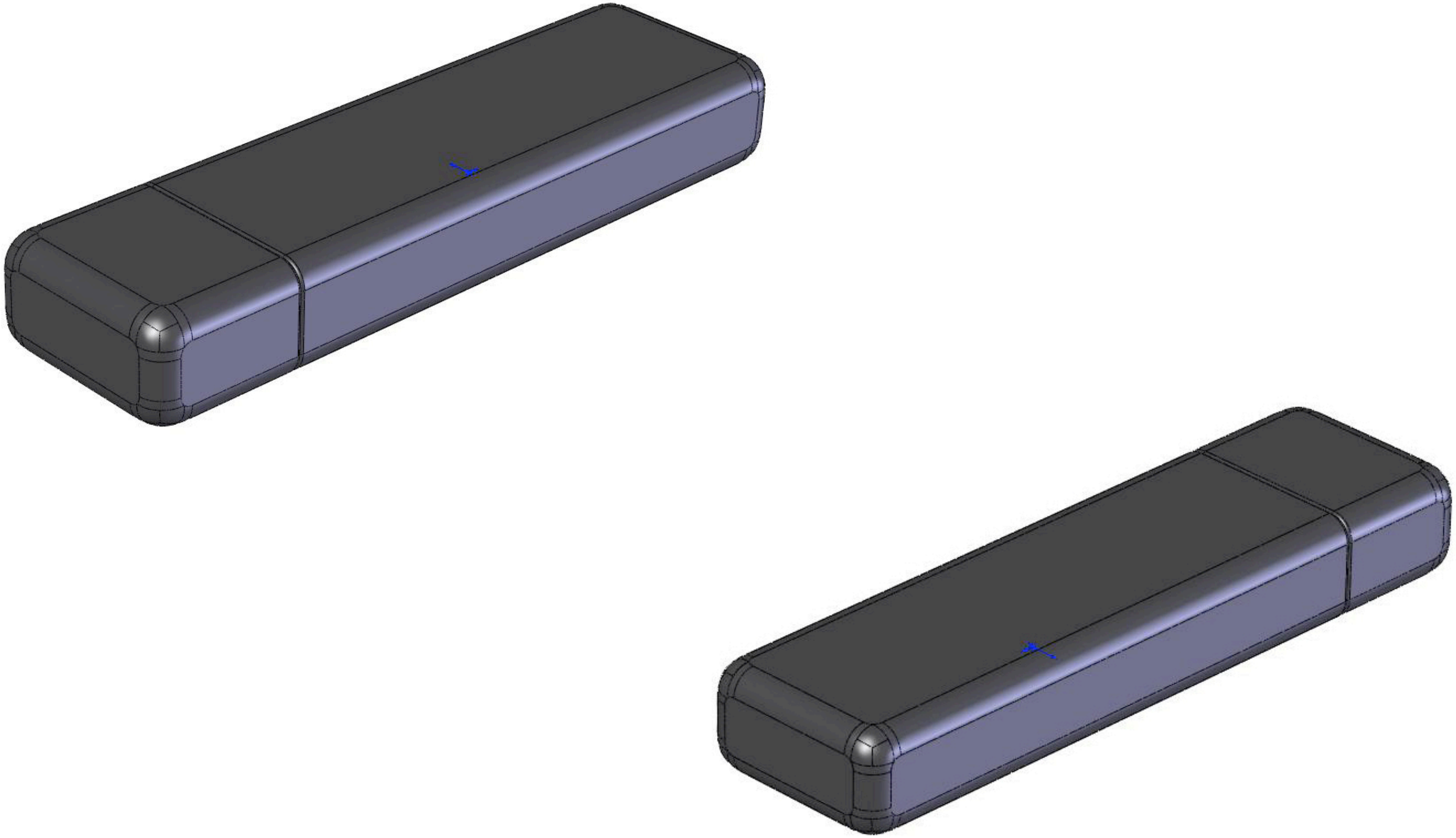
Signature: ....

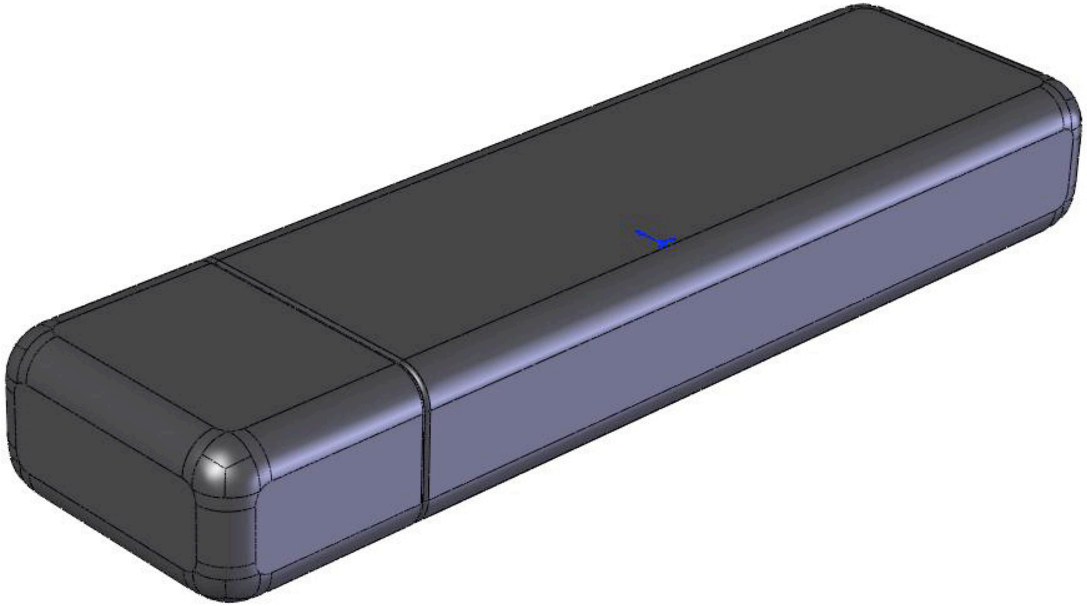
I give permission for my details and designs to be published for academic purposes (thesis, conference papers etc) YES/NO

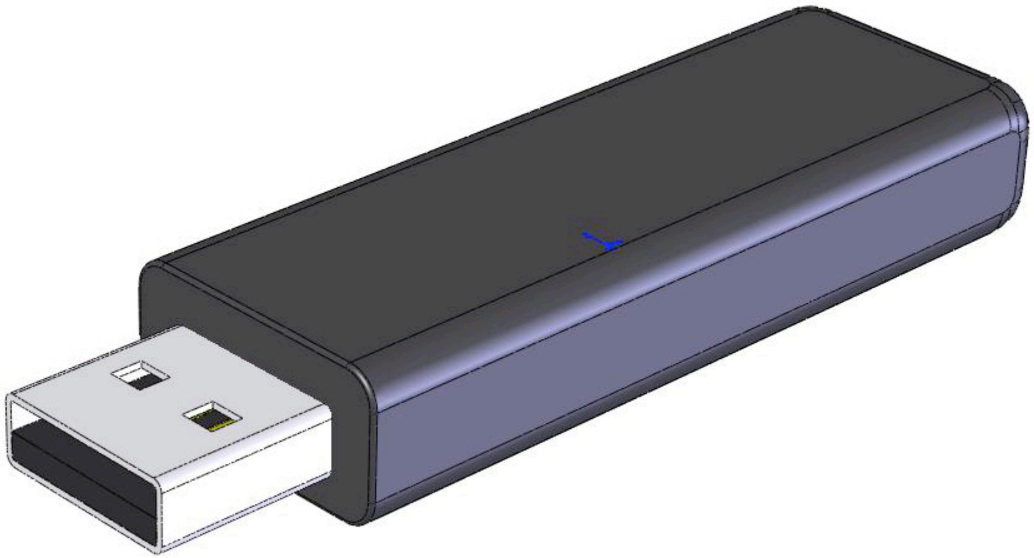
I give permission for my details and designs to be published for publicity purposes (websites, magazines etc) YES/NO

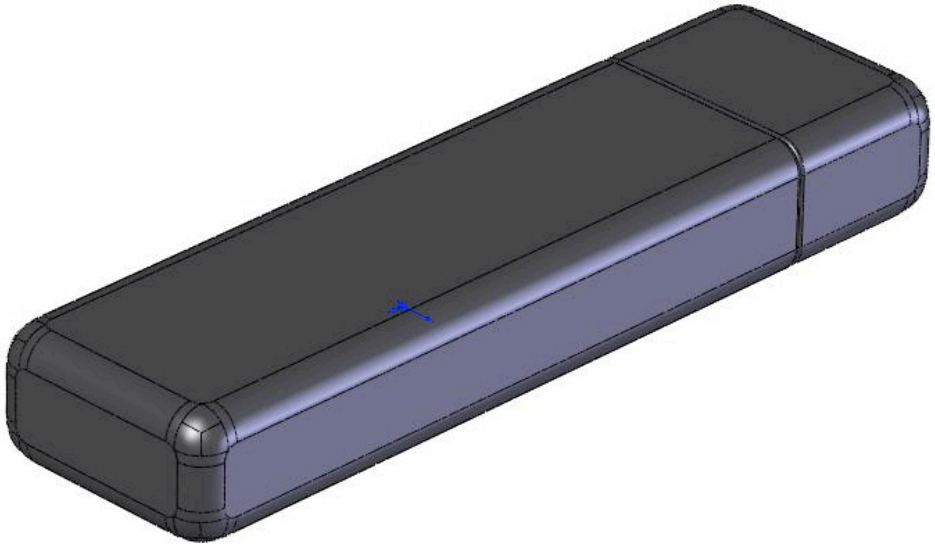
You should design the body and the cap of the memory stick. The join between the body and the cap must be a flat, straight line.

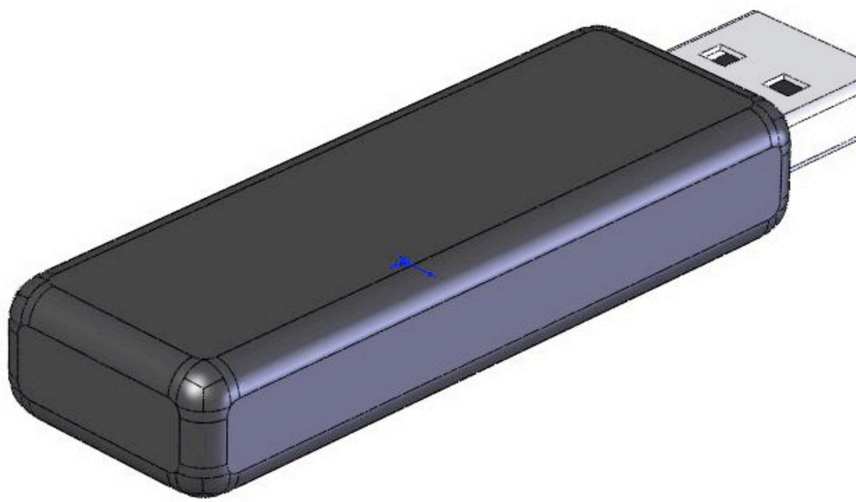


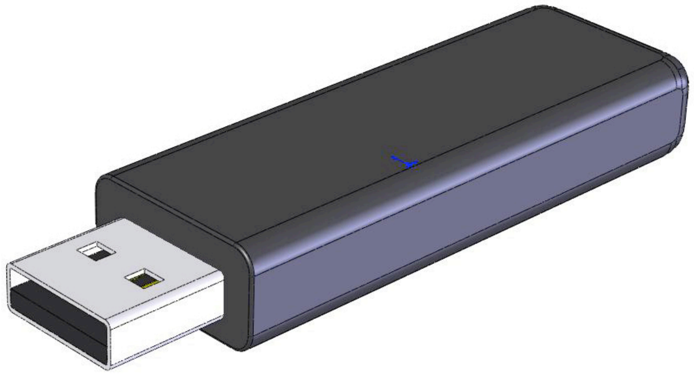


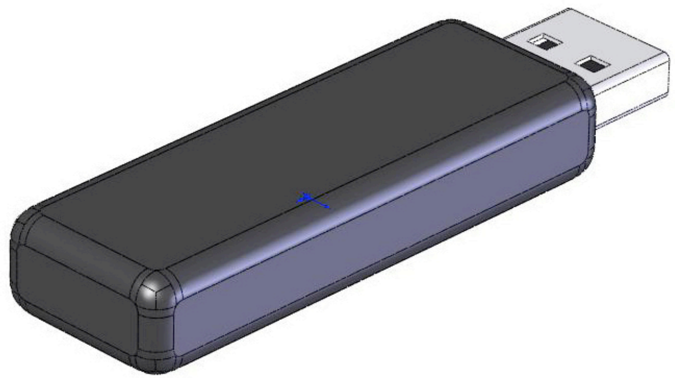













STICK


SURVIVOR


cruzer


Windows Live

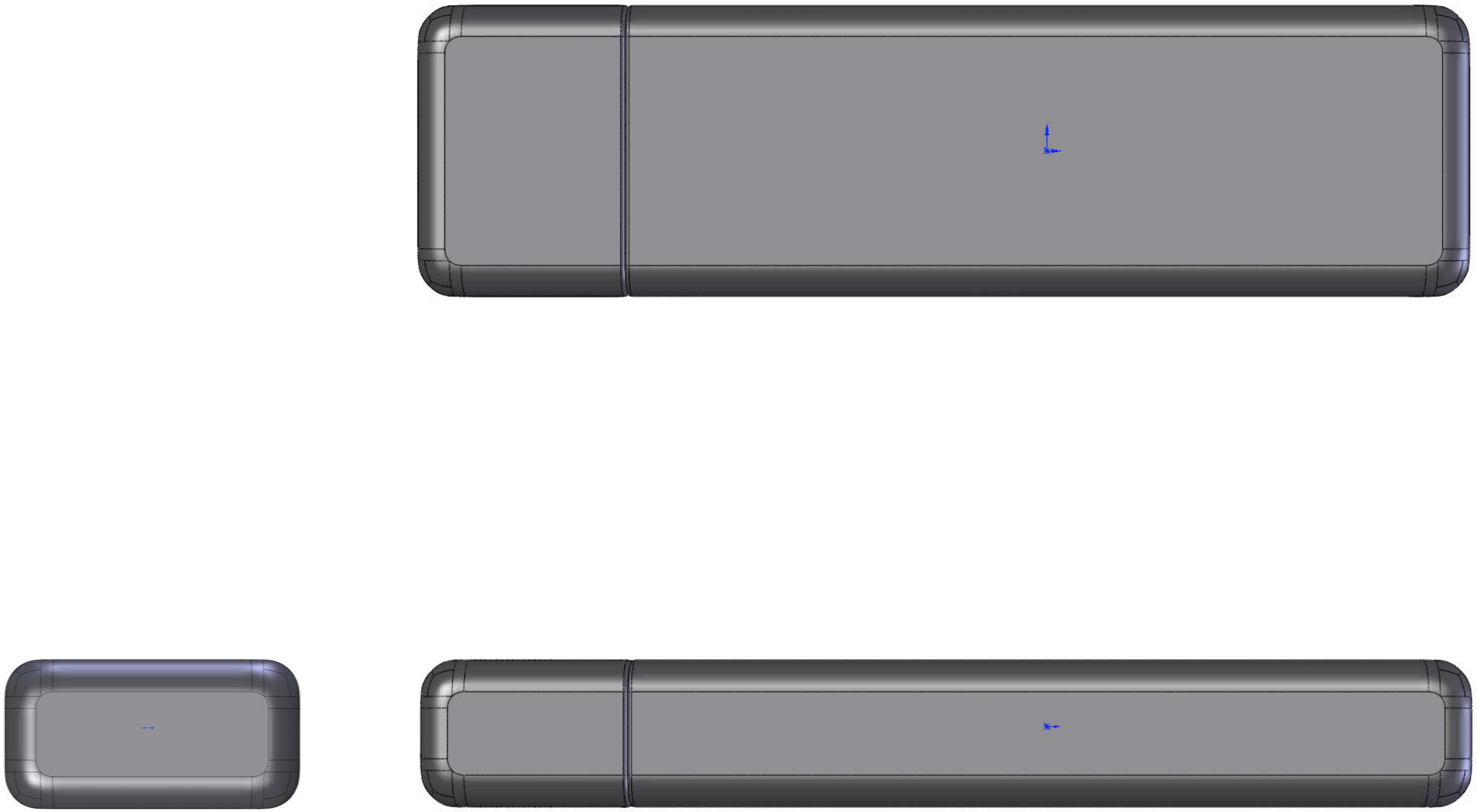

DataTraveler
2GB

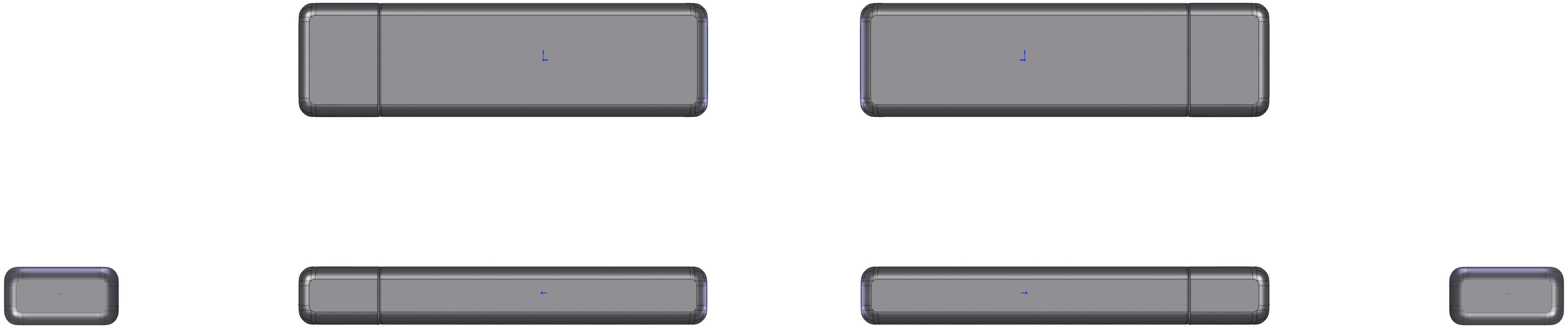

CRUZER


PUMA



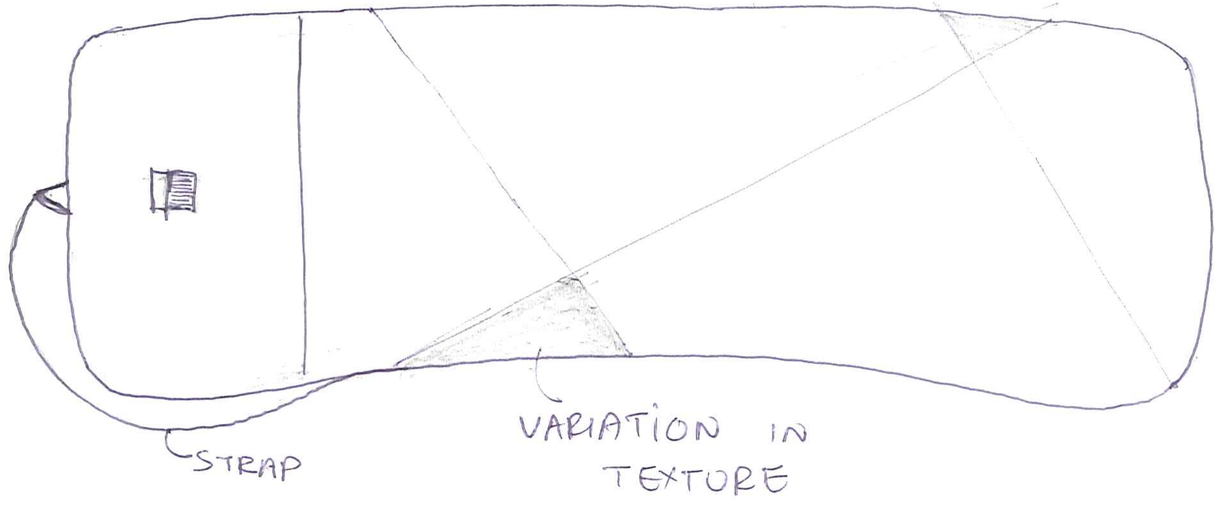


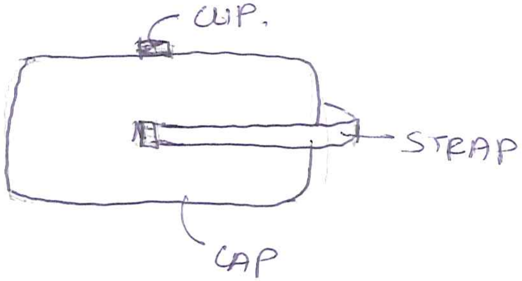



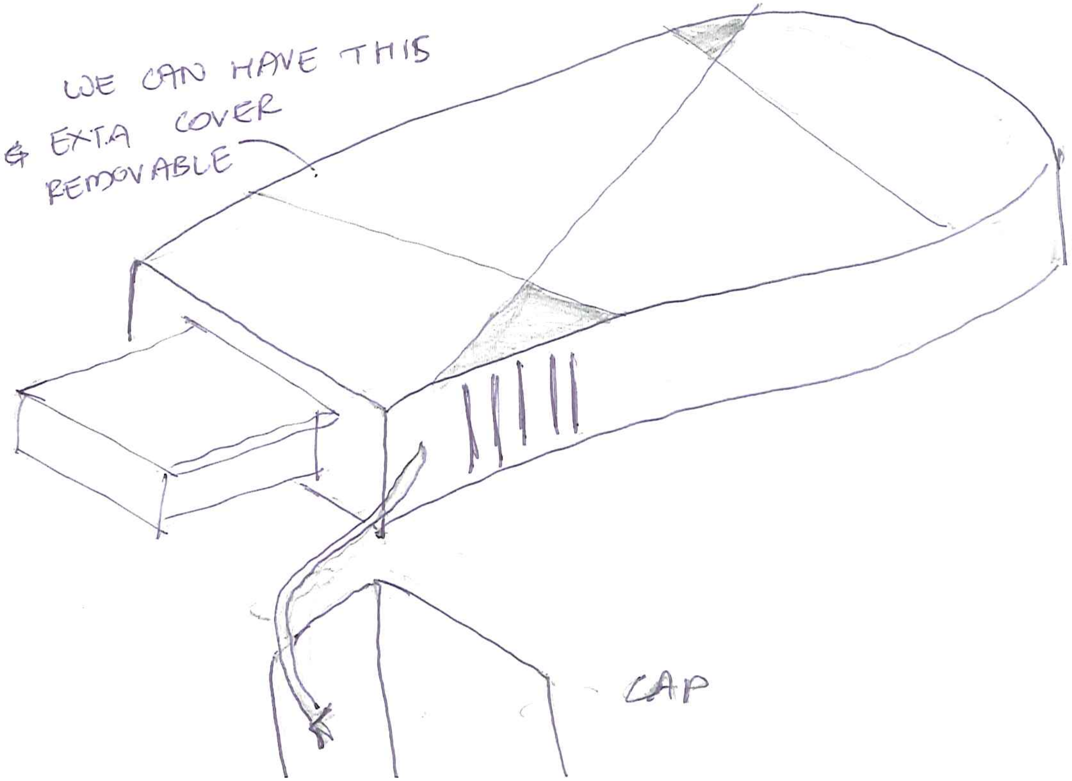


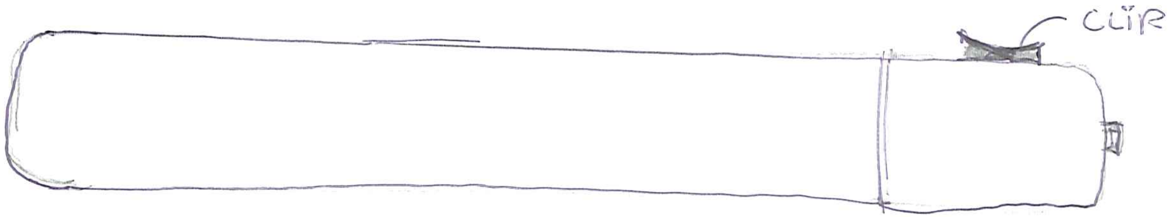
Scale 1:1

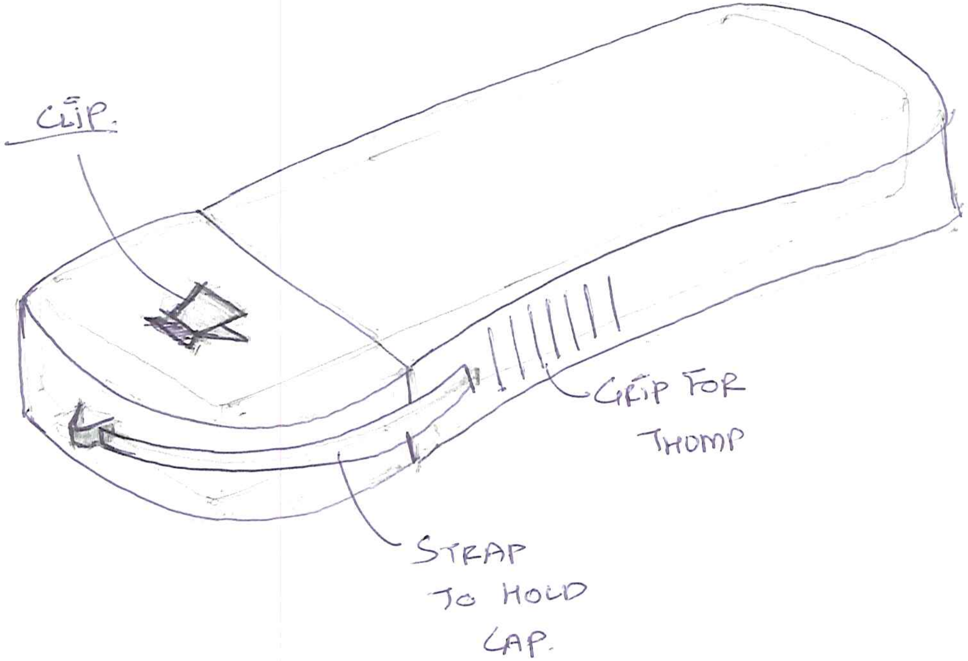
APPENDIX 9.2 Images of USB Memory Sticks

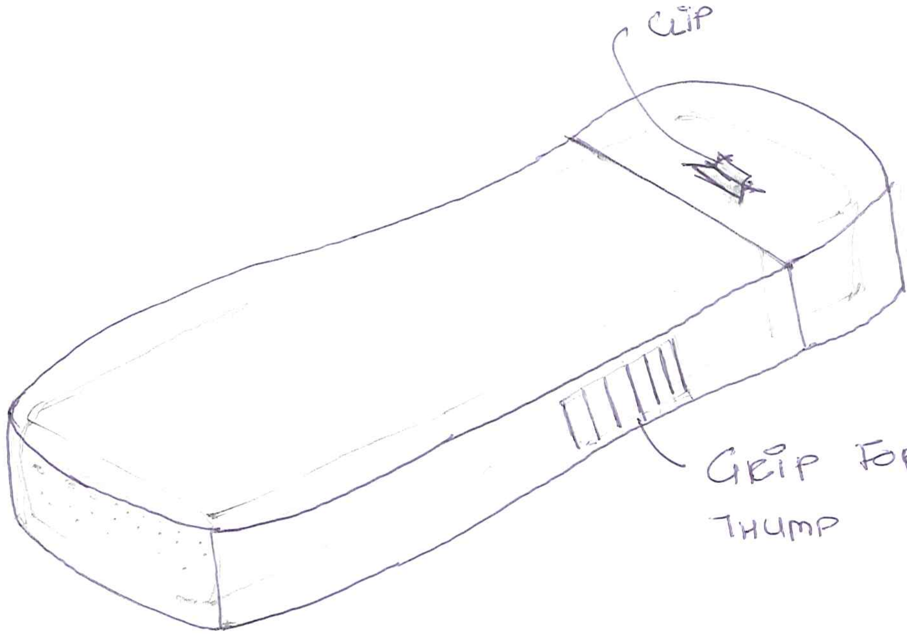

STRAP
VARIATION IN TEXTURE

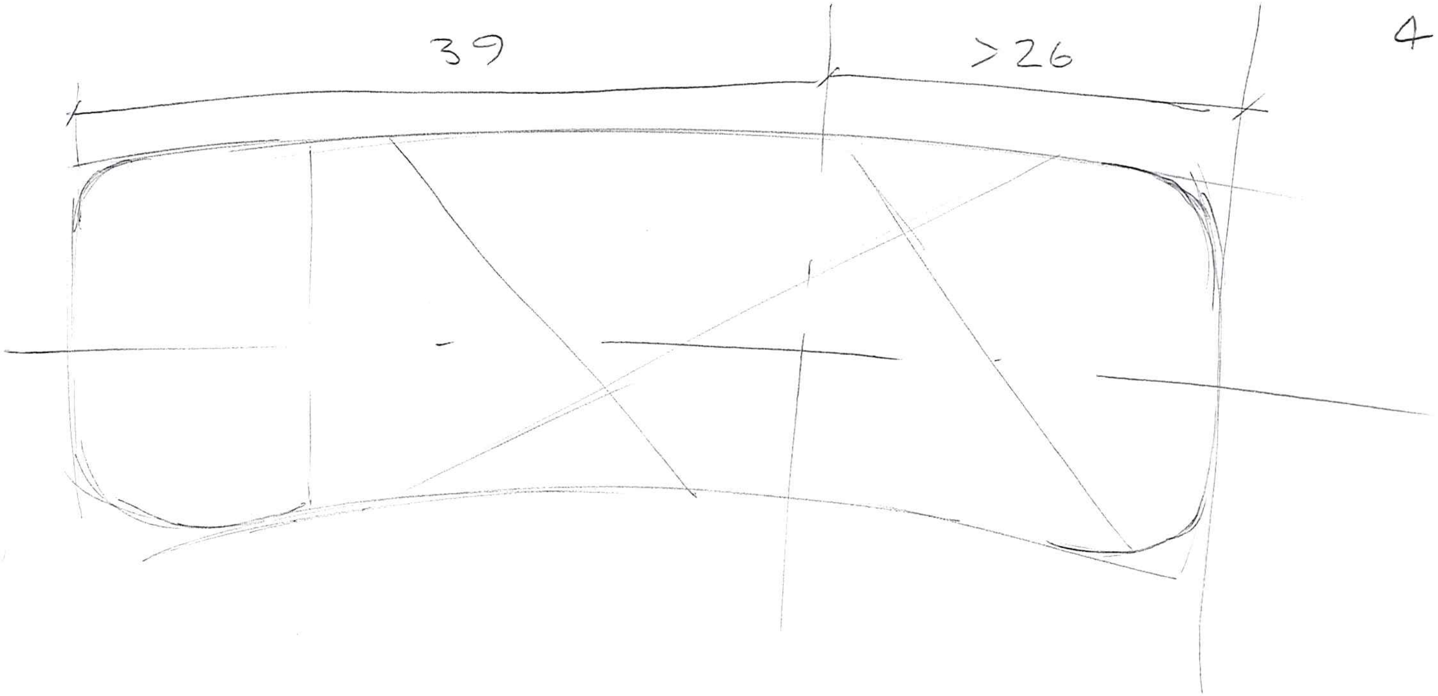

CLIP.
STRAP
CAP


WE CAN HAVE THIS
& EXTA COVER
REMOVABLE
CAP


CLIP


CLIP.
GRIP FOR THOMP
STRAP TO HOLD CAP.


CLIP
GRIP FOR THUMP



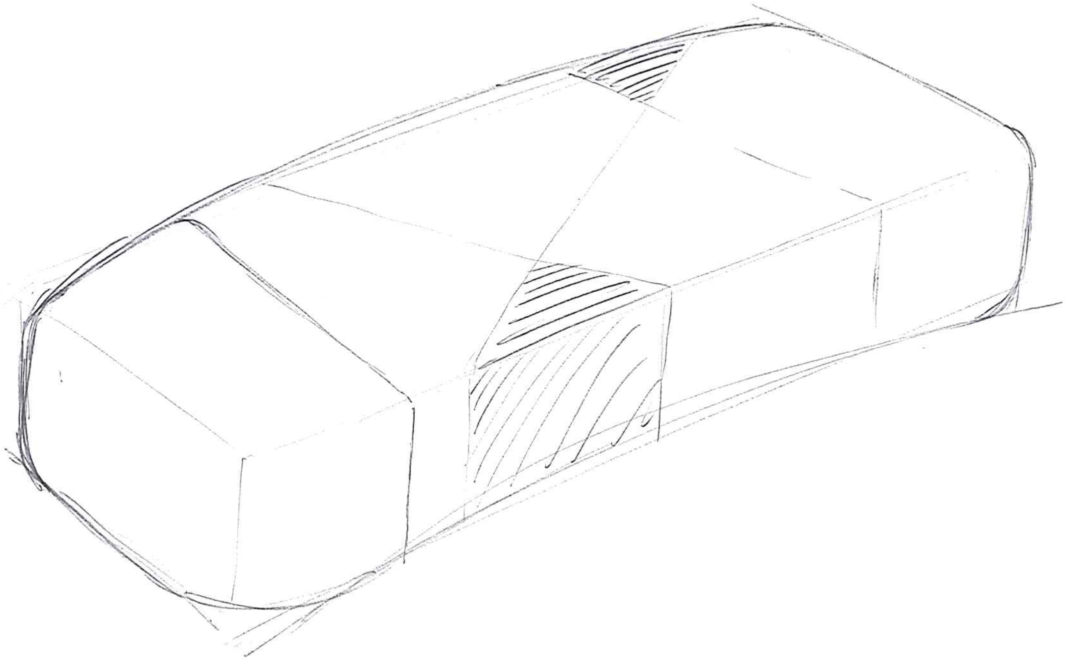
4.55

4.8

2.8

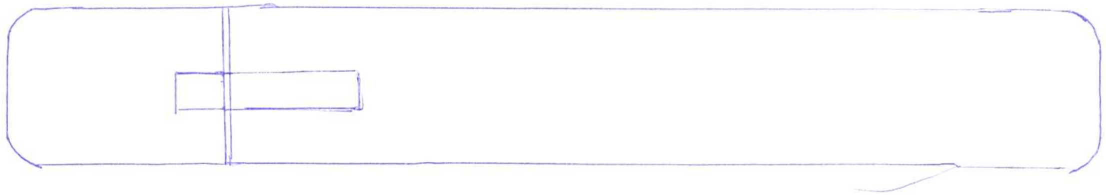
1.4
2.7

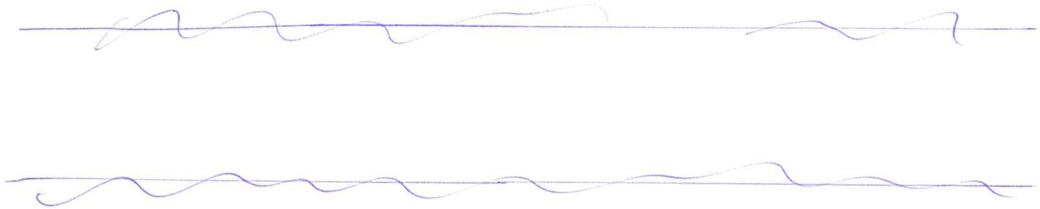
4.1



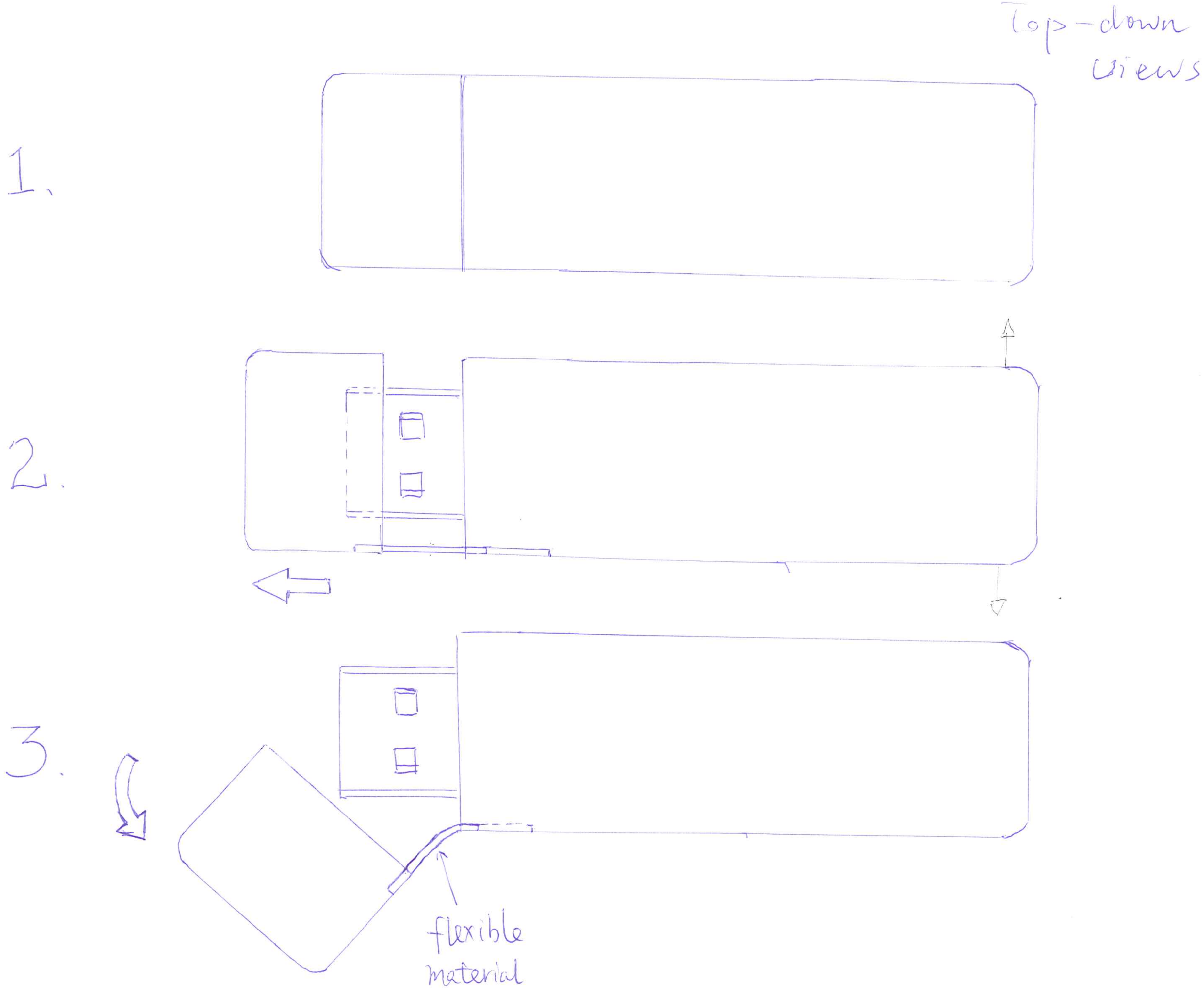
Side views

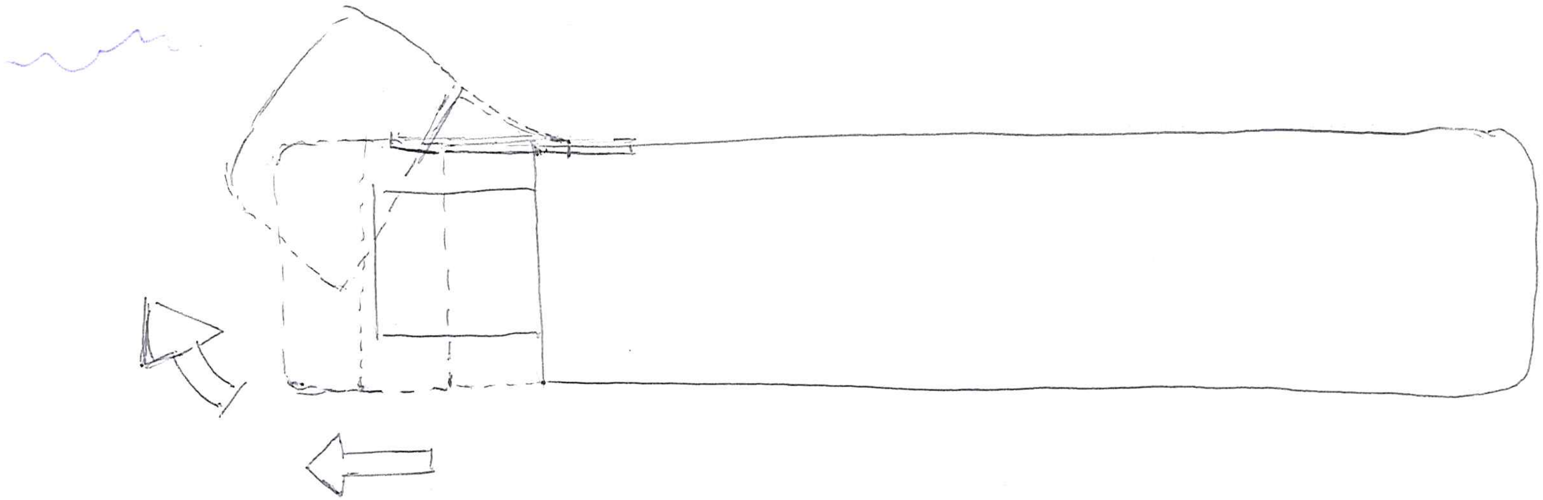
1.

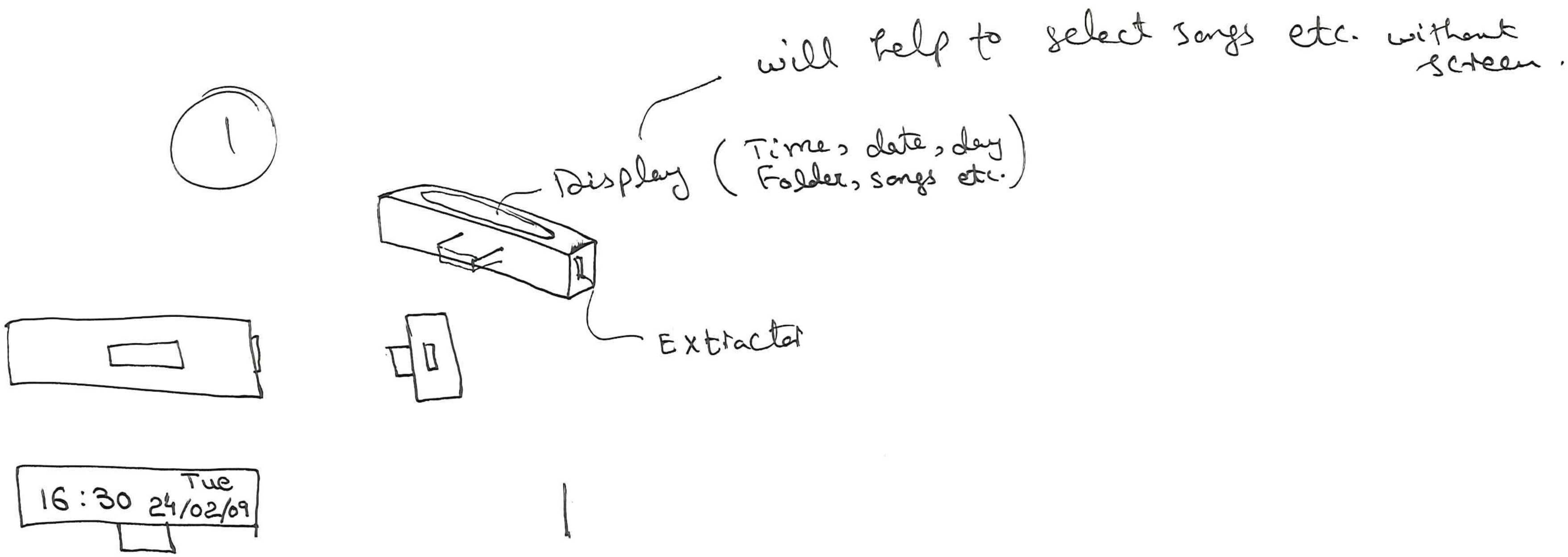




2.

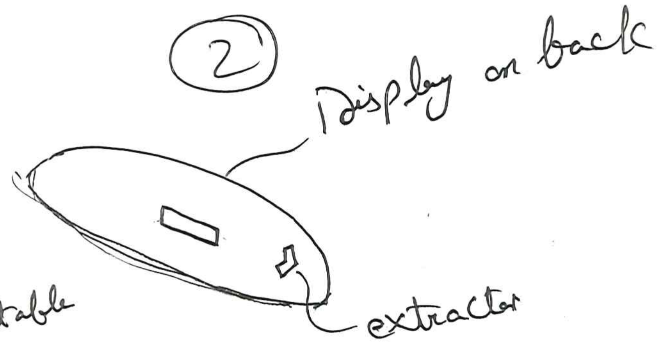

Top-down views
1.
2.
3.
flexible material

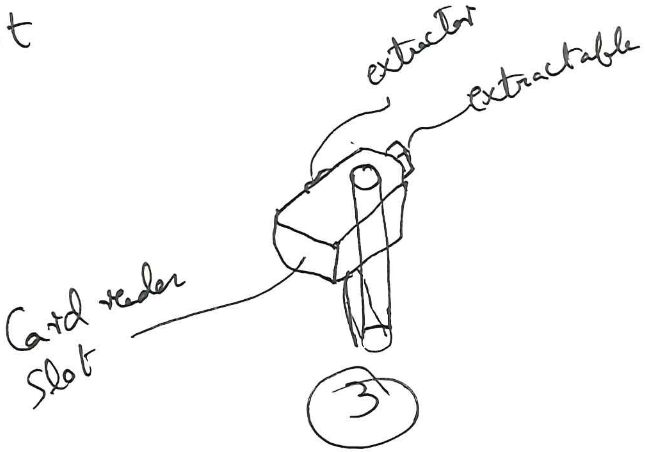


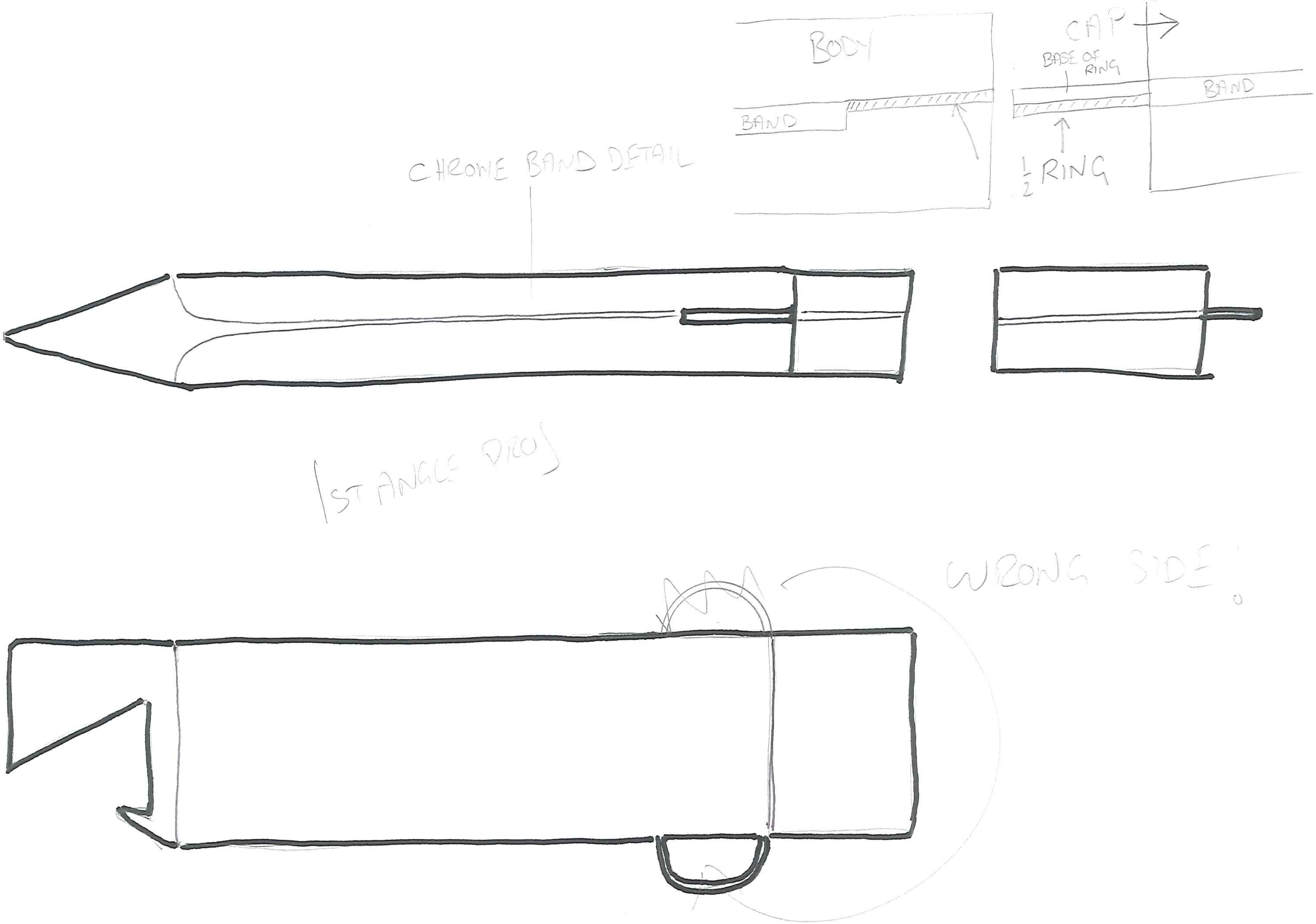


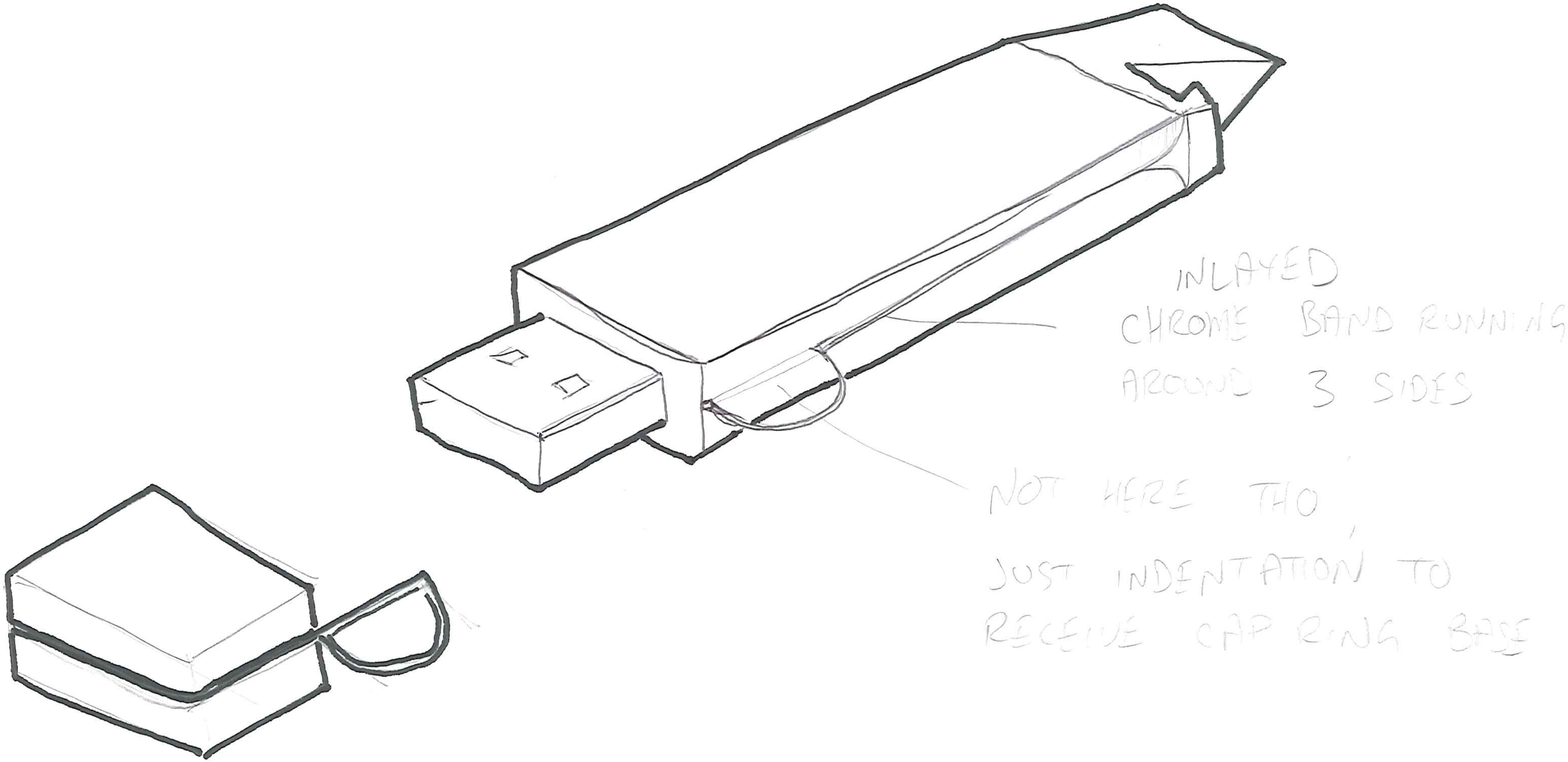
May be added features include:-

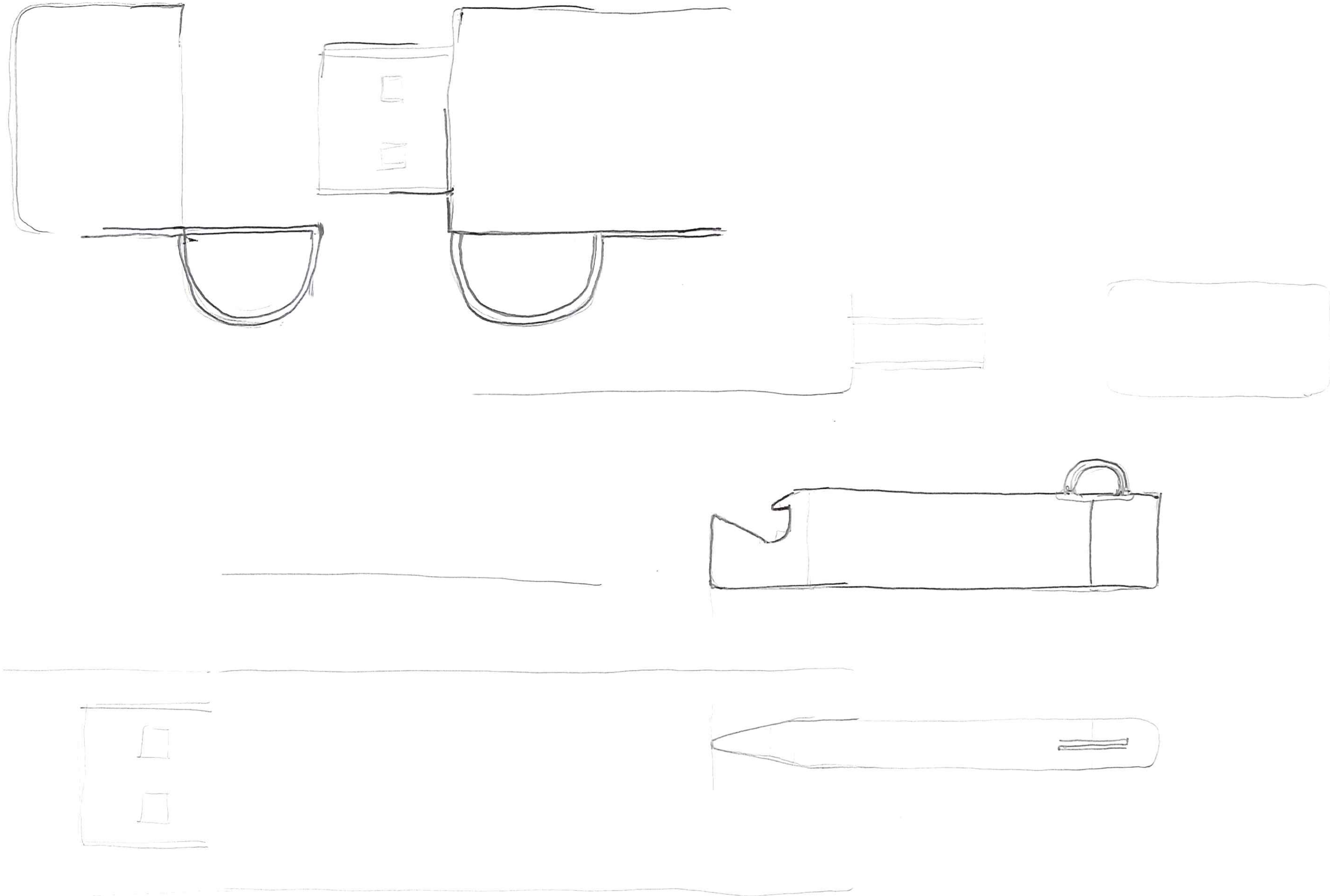
* Bluetooth
* Card reader slot



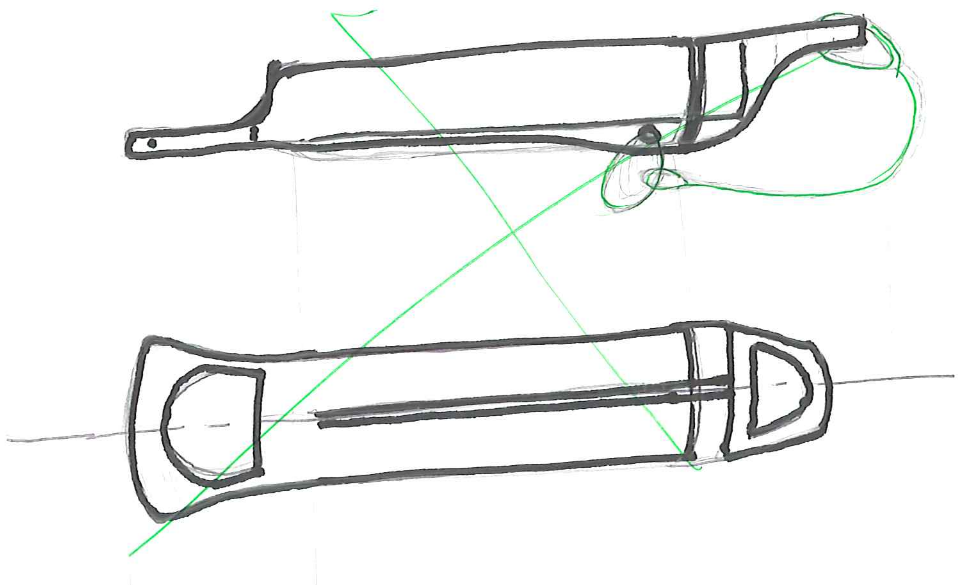


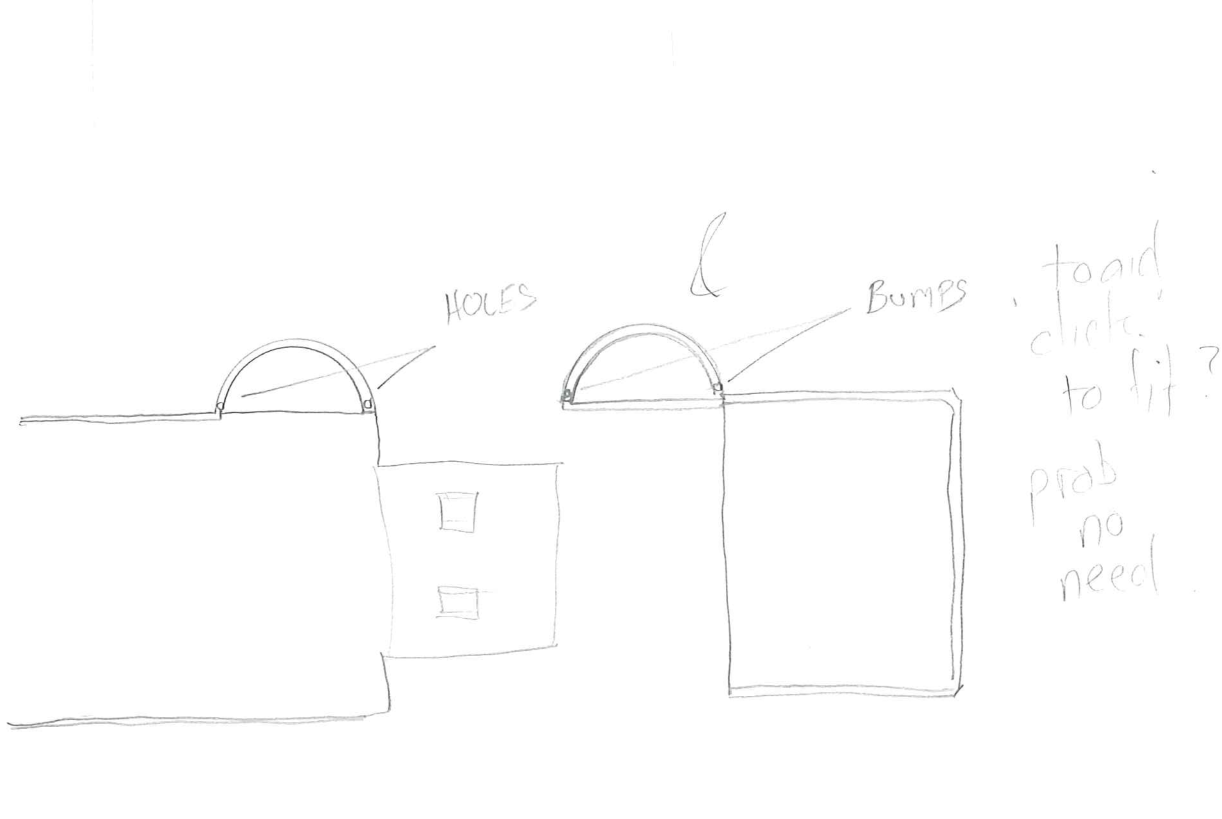

BODY
BAND
CAP
BASE OF RING
BAND
1/2 RING
CHROME BAND DETAIL
1ST ANGLE PROJ
WRONG SIDE!

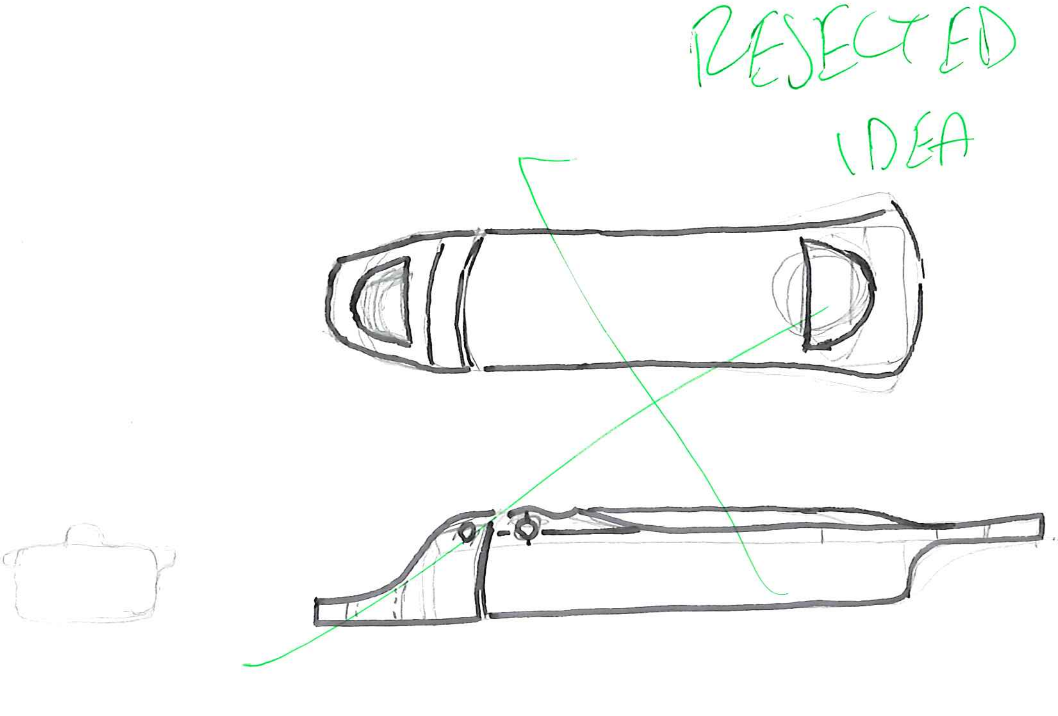

INLAYED
CHROME BAND RUNNING
AROUND 3 SIDES
NOT HERE THO,
JUST INDENTATION TO
RECEIVE CAP RING BASE

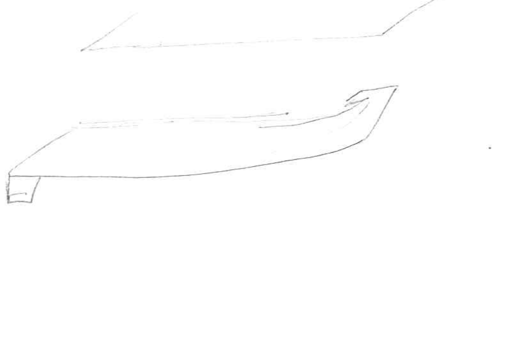


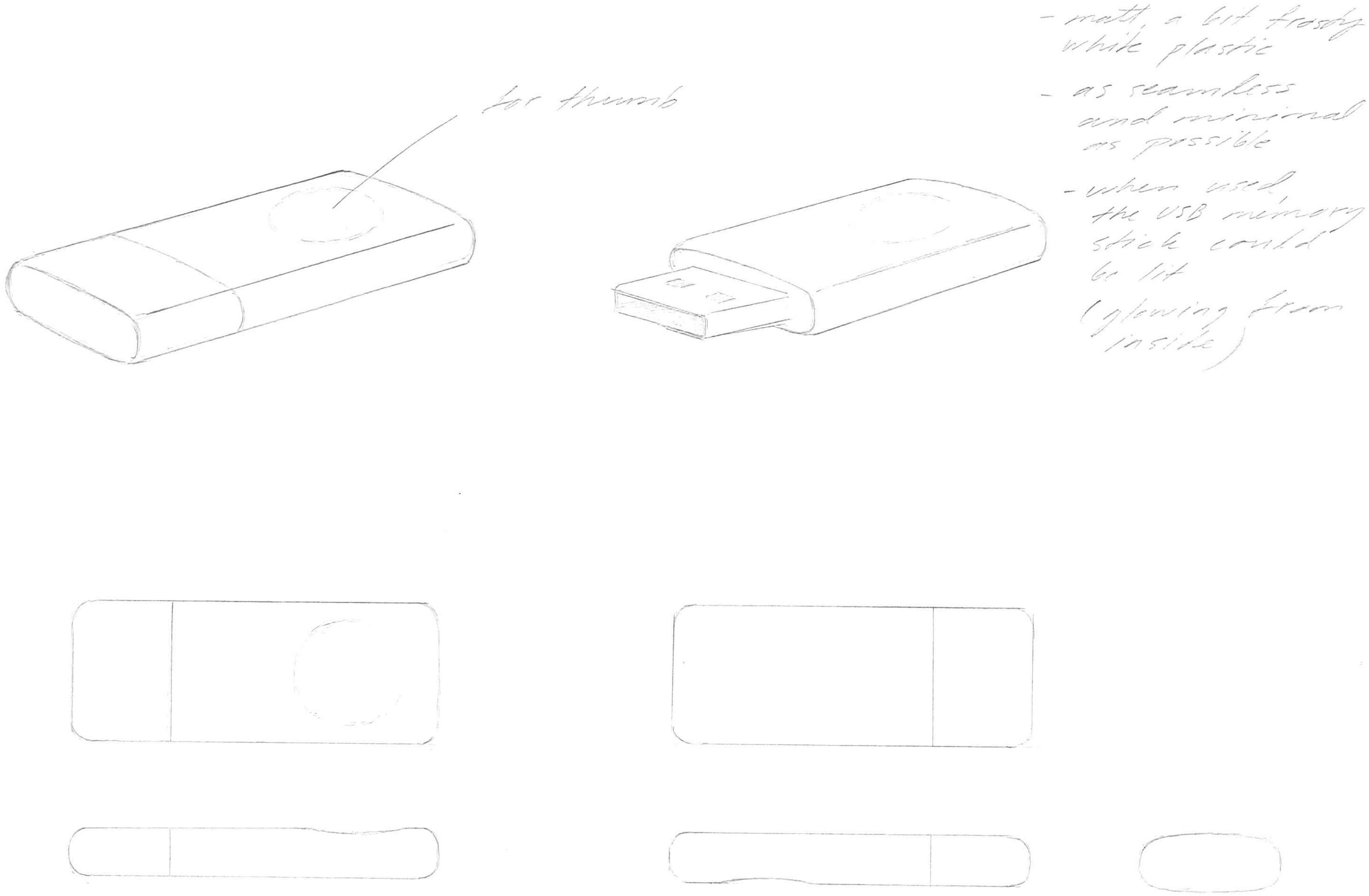
REJECTED IDEA

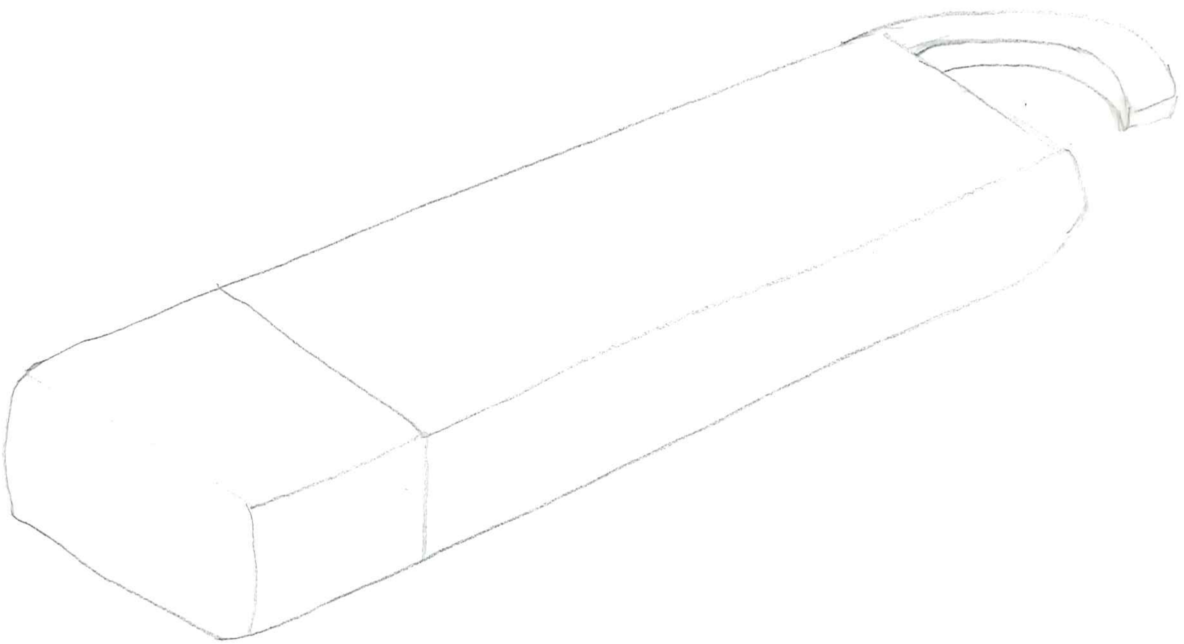


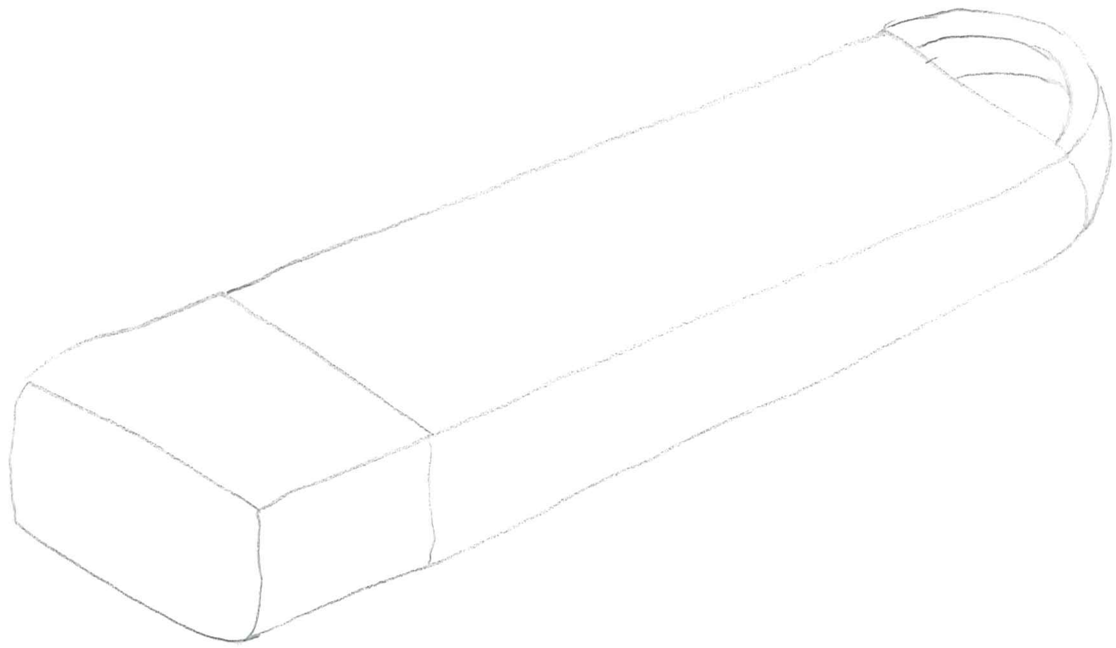


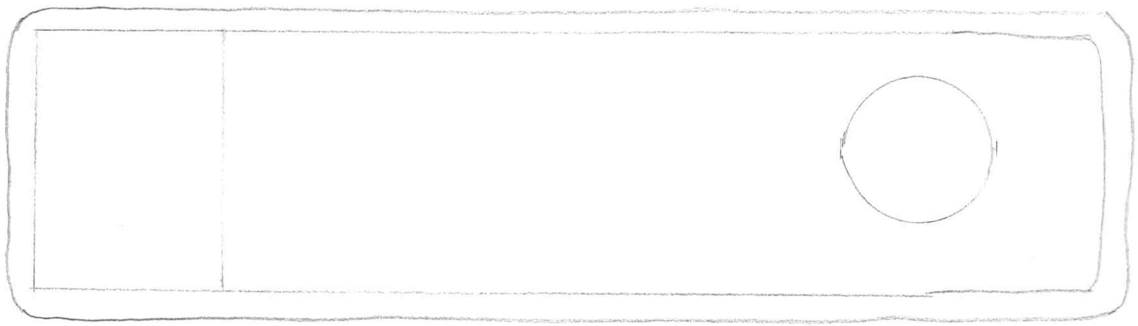

REJECTED
IDEA

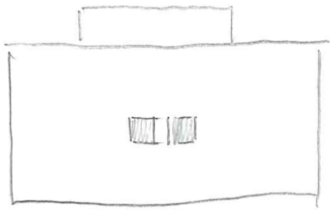



for thumb
- matt, a bit frosty white plastic
- as seamless and minimal as possible
- when used, the USB memory stick could be lit (glowing from inside)

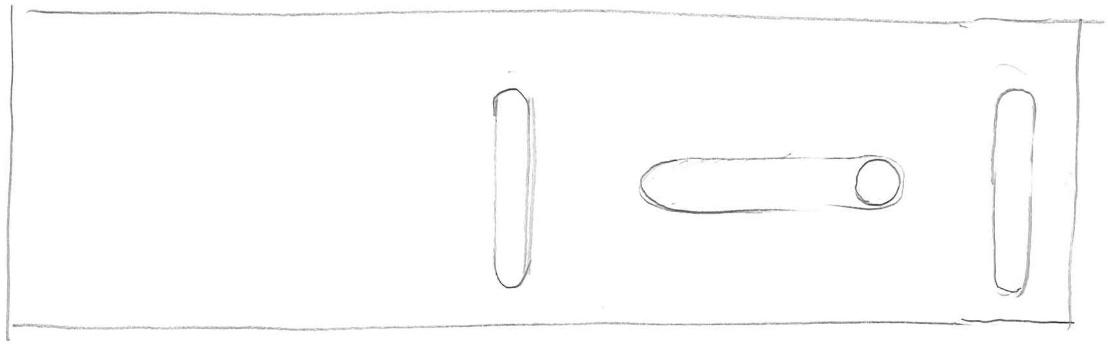




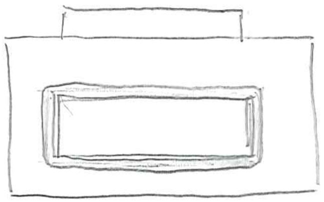




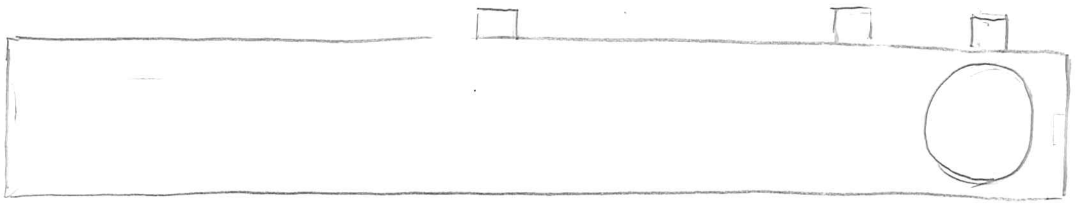
BACK



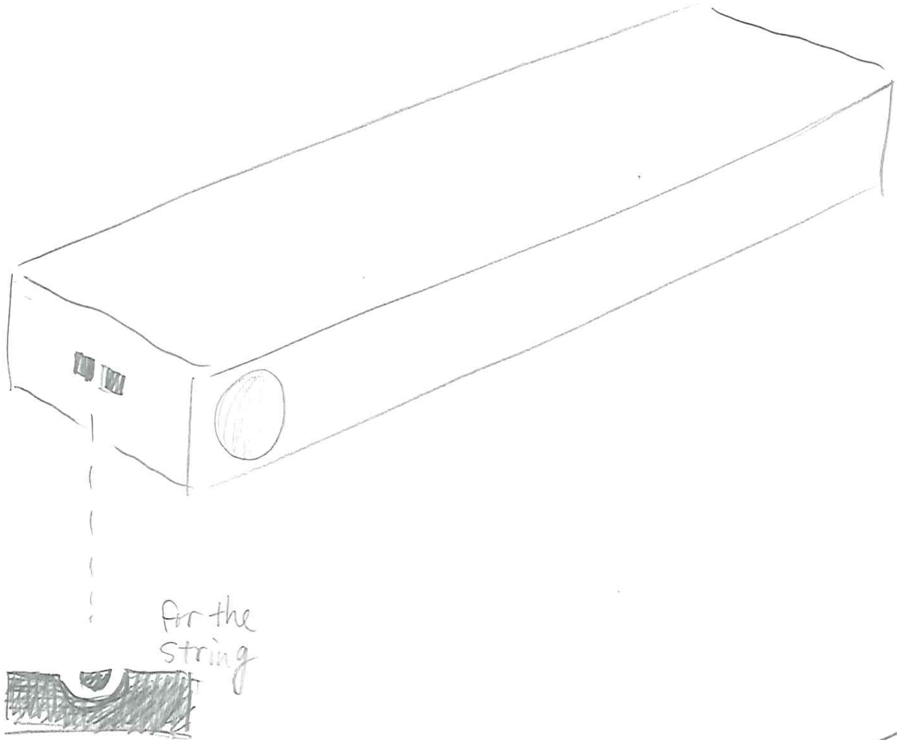
TOP

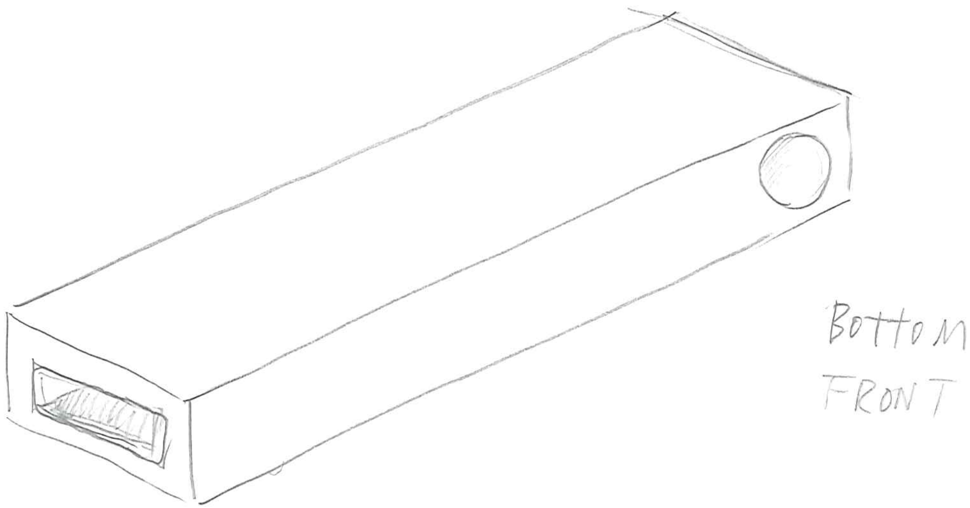


FRONT

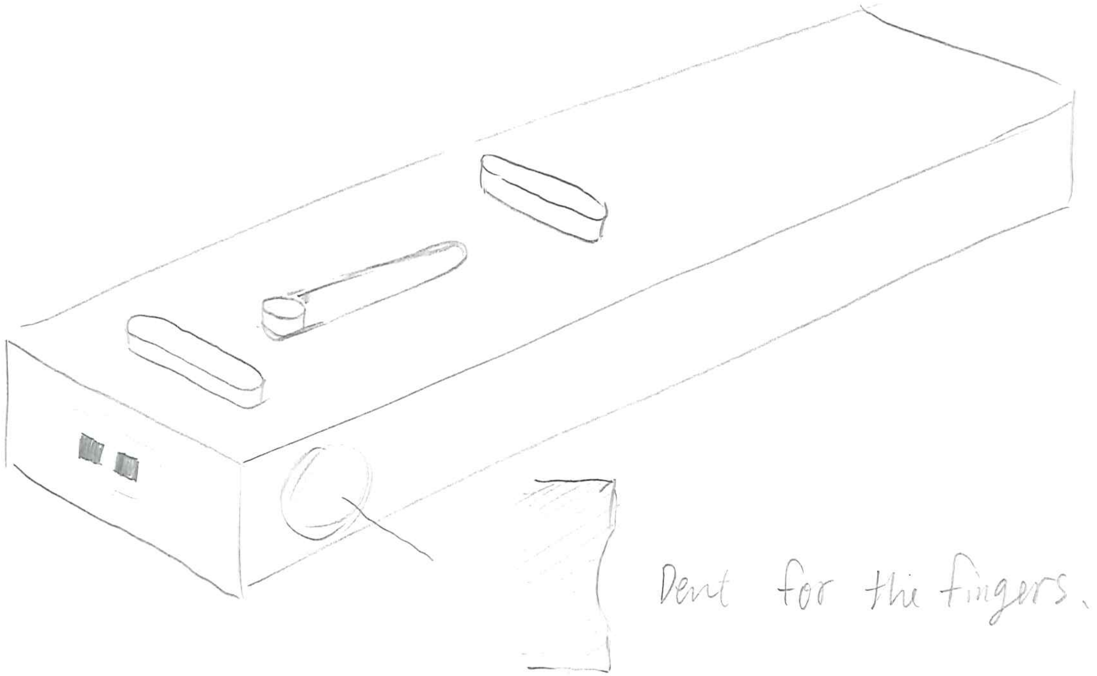


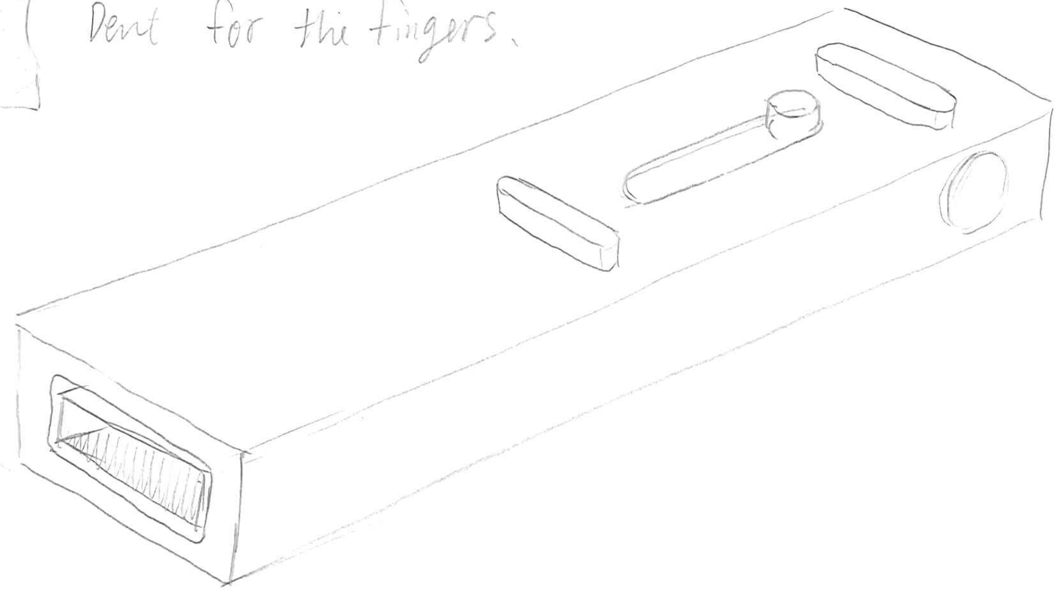
side.


for the string

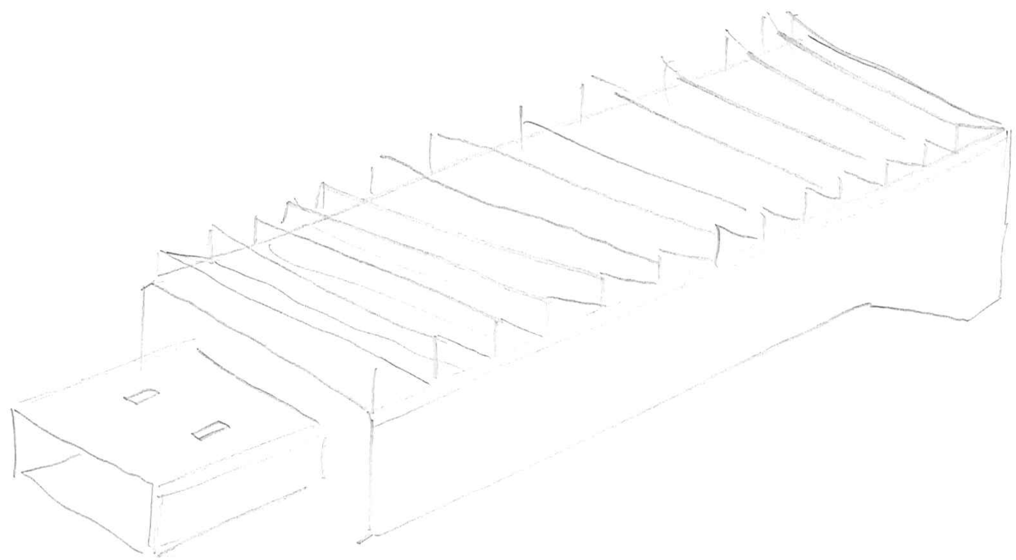

Bottom
FRONT

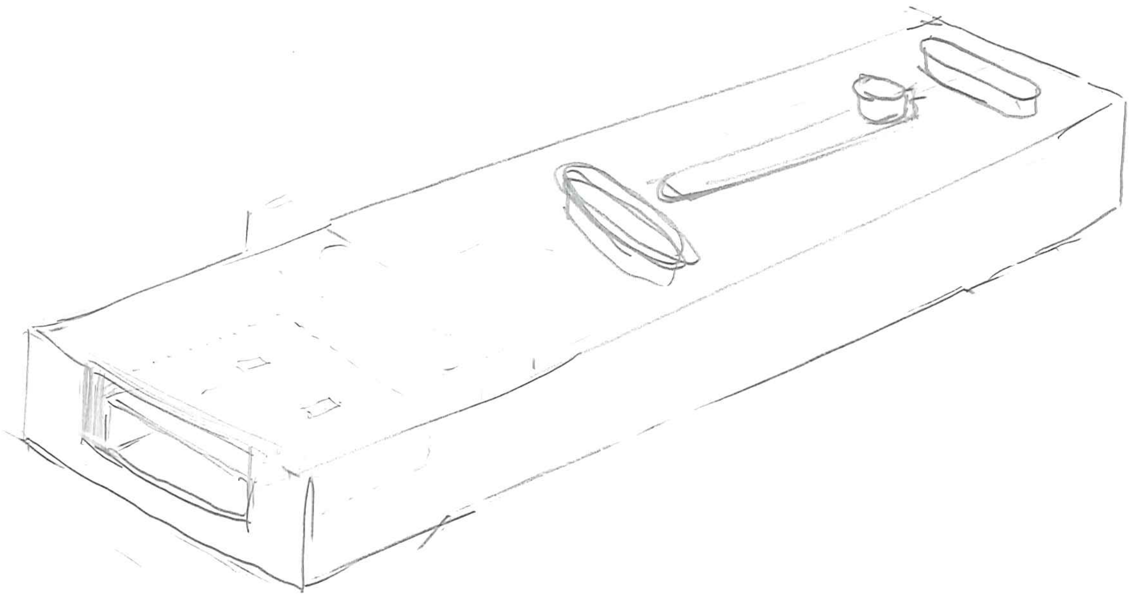
TOP + BACK

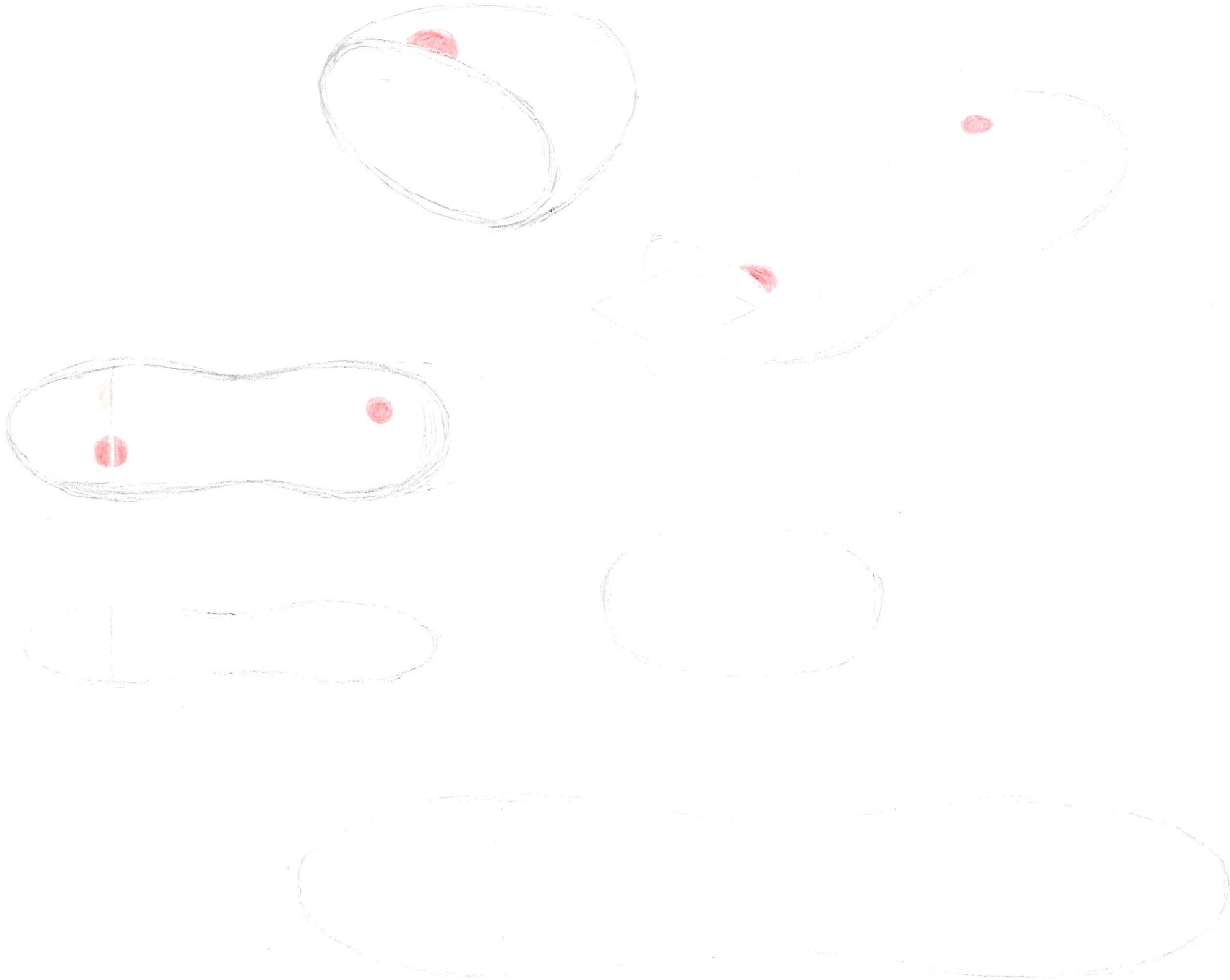


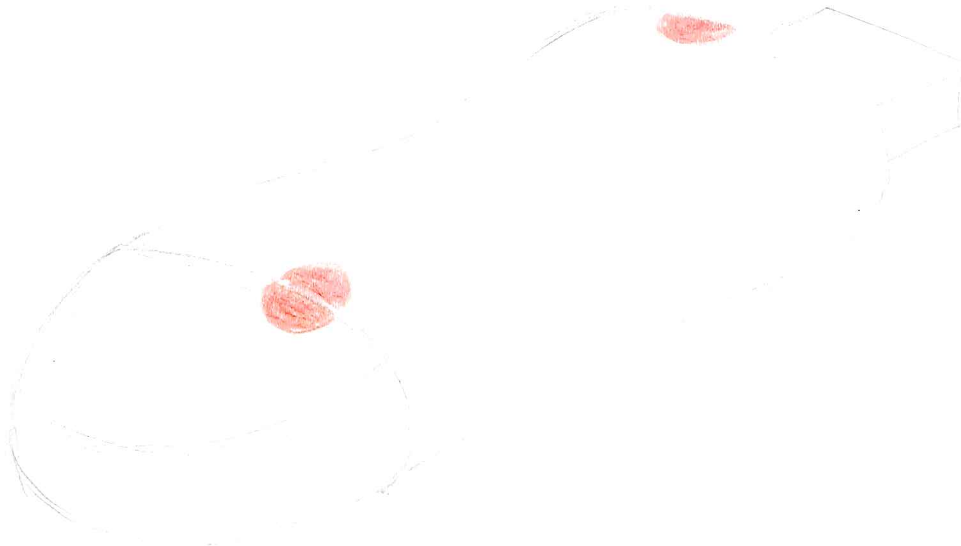


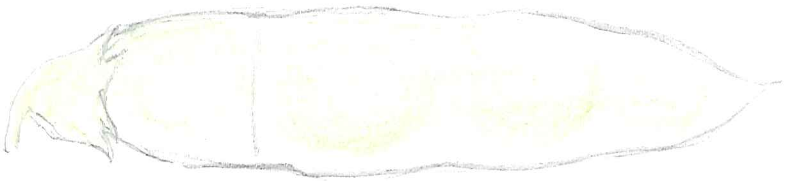
TOP + FRONT

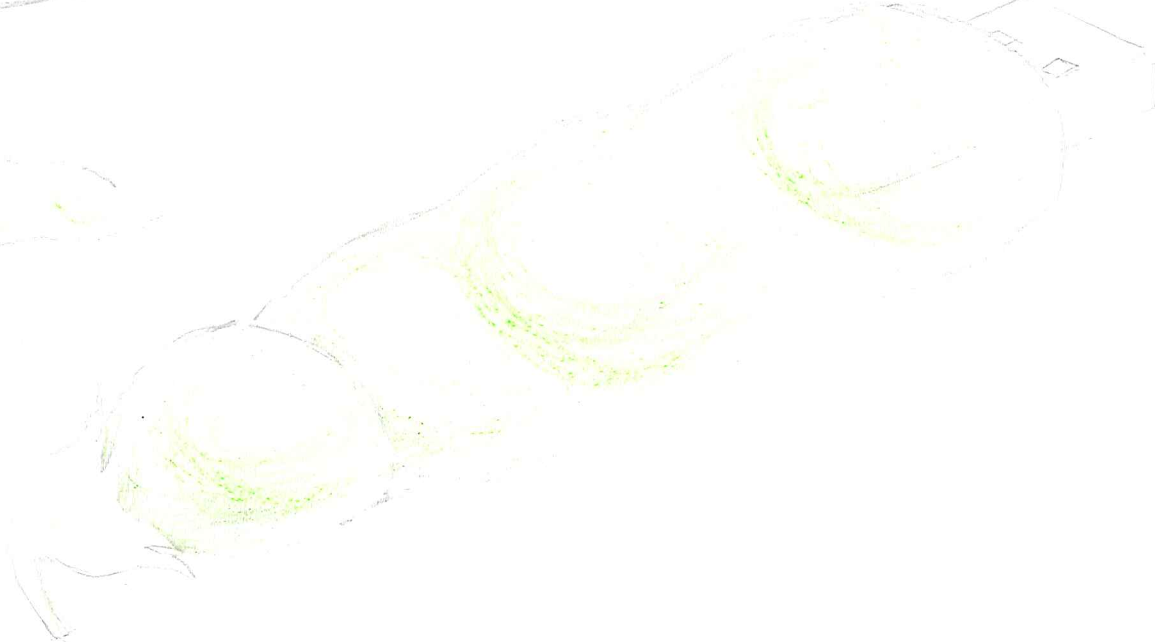












APPENDIX 10.1 Google SketchUp Diary Entries and Sketches

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 1		
23/02/11	Google SketchUp	Download, Installation, Tutorials
24/02/11	″	Tutorials, Search Google 3D Warehouse
25/02/11	″	Tutorials
26/02/11	″	Tutorials + Image Search
Week 2		
28/02/11	″	Modelling a Camera Tutorial
01/03/11	″	″
Week 3		
08/03/11	″	Sketch Sheets, Moodboards
09/03/11	″	Moodboard, Modelling, Sketch Sheets
10/03/11	″	Modelling, Sketch Sheets
11/03/11	″	Modelling, Sketch Sheets
12/03/11	″	Modelling

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 4		
14/03/11	Google SketchUp	Sketch Sheets, Modelling.
16/03/11	"	Meeting with Ian
Week 5		
22/03/11	"	Research Import Options
23/03/11	"	"
27/03/11	"	Sketch Sheets, Import Sketches.
Week 6		
28/03/11	"	Modelling
30/03/11	"	Meeting w/ Ian.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 7		
04/04/11	Google SketchUp	Modelling
07/04/11	〃	〃
08/04/11	〃	〃
09/04/11	〃	〃
Week 8		
12/04/11	〃	Modelling
14/04/11	〃	Meeting w/ Ian
15/04/11	〃	Modelling
16/04/11	〃	Modelling.
Week 9		
18/04/11	〃	Modelling
19/04/11	〃	Exporting.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 23/02/2011	Software Google SketchUp

Description of Activity

Software downloaded and installed. Download required creation of a Google account. Time to download + install approximately 3 minutes. Installation was automated + easy, though it tried to install Google's toolbar in my browser (annoying)

Went through the first 6 tutorials. These are YouTube videos, easy to follow, narrated by a woman (unusual for CAD tutorials) Only one (tutorial 4) is a directed tutorial (ie one that you follow) the rest are just watch + learn

Modelling style is unlike anything I've experienced, create a surface, extrude to make solid, then select any surface or edge + drag to change the shape. Very easy to understand, though controlling extrude direction can be tricky at first. Perspective view is default. Annoyed by inability to choose views (front, side etc) until I discovered the toolbar. Drag click left-right and right-left imitates other software (Illustrator, Solidworks)

See files: Chairs.skp and chairs.tif

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 24/02/2011	Software Google SketchUp

Description of Activity

Watched two more introductory tutorials but felt I'd already covered them by 'playing around' myself. Moved onto advanced tutorials but most of these aren't relevant or still too basic. Copy/Array was useful as I'd been trying to figure it out yesterday.

Discovered link to 'Ruby Scripts': plug-ins that extend functionality. Free to download. I need to investigate these further after I understand the software better; they are an inherent part of the 'ecosystem' so it's not reasonable to ignore them.

Looked through Google 3D Warehouse, a collection of models available to import to SketchUp. However not all are made in S.U. (they've just been imported) so not necessarily a good way to learn the software. Found some tutorials + downloaded - will try them tomorrow. Warehouse is kind of crude - difficult to find good models (or sort good from bad). A lot of models have hundreds of tags so appear in a search even if not relevant. Also downloaded some 'interesting' models to see if I could learn from them.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 24/02/2011	Software Google SketchUp.

Description of Activity

Found a link to 'Massive Black' a game design studio which uses S.U. Some images of vehicles show an interesting aesthetic that might be worth following (flat intersecting panels, machine-like, robotic).

SketchUp uses layers, but these only affect visibility. Invisible layers are still editable, though you don't know what's being edited until visibility is turned back on. Kind of confusing, and unlike most other software (Illustrator, Rhino for example). Can get round limitation by creating groups + components (only one of which can be edited at a time).

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 25/02/2011	Software Google SketchUp

Description of Activity

Started to work through a number of tutorials downloaded yesterday. Most are disappointing and highlight the software's limitations, tending to 'bodge' features rather than build models appropriate to the tools provided.

There is no fillet command in SketchUp, but it's possible to create fillets via a long-winded process

Downloaded a Ruby script which provides bezier curve drawing tools. Frustrating to use (curves are manipulated by pulling control points rather than handles) but at least splines become possible.

Spent most of the time working through one tutorial to build a car model. Not finished yet (only one window can be open in S.U., very annoying). Has taught me quite a lot about intersect command. But think it will influence what not to do rather than lead to insights into how to model.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 26/02/11	Software Google SketchUp.

Description of Activity

-Continued with previous days tutorial, but increasingly felt it was a waste of time because the model was so poorly constructed - triangular surfaces, lack of tangency, no fillets etc. Basically an attempt to make one kind of model with a tool that was never intended to be used in that way

Decided better approach was/is to work to the software's strengths - planar surfaces. Looked for picture inspiration. Some products: Boxee, HTC Diamond, Lamborghini Reventòn, Stealth bomber, Wally boats.

Constantly annoyed by view functionality - rotate + zoom are on MMB, but pan requires MMB + shift (i.e 2 hands). And no way to customize.

Detail of day's activity

Date 28/02/11	Software Google SketchUp

Description of Activity

Set myself the task of modelling/copying a camera which I found in Google 3D Warehouse. Intention was to try to understand modelling techniques but build to my own standards. Some details changed when I was experimenting with other techniques.

First thing I noticed was the scale the original was built to (it was 18' in length) Read later this is because rendering engine doesn't like small objects and clips badly, so recommendation is to build in metres and at the end scale to mm.

At one point re-watched video tutorial about arrays.

Learned how to increase segments of circle to increase smoothness/accuracy. Don't know what the maximum is. Difficult for beginner, why not just use circles?

Starting to find rotate v. annoying, sometimes difficult to align model how you want.

So far my conclusion is that SketchUp is easy to pick up + has some v. simple to use tools, but rapidly starts to feel limited as far as product modelling is concerned. E.g. - no fillets etc etc

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 01/03/11	Software Google SketchUp.

Description of Activity

Finished modelling the camera, or at least got to a stage where I felt I wouldn't learn any more by continuing. Imported dxf files to create logos.

Part of the model isn't solid, but no way to tell where the problem is. Not sure if it's a missing surface or 'unstitched' surfaces. SketchUp has no tools for analysis - could be a big problem for creating files for 3D printing.

Also no way to save or export for 3D printing (even though it's suggested on SketchUp home page. 3D formats are .skp (SU's own), .3Ds, .dxf, .fbx, .obj and .vrml. Fbx and Obj could be taken into Rhino and converted to .stl (assuming everything remains stitched together).

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 08/03/11	Software Google SketchUp

Description of Activity

Made moodboard from images previously found

Started sketching exercise, using images of safe model as underlays. Not really interested in the design as a functional object to begin with, more an exploration of sculptural form.

Found myself questioning whether some shapes/surfaces could be modelled in SketchUp – will need to test.

Even at this very early stage, I feel like the constraints of the software will lead the design in an interesting direction.

See sheets 08.03.11-SU-01.psd
08:03.11-SU-02.psd
08.03.11-SU-03.psd
08.03.11-SU-04.psd

Noticed while I was drawing that I needed to annotate more, not something I do that often as I don't usually show sketch work to clients or others without presenting.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 09/03/11	Software Google SketchUp

Description of Activity

Following the previous days sketching activity I felt the moodboard images were a bit limiting so did a new search to create more diversity.

Spent approx 2 hours modelling + experimenting in SketchUp. Seems there is a pretty close correlation between my expectations (of what SU can achieve) and reality - implies I've picked it up + understood well. The models I'm able to create are quite close to the drawings I've sketched, this is good, but I need to push the limitations more.

After modelling returned to sketching. Tried one (design) direction but was a dead end. Began to introduce assymetry to design + realised may be ergonomic/functional reasons for doing so. Left/right handedness.

Then introduced curved lines to the designs. Theme is somewhat 'watered down' but resulting design is more interesting + challenging for software.

See sheets 09.03.11-SU-01.psd → 09.03.11-SU-04.psd

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 10/03/11	Software Google SketchUp

Description of Activity

Started by modelling some of the designs from yesterdays sketches. Disappointing results. Even though I can draw arcs or splines and extrude, the faceted surfaces on curved edges have to be swept surfaces, which S.U. can't handle very well. Simply no way I can tell to control both profile + path.

Abandoned those designs + moved on to others I'd sketched, but taking too much time to get right and not moving the design forward.

Returned to sketching. Because I'd not had much success modelling I returned to the earlier theme. This didn't really develop until I started to draw surfaces at different levels. Then two new themes quickly emerged, one of which seems to have further value.

A third theme emerged 'by accident' when I saw something interesting develop in a sketch + went along with it. Turned into a much simpler direction of internal form partially exposed through an external 'skin'.

See sheets 10.03.11 - SU - 01.psd →
10.03.11 - SU - 03.psd

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 11/03/11	Software Google SketchUp

Description of Activity

Started the day again by modelling some of previous days designs. My main reason for doing this is to check whether the software is capable of modelling what I've drawn - not much actual design activity coming from within the software, though SketchUp's limited toolbox is without doubt influencing the product's aesthetic. Without doubt the biggest constraint is an inability to loft or create twisted profile surfaces eg

Quite happy with new concept direction, day's sketching spent developing this. Began to introduce curved surfaces into the design, keeping in mind previous modelling problems. Concerned that even though I liked the design direction, I wasn't fully exploiting either the SketchUp's capabilities or those of the AM processes to be used to make the proto. Therefore began to look at decorative elements. See sheets 11.03.11-SU-01.psd → 11.03.11-SU-04.psd

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 12/03/11	Software Google SketchUp.
Description of Activity Modelled two of previous days sketches. Feeling very happy with where this direction is going. I'm fairly confident this will provide the final design.	

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 14/03/11	Software Google SketchUp.

Description of Activity

Arrived at some sort of conclusion yesterday regarding concept direction, and so began today by drawing the concept with introduction of 'realistic' considerations - part breakdown, split lines etc. Realised that visually the scroll wheel won't be in the centre (though geometrically it will be). Sketched three concepts for how the buttons will work, with one of these as 'favourite'

Modelled all three concepts, but in process of modelling changed my mind about which concept was favourite. A familiar situation! Need to get more realistic in terms of fitting the pcb and making the product work before I can make a final decision.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 16/03/11	Software Google SketchUp

Description of Activity

Meeting with Ian today, purpose was to go through everything I've done and make sure (i) the process still aligns with the desired outcome (research question) and (ii) there's nothing I'm missing.

Discussed the strengths + weaknesses of SketchUp – strengths: ease of use, speed of learning

– weaknesses: limited functionality (lofts, fillets), accuracy

Confirmed something I've been thinking around recently which is that what I'm doing is testing each piece of software 'to destruction'. I.e. I'm pushing it to its limits in order to discover where it fails (in terms of modelling a product). Also talked about my analysis of sketches – I've been concerned about the value of my own comments. Agreed to continue in same way with SU but review before I start next piece of software. What I should be looking for are 'remarkable' (i.e. worth remarking on) images/notes.

A key feature at this stage for any consumer software seems to be real-time editing/feedback, rather than modification + wait to update.

Detail of day's activity

Date 22/03/11	Software Google SketchUp.

Description of Activity

Spent the day experimenting with options for importing mouse features into SketchUp. Software can export .3ds, .obj and .vrml, but can only import .3DS One option is to take Solidworks model into Rhino + export.

Found better solution. Ruby script for an .stl importer. Appears to work well, dimensionally accurate, although model comes in with wrong orientation. Not serious though, stl imports as a group, so can be rotated + all parts maintain relations.

Also found an .obj importer, might be useful for others but no advantage over .stl importer for me.

Found a commercial option by Okino Computer Graphics (www.okino.com/conv/exp-sketchup.html) Creates SU files from Rhino, SW, ProE, STEP etc Costs \$395/\$495 (limited UI / full UI)

Found commercial STEP translator (www.sycode.com/products/step-import_su/index.htm) Costs \$95

Initial thought is that best working method is to import all features (on separate layers) before building the model.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 23/03/11	Software Google SketchUp.

Description of Activity

Converted features + cutters for original mouse to .stl + imported to SketchUp. Positioning correctly was easy enough Cleared up .stl files by deleting lines on flat faces (i.e converting to single surfaces). Laborious, but necessary to make final modelling easier

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 27/03/11	Software SketchUp.

Description of Activity

Drew the final design elevations at 1:1 scale over internal safe model. Still not decided on part break up but this can come while modelling.

Imported elevations into SketchUp. Rotated, scaled + placed. Scaling is particularly difficult because images automatically scale from a corner or edge, can't pick a point on the actual drawing. Have probably introduced some inaccuracies here, but hopefully I will notice + resolve in the modelling

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 28/03/11	Software Google SketchUp

Description of Activity

Started on the 'final' design model, using imported sketches as underlays

First task is to make sure I can create a model using the imported features. If that's the case I'll refine the design, assuming there is some time left.

Made basic shape of internal + external parts

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 30/03/11	Software Google SketchUp

Description of Activity

Met with Ian and showed latest developments. Ian is concerned that each phase (ie each software review) doesn't drag on too long, so agreed I will try to have this wrapped up by our next meeting (14th April). Gives me about 1 week of work (because of preparing DesRes presentation)

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 04/04/11	Software

Description of Activity

Previously Ian had suggested that the internal part didn't need to be faceted, however for me this is an important part of demonstrating how the tool (SU) generates its own aesthetic. Spent the day making this faceted part. When overlaying with internal features I thought I may need to make it bigger, but after taking the original mouse apart + placing PCB inside the SLS's I previously made, it seems there's enough space

Design Diary

Analysis of Consumer-oriented CAD Software

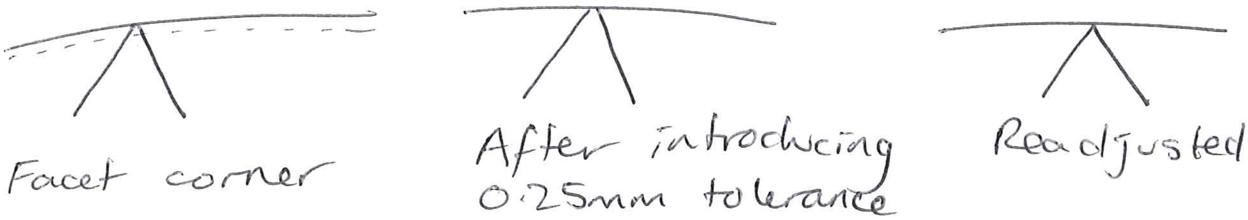
Loughborough University

Detail of day's activity

Date 07/04/11	Software Google SketchUp

Description of Activity

Realised I hadn't modelled internal part with tolerance to enable fit, so remade that part (0.25mm gap). This required adjusting the facets, probably could have got away with not bothering, but wanted to be as exact as possible



Began considering part breakup, in particular whether internal part is open at top or bottom (decided on top). Opened up the bottom of main body to reveal internal faceted part.

Decided to extend width of body by 1mm to help w/ fit of internal parts

Layer system of SketchUp is increasingly annoying - parts on different layers will merge, even if invisible. Also buggy – often changing layer of part doesn't update in terms of visibility.

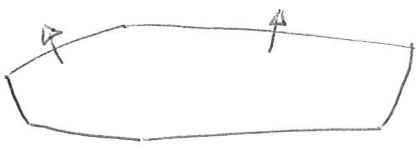
08/04/11 | Google SketchUp

Most of the day spent remodelling area around buttons to allow for travel as they are pushed. Buttons need 1mm movement. I'm designing as you go along here...
Realised that as the design currently exists, can 'see through' ~~th~~ product in side profile. Need to model a cut-out to allow buttons to travel, then extend inner body.

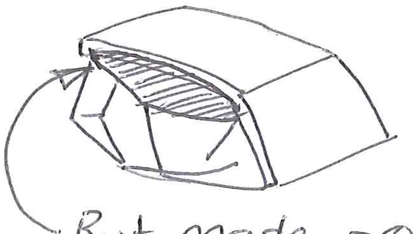
There will be a problem exporting stl file for manufacture if parts are not solid. No way of checking in SketchUp, but found ruby script which allows you to check, plus shows where errors are. This sums up one of my prominent feelings about SU, the basic package is lacking in some quite fundamental areas, but the open nature allows user community to fill the gaps. Plug in works quite well, but awkward - usual problem is tiny surfaces not deleted, but (OGL?) rendering means inaccurate when zoomed right in.

09/04/11 | Google SketchUp

Frustrating day. Began by increasing size (height) of inner body, but realised when finished this created problems where inner body protrudes.



Increased...



But made problems here

Then realised I had no way to return to state before I began — I hadn't created a new save version. Too used to a history tree... So 3 hours work wasted.

Came up with a different solution which doesn't increase the whole thickness

Also noticed zoom in/out in SU is counter-intuitive - roll forward (away) to zoom in, roll back (~~towards~~) to zoom out. Strange I haven't noticed this before.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 12/04/08	Software Google SketchUp

Description of Activity

Continued with modelling. Shelled out the inner part and created a recess in the top part to allow 'travel' in the keys. Laborious, as there's no 'shell' or 'offset surface' command, so all the surfaces need to be built manually. The 'Solid Inspector' plug-in is a god-send, ~~even though~~ it doesn't make everything easy, but I'm pretty certain it would be impossible to find all the errors without (most are small edges or surfaces that only become visible when zoomed really close). Feels like I'm getting near the end now though...

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 14/04/11	Software Google SketchUp.

Description of Activity

Meeting w/ Ian. Discussed how to output the finished model, I should be able to use the department's Objet machine as long as final year students aren't using it. Aim is to finish the model by the end of this week, then review software, also method of diary keeping.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 15/04/11	Software Google SketchUp

Description of Activity

Continued with process of adding internal features. Some design changes required because my new design breaks the parts differently to the original, but fairly straightforward.
Split the top ~~soft~~ part to create both buttons, + added features. Filleted some edges. Started to add features to internal part, this is more laboured.
Because there's no (simple) way to keep 'old' or reference surfaces, I find myself more + more going back to old save points to copy untrimmed surfaces + paste them into the current model. This (surprisingly) works very well - the surfaces come in in exactly the right position.

Design Diary

Analysis of Consumer-oriented CAD Software

Detail of day's activity

Date 16/04/11	Software Google SketchUp.

Description of Activity

Was hoping to finish today but not quite. The task of adding internal features is a lot worse (more laborious) than I anticipated, especially the process of finding surfaces + edges to delete when a volume won't knit to solid.

Redesigned the snap feature on the fly (for bottom cover to internal part) because features 'inherited' from original model were too complex.

Quite late in the day, noticed some of my surfaces (in particular the faceted ones) had had the ~~g~~'soften edges' command applied. Not sure if I'd (mistakenly) done that, or it was some kind of bug. Anyway, it meant copying surfaces from a previously saved model + re-inserting – took about an hour to fix.

Also noticed a seriously dodgy feature this shape  instead of . Not sure where it came from, but another hour spent (unsuccessfully) trying to fix. Couldn't solve, in the end gave up (the feature is internal, so not ~~in~~visible, but offends my perfectionism ;-))

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 18/04/11	Software Google SketchUp

Description of Activity

Continued with creation of internal features. Realised there was a problem with main screw tower due to my changing design of how parts fit together, so had to redesign this. Also redesigned snaps at front of the mouse to make simpler.

Imported stl file of mouse scroll wheel which made model perform much more sluggishly but was necessary to create hole ~~for~~ I am at limits of where the top part will interfere with scroll wheel when buttons are depressed - should have noticed sooner but hadn't checked scroll wheel in model because of the performance issues - need to be more careful in ~~other mo~~ future models.

But... its finished.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 19/04/11	Software Google SketchUp

Description of Activity

Experimented with different export options.

VRML works (i.e. it exports a file). File can be opened in Rhino but all parts centred and combined (i.e. 3 parts become 1). File can be opened in ProE but same problems. File can't be opened in Solidworks (solid option gives empty part, surface option brings in 2 surfaces, graphic option fails.

Obj works. ~~File can be opened in Rhino but 3 parts are exploded.~~ Wrong. After checking again realised it works if I choose open rather than import. 3 separate parts. According to Rhino's analysis tools bottom part is solid, but top and centre parts have gaps in surfaces (i.e not solid). Not able to import to ProE or SW (no obj option).

Found rubyscript to allow .stl export. File can be opened in Rhino, 3 seperate parts, all are closed volumes. Same in Solidworks. Same in ProE. (Yet again user-generated tools work better than native.) Model is the correct size. Unfortunately exporter doesn't give options for number of triangles, looks a bit crude.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 19/04/11	Software Google SketchUp.

Description of Activity

Brought stl export into Solidworks assembly to check sizing etc. Noticed a mistake - ~~differ~~ distance between uprights which support mouse scroll wheel was 14.67mm instead of 16.30mm. Not sure how this happened, but it basically means wheel will not turn. Modified SketchUp model + exported again. This is a bit of a 'cheat' - assumption was meant to be no access to professional CAD, but I consider it okay if noted that in 'real-life' the first manufactured parts wouldn't have worked.

But then noticed, after further checking, other dimensions were wrong. After investigating for about an hour, turned out ~~an~~ whole model had been scaled down by about 11%. No idea how this happened - disadvantage of non-parametric models, you can't trace your errors.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 14/07/11	Software Google SketchUp
Description of Activity	

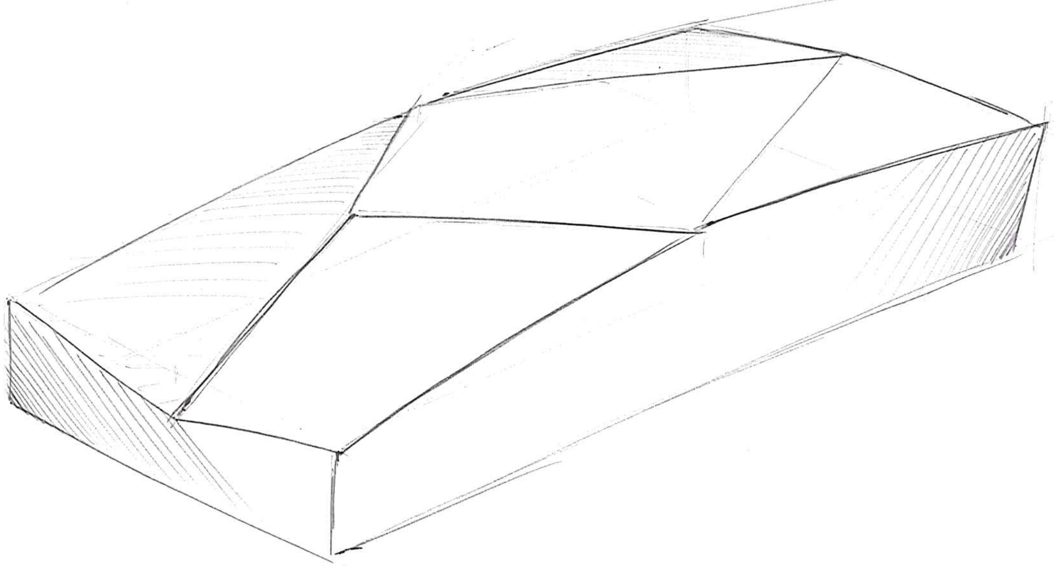
Spent about an hour analysing physical model, fitting PCB, checking fit + tolerance etc. Two main problems are that

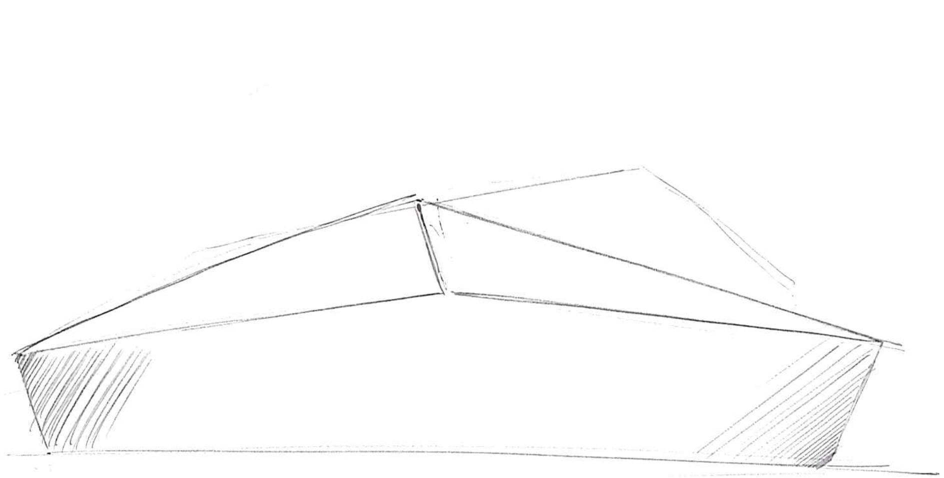
- PCB fit is extremely tight across the interior width
- Fit of bottom mouse part to internal faceted part is very tight

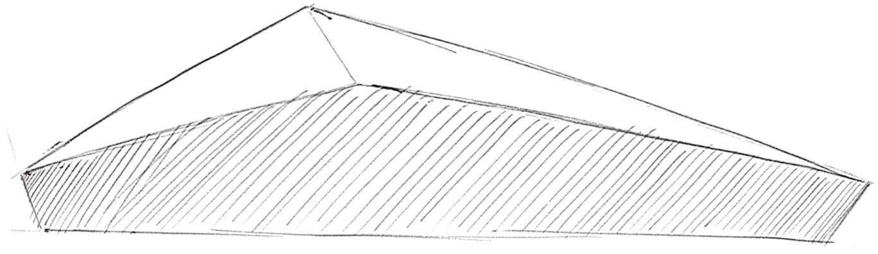
To solve, model was modified in a number of ways:

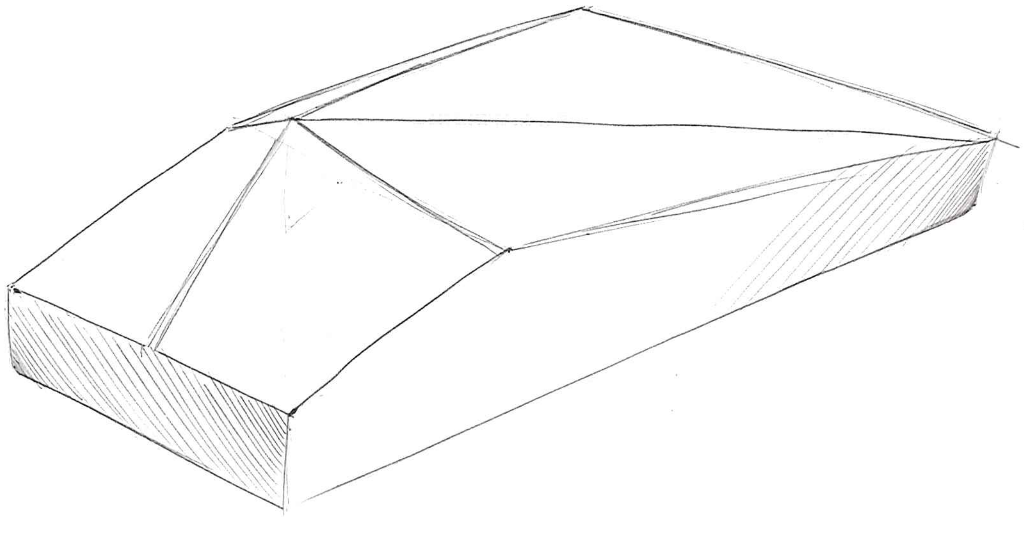
- Overall width increased by 1mm to accomodate PCB
- Snap locators at front reduced in size.

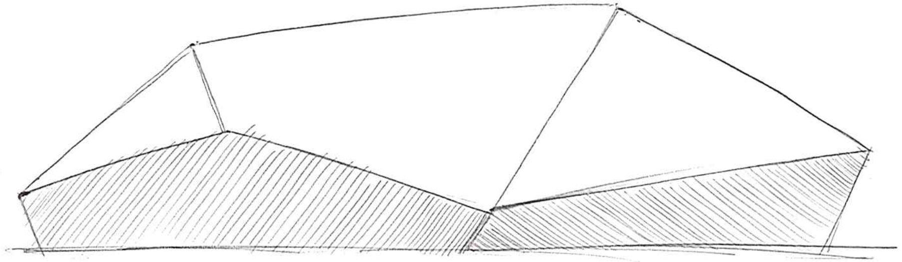
With current model, its possible to assemble PCB inside faceted part. Buttons work surprisingly well. But model broke when trying to fit cable - need more care next time (was an error of clumsiness rather than fit!)

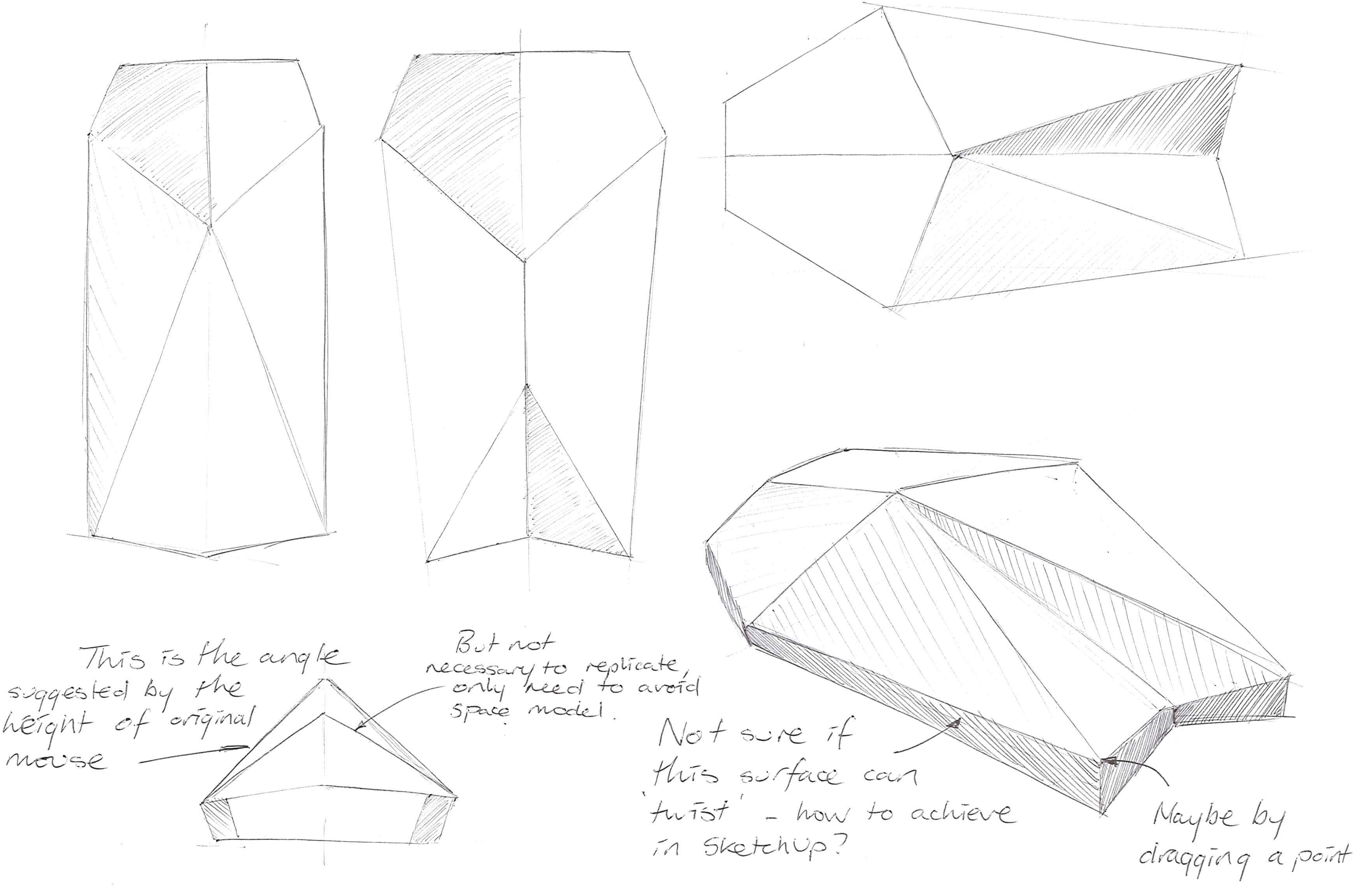




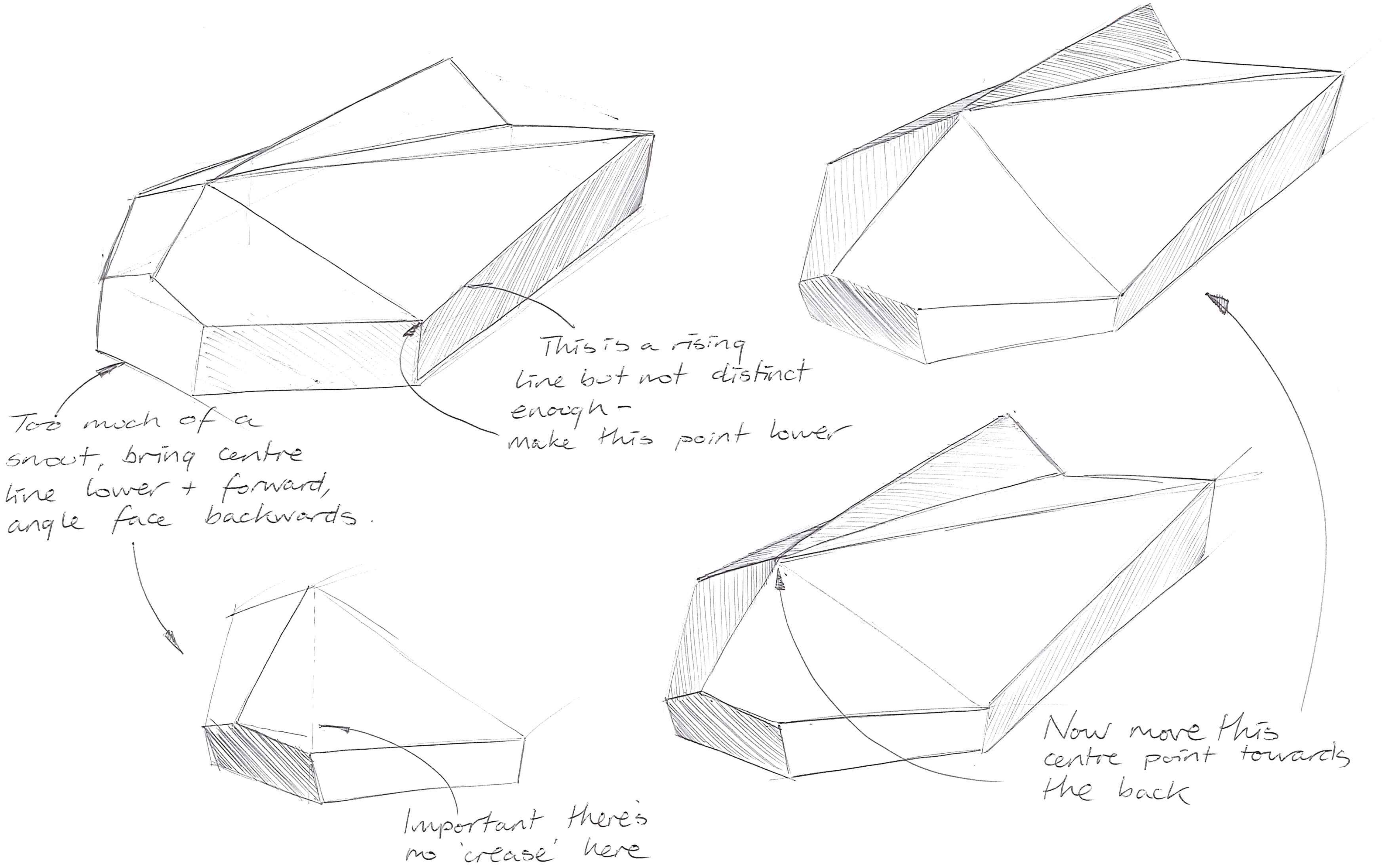


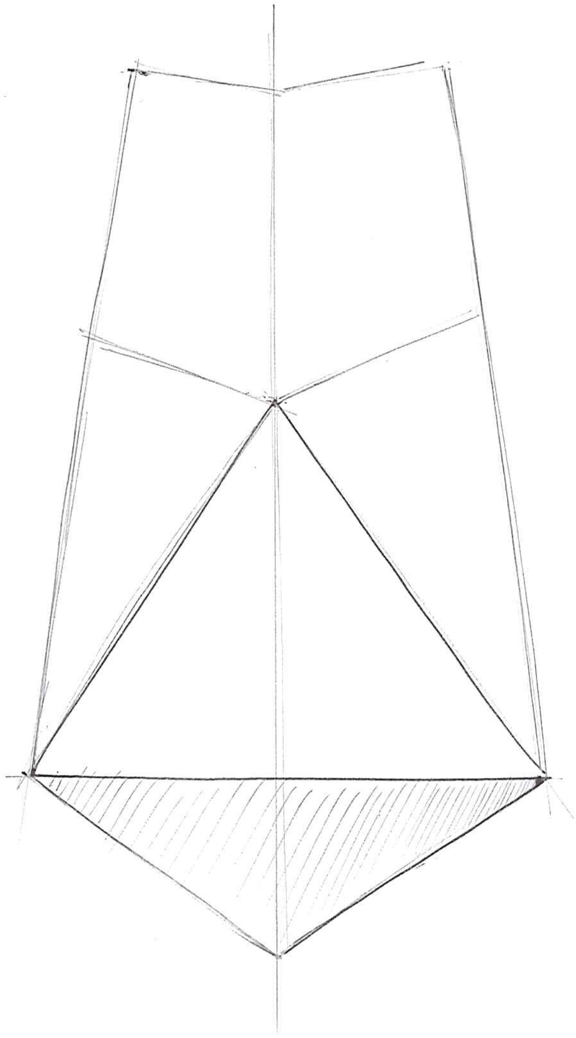


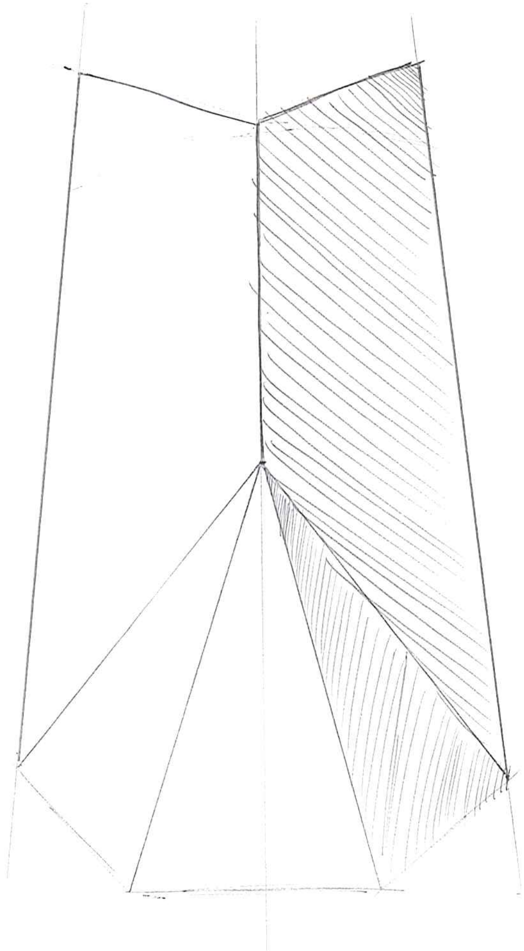


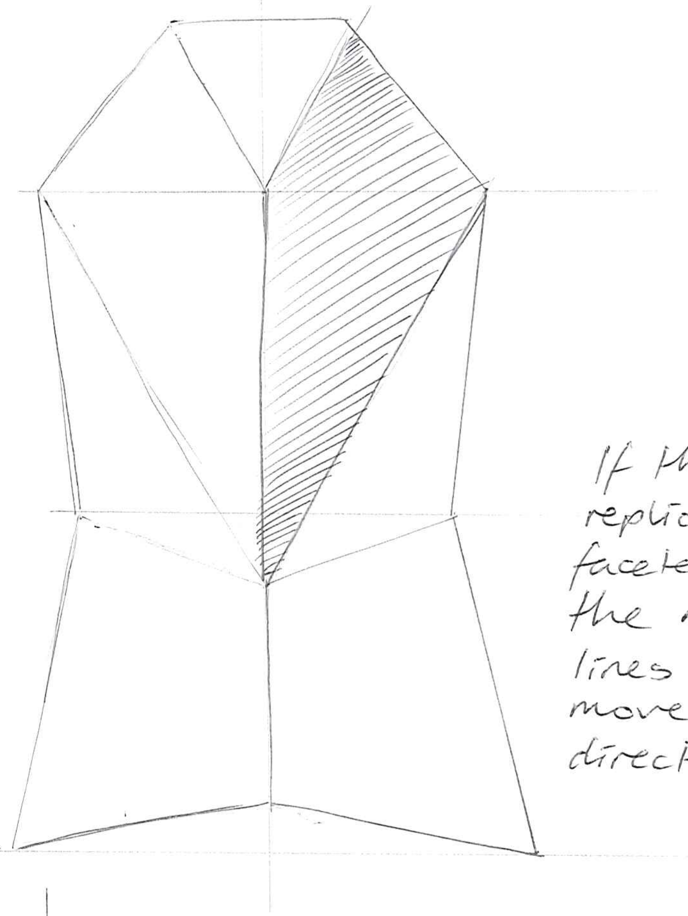


This is the angle suggested by the height of original mouse
But not necessary to replicate, only need to avoid space model.
Not sure if this surface can 'twist' - how to achieve in SketchUp?
Maybe by dragging a point

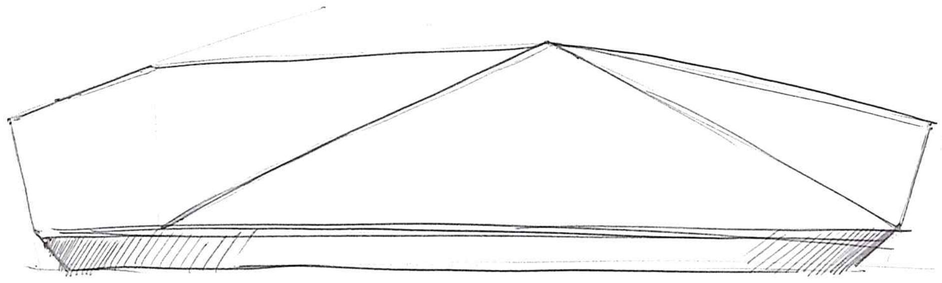

Too much of a snout, bring centre line lower + forward, angle face backwards.
This is a rising line but not distinct enough - make this point lower
Important there's no 'crease' here
Now move this centre point towards the back

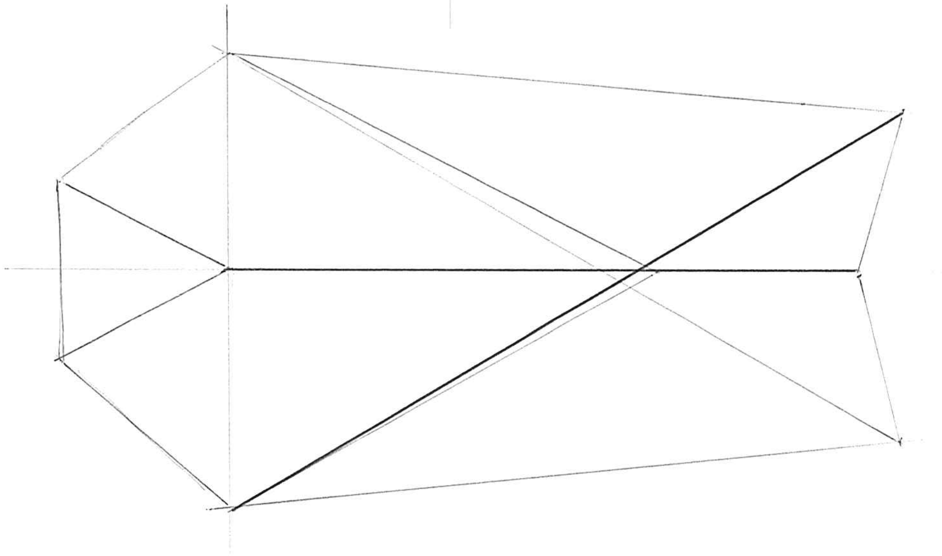


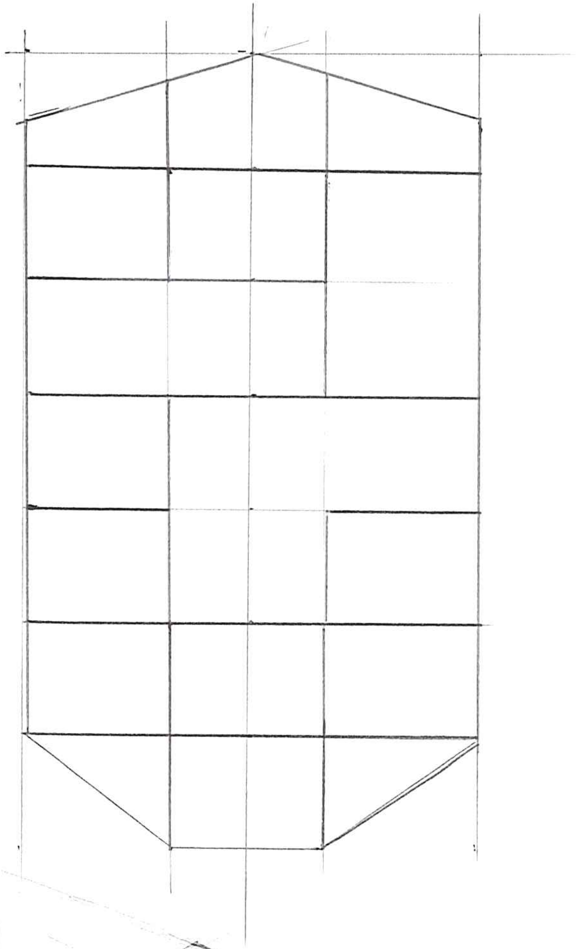


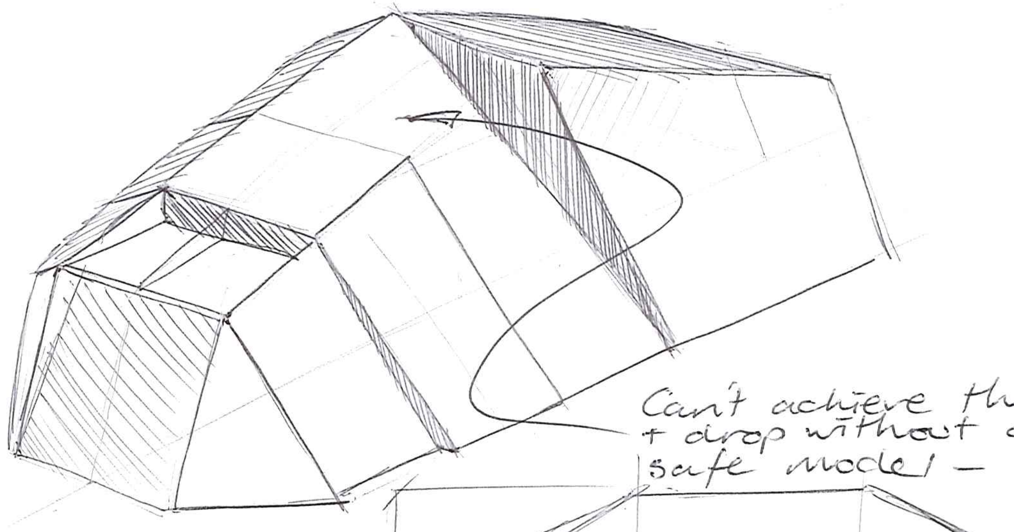


If the aim is to replicate the faceted look from the moodboard, lines need to move in opposing directions.

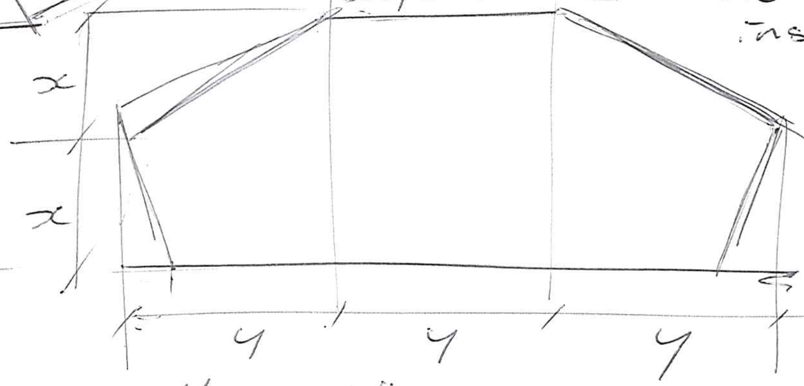


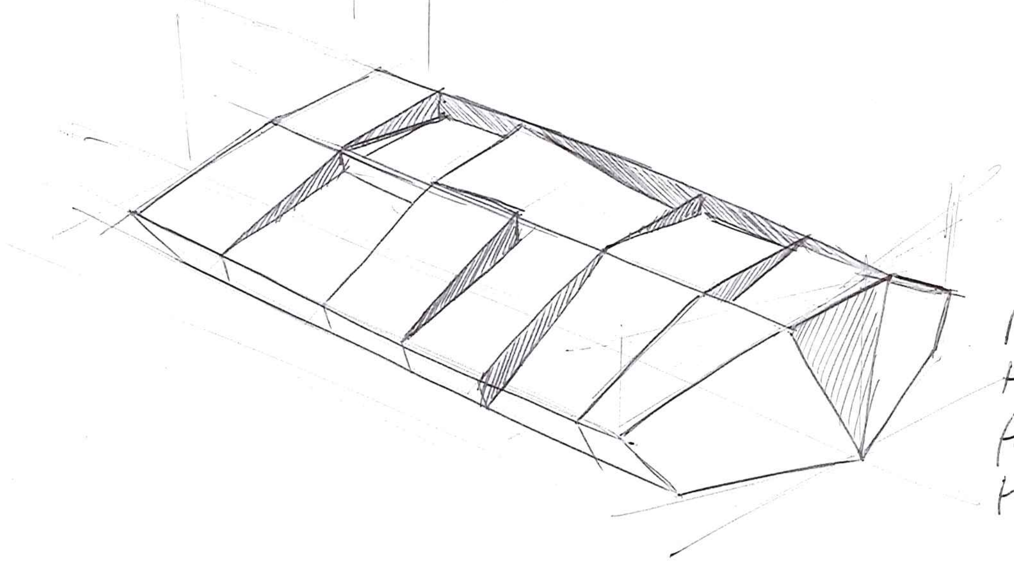




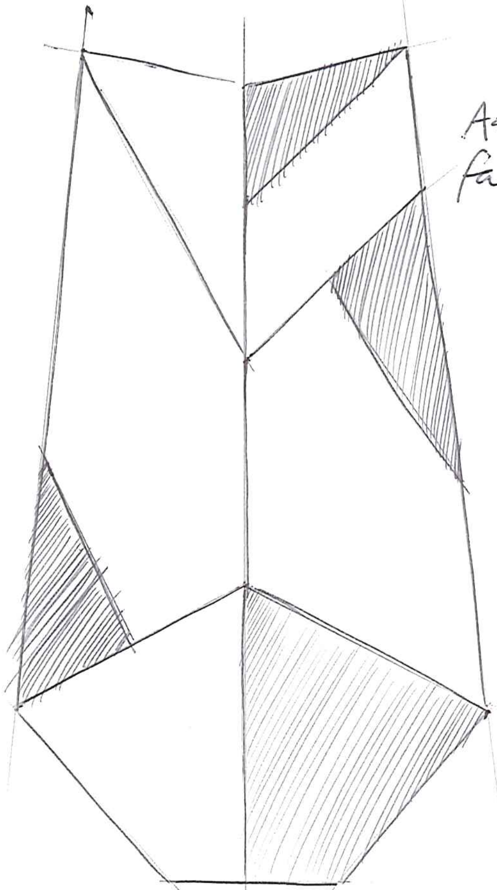


Can't achieve this height + drop without compromising safe model – do this instead

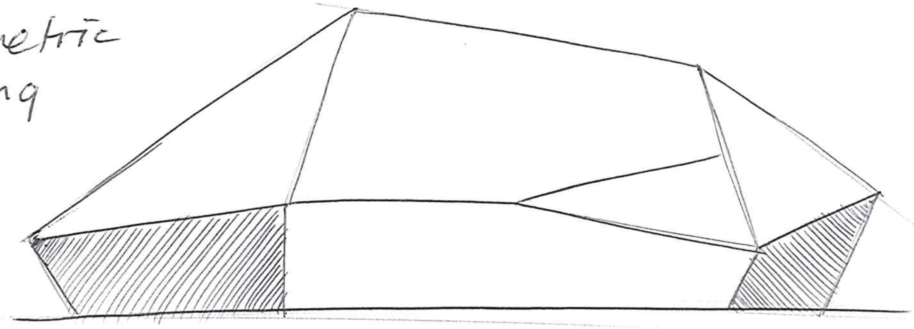




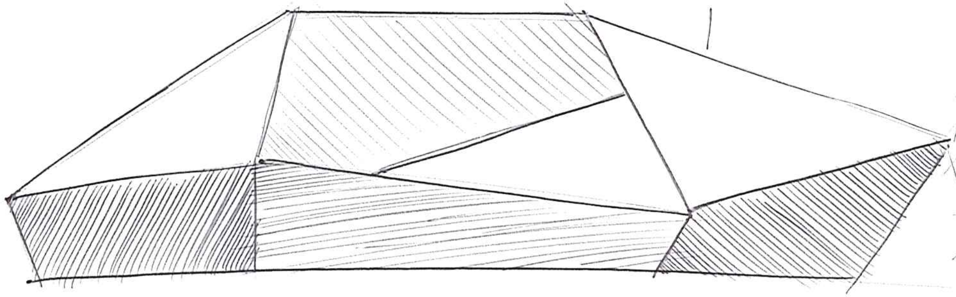
Might be worth modelling to see if anything interesting falls out, but don't really see this line going anywhere.

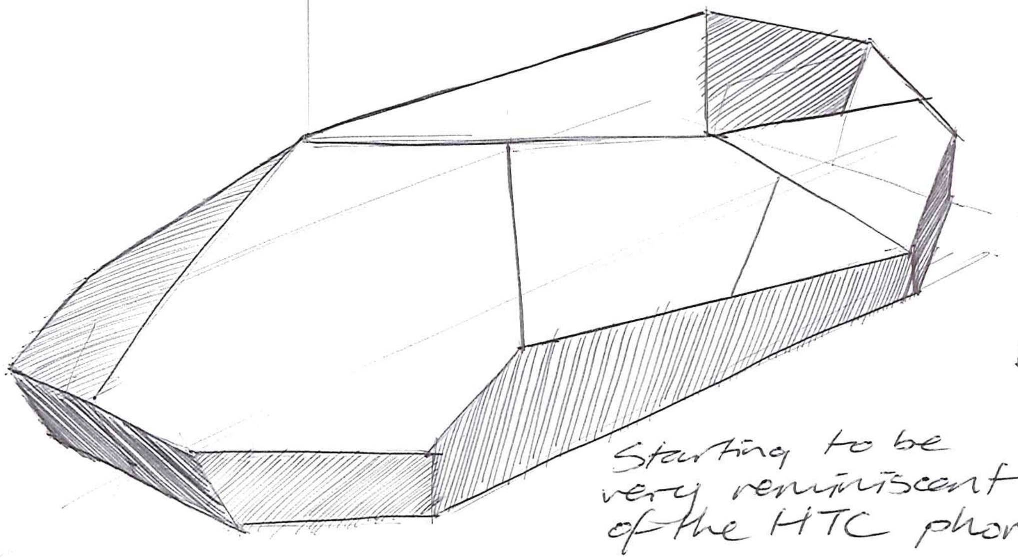


Assymetric faceting

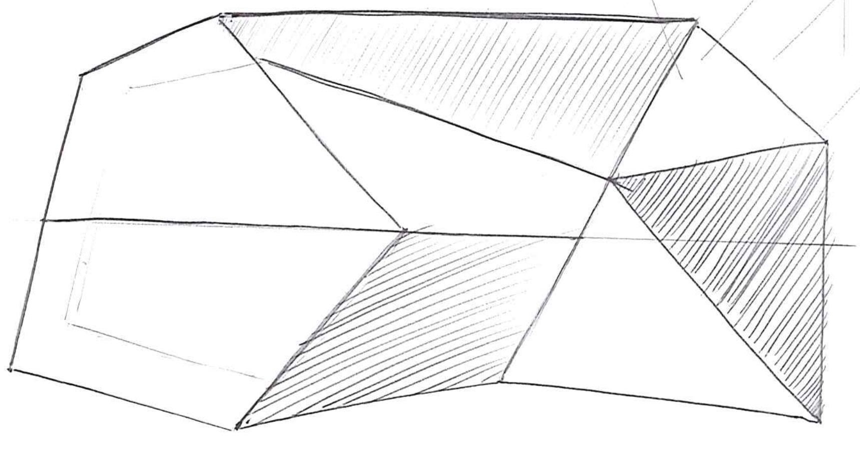


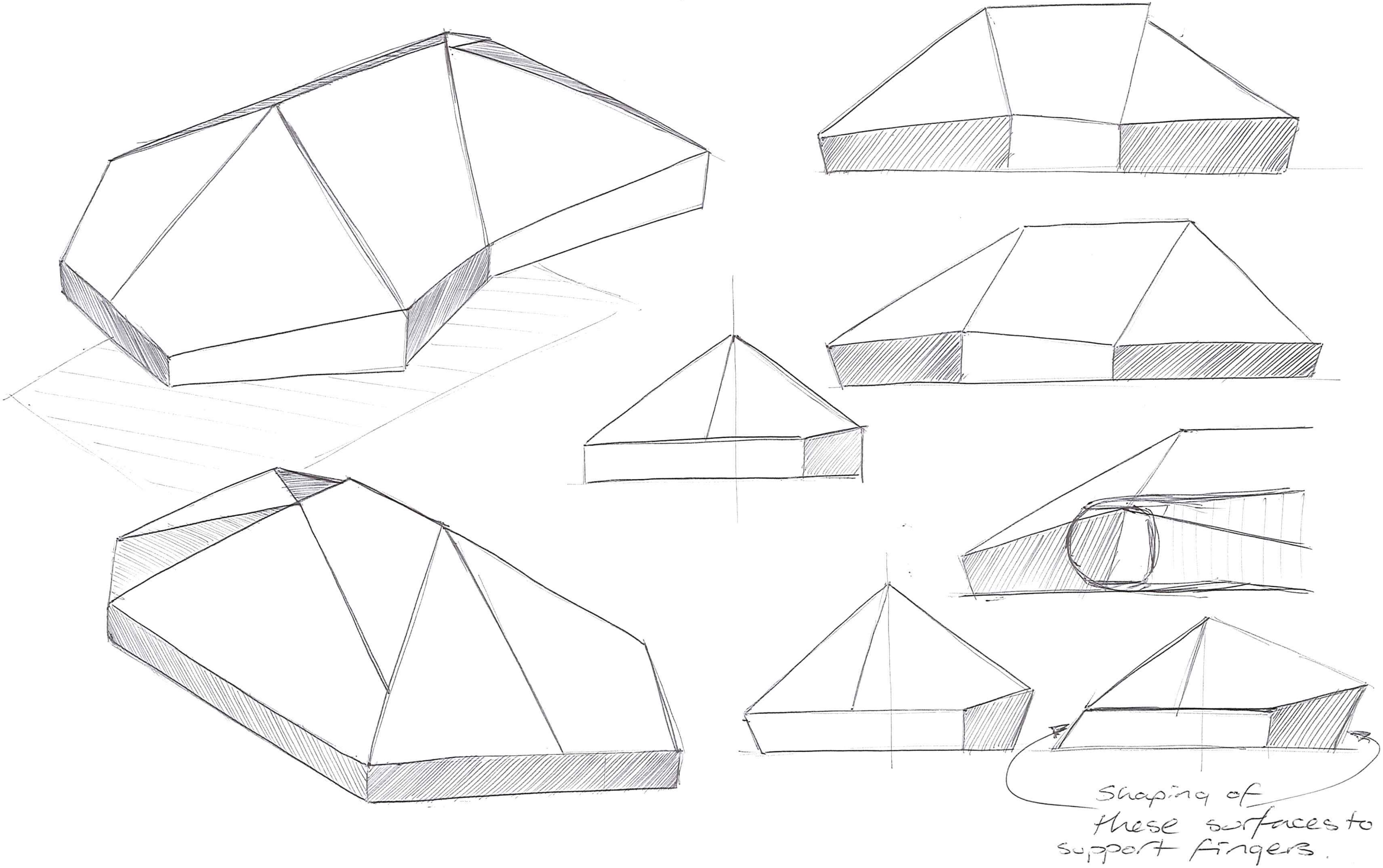
ergonomic reasons for assymetry

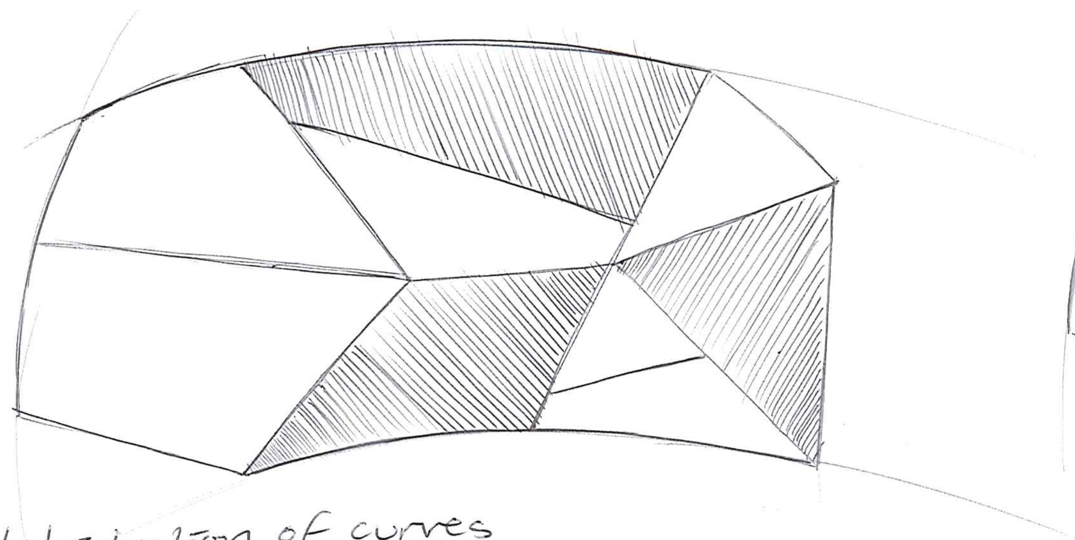


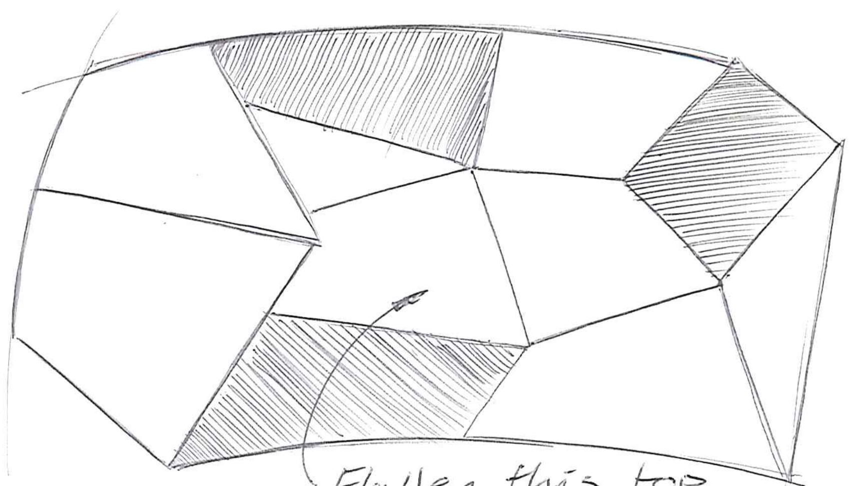


Starting to be very reminiscent of the HTC phone



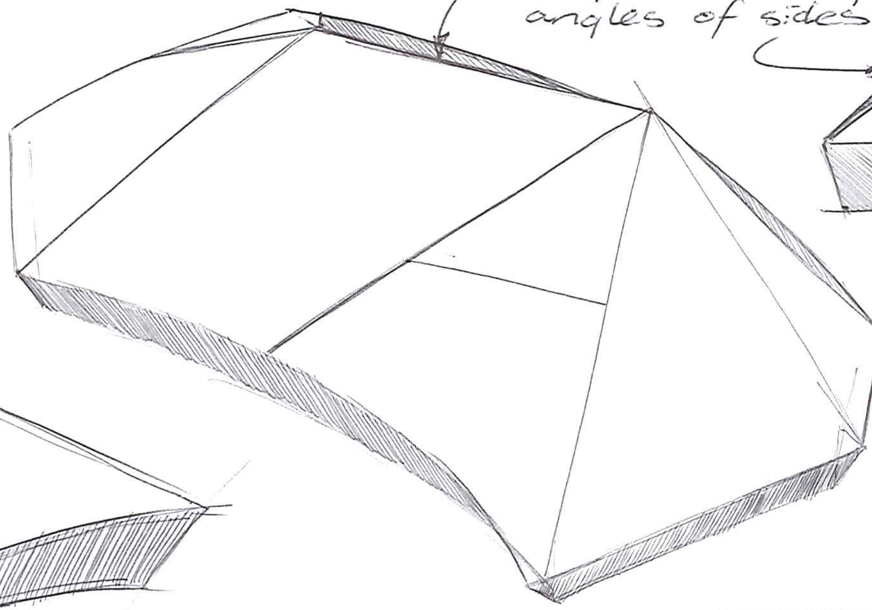

Shaping of
these surfaces to
support fingers.

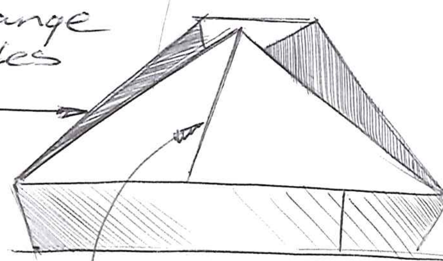




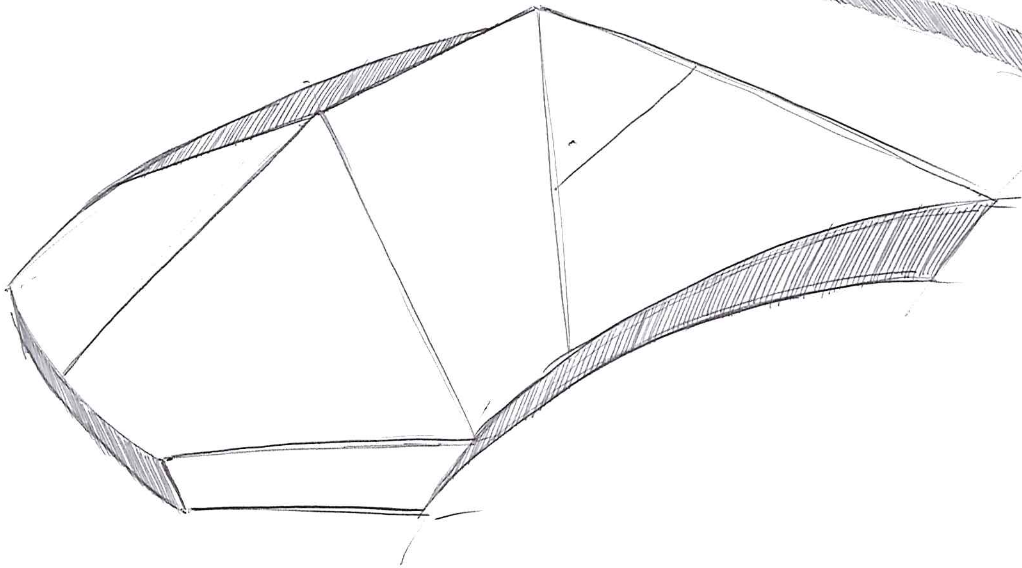
Introduction of curves into plan view.

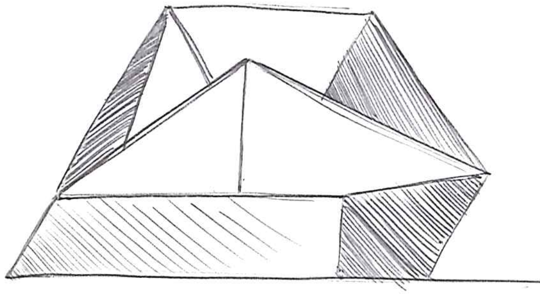
Flatten this top ridge to change angles of sides

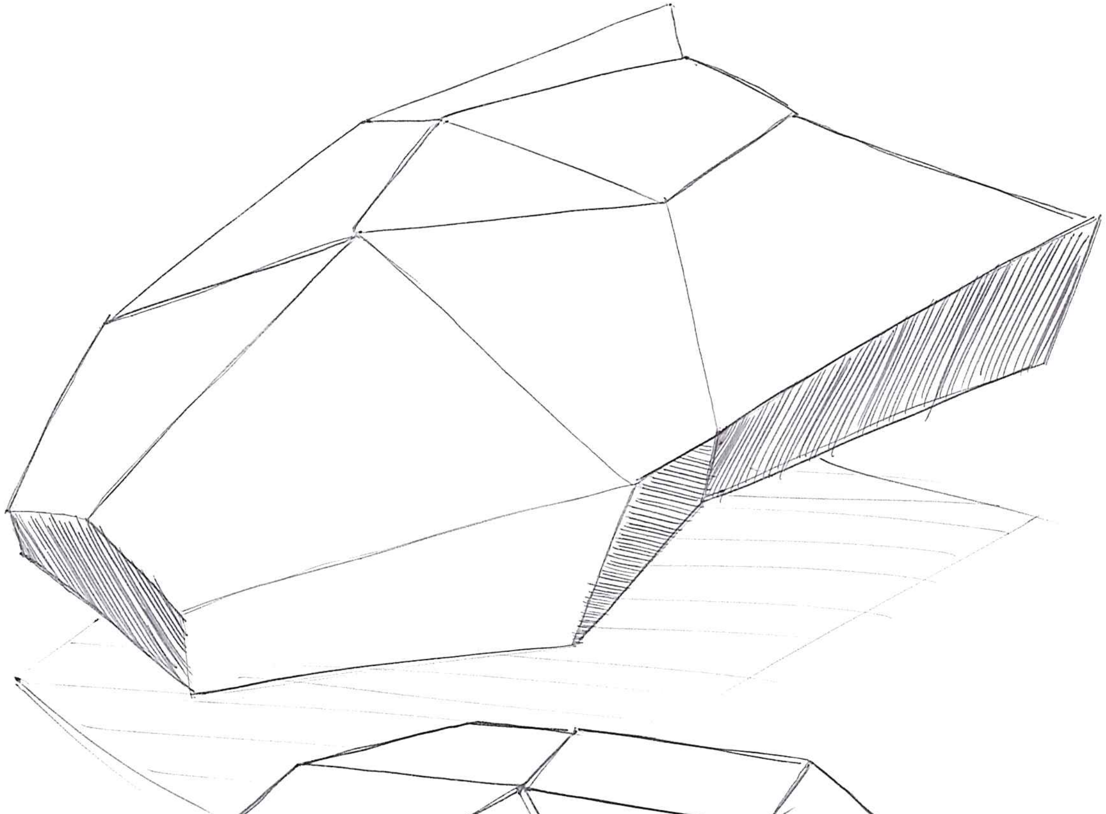


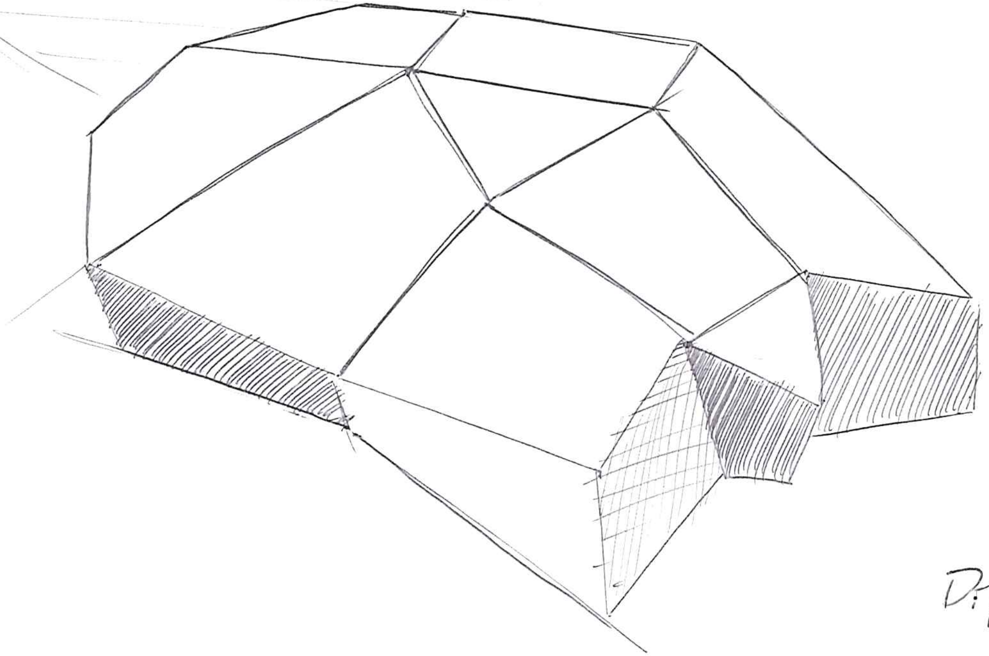


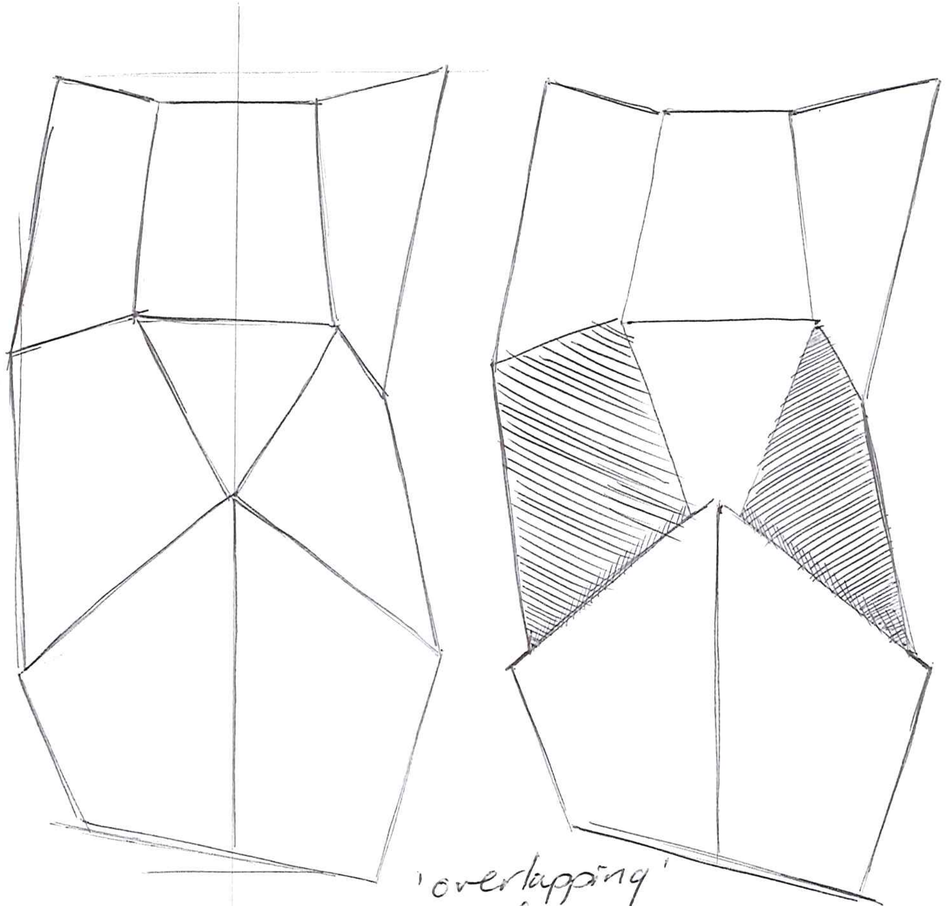
Realistically this line will need to be straight when scroll wheel is introduced



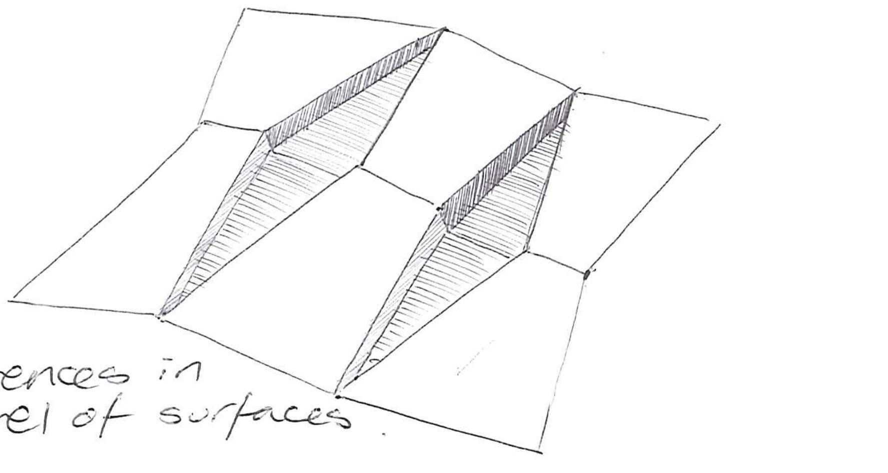




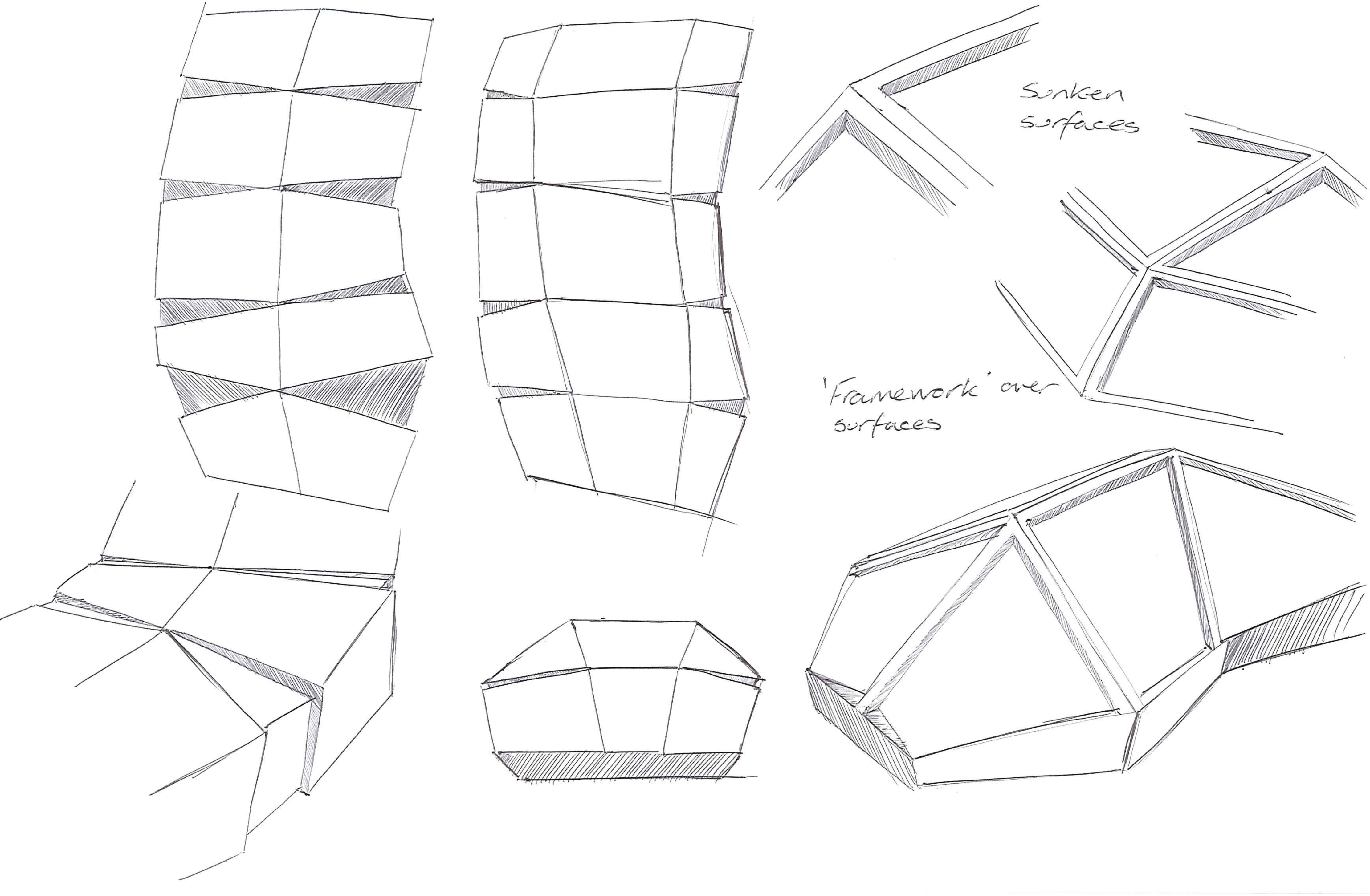


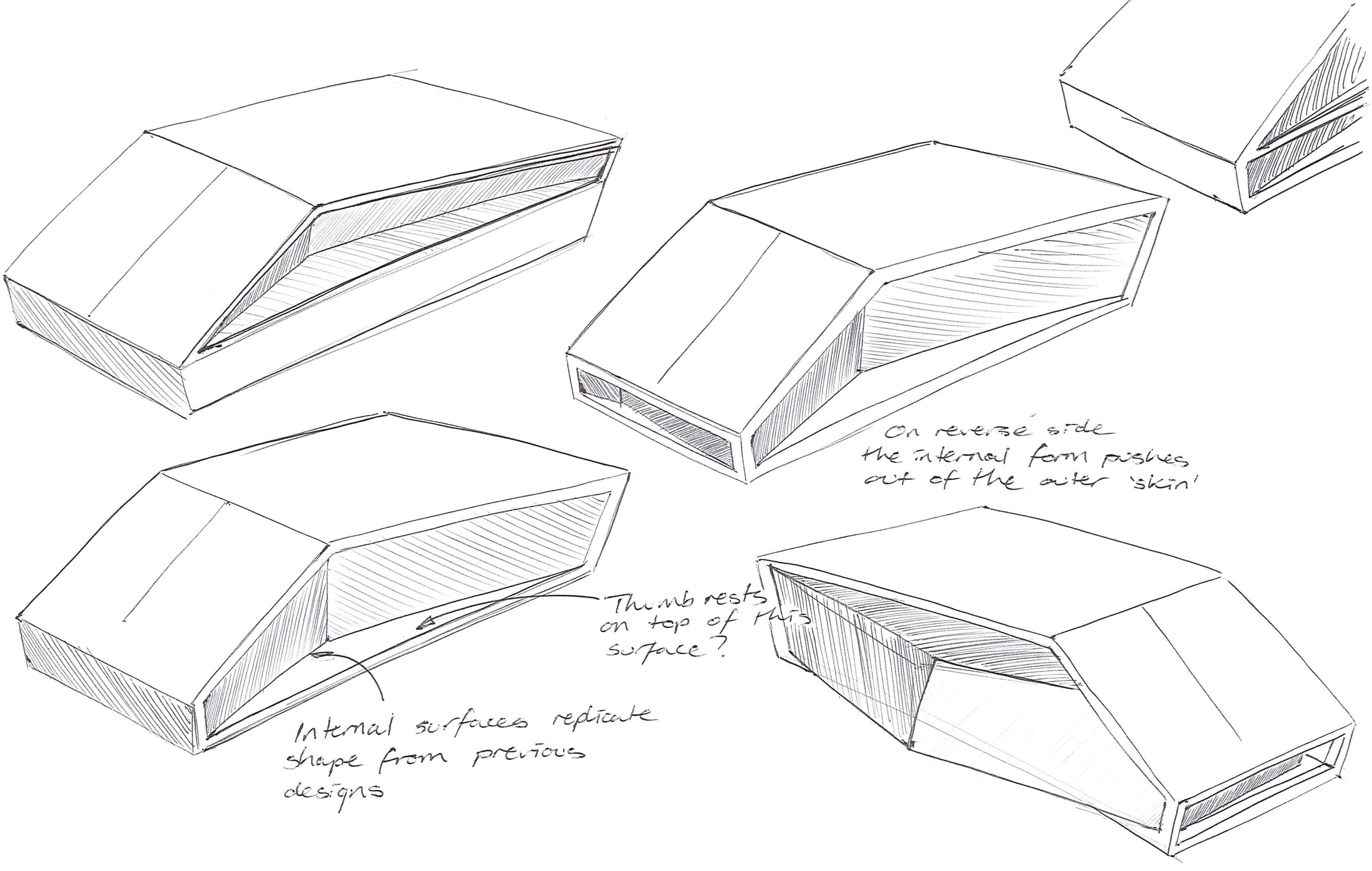


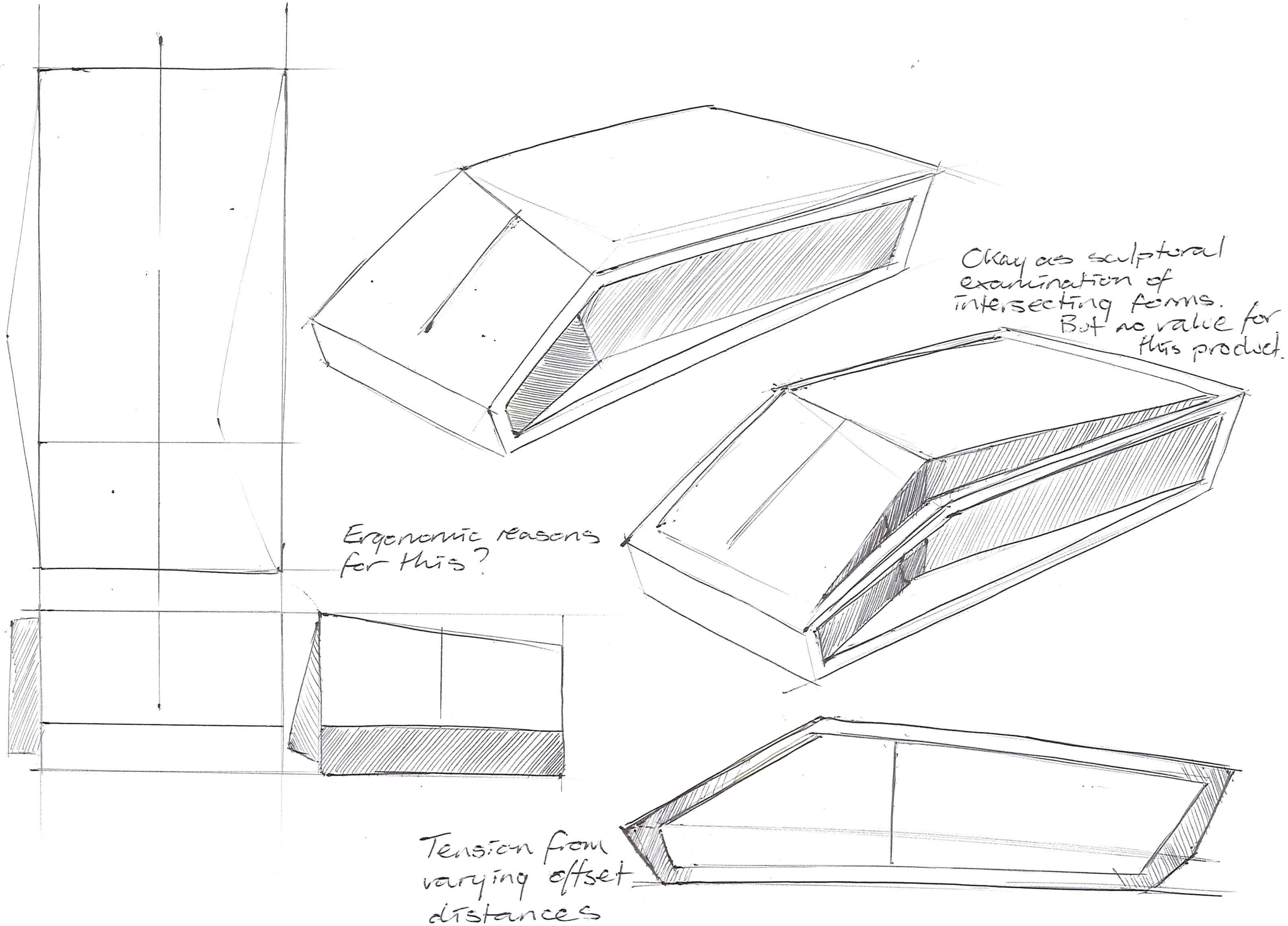
'overlapping' surfaces.

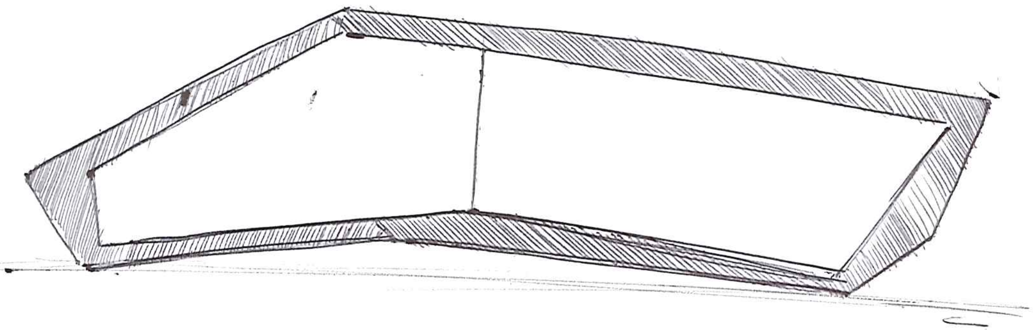


Differences in level of surfaces.

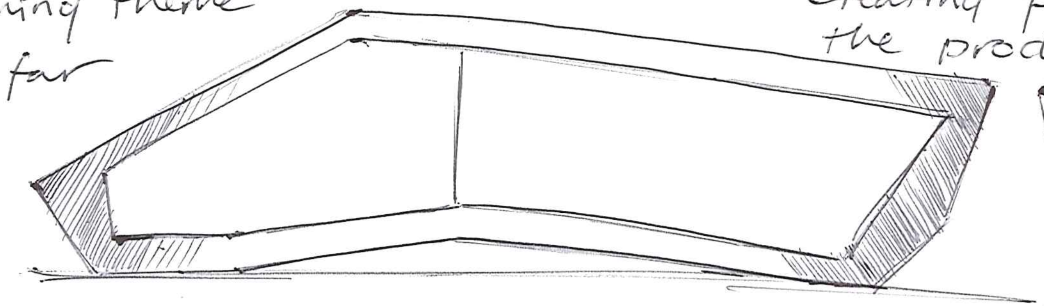

Sunken
surfaces
'Framework' over
surfaces


On reverse side the internal form pushes out of the outer 'skin'
Thumb rests on top of this surface?
Internal surfaces replicate shape from previous designs


Okay as sculptoral examination of intersecting forms. But no value for this product.
Ergonomic reasons for this?
Tension from varying offset distances

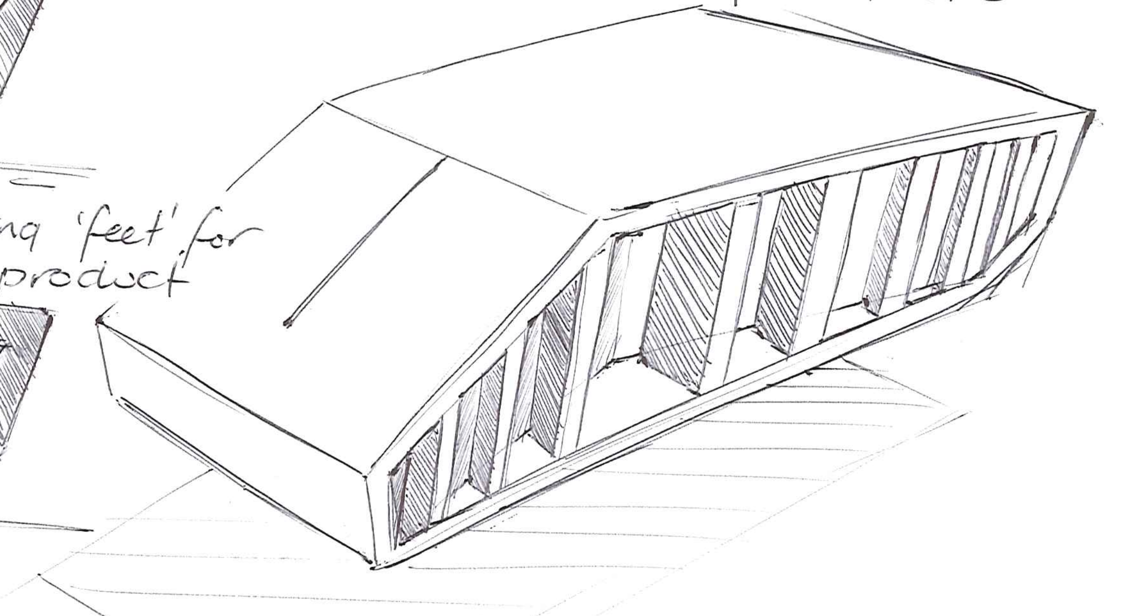


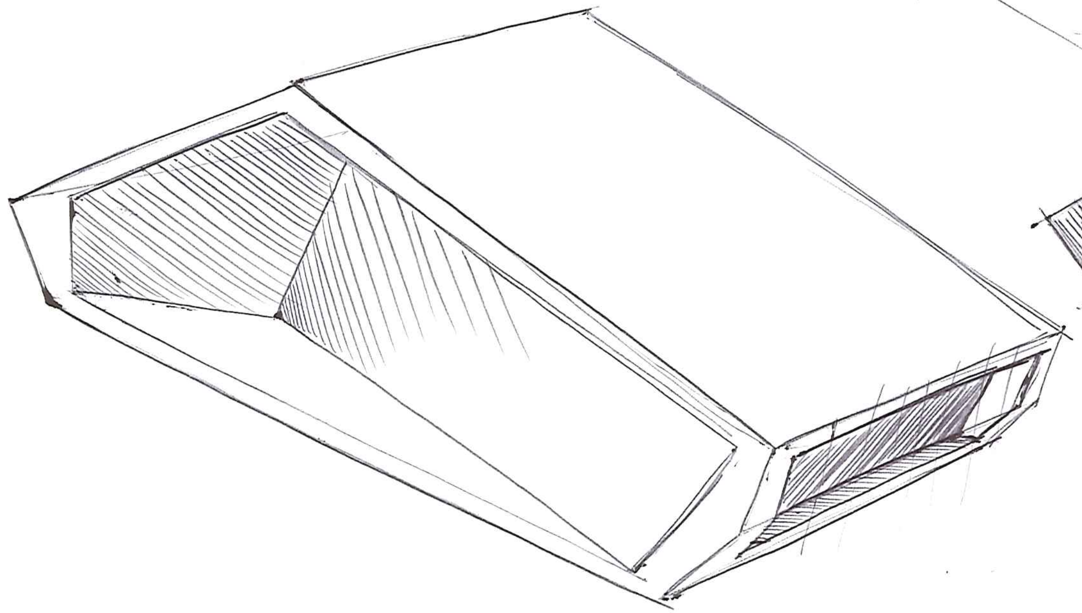
Pushing theme too far

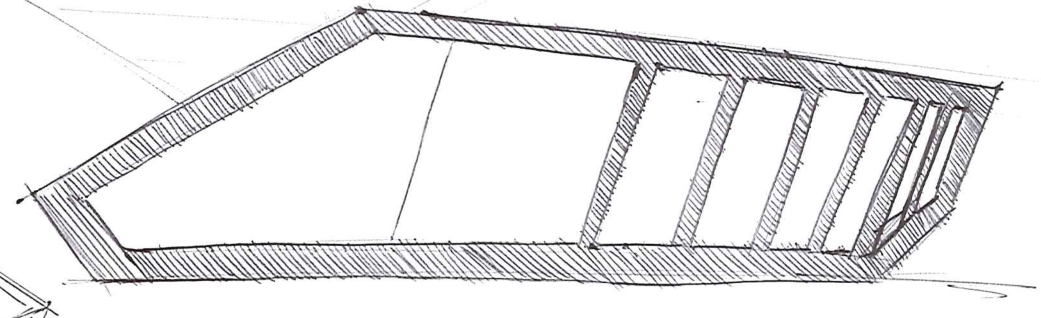


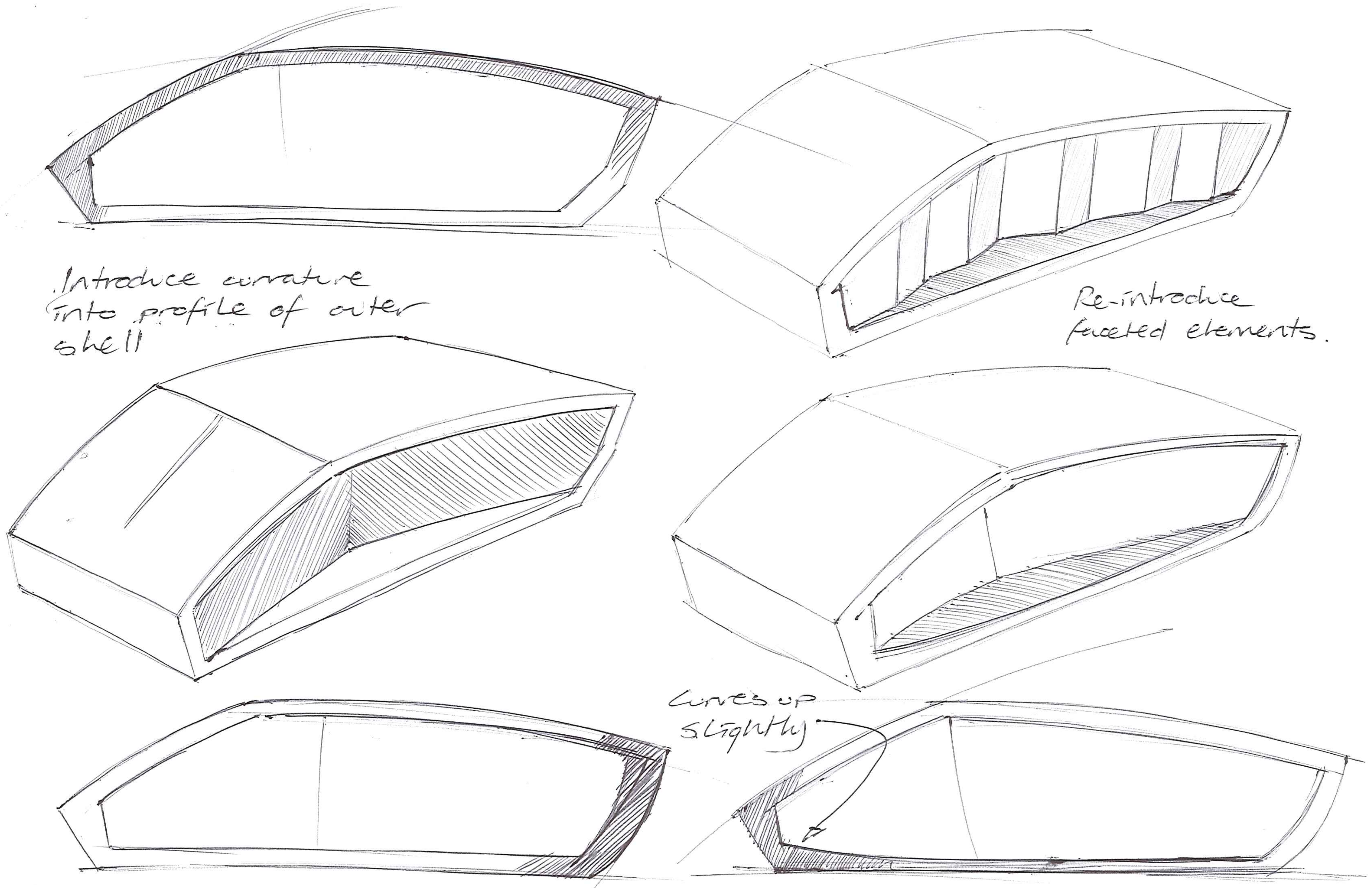
No ergonomic reasoning, purely aesthetic

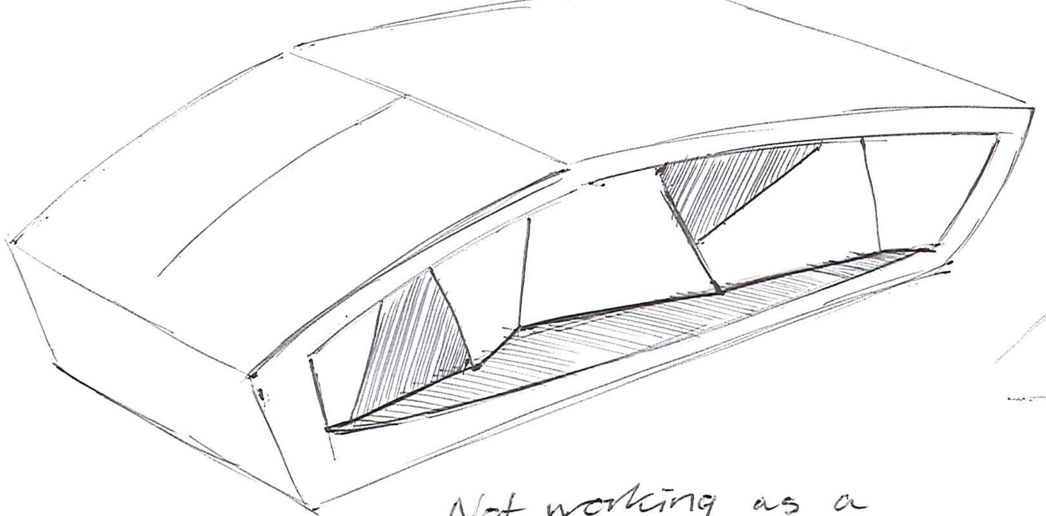
Creating 'feet' for the product

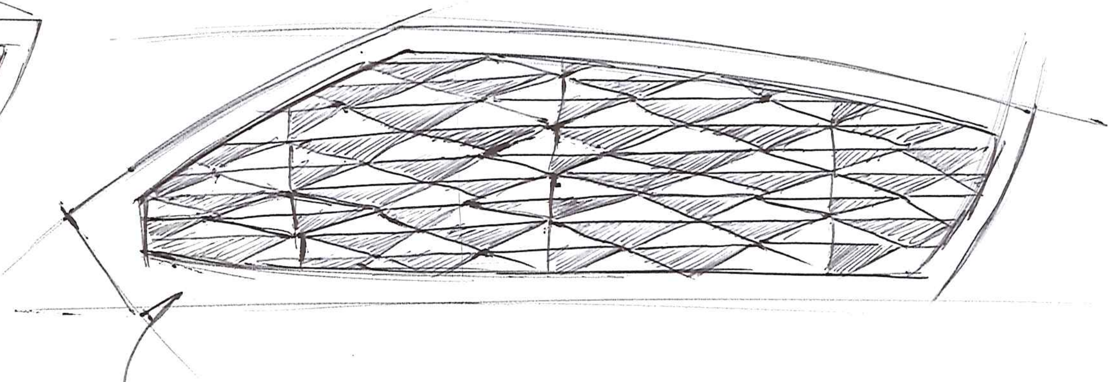




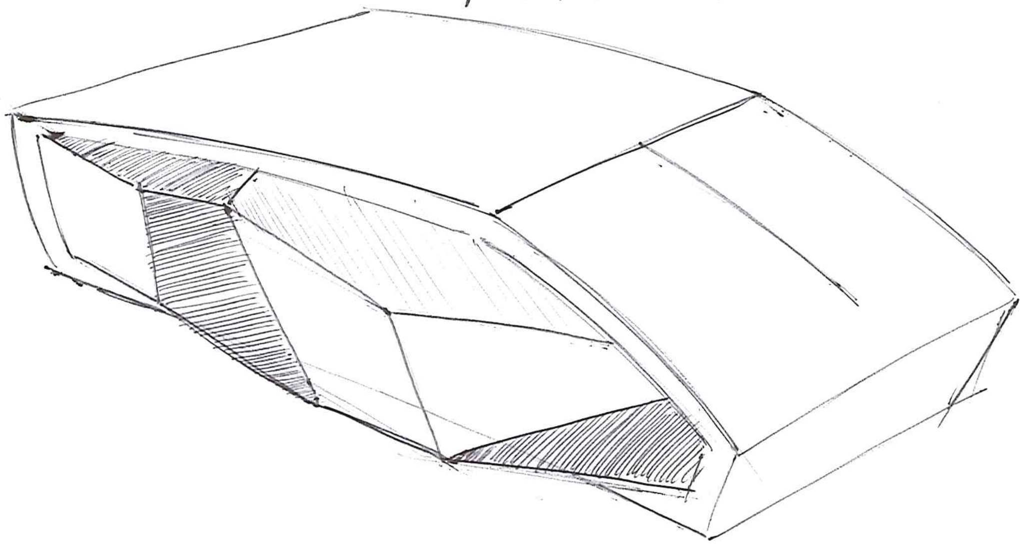


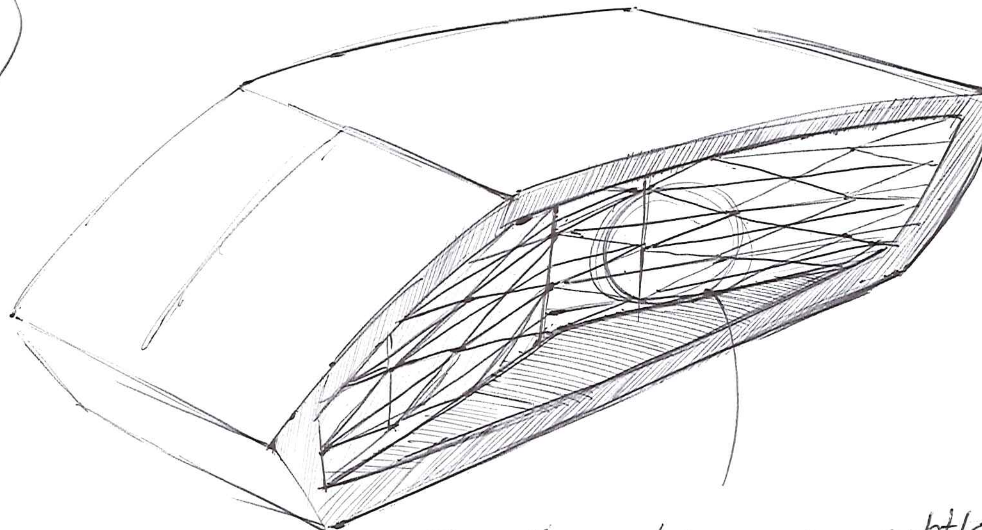

Introduce curvature into profile of outer shell
Re-introduce faceted elements.
Curves up slightly



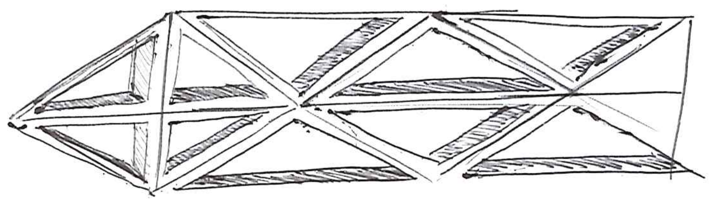


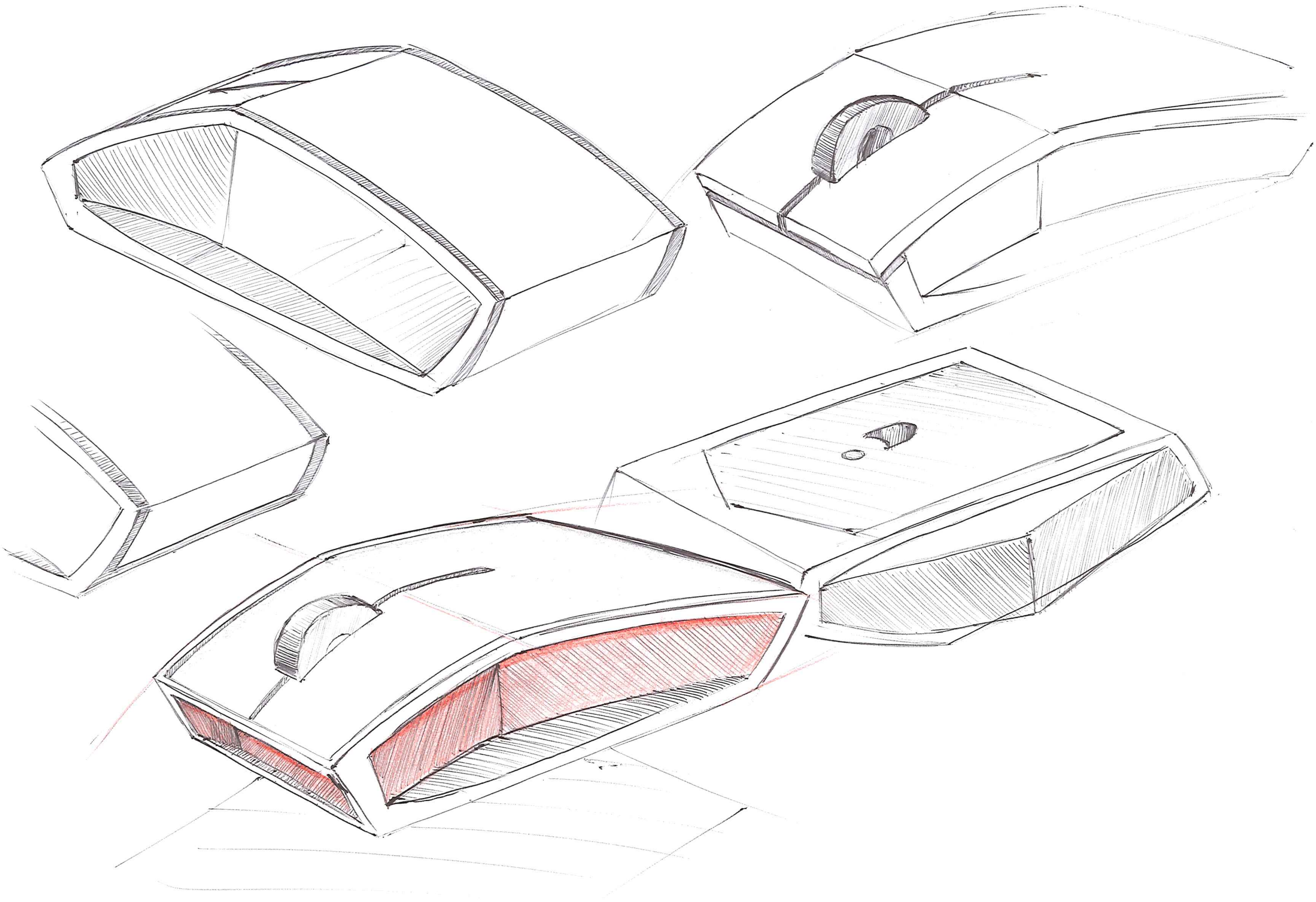
Not working as a strong element of form, the facets just confuse + dilute the overall concept. Decorative instead?

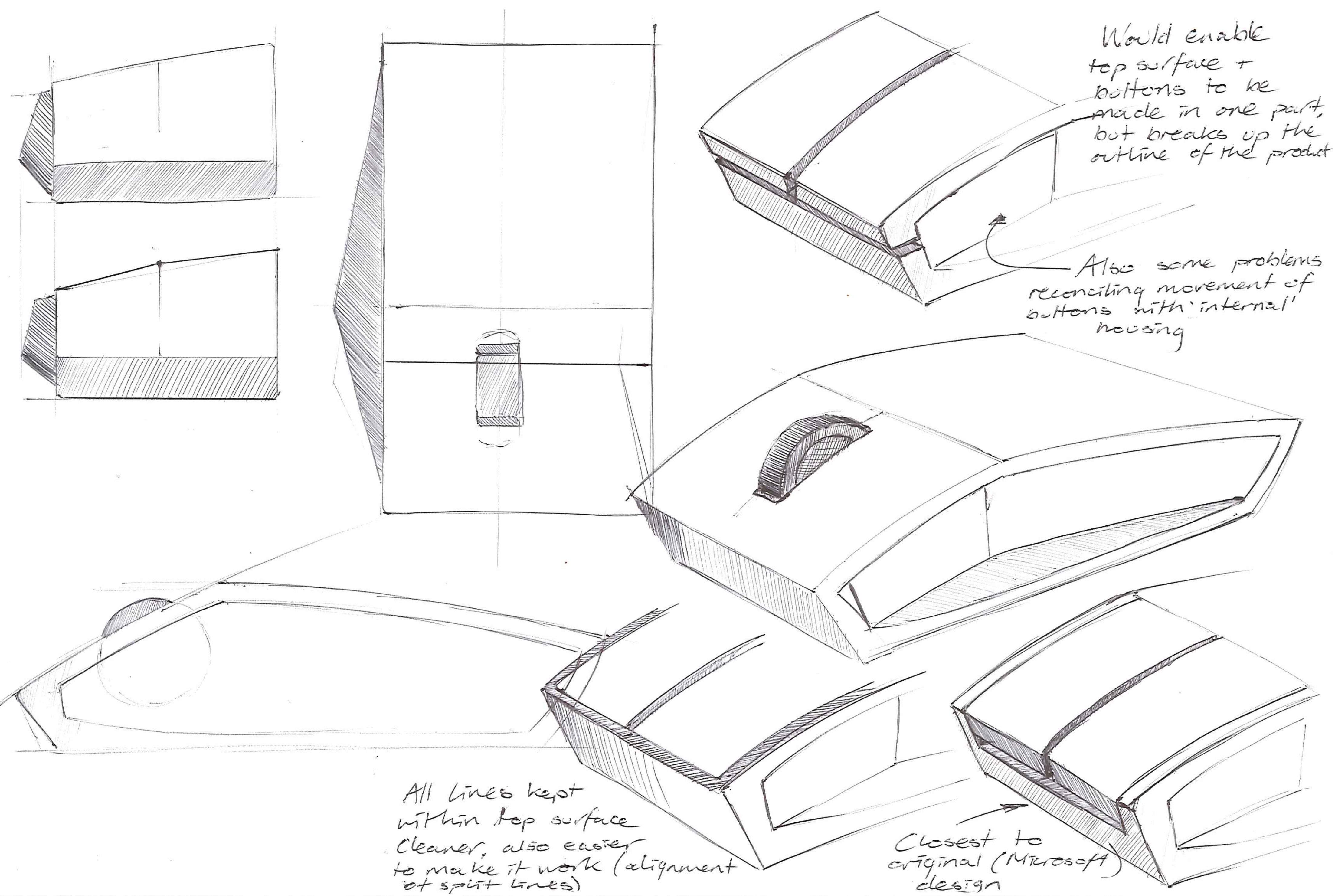


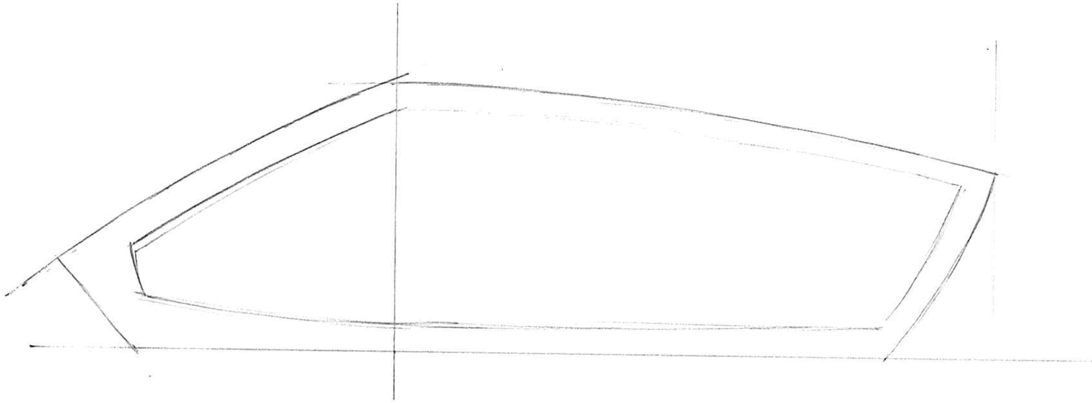


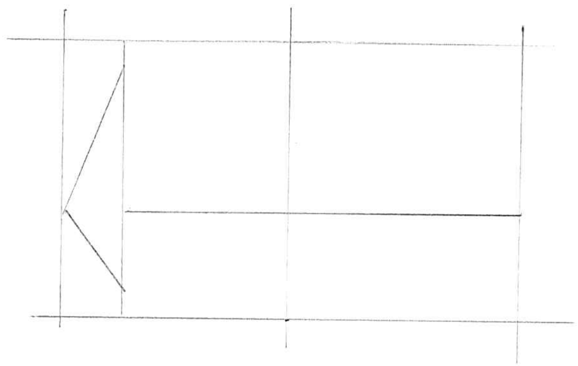
Facetting becomes subtle element. Question then is how intricate to get

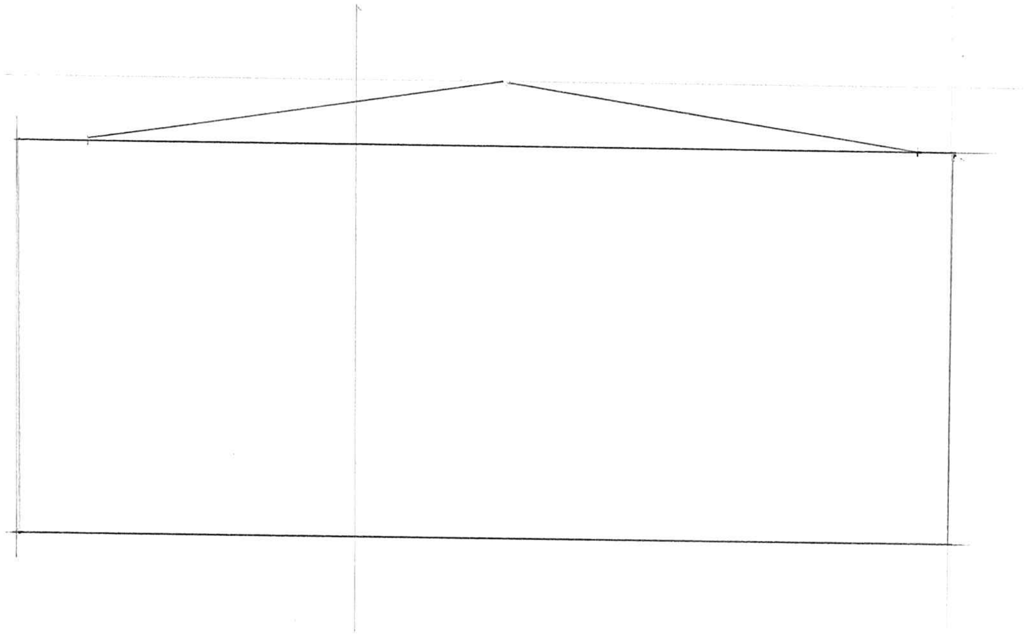


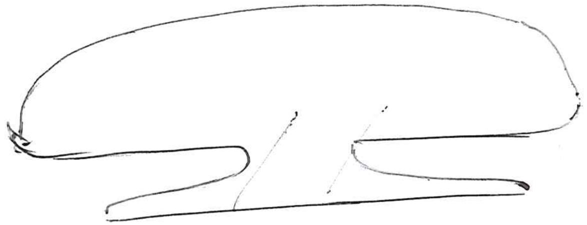


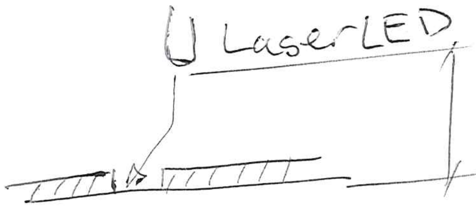

Would enable top surface + buttons to be made in one part, but breaks up the outline of the product
Also some problems reconciling movement of buttons with 'internal' housing
All lines kept within top surface
Cleaner, also easier to make it work (alignment of split lines)
Closest to original (Microsoft) design











Does this distance have to be constant? What if it increases?

APPENDIX 10.2 Moments of Inspiration (MoI) Diary Entries and Sketches

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 1		
18/08/11	MoI	Installation + Exploration
19/08/11	MoI	Tutorials
20/08/11	MoI	Tutorials
21/08/11	MoI	Tutorial
Week 2		
22/08/11	MoI	Tutorial
25/08/11	MoI	Tutorial, Image Search
Week 3		
30/08/11	MoI	Moodboard
31/08/11	MoI	Sketching
01/09/11	MoI	Sketching
02/09/11	MoI	Sketching
04/09/11	MoI	

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 4		
05/09/11	MoI	Organising Model, Initial Modelling
06/09/11	MoI	Modelling
07/09/11	MoI	Meeting + Review w/ Ian
08/09/11	MoI	Modelling
09/09/11	MoI	Modelling
10/09/11	MoI	Modelling + Sketching
11/09/11	MoI	Modelling
Week 5		
12/09/11	MoI	Modelling
Week 6		
20/09/11	MoI	Modelling
22/09/11	MoI	— 〃 —
23/09/11	MoI	Exporting, Checking, Uploading
02/11/11	MoI	Revising + Remodelling

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 18/08/11	Software Mol

Description of Activity

Downloaded software (13.6Mb file took about 20seconds) + installed, followed usual automated process.
When MoI first opens you're presented with a split 4-view interface, tools down one side. Views can be changed - Front, top, 3D etc. double clicking a button reverses view (eg right goes to left).
Help takes you to a page w/ links, some to files on system, some to external web pages.
'Open' opens existing file, import combines w/ currently open file
Went through 'Introduction to MoI' - basic guide to interface, commands + modelling concepts. Some options referred to not available to me (e.g. full screen on-off)
Command icons often expand to show fuller set of options, e.g. 'Construct Boolean' expands to show 'Difference', 'Union', 'Intersect', 'Merge'. Good way to make UI appear simpler

View commands - rotate : RMB
- pan : MMB
- zoom : scroll wheel

Can customize ~~zoo~~ rotate (about axis, free etc).

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 18/08/11	Software MoI

Description of Activity

Advertises that MoI works w/ pen input, but lack of mouse scroll or MMB equivalent on my tablet (Wacom Intuos 2) makes pan + zoom impossible. Navigation icons at bottom of screen allow these functionalities, but much easier (for me) to use mouse.

MoI definitely promoted as 'simple software': "MoI's sleek, intuitive UI blends a fluid, easy workflow with powerful tools, making it the perfect choice for someone who has been frustrated with the complexity of existing CAD tools."

When you pick a command, instuctions are given as to what to do to complete the command, e.g. 'Draw Solid - Box'
- Pick Corner Point
- Pick other Corner
- Pick Extrusion

First impression is that MoI is a lot more powerful (+ complex) than SU or Cosmic Blobs. A lot of hidden commands + a lot of references to CAD conventions which are unlikely to be known by non-CAD experts (G1, G2, G3 continuity for instance).

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 19/8/11	Software MoI

Description of Activity

MoI has 3 'official' tutorials though the help file links to a number of user created tutorials. The official ones are narrated videos.

Did 'Sunburst' tutorial. Doesn't seem to be a realistic representation of how MoI should be used (create solid then scale rather than use sketches) but v. basic introduction.
Fillets appear to be very powerful - normal, constant distance, G1, G2, G3 options - though no variable radius apparently

Did 'Crown of Clubs' tutorial - teaches constuction lines, hide, select etc.

If snap is turned on, pressing Alt temporarily disables
When using boolean operations, not all entities need to be solid - can project sketches also
Can turn history on for certain objects. No history tree, just means the shape changes if its underlying curves are updated

Commands work equally for sketches and 3D objects (surface or solid). This is very interesting concept. E.g. fillet, move, booleans etc. Does this make things simpler or more complex?

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 19/08/11	Software MoI

Description of Activity

Boolean operations seem to have problems if parts are touching but not intersecting (i.e. a shared surface). Sometimes operation completes w/ errors, sometimes just hangs

Did 6-legged pod tutorial

Rail revolve allows non-circular (eg spline) revolves

When making a sweep, possible to use multiple profiles (like variational sweep in NX) and/or 'scaling rail' (to define an outside shape).

Started lamp tutorial. This is an external (community) developed but linked from homepage.

MoI saves as .3dm (Rhino native format).

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 20/08/11	Software MoI
Description of Activity	

Started part 2 of lamp tutorial, but realised it's not really teaching me much. Maybe okay for someone who's never done modelling before, but it's basic (mainly boolean ops) and repetitive. I watched all 5 parts but didn't bother actually modelling

Looked at import options. MoI can open/import .3dm (Rhino), IGES, SAT (ACIS), STEP and illustrator. No STL import, though can save as .stl. Created STEP file of critical features + imported – everything fine.

Watched SpacePilot tutorial (non-official but linked): http://moi3d.com/tutorial/index.php?webtag=moi&msg=3842.1

Seems to be much more complex surfacing + open surface modelling. Will try this one tomorrow.

Design Diary

Analysis of Consumer-oriented CAD Software

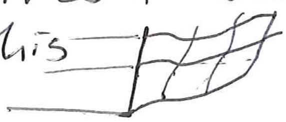
Detail of day's activity

Date 21/08/11	Software Moi

Description of Activity

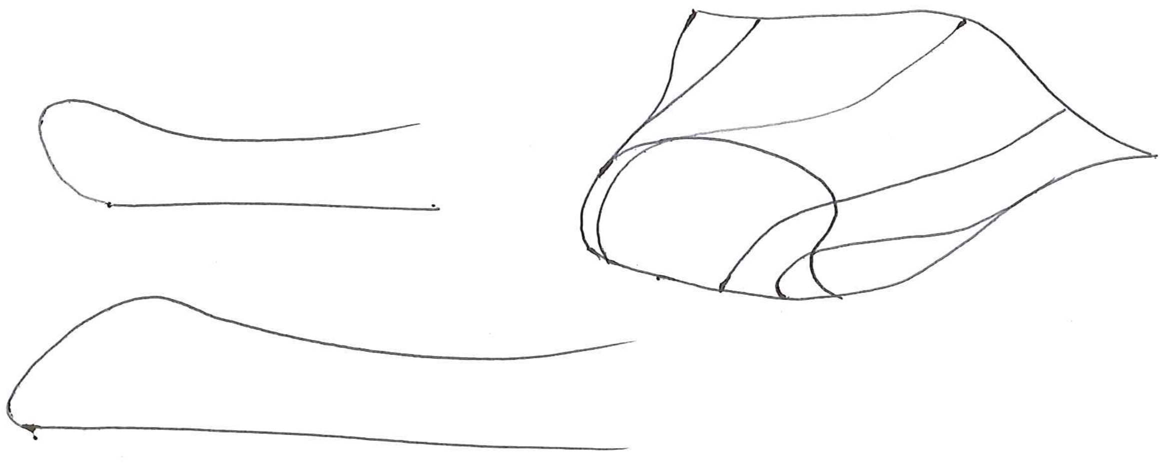
Started SpacePilot tutorial. Unofficial.

Can import images to trace over, but asked to pick corners + size when placing, i.e. no way to bring in at 1:1 at size its been scanned at. Means you have to resize manually (same fault as w/ Sketch Up). Why?

Surfacing commands are quite sophisticated an quick, especially sweep. G2 + G3 radius options mean you don't need ~~to~~ so much set up time with curves + blend surfaces - can construct like this  and blend afterwards

Can name objects (or surfaces, curves etc) to track more easily.

I'm thinking of some big, oversize, sweeping surfaces



Design Diary

Analysis of Consumer-oriented CAD Software

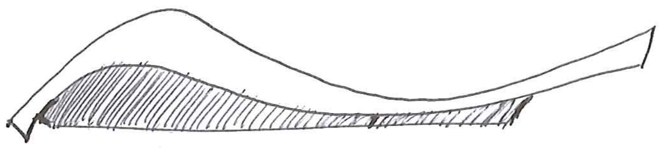
Loughborough University

Detail of day's activity

Date 21/08/11	Software Moi

Description of Activity

A single, flowing surface which seems to float over the base, which is 'hidden'.



Blend tool seems to work well also.
Some issues I'm not sure about - trimming a solid w/ a sketch doesn't always seem consistent. Sometimes works, sometimes holes in surfaces, but also not sure how much is graphic glitches. What does joined surface mean - presumably non-solid?

Tutorial is good, but as with some community generated SU lessons, can't be sure it's teaching 'best practice'. Model isn't actual size (imported image not scaled correctly) also its a symmetrical product but modelled 'whole' rather than in half then mirrored. Is there a reason for this, or just preference of person who made tutorial?

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 22/08/11	Software MoI

Description of Activity

Completed SpacePilot tutorial. Good, but a little frustrating because not narrated. In some places had to watch a few times to understand what was being done.

Loft + sweep work differently to how I'd expect. In SW can only have one section in sweep, + guide rails; if you want more control over multiple sections you need to use loft. In MoI can use multiple sections + rails for sweep, but loft uses only sections (no rails).

Although not open source, is possible for users to create scripts + extend MoI's capabilities. Not all in central repository though, so difficult to find. Also 'hidden' features accessed by adding scripts to key shortcuts. Way of increasing complexity for expert users? Or is it these are 'beta' features?

Distinction between edges + surfaces is 'blurred' but also important. For example if you join a number of edges it will create one curve which matches the chosen edges. But if you create a surface from curves seems not to stitch w/ original edges. Need to use hidden command (merge edges) before creating surfaces.

~~Ba~~ This kind of complexity / knowledge requirement somewhat at odds with 'simple software claims.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 30/08/2011	Software MoI

Description of Activity

Finished collecting, scanning + printing images, and assembled them into an inspiration board on the wall. This is much ~~more~~ 'freer' than the images gathered for SketchUp, perhaps reflecting that MoI has greater capabilities. Whereas before (with SU) the software's constraints dictated the form, this time it's more like the software's possibilities will push the design.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 31/08/2011	Software Mo1

Description of Activity

Began sketching ideas for the product. At this stage both the ideas and the nature of sketching are much looser than they were when investigating SketchUp. I'm not using underlays, there's not really a sense of scale yet, just trying to identify routes I want to explore. At the moment it feels like there are three distinct ones. As well as the overall form, I'm also keen to try playing with decoration and complexity, something I didn't get into with the SU design.

See sketches 31.08.11 - Mo1 - 01.psd - 31.08.11 - Mo1 - 08.psd.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 01/09/11	Software Mol

Description of Activity

Sketches continue in a very loose vein. Reviewing at the end of the day I can see its perhaps not possible for an external observer to get a sense of the design. What I've been doing really is trying to get a 'feel' of whether the concept will work or not. There's a mismatch between what I want the product to evoke - ~~th~~ hyper futuristic + otherworldly - and my certainty of how the two elements making up the design interact with each other. This is compounded by my apprehension of how well the software is up to the task - I'm worried that the lack of dimensioned sketches might make it difficult to control things the way I want.

See sketches 01.09.11-Mol-01.psd - 01.09.11-Mol-07.psd

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 02/09/11	Software Mol

Description of Activity

Not too happy overall with the day's work. I've been concentrating on a couple of images of a building concept by Zaha Hadid, I feel like they should translate into an interesting concept but I just can't get it to work, my drawings don't have the same quality of curve. In the end I put that concept to one side + worked on another (though similar). More successful, but still a frustrating day. I feel like I need to be working in 3D, carving foam, but I'll have to wait until next week to get in the workshop.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 04/09/11	Software Mol

Description of Activity

After yesterday's frustration, I sit down and the first thing I draw nails it - exactly what I spent a couple of hours trying to capture the day before. Just happens sometimes.

Still, I don't feel able to choose between two of the concepts from what I have on paper. One I find more exciting, but I'm not totally sure I can model it in Mol. So the plan is to work on two concepts early on and hopefully decide once I'm in the software.

Drew up the two concepts as orthographic views, sketched over the safe model underlays. I'm conscious of the problems I had with the SketchUp model (i.e. it was too small) so I'm not trying to push the volume too much (not so important with this version anyway.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 05/09/11	Software Mol

Description of Activity

Scanned orthographic views and imported to Mol. Lack of an automatic image size option is annoying. I contemplated taking images into Illustrator, drawing curves and importing Illustrator file into Mol, but felt this went against spirit of the exercise (by assuming a user would have access to Illustrator).

Created step files from SW and imported. They come in fine, exactly to scale and features in correct relationship to each other (even though I imported them as separate files). Impressive. Whilst trying to check size of parts, found ~~an~~ script to enable measuring between points. Also set up a few more I discovered in same place:

- merge curves (in sketch or edge)
- select loop (——||———)
- incremental save

Began creating curves for first concept, after about 30 minutes we had a power cut here. Still waiting for power after 2 hours, I'm going home...

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 06/09/11	Software Moi

Description of Activity

Continued creating curves and built top body (the part that will contain the buttons). Encountered a problem with surfaces not knitting to a solid, but found a hidden command which shows up problem edges. Seems to work well (the actual edge is highlighted, rather than the region as in SU); problem was due to original sketch where 2 lines did not meet at one point:

can create a surface inside these lines, but it won't knit with other surfaces.

Also found something incredible - the 'show points' command also works on surfaces, so its possible to pull points on a surface, i.e. freeform modelling. Not seen this in any documentation or tutorials. My design would probably have been different if I'd known about this...

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 08/09/11	Software MoI

Description of Activity

Not much time spent on the project today.
Modelled the base in outline.
So far my feeling ~~for~~ as to the biggest limitation of the software is a lack of constraints within sketches. Cannot define tangency, alignment etc - basic functionality in other software.

Design Diary

Analysis of Consumer-oriented CAD Software

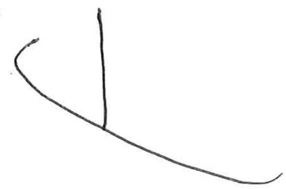
Loughborough University

Detail of day's activity

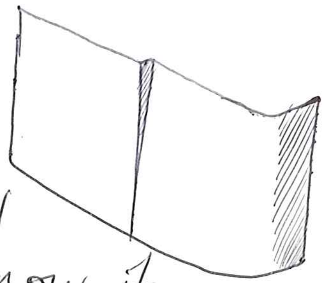
Date 09/09/11	Software MoI

Description of Activity

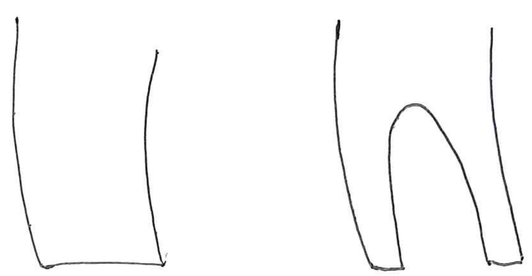
Modelled the middle part of the mouse. I thought this was going to be relatively simple but the software threw up a number of problems. In particular, when trying to create a sweep using curves something like this:



it gave me a kinked surface



From experience I know this is most likely caused by bad sketch curves, but couldn't find any problems. So don't know if this is a software bug or problem I created. Solved it in the end by a different approach. Unsure how to finish the 'tail', whether straight or with cut-out



Design Diary

Analysis of Consumer-oriented CAD Software

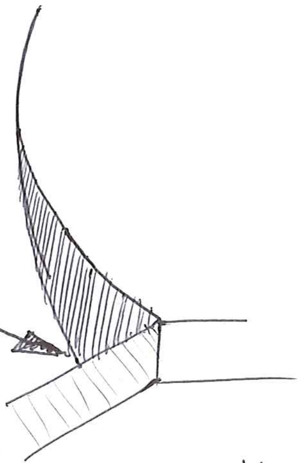
Loughborough University

Detail of day's activity

Date 10/09/11	Software MoI

Description of Activity

Continued modelling. Decided on 'fish tail' design but this created problems with creating a smooth surface between top + bottom parts here



Most frustrating is that this isn't really due to limitations of modelling features. The software is capable of modelling these things, but lack of constraints mean its difficult to set up the curves which generate the surfaces. ~~Once~~ ~~they~~ The software makes really nice, clean surfaces, but constraining them is the problem.

Unable to make a decision regarding the decoration of middle part. Made some sketches, but not conclusive. I will model the alternatives + decide.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 11/09/11	Software MoI

Description of Activity

Spent most of the day modelling the decorative elements on the middle part, and decided to go with the more complex version. I feel like I'm getting the hang of the software now – when things don't work I usually know where to look to find the problem. I find the graphics an issue though – software is advertised as beeing able to run w/ low end graphics cards, which I'm sure it does. But when theres a problem w/ surfaces knitting it's impossible to rely on the graphics to identify the problem, theres just too much overlap on edges.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 12/09/11	Software Mol

Description of Activity

Started to integrate imported step files (i.e. critical features) into my parts. Everything works smoothly. Construction is more along lines of original mouse than the SU design was. Interesting that I'm making so many decisions in the software, rather on than on paper. Kind of the nature of this design exercise, it seems.

Bottom and middle parts are finished, just need to model features of top part, most importantly the buttons.

Design Diary

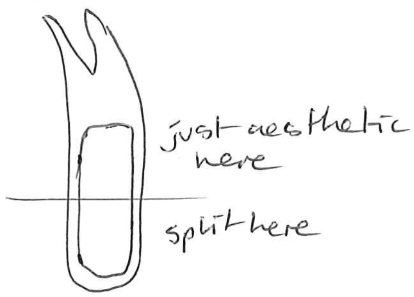
Analysis of Consumer-oriented CAD Software

Detail of day's activity

Date 20/09/11	Software MoI

Description of Activity

A week's break due to travelling to a conference. The main task left is to model the buttons and scroll wheel details. Spent the day creating a split for the buttons to move, combined w/ a non-functional detail line. Some problems due to surfaces not knitting, but biggest issue is graphics not rendering hidden lines correctly, makes it really difficult to see what's going on, especially when zoomed in close.



Also created a cutout detail to allow middle part to sit correctly in top part.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 22/09/11	Software Moi

Description of Activity

Finished the model today. Created detailing around scroll wheel, this caused problems because 'blend' and 'network' functions didn't work as I expected. But got there eventually. Decided I needed more snaps/locators so also modelled these - not totally sure if they're necessary but thought it's better to include than not. Almost forgot the hole for the cable (it comes out the back on this design) and then modelled it wrong at first (can't be an enclosed hole or USB block won't fit through. Quite pleased w/ how the model turned out, I'd probably change it given the opportunity, but it shows the capabilities of Moi pretty well.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 23/09/11	Software Mol

Description of Activity

Exported files ready to print. Mol provides .stl export as standard. Default quality is an angle of 12°, but can go down to 3°. When I tried this SW refused to import (too many triangles). 10° worked okay, and gave file sizes of around 500Kb.
Hit a problem w/ middle part though - when imported to SW were a number of overlapping surfaces / vertexes. Auto repair could not resolve, + manual repair impossibly complex - I spent about 2 hours + got nowhere. Tried exporting as .igs which gave better results but still couldn't be resolved. Beginning to think I wouldn't get a model at this point. Tried exporting as .stp, SW still gave errors, but different (only one missing surface). I patched this in ~~exported~~ and exported an .stl from SW. When this .stl re-imported it gave errors, but instead I uploaded to Shapeways site which reported all 3 files as okay. Since this is a commitment to actually manufacture, I trust the report...

Design Diary

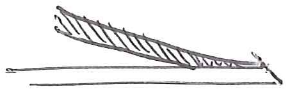
Analysis of Consumer-oriented CAD Software

Detail of day's activity

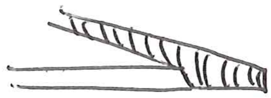
Date 02/11/11	Software Mol

Description of Activity

Got the physical model from Ian that had been made on the department's Connex 500 machine. In general the model is good + fits together well, but a few changes needed to be made. Major one was where top body + bottom body meet - I had modelled this as a knife edge + knew it would be a problem but wanted to see how it would turn out. Actually it had already broken. Changed from this



to this



PCB fits fine so no changes needed there. Locating feature at front broke due to rough handling but don't think it needs strengthening - once assembled there will be no movement. Buttons stick, this is because of rough edges around the split line gaps. Ian recommended increasing the gap (currently 0.25mm) but I will leave the same + smooth by hand using wet or dry paper.

Top body is quite faceted. Oh I had decreased .stl resolution because

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

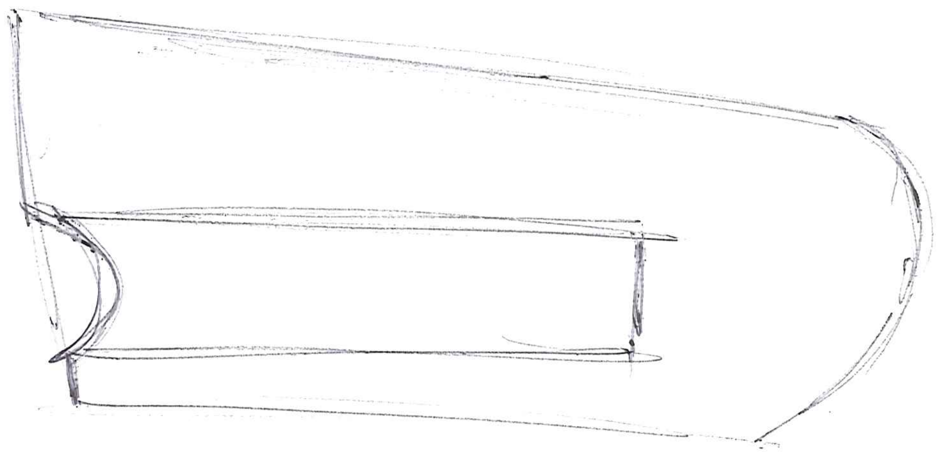
Detail of day's activity

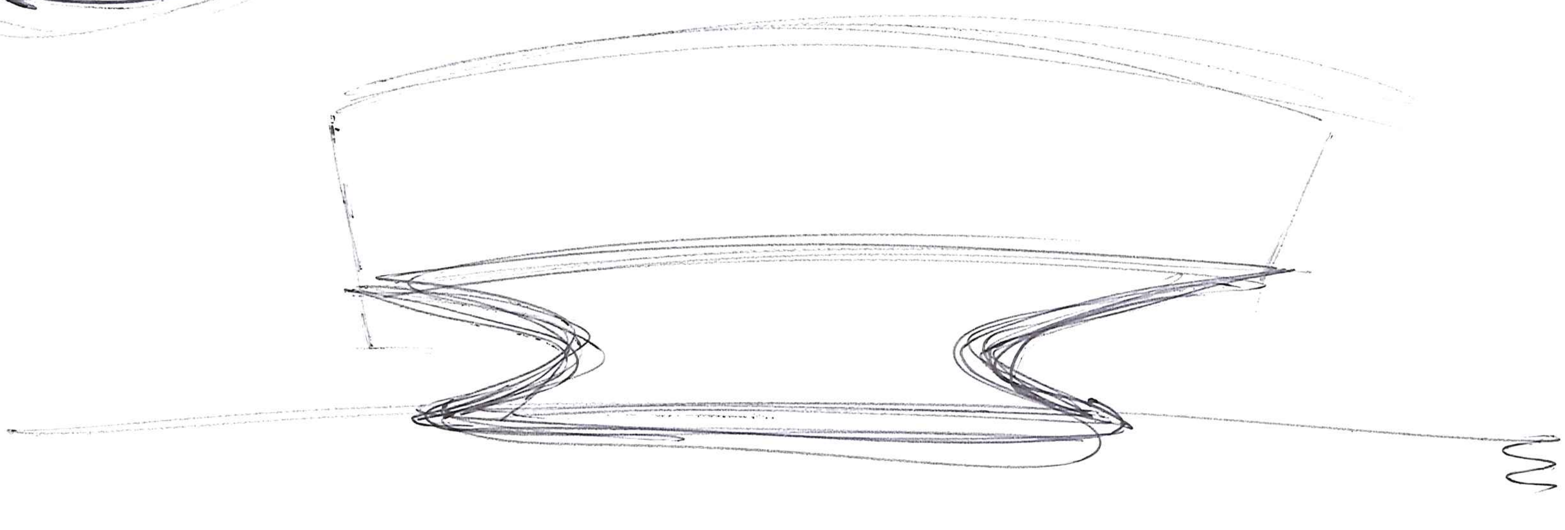
Date 02/11/11	Software Mol

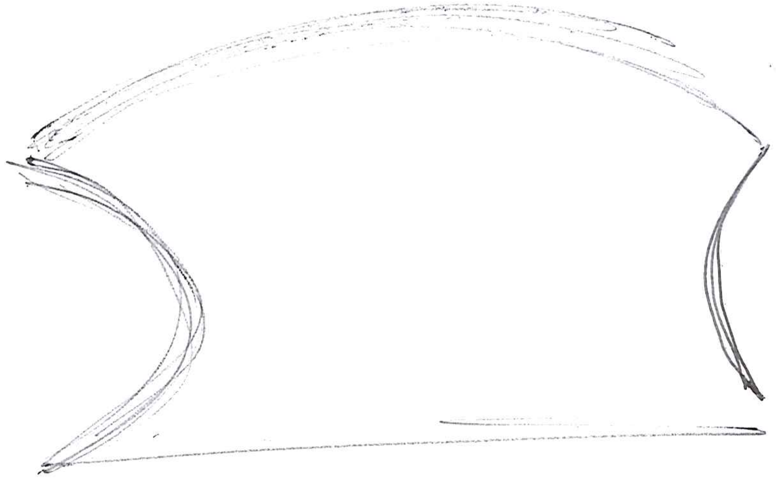
Description of Activity

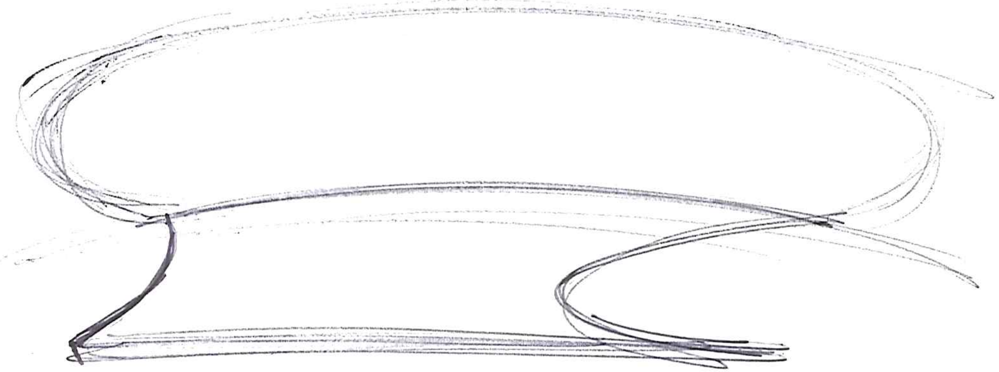
Solidworks couldn't import (and ∴ I couldn't check the .stl model). This time I used the finest resolution, so hopefully faceting will disappear.

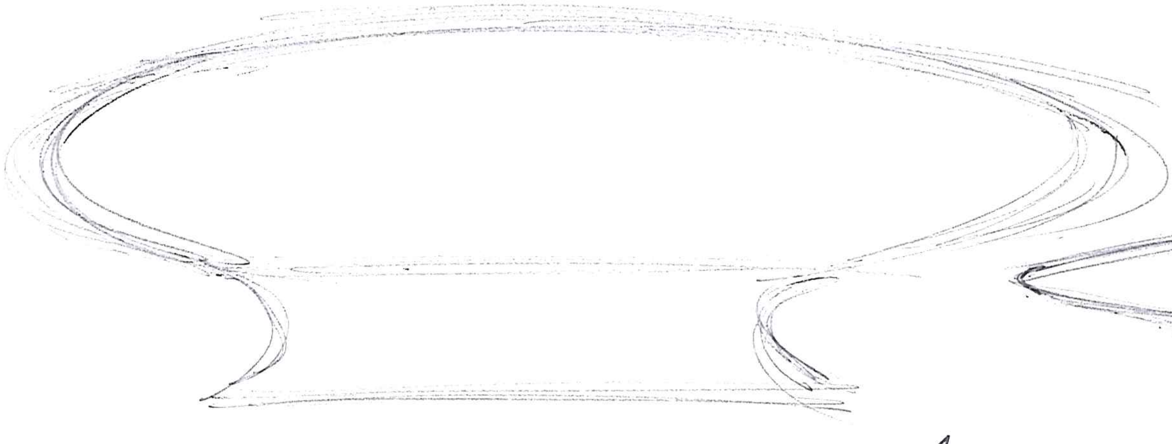
Having updated the models I exported new .stl files + uploaded to Shapeways.

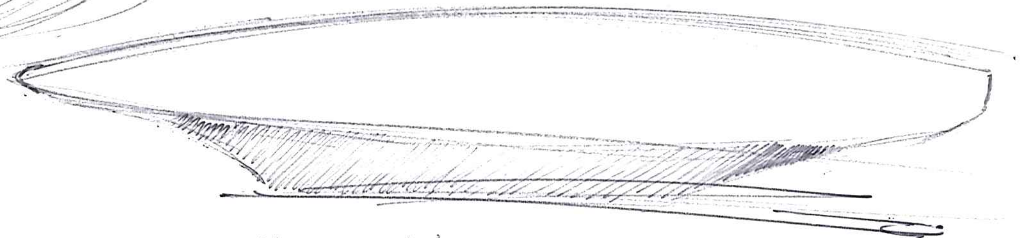




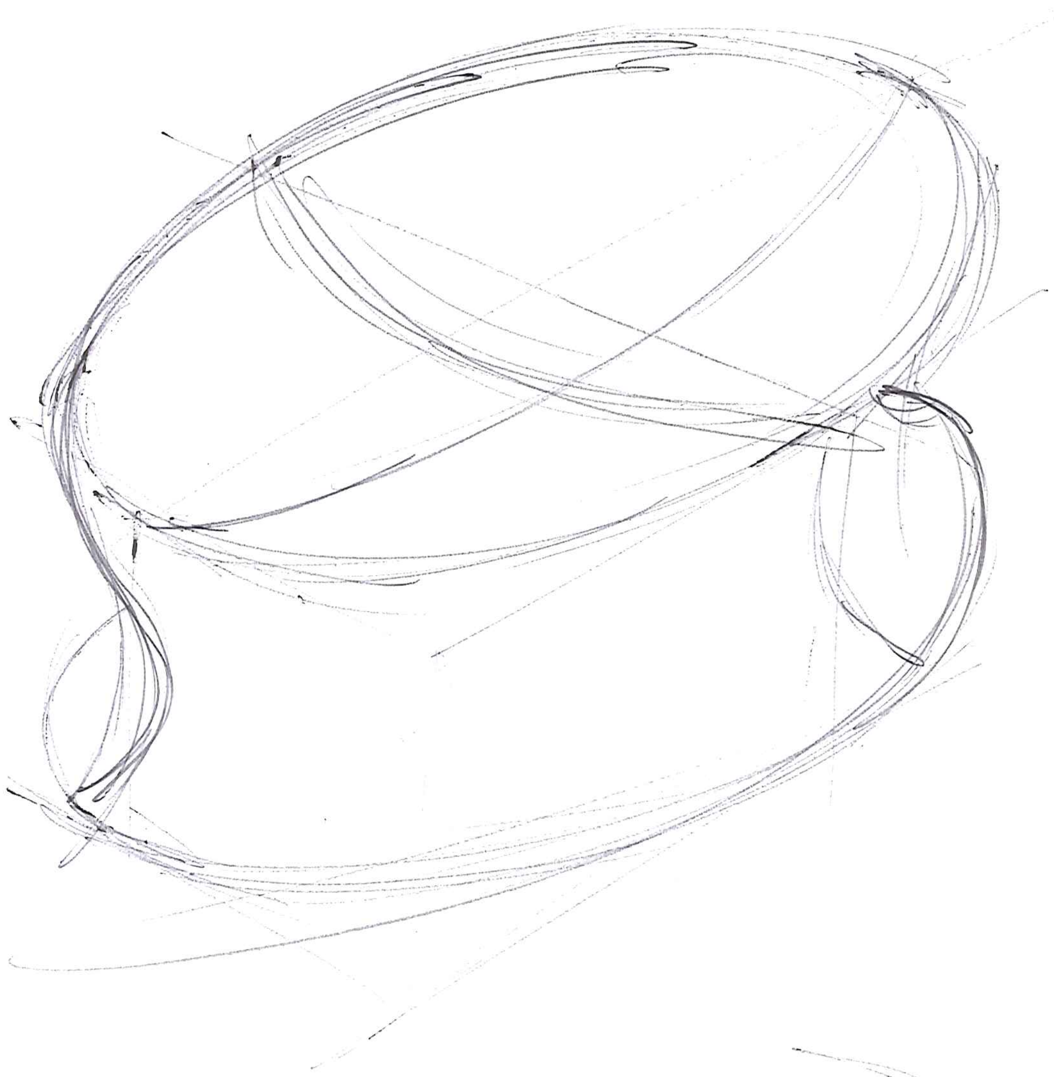


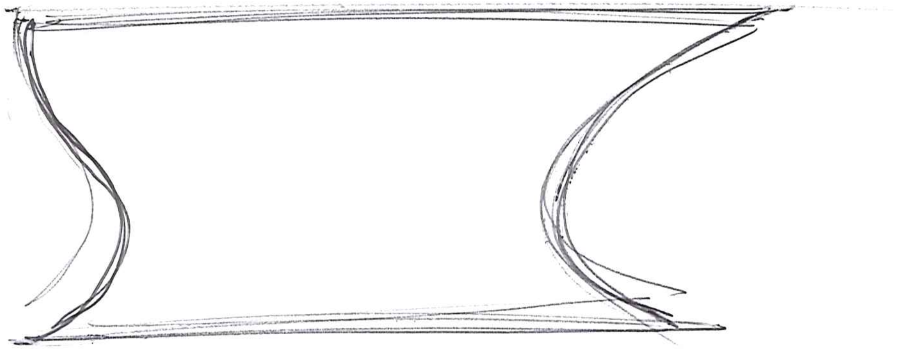


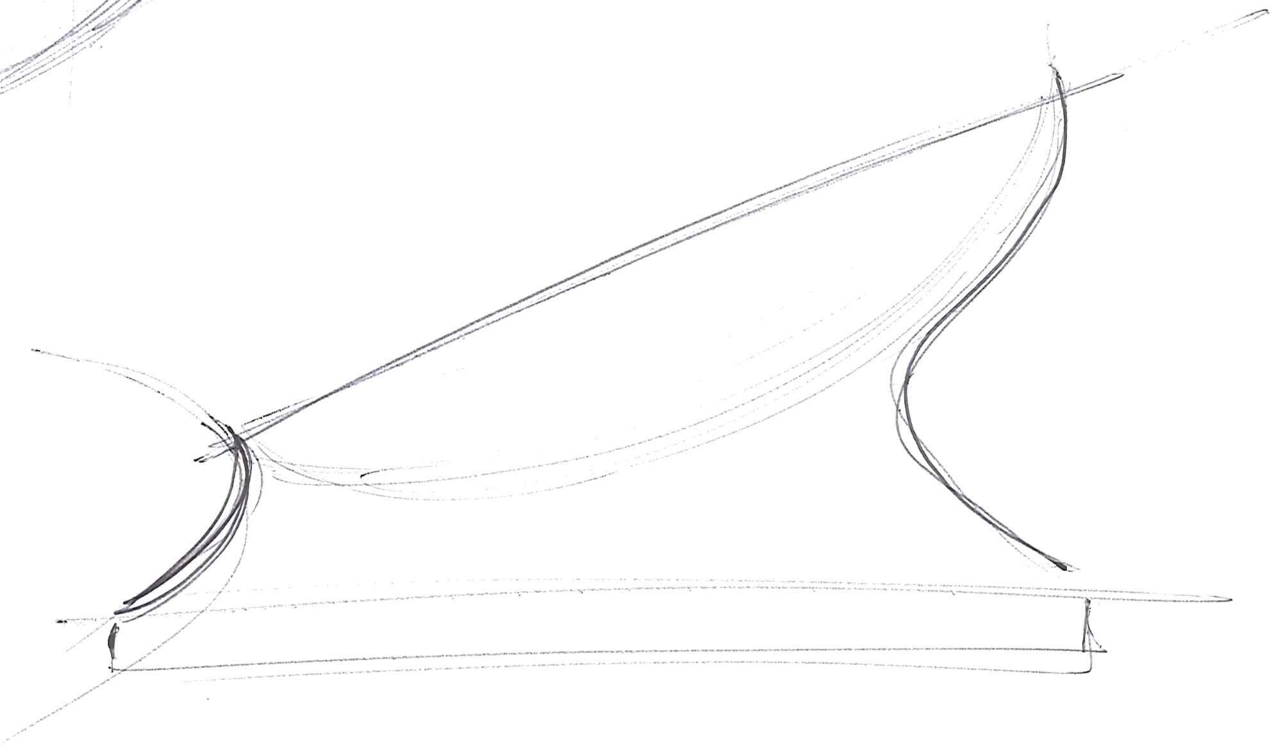


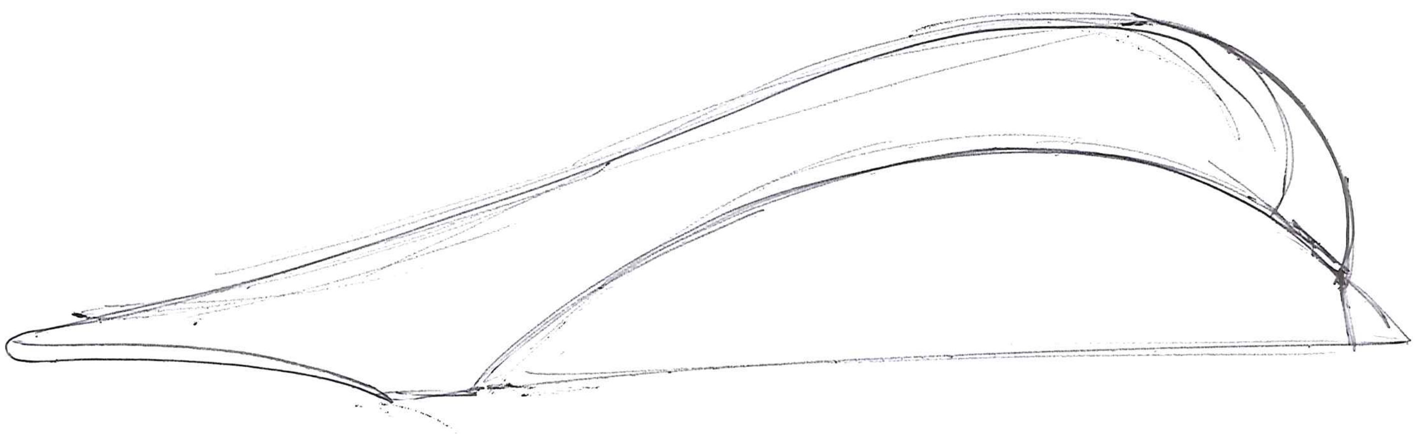


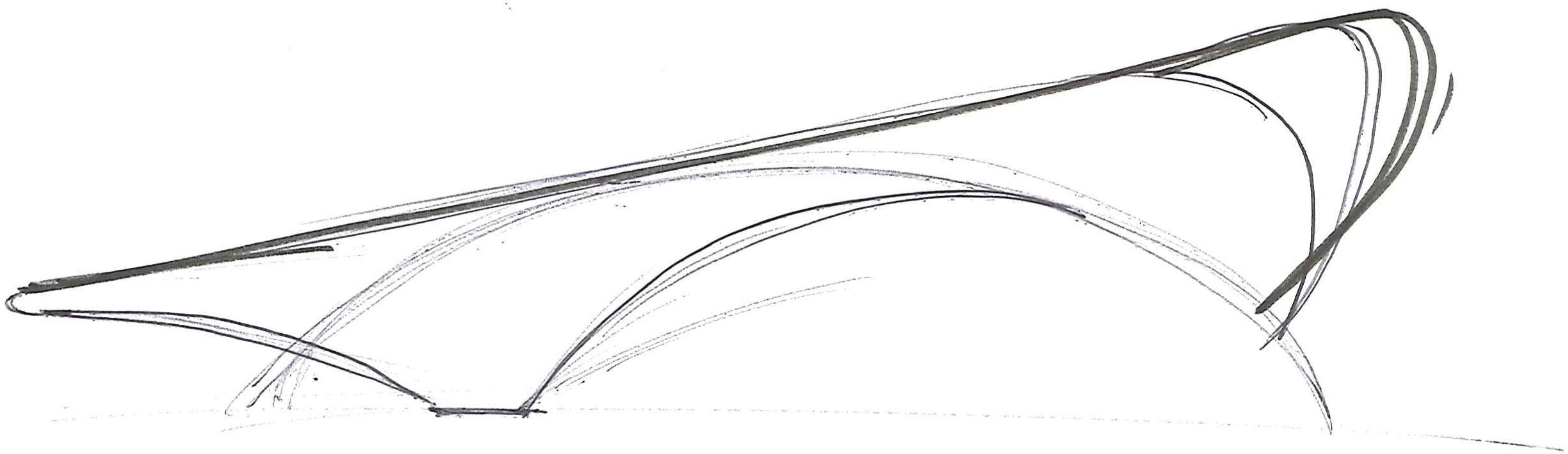
Appears ultra-thin

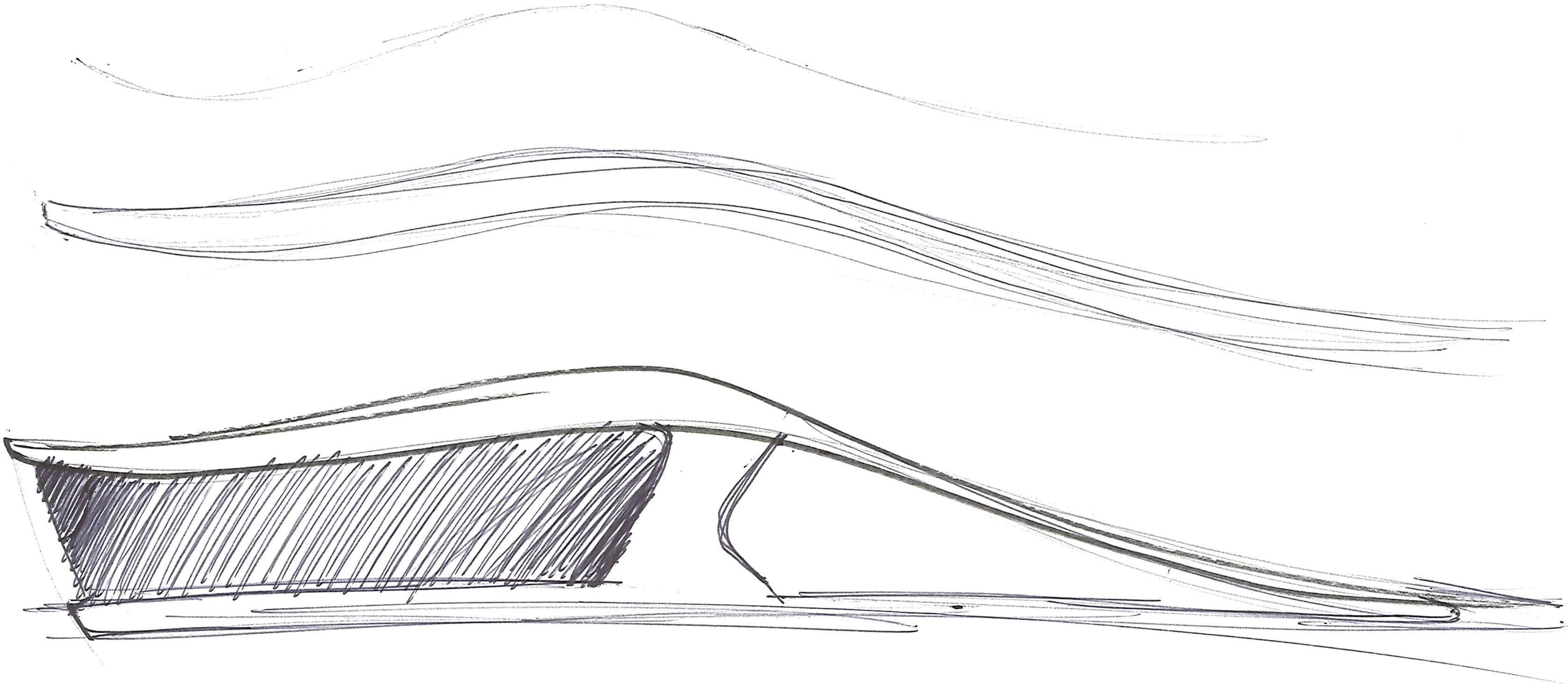


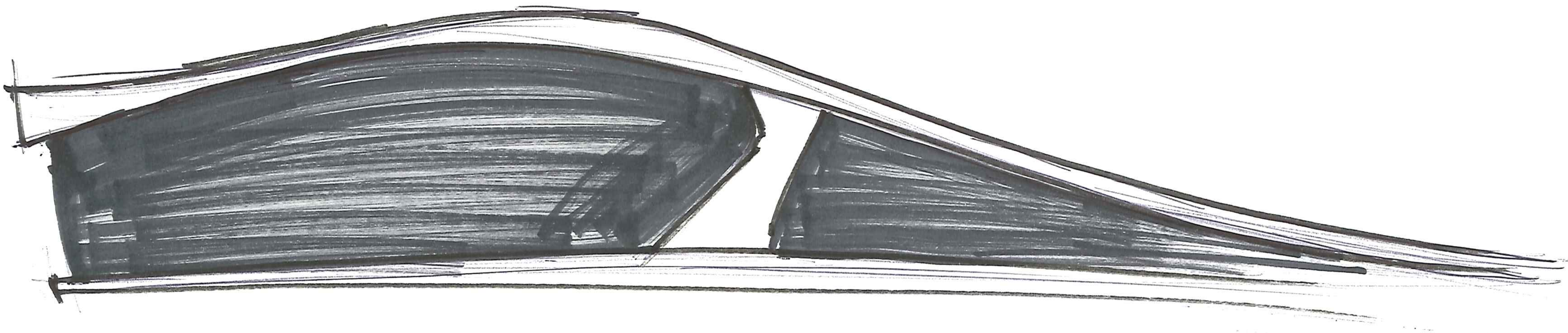


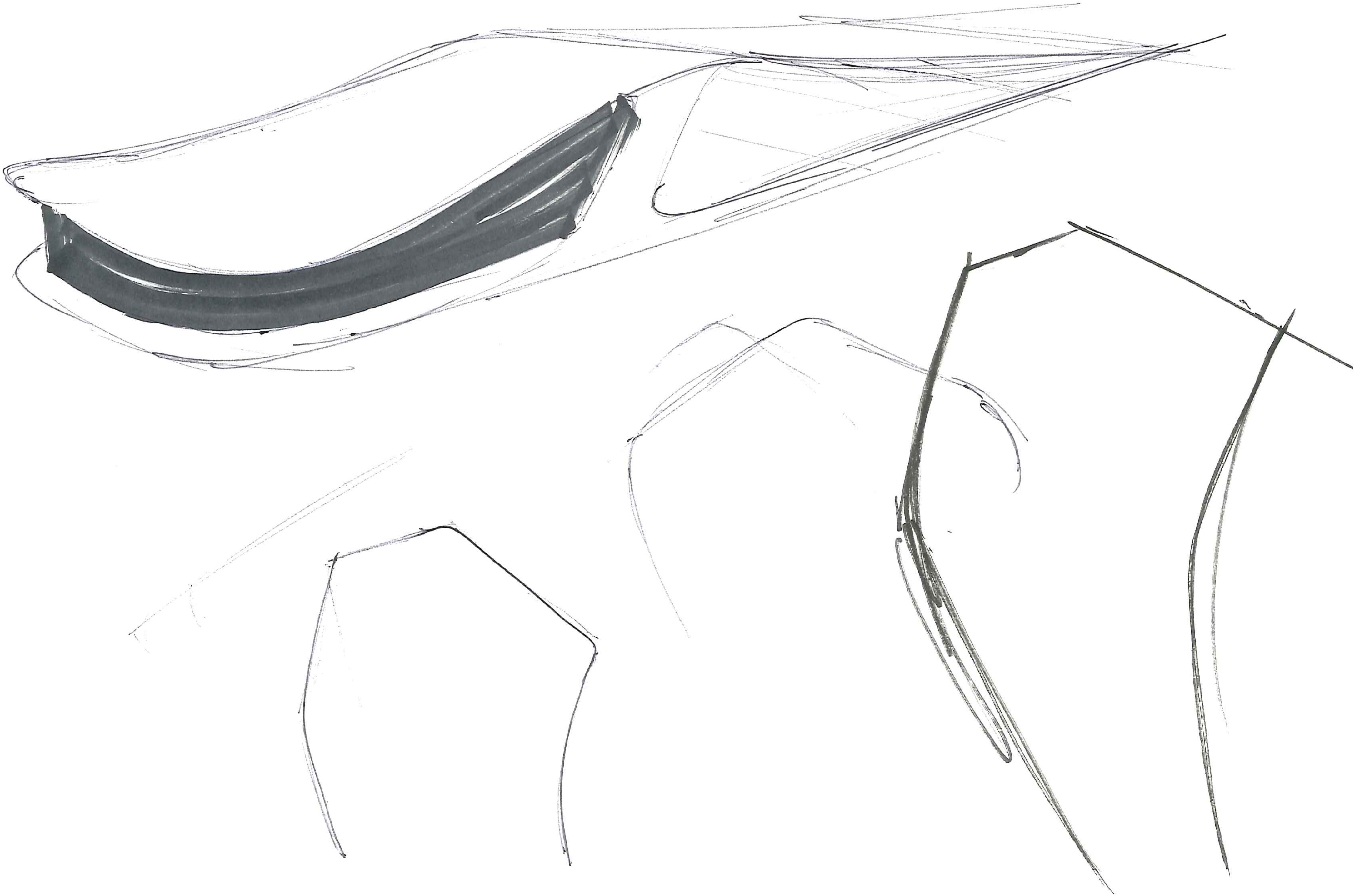


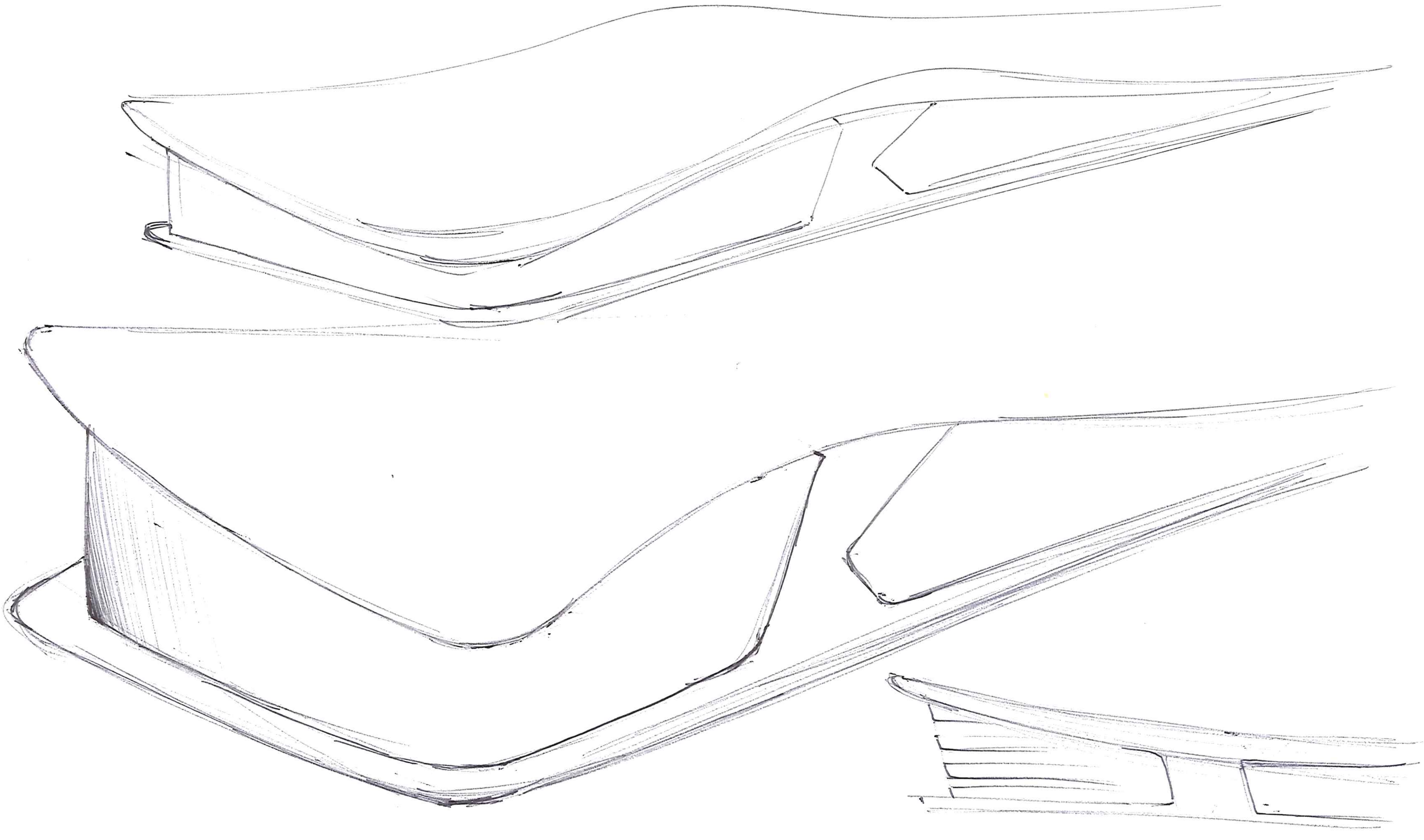


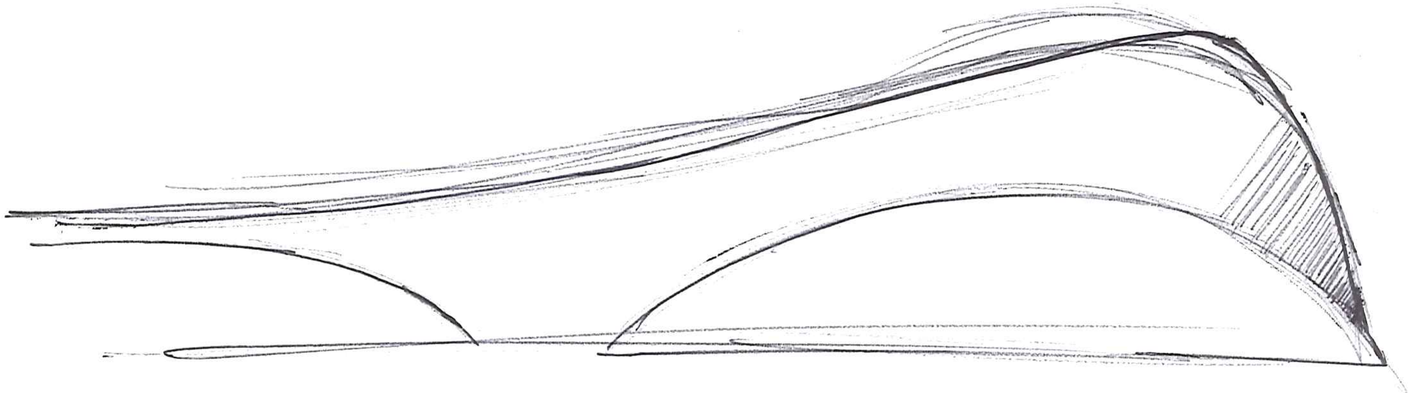


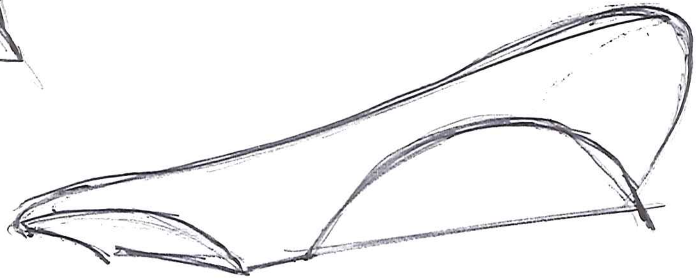


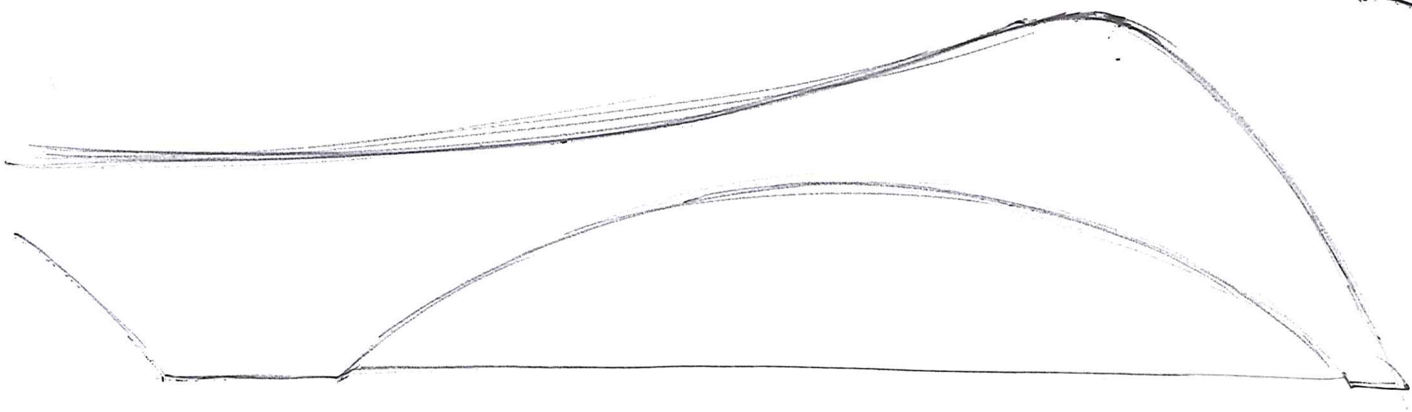


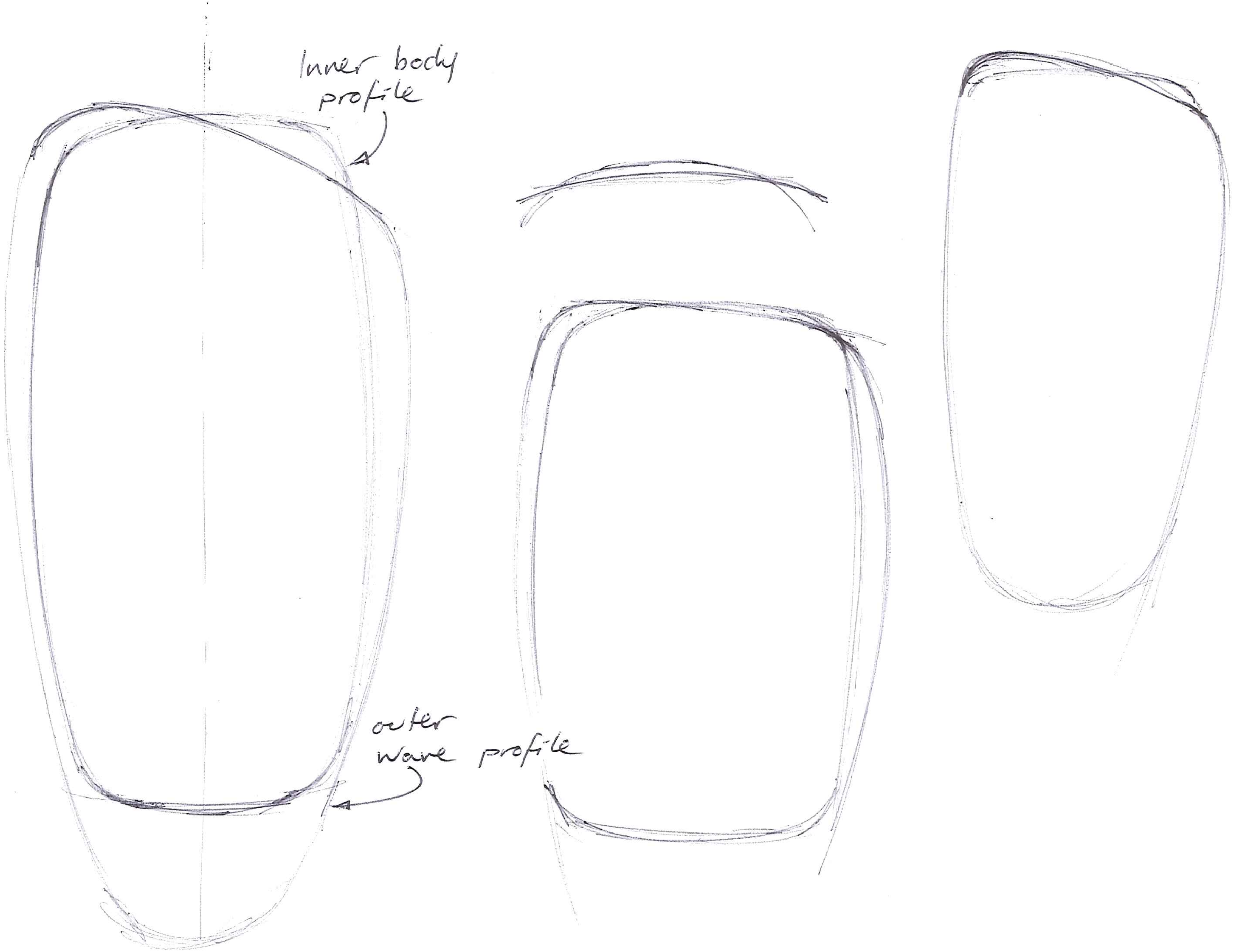


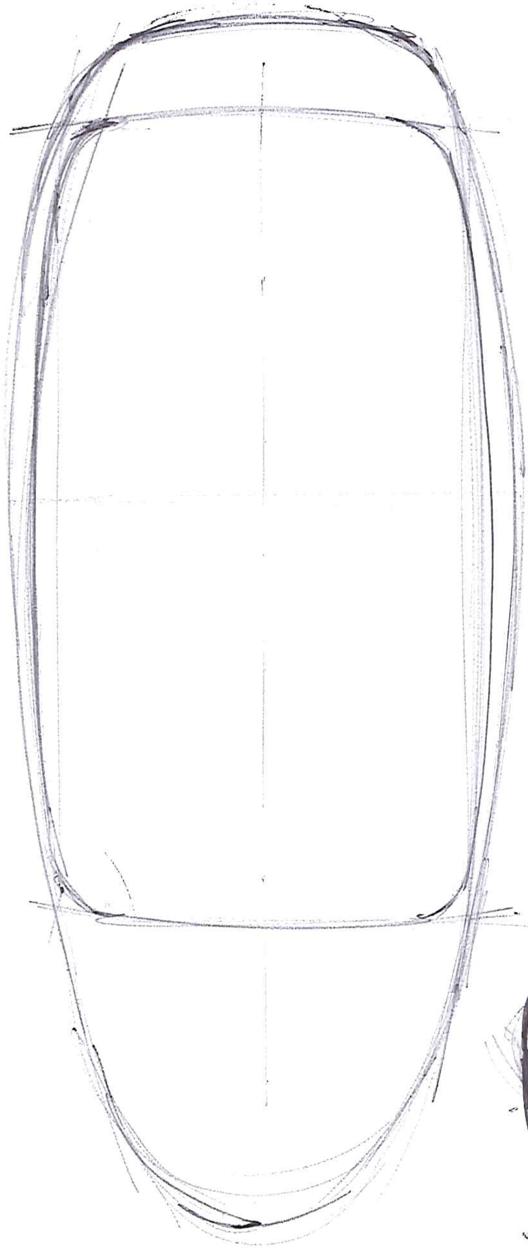
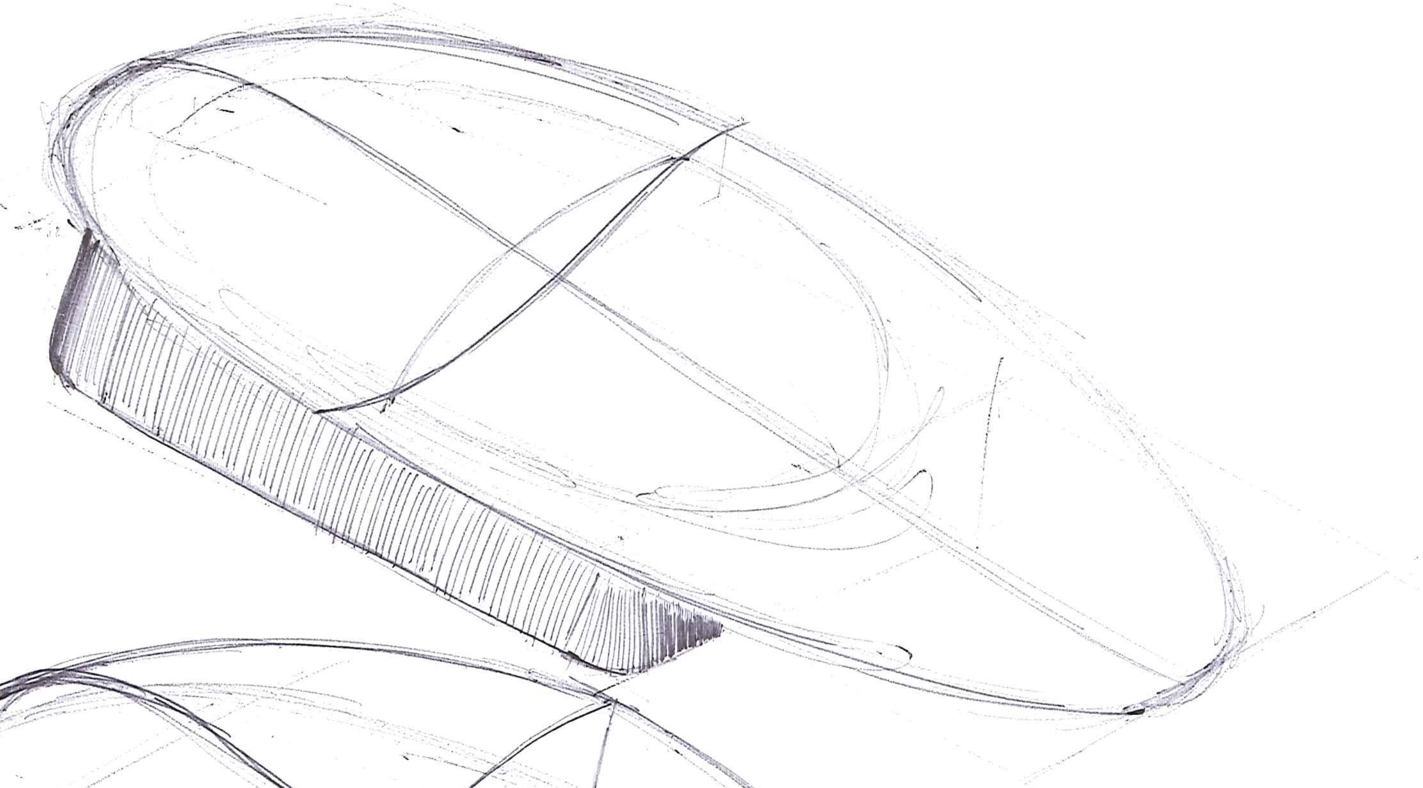
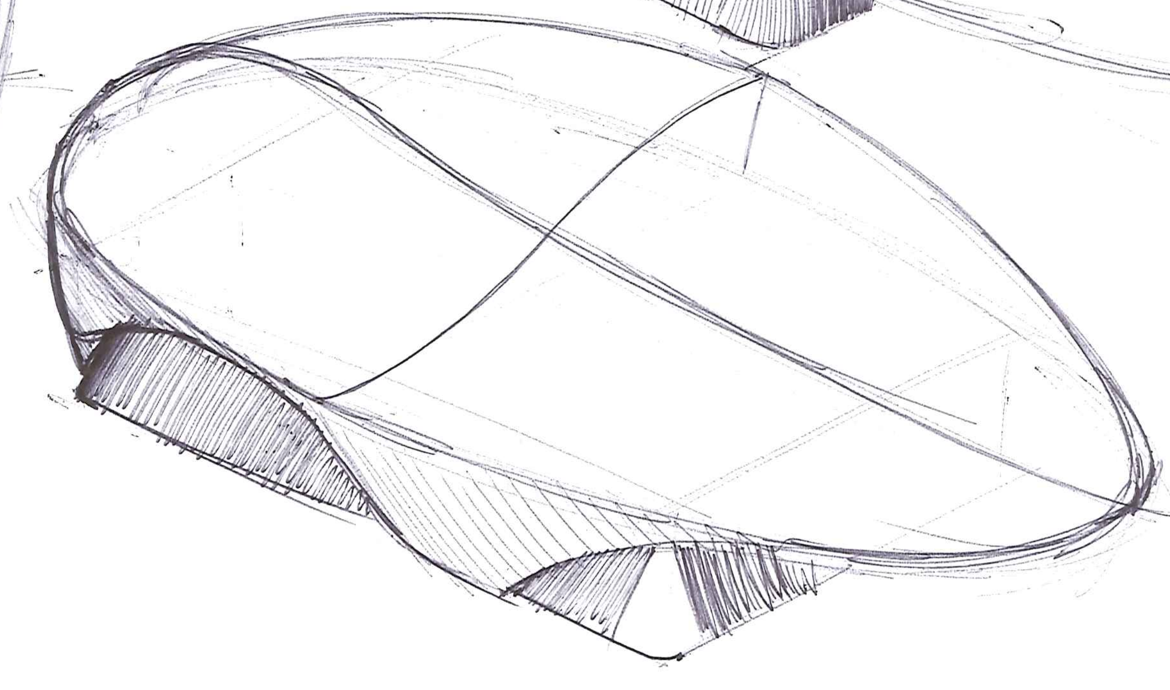


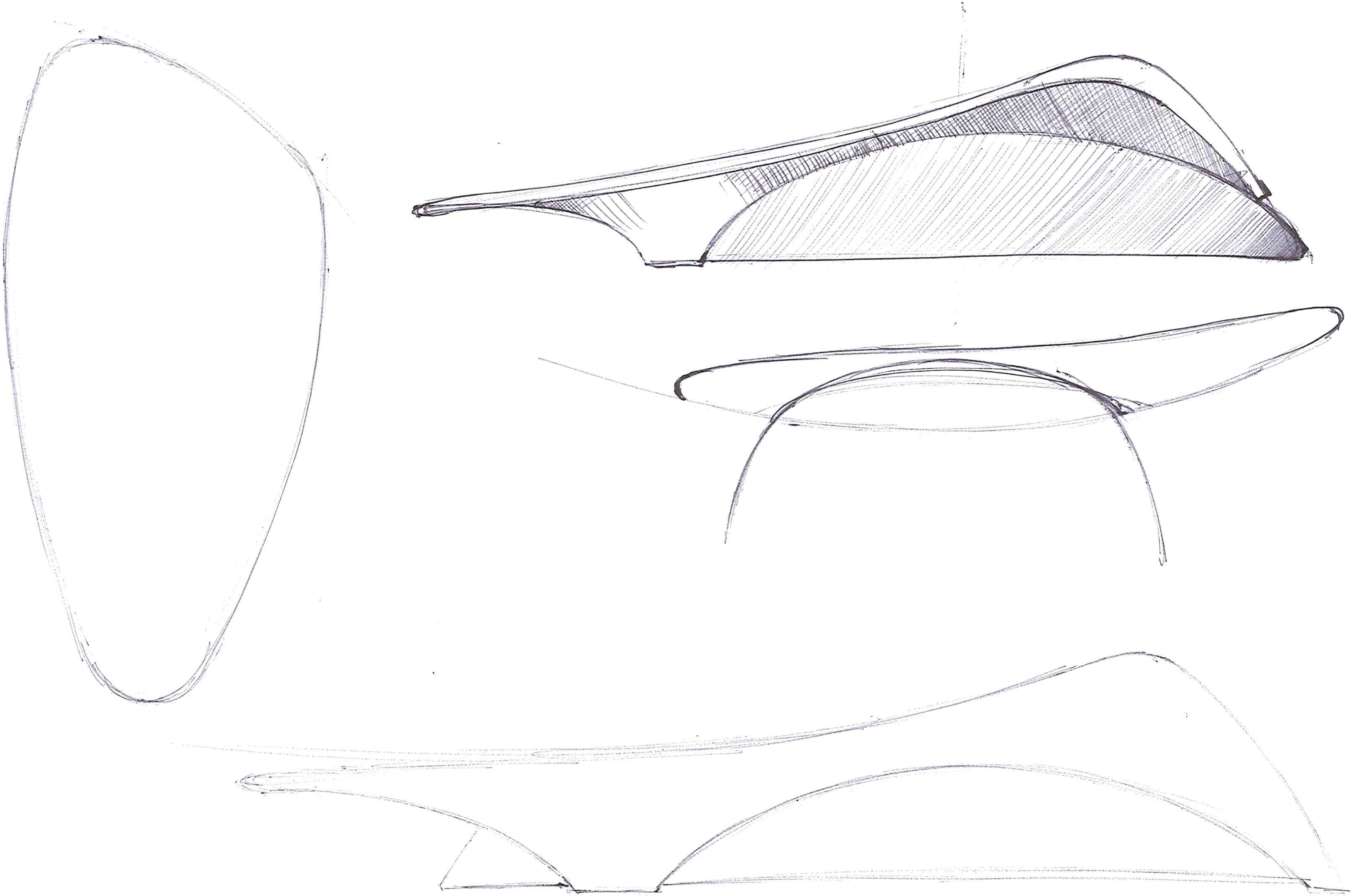


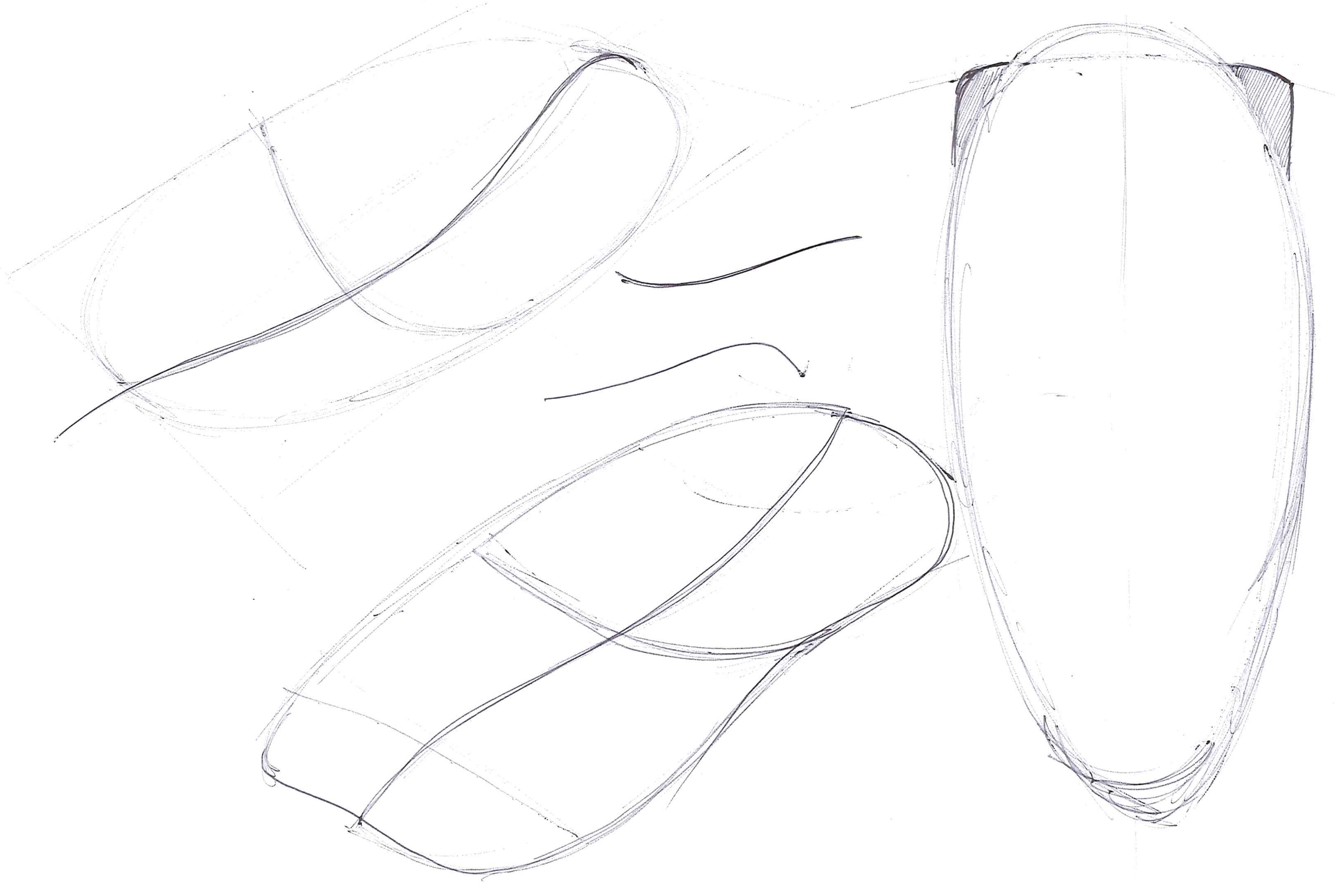


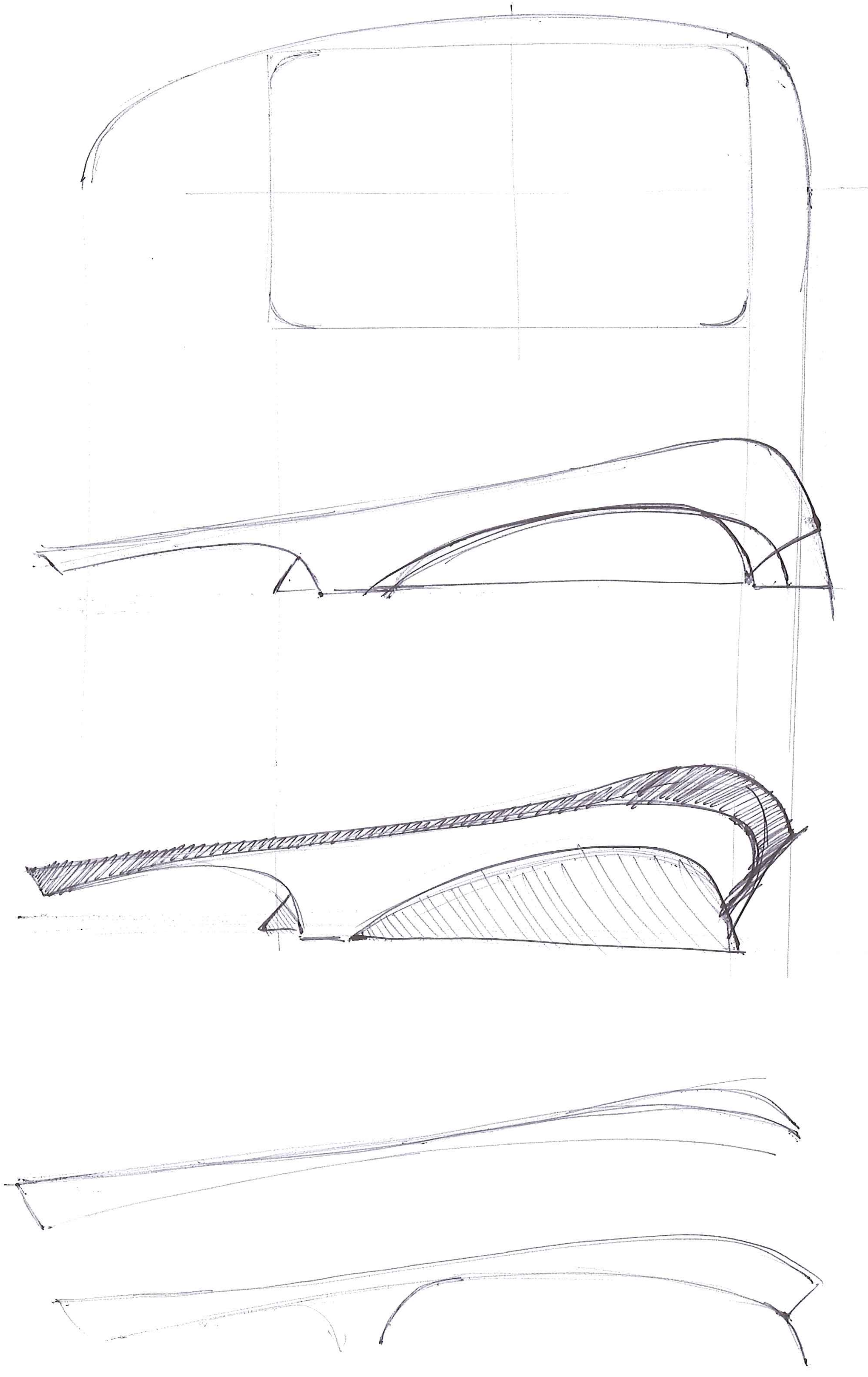


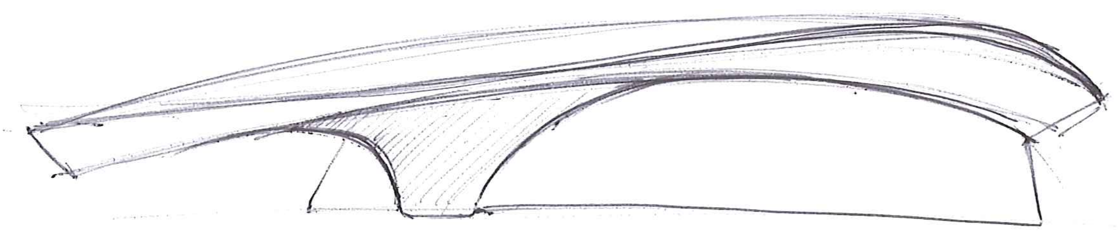
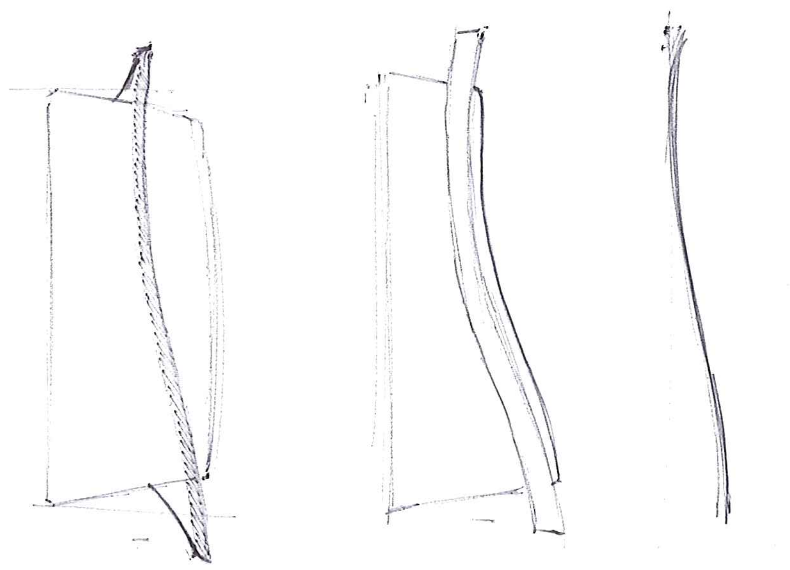
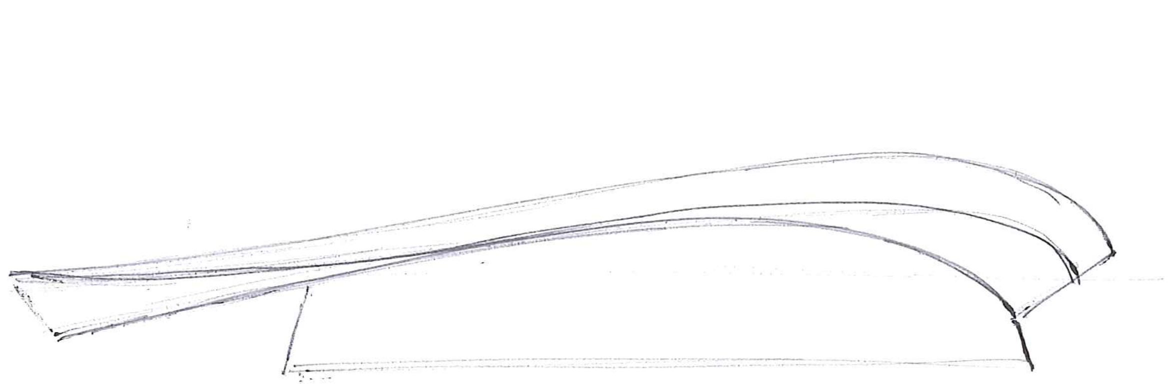
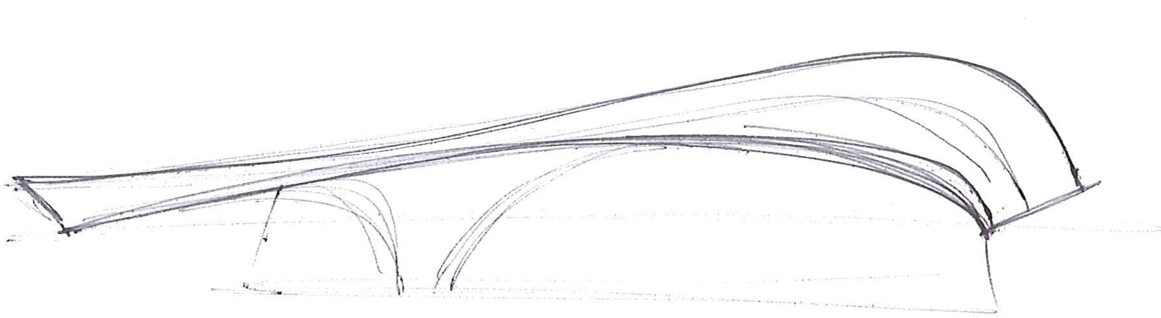

Inner body profile
outer wave profile

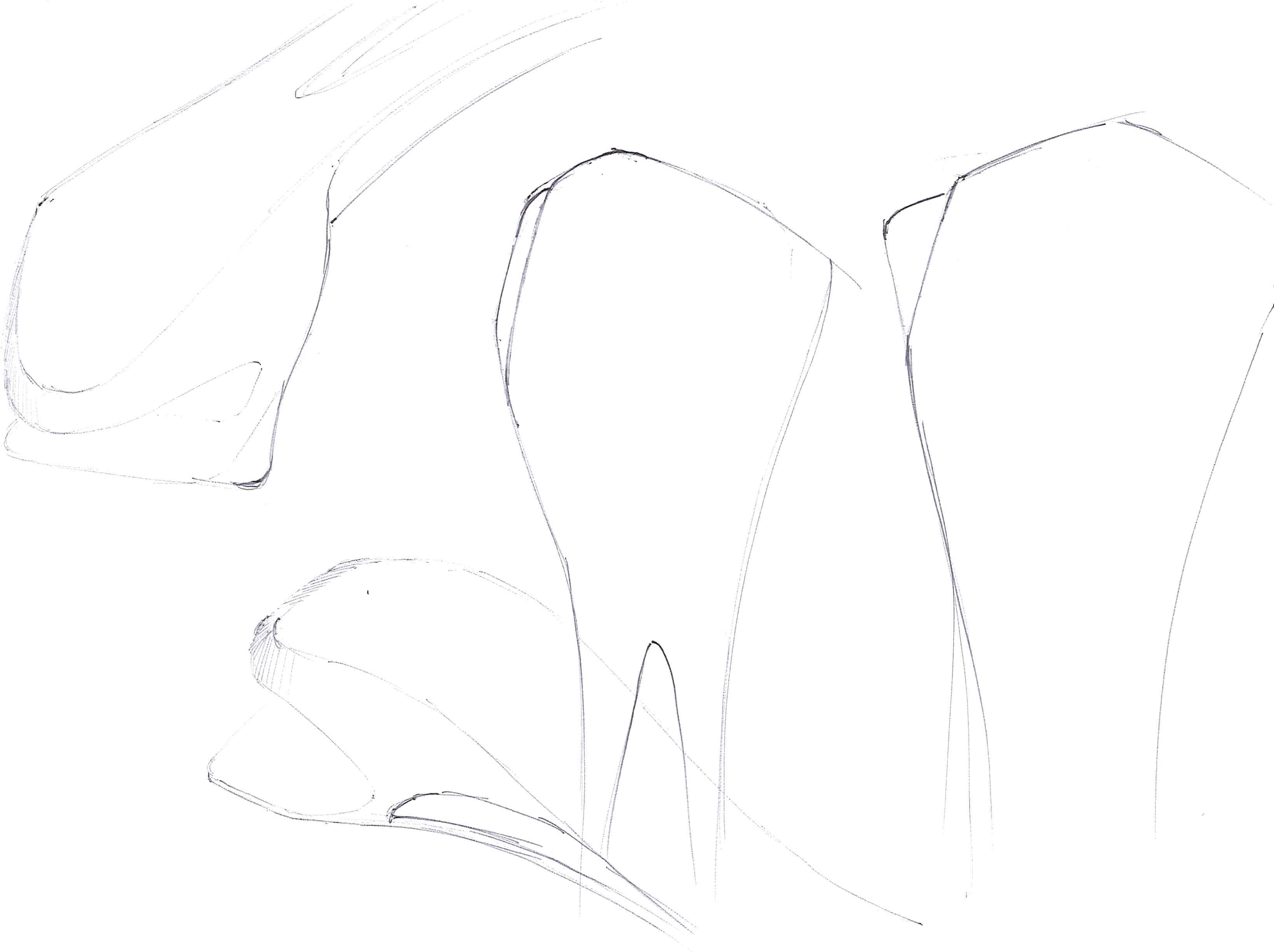




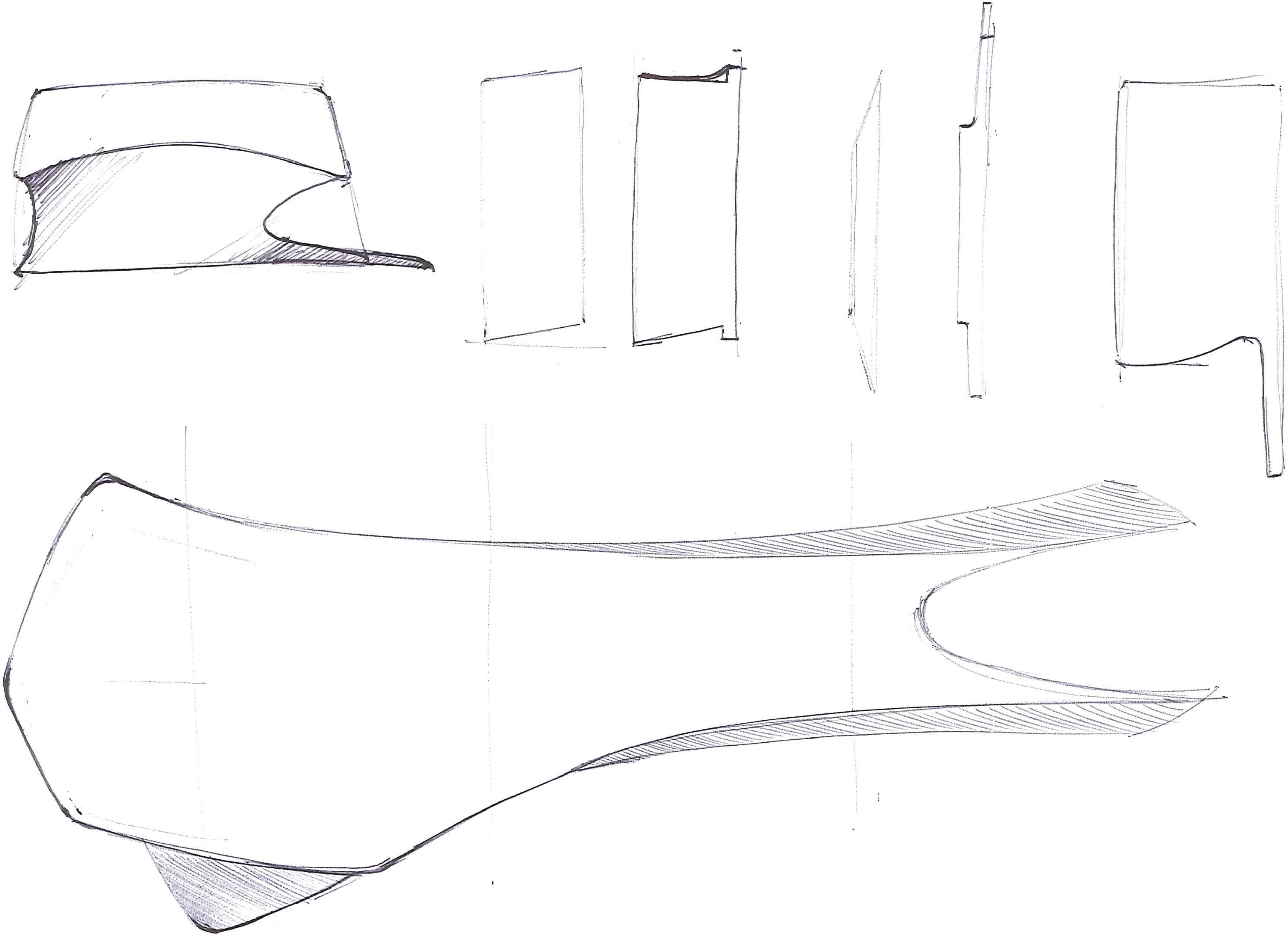


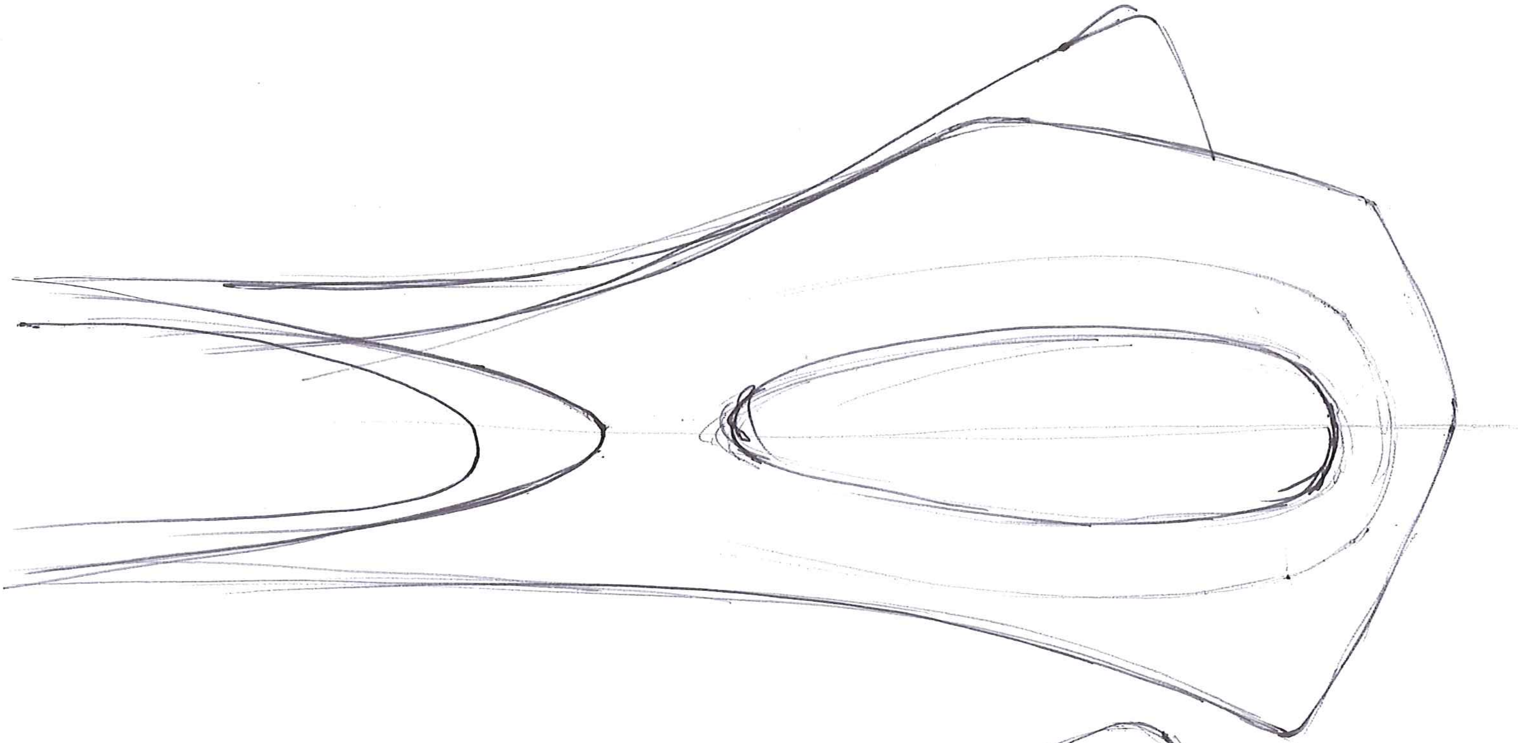


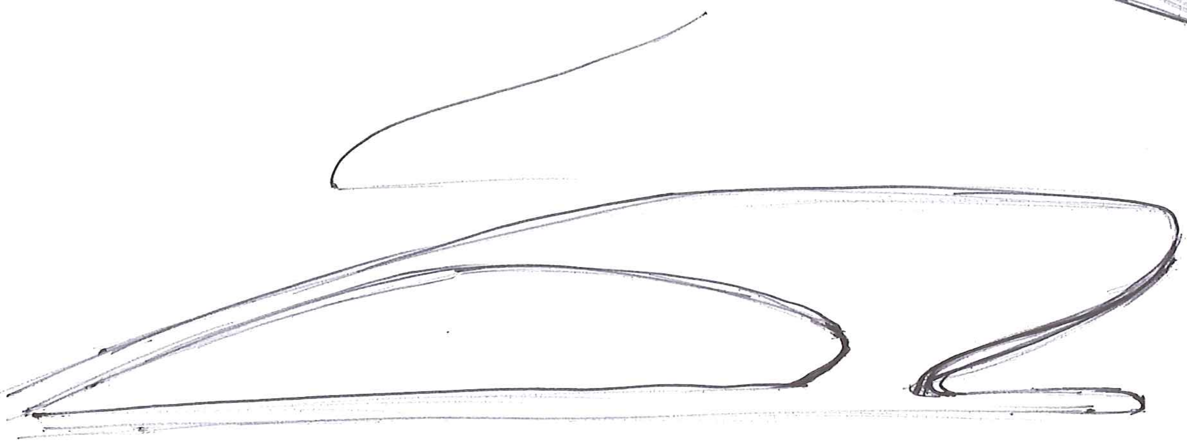
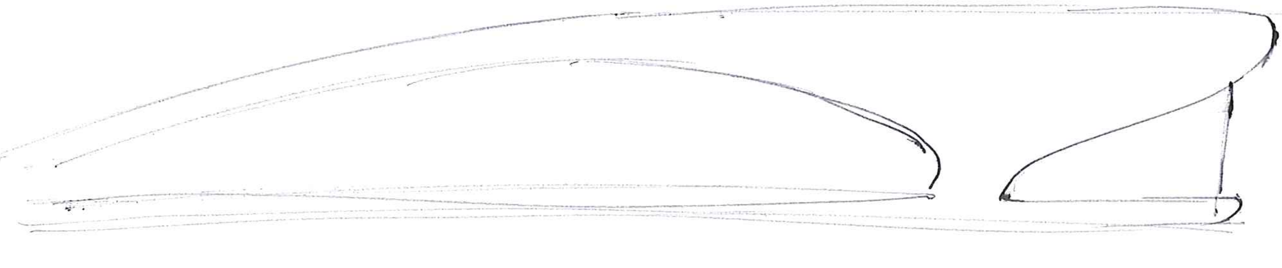


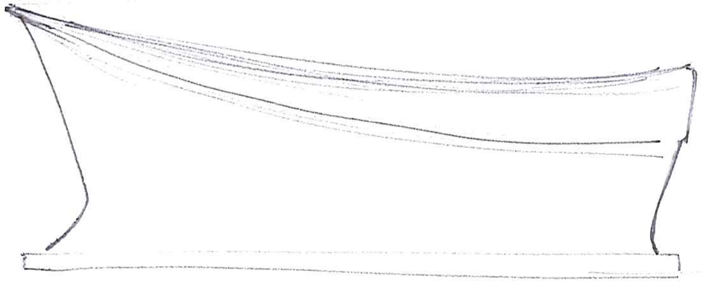





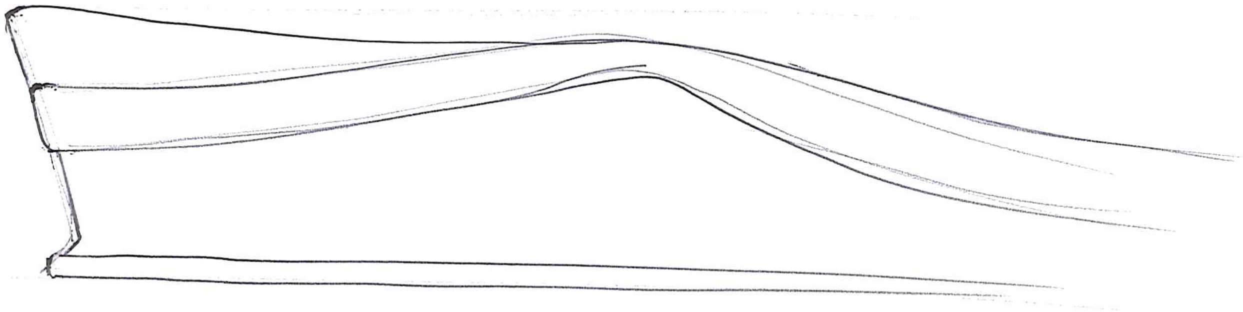


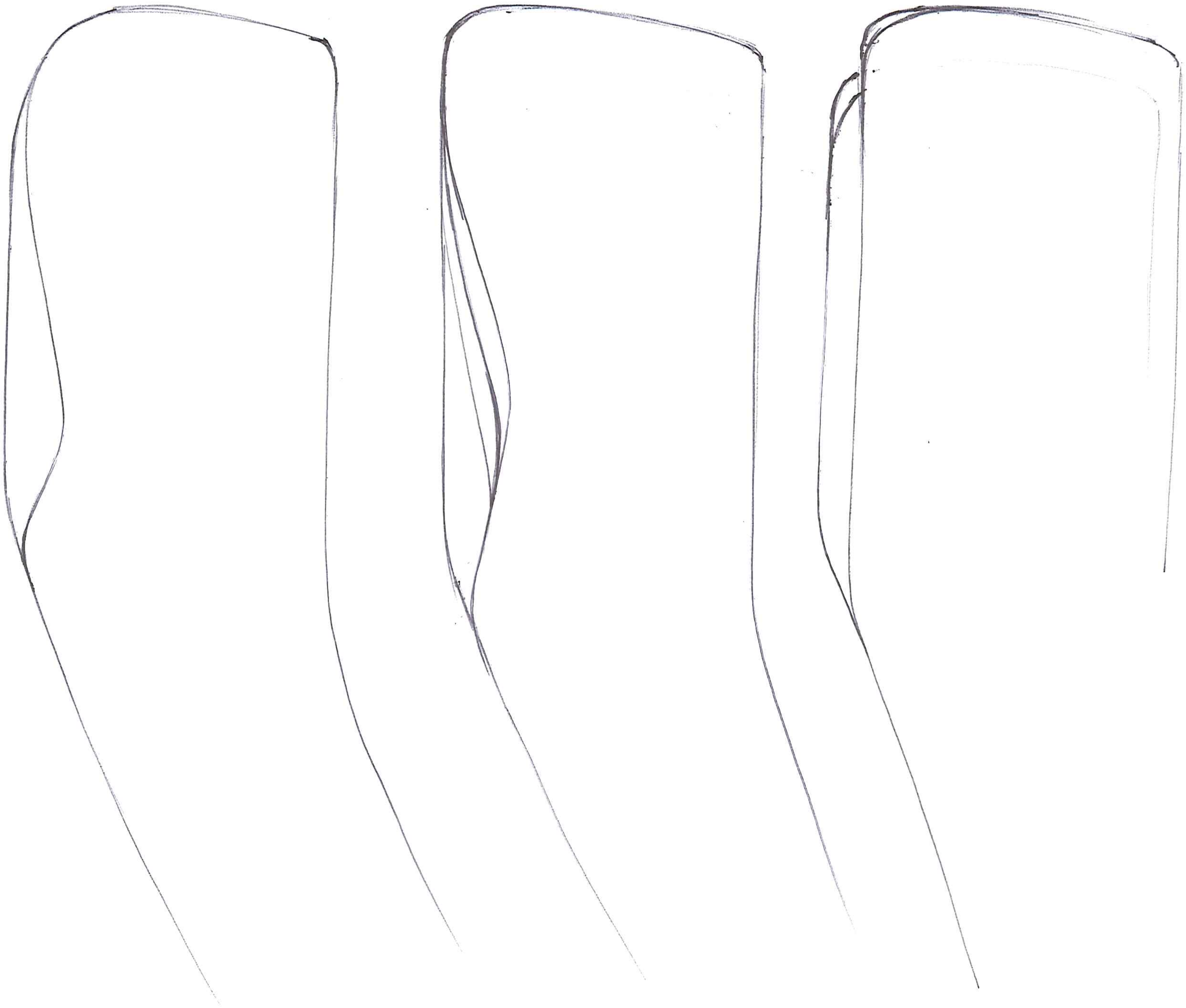


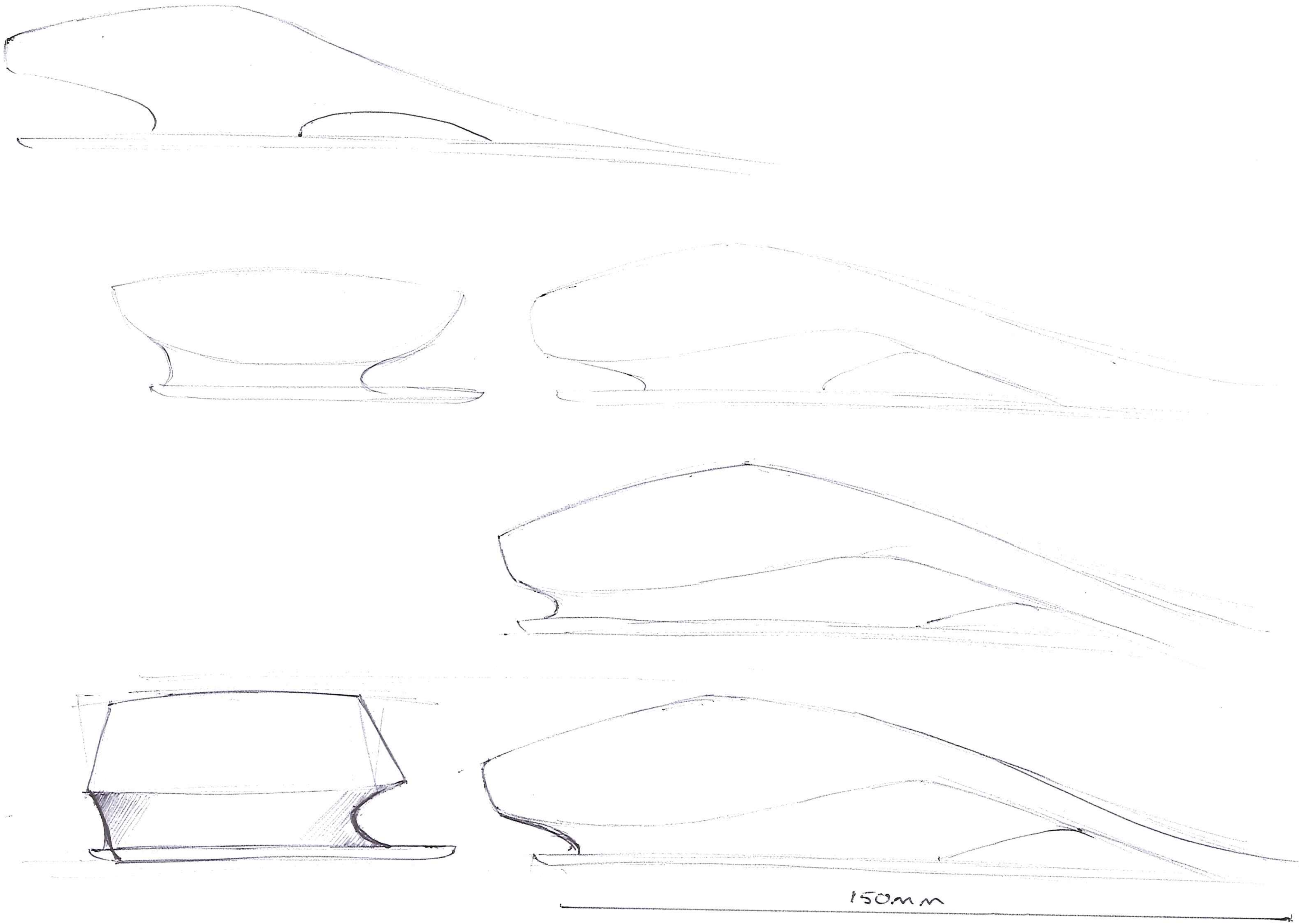


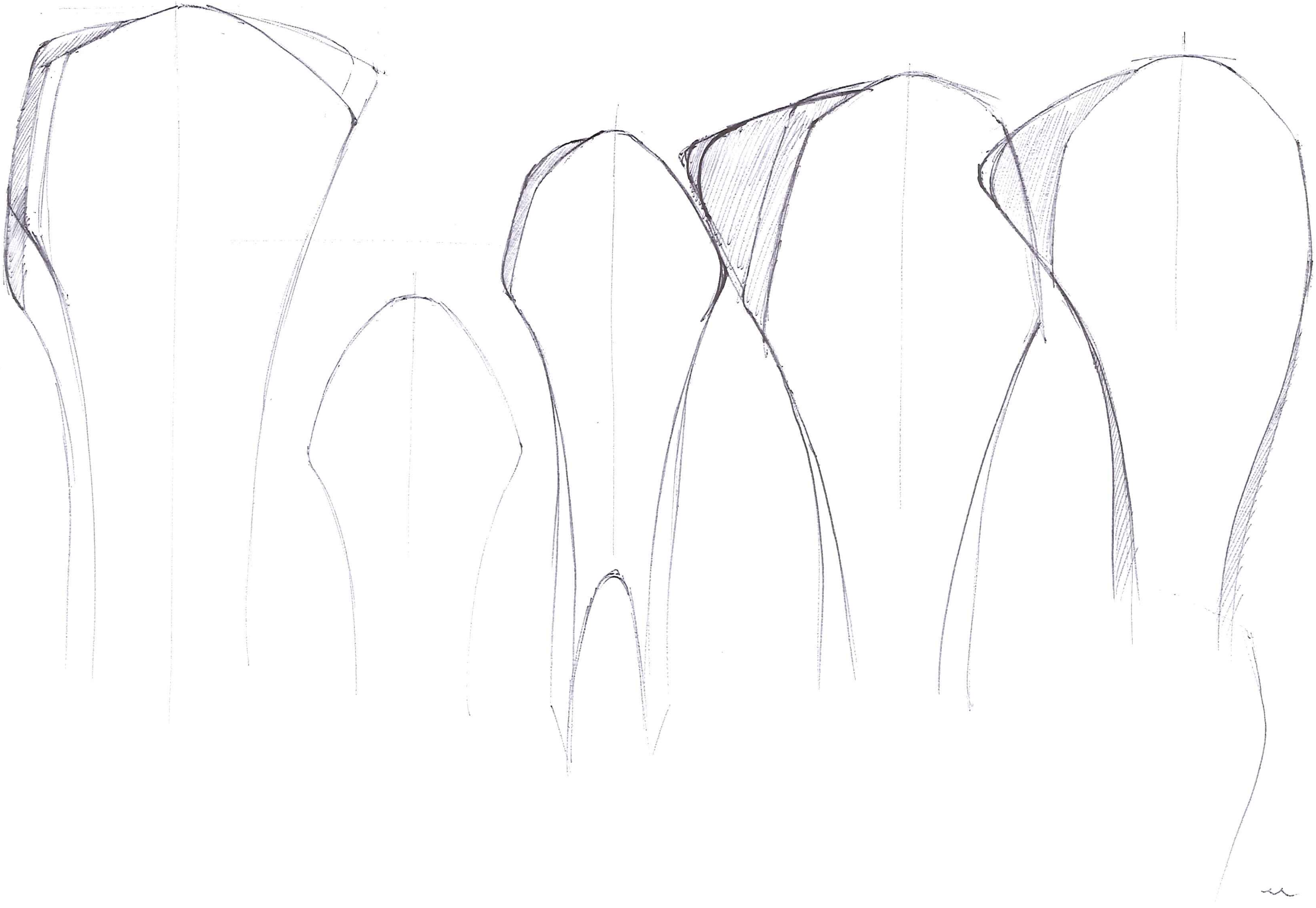



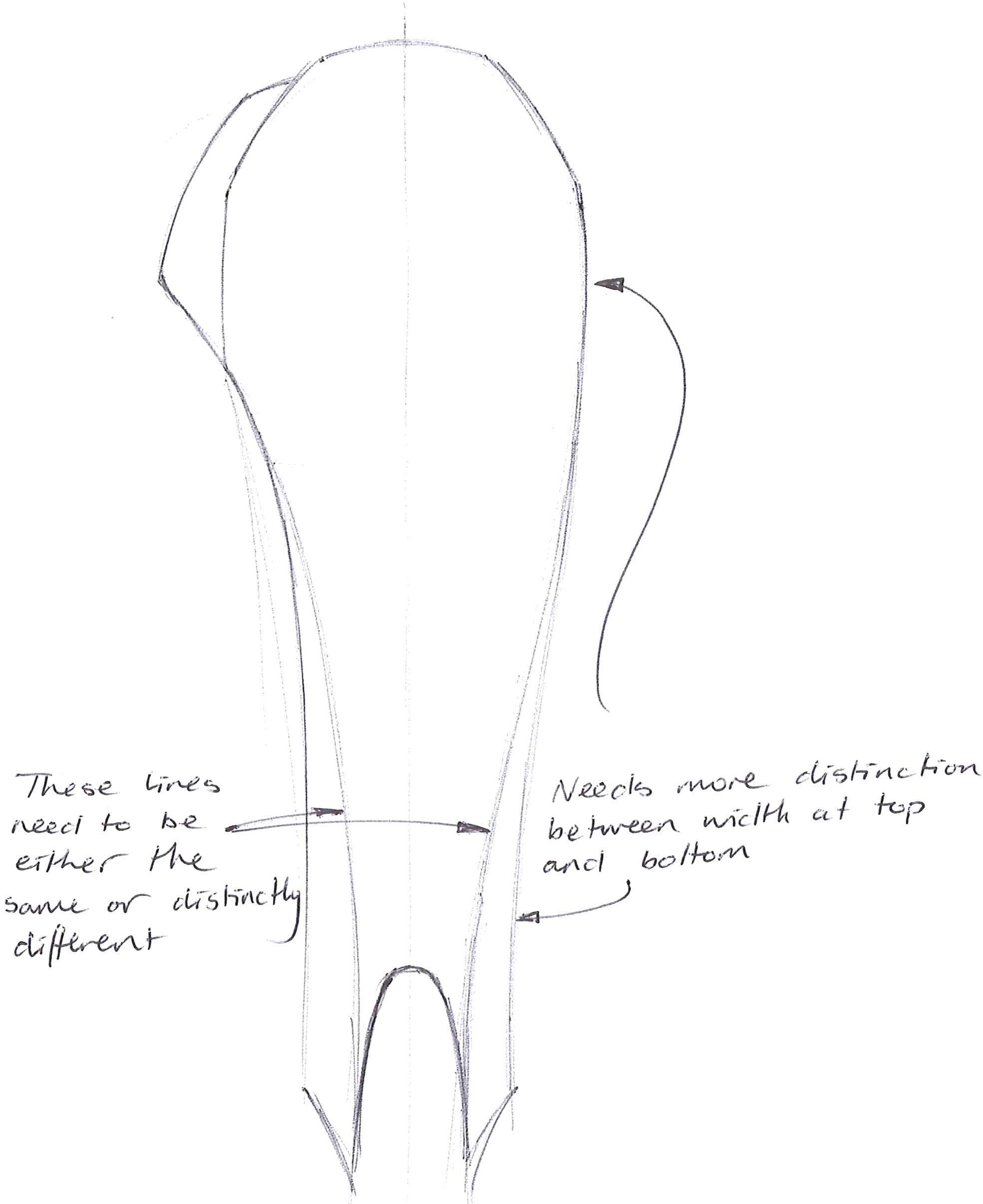




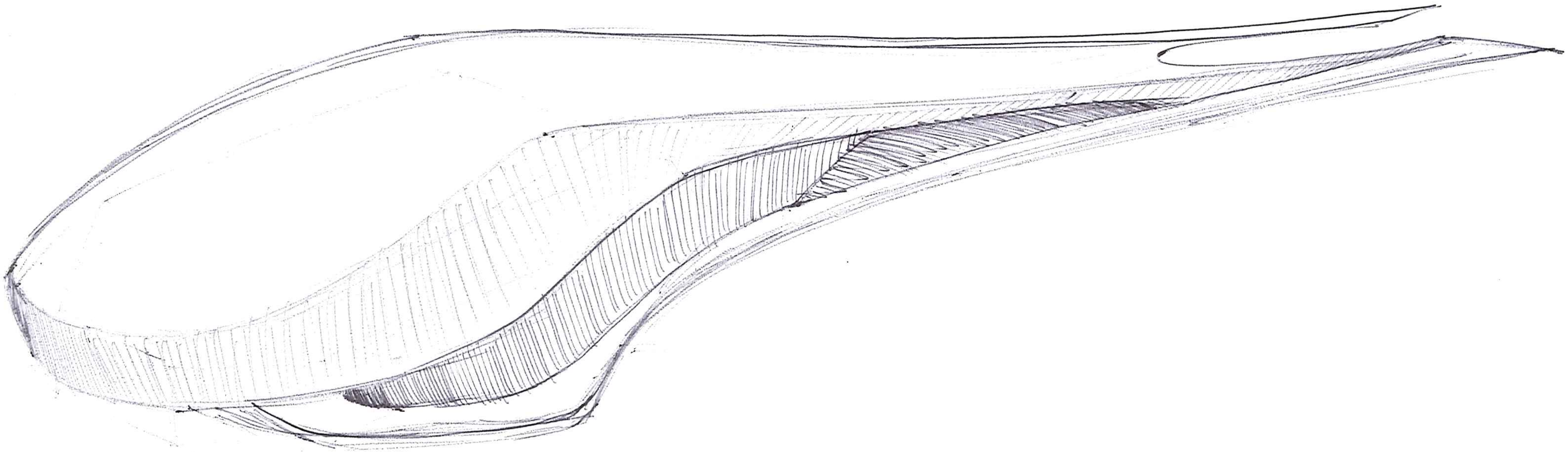


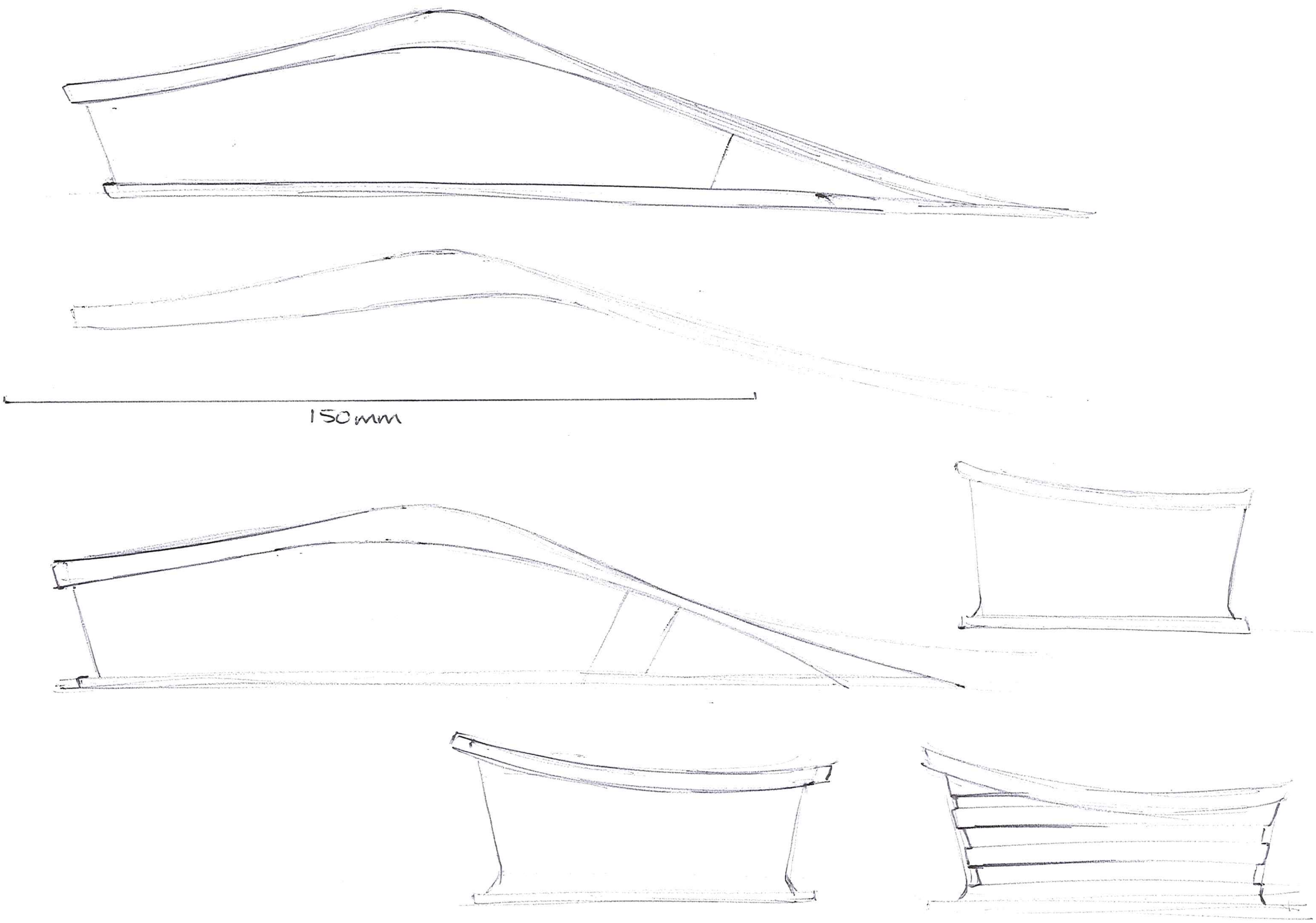

150mm

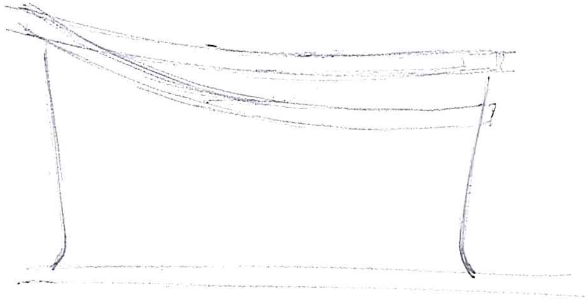


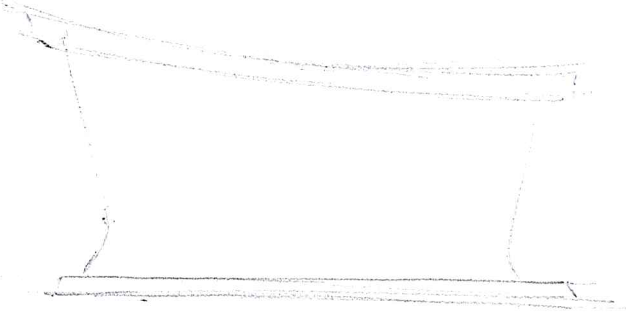

These lines need to be either the same or distinctly different
Needs more distinction between width at top and bottom

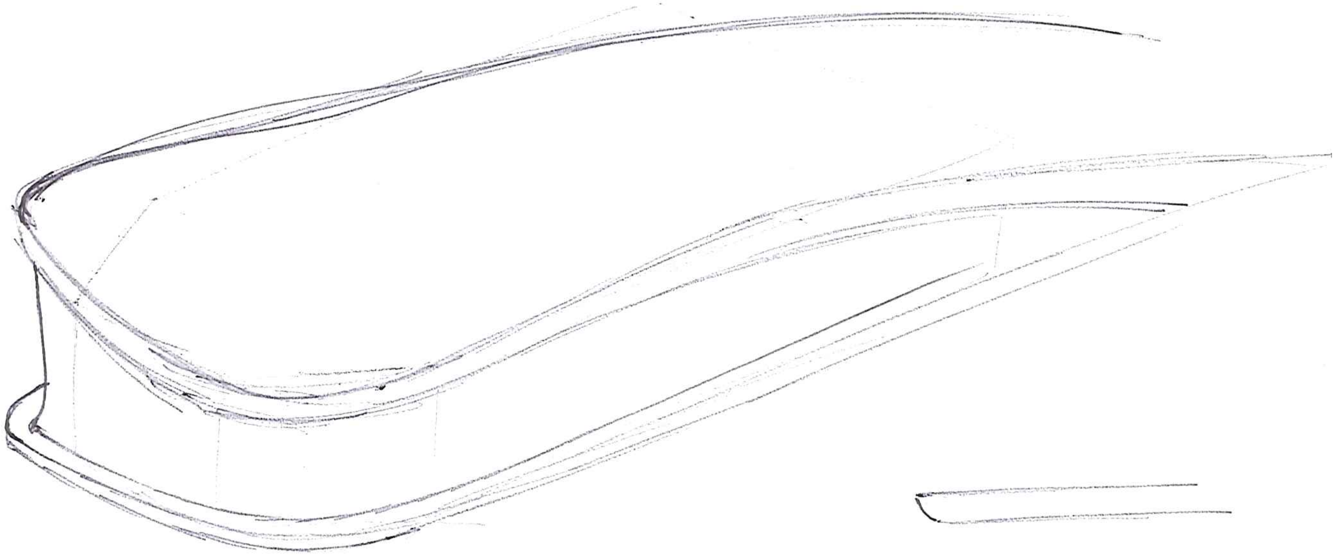

120mm
run the cable out the back

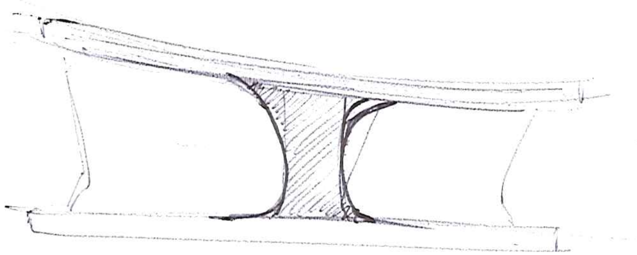


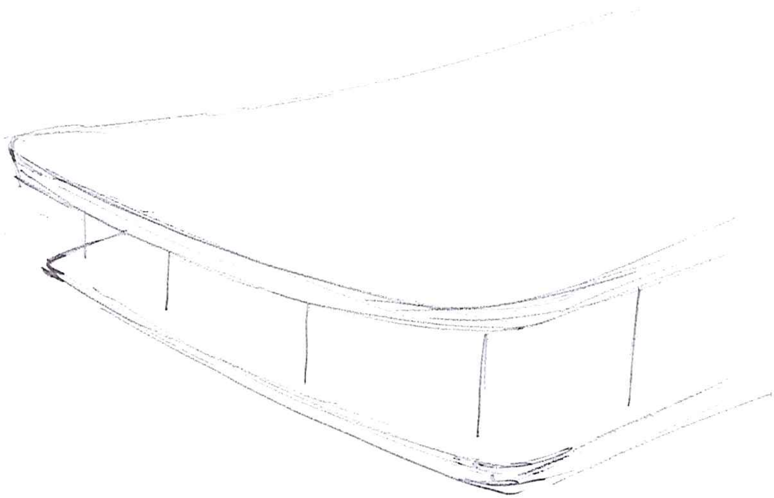

150mm

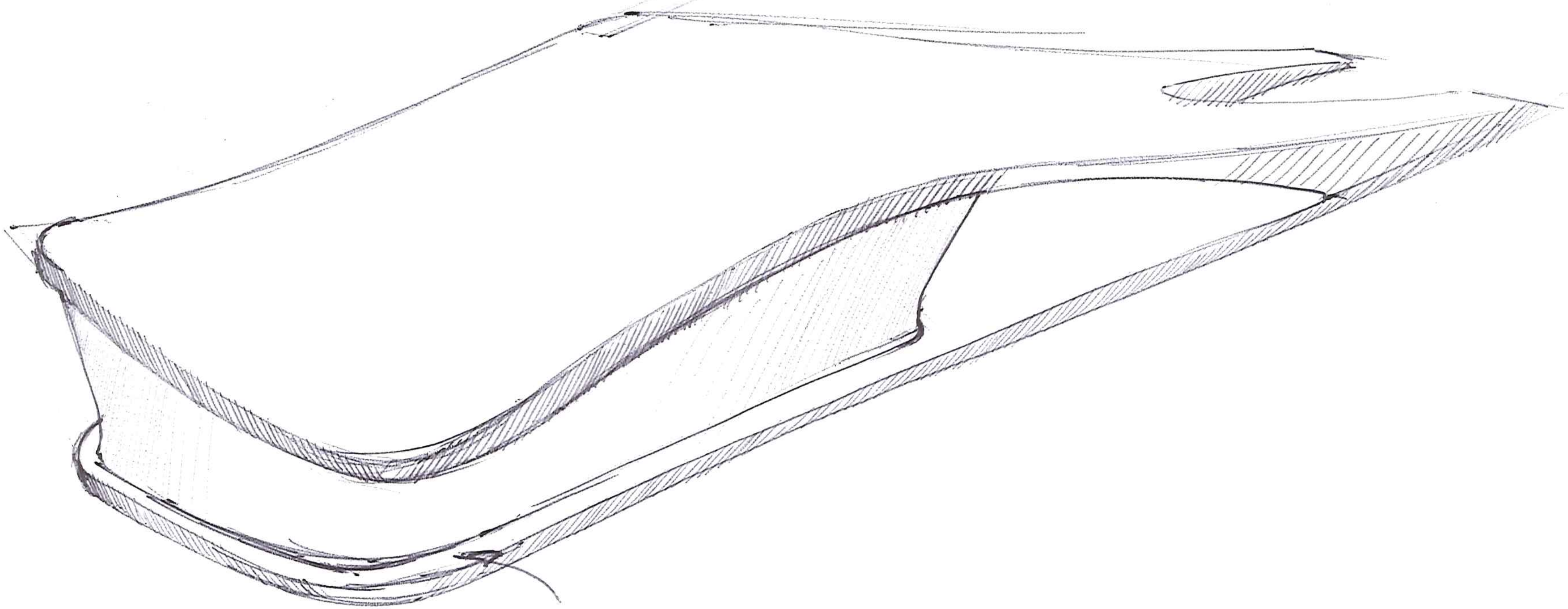




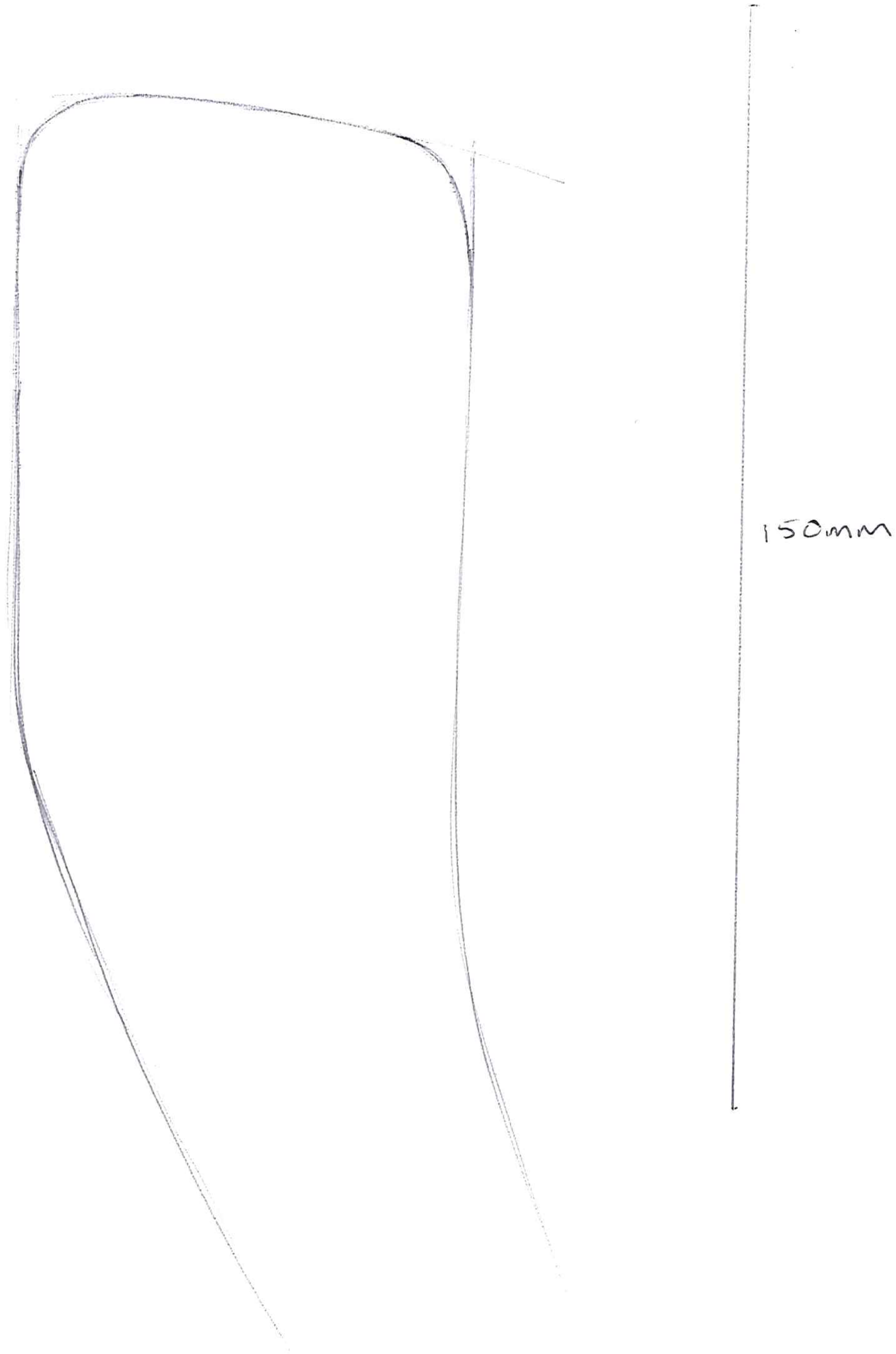


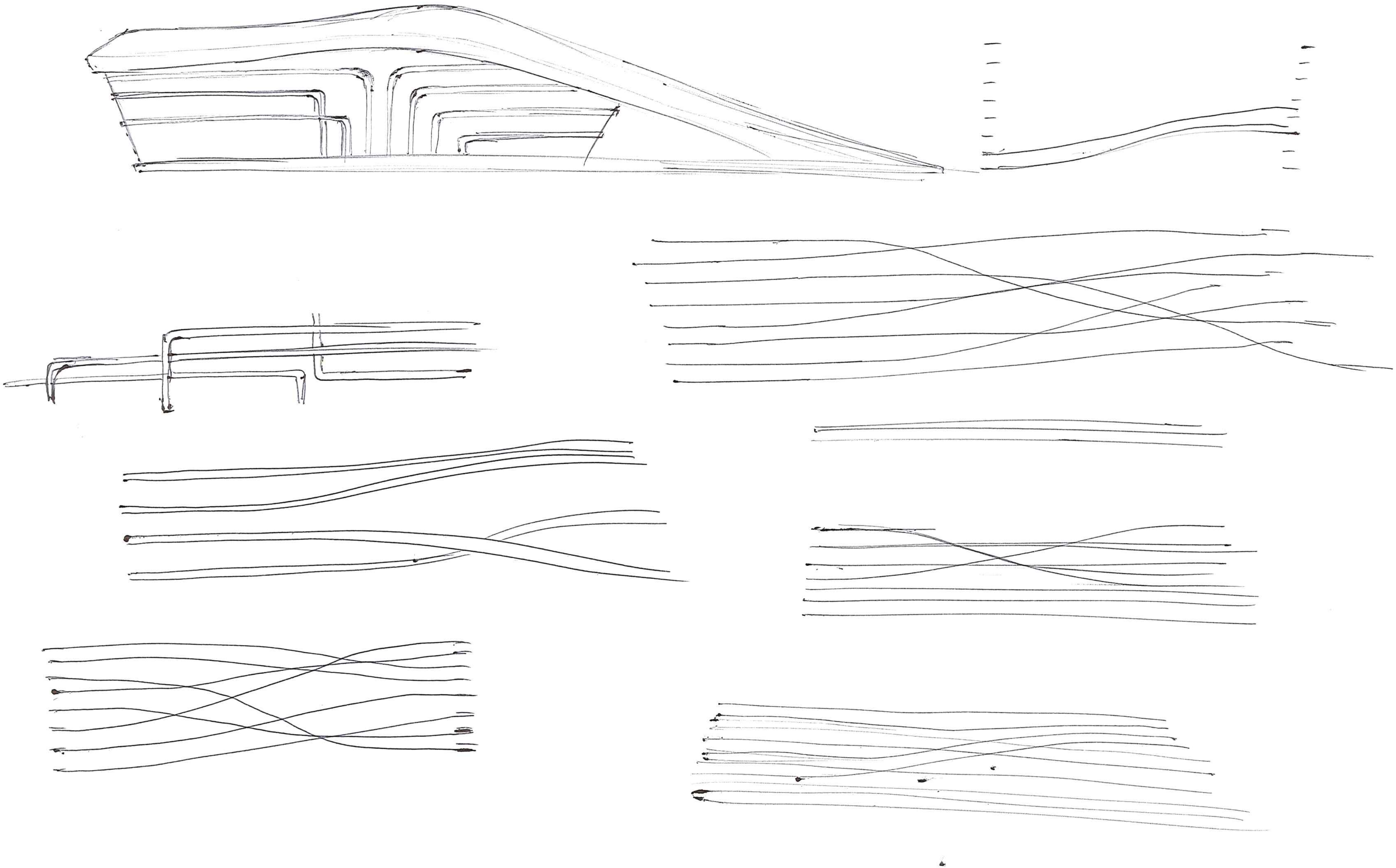






Not sure if this
corner should be the
same top + bottom -
wait + see in 3D


150mm



APPENDIX 10.3 Sculptris Diary Entries and Sketches

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 1		
01/10/11	Sculptris	Download, Installation, Tutorials
02/10/11	"	Tutorials
~~03/10/11~~	~~"~~	~~Tutorials~~
Week 2		
03/10/11	Sculptris	Tutorials
04/10/11	"	Tutorials + Practice
07/10/11	"	"
08/10/11	"	Practice
Week 3		
18/10/11	Sculptris	Modelling Practice
20/10/11	"	"
21/10/11	"	Modelling Practice
23/10/11	"	Inspiration Images

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 4		
13/11/11	Sculptris	Sketching
14/11/11	〃	Import Primitive + Modelling.
15/11/11	〃	Modelling
16/11/11	〃	Sketching, Modelling
17/11/11	〃	
Week 5		
22/11/11	Sculptris	Modelling
24/11/11	〃	〃
25/11/11	〃	〃
Week 6		
28/11/11	Sculptris	Modelling
01/12/11	〃	〃
02/12/11	〃	〃
03/12/11	〃	〃
06/12/11	〃	〃
09/12/11	〃	〃
10/12/11	〃	〃
19/12/11	〃	Remodelling

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

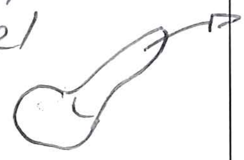
Date 01/10/11	Software Sculptris

Description of Activity

Downloaded + installed. Download required filling in details then receiving mail w/ link, but link did not work (malformed address). Managed to work out URL + type in manually. 19.2Mb download, installation followed usual process and worked smoothly. Sculptris marketed by Pixologic. Website contains some introductory videos which I began watching. 'Introduction' is just marketing. '3D sculpting' introduces interface + some tools, but last part of video is all about Z-brush, Pixologic's paid-for software.

UI consists of set of 9 'brushes' above other 'utility' tools. Sliders to affect brush size, strength etc are at top of screen, can also be accessed 'under' brush by pushing space. Overall feel is very different from normal modelling application - dark grey background, animated icons

Some brushes have 'global' setting - affects whole model rather than parts of model. So e.g. 'Grab' pulls part of model unless global turned on, when whole model moves.



RMB = rotate

MM Scroll = zoom

To snap to views (top, left, etc) rotate to roughly correct position and hold SHIFT

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 01/10/11	Software Sculptris

Description of Activity

Default is for symmetry to be turned on
Very very smooth rotation, zoom a little less so.

Basic metaphor is sculpting a piece of clay, but tools can add material as well as subtract. Can mask areas to prevent area being manipulated

Can import OBJ files

Files on Pixologic website play in proprietary viewer 'above' website. Annoying, because can't click around website without need to reload video after.

Paint mode allows colouring + texture mapping. Non-reversible action (can't go back to 'sculpt' operations). Watched 'Paint' video but nothing useful for my exercise. Last 1/3 of video is about Z-brush.

Under 'Features' page of Pixologic website 12 features of Sculptris. Looks like a tutorial page, however only 6 have videos, others coming later(?) 2 of the 3 'basic' features have no videos.

Watched 'Navigation' video - pretty pointless, could work it all out just by opening the program. Last 1/3 is Z-brush tutorial.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 02/10/11	Software Sculptris

Description of Activity

Tried importing .obj file into Sculptris. At first i received an error – 'cannot import face with more than 4 sides'. Realised this was due to the export options (from MoI, which I was using) so changed 'N-gons' to 'Quads + triangles'. Then got an error – 'too many connections to a vertex (max 24). Changed export options to angle of 30° and then it worked.

Can import a crude model, but not good enough to create real parts, + in any case no way to check size or do boolean operations necessary. Probably will have to import safe model, create my design + export to another program

Can work in symmetry mode or assymetrically. However if working A-sym then change to symmetric mode, A-sym features then get copied.

Watched video about brushes: demonstrates, but no tutorial. Last ⅓ is about Z-brush. A few videos refer to 'documentation', but I can't find any. There are tutorials + manuals on website but only for Z-brush

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 02/10/11	Software Sculptris

Description of Activity

'Community' includes Sculptris but only one section for all discussions, vs 22 for Z-brush. I'm starting to find this really annoying - seems like Sculptris is treated only as a 'loss-leader' by Pixologic, to get people to buy Z-brush.

Watched all videos on Pixologic site but not very good + no tutorials. Searched on YouTube + Vimeo + found others, started watching one (http://vimeo.com/12186535). Not a tutorial but much better than 'official' ones. Will continue tomorrow.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 03/10/11	Software Sculptris

Description of Activity

Overnight found manual for Sculptris. Program was originally developed by 'Dr. Petter' on website is a forum where someone asked where is documentation (its included with the download). Also some tutorials, but don't look that good.

Finished watching 'Primer' video, a really good introduction. Started to watch 2nd part but a lot different: in depth of how to model a human nose. Looked for other videos but couldn't find any good tutorials - a lot of sped-up demos, some (fewer) in real-time, but none w/ explanations of what's happening. I didn't expect to find anything directly related to this project but thought there'd at least be some tutorials.

Because this is aimed at character modelling, outcome is probably going to be very 'organic'. Not sure of design direction by any means yet. May try to model Ron Arad chairs that I used for Cosmic Blobs (?)

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 04/10/11	Software Sculptris

Description of Activity

Spent most of the day reading through forum on Pixologic site, looking for advice + clues on modelling. Found a few things but not a lot. There are a lot of good models + modellers (to my eyes) but v. little concrete ~~exam~~ guides to follow - for a complete novice to this kind of modelling (like me) this is really frustrating. And add to that the fact I'm trying to do something very different to any of the examples.

Found one page showing (though not clearly) how to make a cube. It works, but not very precisely.
www.zbrushcentral.com/showthread.php?162073-Hard-surface-Modelling-tests-in-Sculptris
Found another page showing how to create holes in objects. Will try this tomorrow.
www.zbrushcentral.com/showthread.php?143454-My-beta-testing-doodles&p=862363&viewfull=1#post862363

Design Diary

Analysis of Consumer-oriented CAD Software

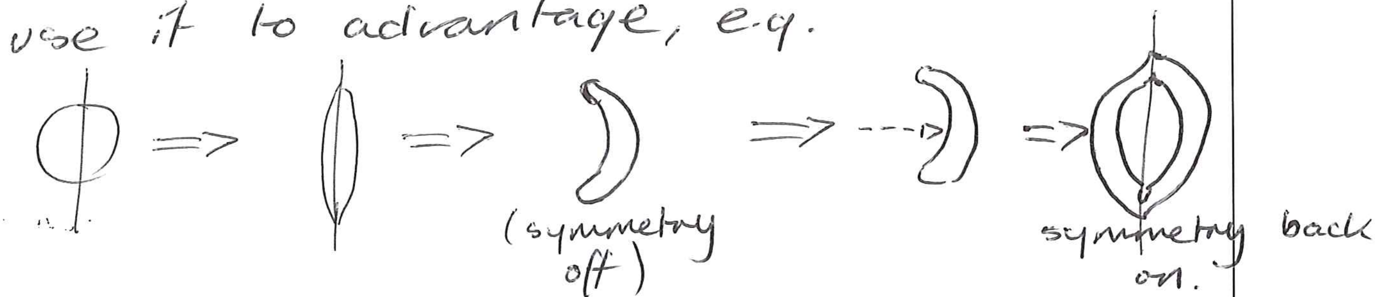
Loughborough University

Detail of day's activity

Date 07/10/11	Software Sculptris

Description of Activity

Started by playing around w/ symmetry button + following instructions for making holes. If you work w/ symmetry off + then turn it on, non-symmetrical features are mirrored over. At first this seemed really annoying, but you can use it to advantage, e.g.



Not many examples where this is explored, it seems. Also a way to get round lack of boolean features.

Watched one YouTube video www.youTube.com/watch?v=ATeNfYzLUY, sped up modelling video but w/ written narration.

Began to model Munny figure. I'd tried to do this in Cosmic Blobs but without much success

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 08/10/11	Software Sculptris.

Description of Activity

Finished modelling Mummy character. It's not great, but learnt a lot doing it, finishing wouldn't teach me a great deal more. One thing I'm going to need to get my head round is the way Sculptris is so 'unplanned' or perhaps 'loose' is better. It's more akin to sketching w/ a pencil than CAD modelling, not like anything I've used before. This is definitely going to be the hardest one to learn/master.

Still not really got any idea or inspiration for how the new mouse might turn out.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 18/10/11	Software Sculptris

Description of Activity

Began modelling 'Big Easy' chair by Ron Arad. It's fairly symmetrical and kind of 'blobby', but has some very sharp edges. Began by taking the sphere and flattening, then using pinch to get a hard edge. This worked well, airbrush mode and then 'lock plane' on flatten tool give a crisp edge. But then what I wanted to do was 'pull' or extrude the half sphere to a cylinder, and this is really difficult. Grab doesn't do it, nor does scale. In the end I decided the build plan would be to get the front shape right + then add material at the back, then sculpt.

A lot of frustration! This is hard work for me, really different to how I'm used to working. Still not sure if I'm approaching things right - should I 'forget' what I know + use the tool like others, or should I try to use it in a way thats not be done before, ~~as~~ a more CAD-like fashion? I'd prefer the second approach, but it's not paying dividends at the moment.

Design Diary

Analysis of Consumer-oriented CAD Software

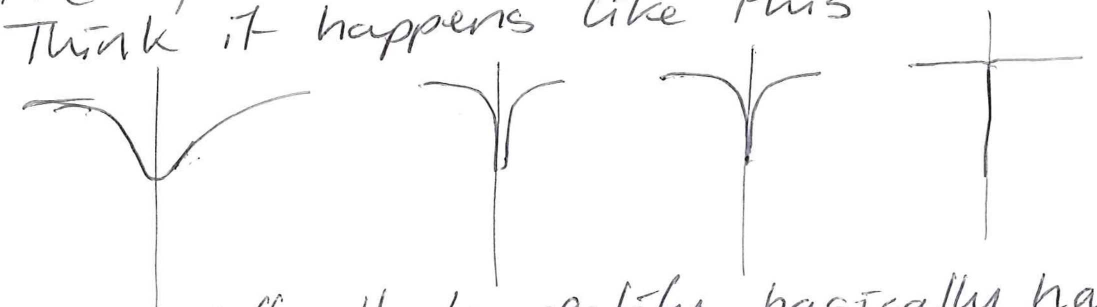
Detail of day's activity

Date 20/10/11	Software Sculptris

Description of Activity

Continued (+ finished) modelling the Big Easy chair. The front looks good, sharp edges, shape + proportion are correct. The back is less successful, not as crisp or refined. I could spend a few more hours trying to improve but not sure how much I'd learn, all I'd be doing was smoothing + tweaking. Feel like a different approach is needed - more use to symmetry tool.

Noticed some problems with (in particular) the inflate tool, producing creases in a surface. Think it happens like this



Very difficult to rectify, basically have to 'de-inflate', this can cause a lot of other details to be absorbed + lost.

Started to model Ron Arad 'Voido' chair. I'll try to use symmetry (+ rotate) tool much more on this model. Starting to worry that I still don't have much inspiration for an actual mouse design...

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 21/10/11	Software Sculptris

Description of Activity

Having thought about modelling the chair overnight I decided my approach was wrong, and started again. This time I used the symmetry / reflect tool much more, sometimes turning it on to reflect a form then immediately off again to rotate the model. More successful, though still not accurate to the degree I wanted. Didn't complete the model, again felt I wouldn't learn much spending hours cleaning up surfaces. I'm acutely aware now that I've spent some time "learning" the software but I'm still not at a point where I feel comfortable using it. Not at all sure I can get a working model out of this. But at least some feeling for a design is emerging - a kind of bio-mechanical theme. Ability to model muscles + animal / human features makes this an obvious choice, though I hope my modelling skill lives up to the ambition. Don't want it to be too Geiger though.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 22/10/11	Software Sculptris.

Description of Activity

Day spent looking for images + generating a moodboard.

I've been wondering how acceptable it would be to import primitive shapes as a basis to begin sculpting – cube, cylinder etc. On one hand it fits with the scenario – easy to create primitives in (eg) SketchUp + import. But then it dilutes investigation of Sculptris' capabilities. Still undecided...

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 13/11/11	Software Sculptris

Description of Activity

Started sketching, drawing heavily on inspiration images. Working mainly in pencil over pen drawings of underlays. Two main themes - one is a primitive shape (which I'll have to model in some other software + then import) which I then sculpt into; the other is a very organic form w/ lots of 'tendrils' At the moment the second feels 'forced' - trying too hard to create something which couldn't be done in some other software.

From the practice I did in Sculptris, fairly sure I won't be able to re-create a design exactly. So sketch sheets will be trying to catch a flavour of a design which I'll develop in the software.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 14/11/11	Software Sculptris

Description of Activity

Started by testing ability + results of importing a 'primitive' into Sculptris. Created a 'cube' 102 x 59 x 20 (approx 5mm bigger than safe model all round) in MoI. Used quads + triangles option to export.

Imported fine to Sculptris but need to use 'subdivide all surfaces' option to create enough triangles to work with. When I tried to smooth corners (i.e. simulate a fillet) nothing happened. Trying to smooth a vertex 'unstitches' the surfaces; it looks like a graphical error, but when taken into Keyshot it confirms the shape is an unstitched surface.

Went back to MoI and exported the shape as triangles only. This made no difference.

Then tried ~~the~~ another tack - modelled fillets in MoI and then exported. This caused problems with the Sculptris limit of only 24 connections at a vertex. Reducing the .obj export resolution in MoI created a very faceted fillet, but since the flat surfaces still needed to be subdivided, this created an unworkable number of triangles around the fillet.

Was beginning to think my plan of starting with a primitive would not work, in which case it was likely that no workable model would come from Sculptris.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 14/11/11	Software Sculptris

Description of Activity

Went back to MoI and selected the 'weld vertices along edges' option. But now when trying to subdivide in Sculptris the part 'ballooned' + became unrecognisable. At least the edges could be smoothed though. Then finally, found an option to 'smooth subdivide' which I unchecked. Now subdivide works without ballooning the object, and smooth also works. Went back to MoI and exported as quads + triangles, will test later which option works best.

As a test, exported a rectangular cube as .obj from SketchUp. With same/similar options as MoI, it also imports + works in Sculptris. ~~Sti~~ Maybe this is a 'purer' test? Still need to decide which software to ~~use~~ use to modify the Sculptris model.

Spent about an hour playing with the model based on the previous days ~~results~~ sketches. Already getting some nice models...

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 15/11/11	Software Sculptris

Description of Activity

Worked on different approach today - plan was to begin with standard sphere + develop to a shape that could be exported for finishing details. First problem encountered was ~~that~~ when using safe model as a guide, sometimes seems to be absorbed into shape being worked on. Not sure if this is actually happening (there aren't any boolean operations) or its just disappearing. Also, when working on one shape tool will affect the other unless its totally masked. A simple 'lock' option would really help.

Also suffered from not really having something to aim at, sketches from previous weren't leading me anywhere. But pinch tool is really good at getting sharp transitions which makes objects much more 'product-like'

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 16/11/11	Software Sculptris

Description of Activity

Began by sketching some new concepts, but quickly moved on to building models in Sculptris. At this point my expertise in Sculptris is low, so it feels more fruitful to be using the software as a design exploration tool. Unexpected results and my lack of skill are both great for leading off in new directions. That said, I think I'm settling on a concept direction, which is the idea of a pure primitive which has been shaped by ~~an~~ natural force There should be enough of the original pure shape remaining to understand what it was. Or some of the shape which is untouched.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 17/11/11	Software Sculptris

Description of Activity

Went back to imported primitive cuboid shape – have decided this is the concept I'll go with. Not much to say except I practiced shaping the starting 'block', trying to achieve the forms I want. Seems that beginning w/ an .obj file creates problems at sharp edges (raggedy surfaces, crinkling, self-interesecting, though I think they can be cleaned up in most instances.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 22/11/11	Software Sculptris

Description of Activity

Again not much to report except I practiced shaping the starting cube to get the forms I want.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 24/11/11	Software Sculptris
Description of Activity	
Started on what I hope will be the final model. Saving new files frequently so I can go back to previous save points. I've realised it's too easy to mess up by 'over-working' an area, and then have no way to return to a good point.	

Design Diary

Analysis of Consumer-oriented CAD Software

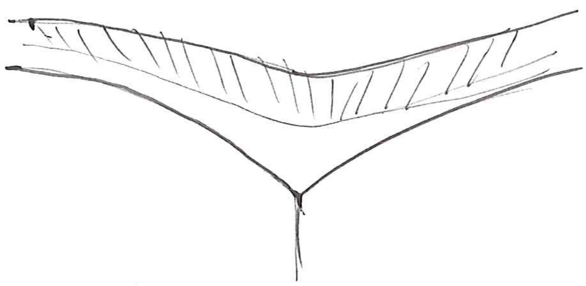
Loughborough University

Detail of day's activity

Date 25/11/11	Software Sculptris

Description of Activity

Continued with the 'final' model. The top sweep is good and I like the way it transitions over the front surface. Am having problems with the side 'cut' though, the inside surface is lumpy and whenever I try to smooth it the corners become rounded off.



Also problems at the edges of the original cube, maybe its because I used an imported .obj to begin with, maybe Sculptris just doesn't like hard edges. But in some places edges are extremely faceted.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 28/11/11	Software Sculptris

Description of Activity

Continued with modelling and got to a stage where I'm close to finished. Spent some time experimenting with the 'paint' side of Sculptris - basically you 'bake' the 'clay' model (which means it can't be sculpted afterwards) before painting. When converting you set a resolution for the new model, this can significantly reduce the file size, even though the triangle count remains the same. What I wanted was the conversion to smooth some of the jagged triangles (I think its called re-topologising) but that doesn't happen

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 01/12/11	Software Sculptris

Description of Activity

Spent half the day basically trying to smooth out the model using 'smooth' + 'flatten' tools, with limited success. Problem is that both tools create smoothing by adding triangles (complexity) rather than reducing. Its also really easy to over-smooth edges, even with 'smooth subdivide' option turned off. Only way to do it is to use the 'reduce' brush - this reduces number of triangles, but can over-simplify the model if you're not careful.

Started trying export the model as .obj + then open in Solidworks - very frustrating. Obj will open in Rhino and can export an .stl but SW won't open it (too many triangles). ProE will open the .stl. SketchUp will open (with the appropriate Ruby plugin) but a lot of surfaces are missing.

Tried exporting STEP, IGES, SAT files from Rhino + ProE but they're all 'empty'. Tried

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 01/12/11	Software Sculptris

Description of Activity

saving a ProE .PRT file, which should open in SW, but no luck - I think its because I have an educational license for ProE. ~~[illegible]~~ Tried using 123D but it will only open .stl as a mesh, not a solid. So basically, I'm stuck. Thinking about trying Blender tomorrow... I'm desperate. Right now there's no way to actually turn the sculptris file into a 'real' object.

Design Diary

Date: 02/12/11 Software: Sculptris

Had a thought overnight as to how to fix the problem - reduce triangle count in Sculptris to get a .stl file that SW will import. Tried a number of different versions: 85930, 56594, 38426, 29808, 23515 and 19912 triangles (numbers are successive reductions). Took these .obj files into Rhino, converted to .stl and then tried to import to SW. Only smallest one works (19912) - I have found limit of SW .stl import is 20,000 triangles, couldn't find it anywhere on internet. But the model is horribly faceted, especially at the edges. You could say it has its own aesthetic, but definitely not what I was after. Tried changing things in Sculptris but problem is it wants to convert things to triangles rather than quads + this gives the ragged edge.

Also there's a scale issue going from Sculptris to Rhino (reduces by factor of 100) but easy enough to re-size in SW.

Seems I have to bite billet + begin modelling features in SW...

Design Diary

Analysis of Consumer-oriented CAD Software

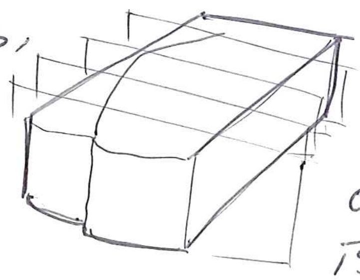
Detail of day's activity

Date 06/12/11	Software Sculptris

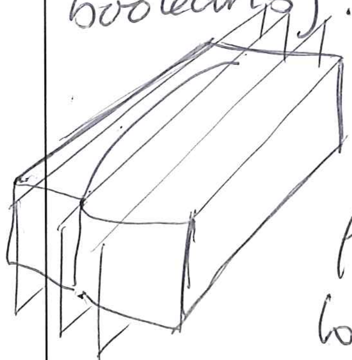
Description of Activity

A number of other options occurred to get a better model into SW, including slicing the model in Rhino so each segment contains less than 20,000 Δ's then reassembling in SW. But I wouldn't be learning anything about Sculptris (in fact I'd be learning about Rhino), so decided to just go with what I have.

Sliced the model inside SW + created sections,



then lofted to approximate the original surfaces. Necessary because each of the 19712 triangles is a surface, mostly non-tangent, so impossible to do anything with the imported model (except booleans). Then created other sections



to check accuracy. Lofted, then offset for interior surfaces. Used this to shell the part, then locally fixed for features that cut into shell.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 09/12/11	Software Sculptris

Description of Activity

Began fixing critical features to mouse parts. Had thought this would only take one day but complexity of cut-outs etc means I have to keep manually fixing where surfaces interfere or wall section is not thick enough. Also the number of surfaces is slowing re-draw rate on my machine - annoying.

Divided part into three (base, body, buttons) Critical features of base are complete, button features done but need to cut scroll-wheel hole. Then body features, though most are simple.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 10/12/11	Software Sculptris

Description of Activity

Finished critical features modelling. Realised I needed to split hole for cable so had to remodel split between base + body, but easy enough. Exported .stl files + sent to Ian.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

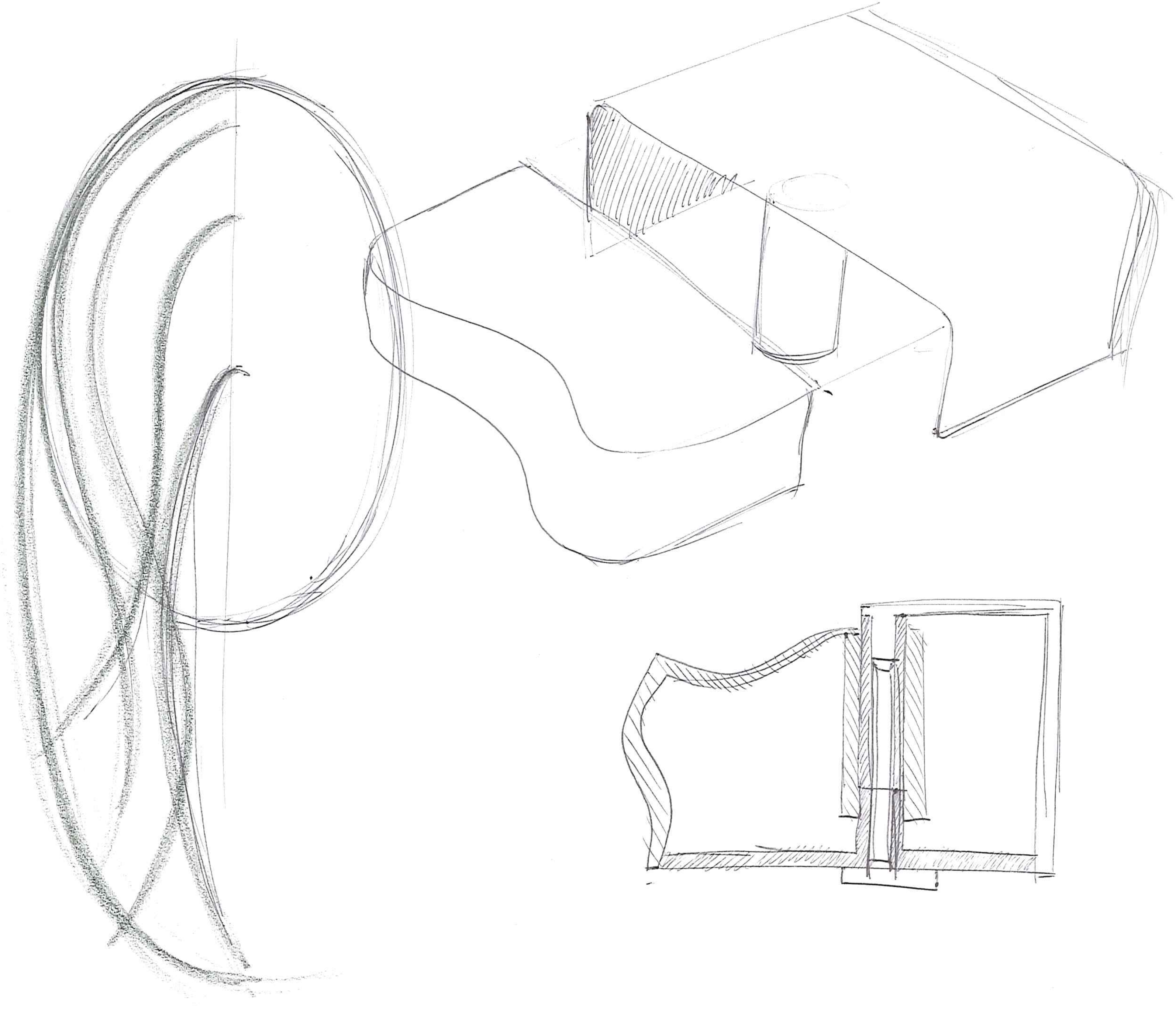
Date 19/12/11	Software Sculptris.

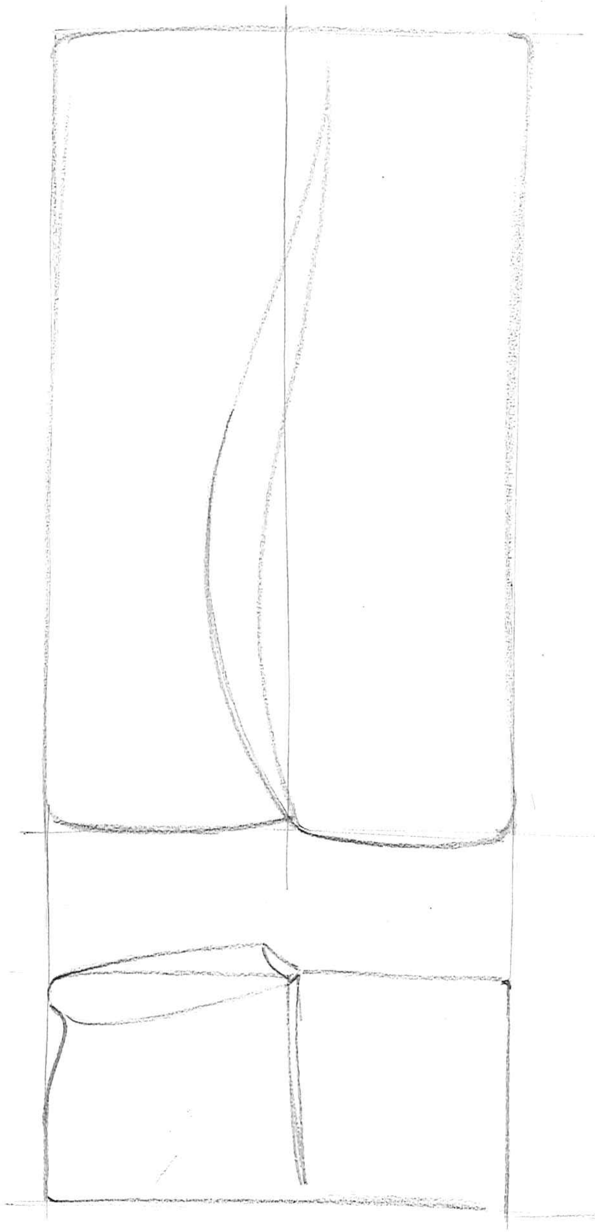
Description of Activity

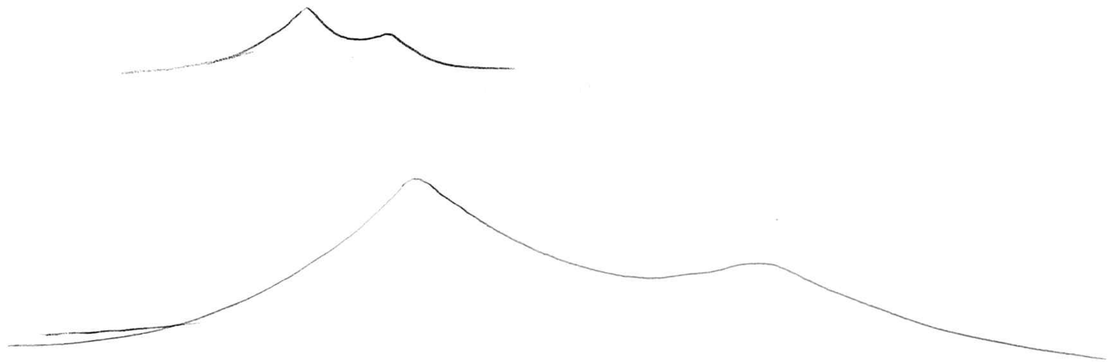
Received files back. One of the button pushers broke off during cleaning so remodelled it to make stronger. Parts are better than I expected, much less faceted actually. But process introduced a lot of 'unclean' surfaces where support structure was used. Orientation needs changing next time.

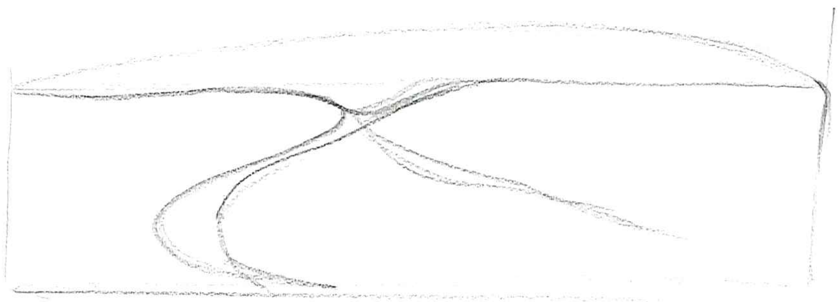
Uploaded files to Shapeways site, will order soon

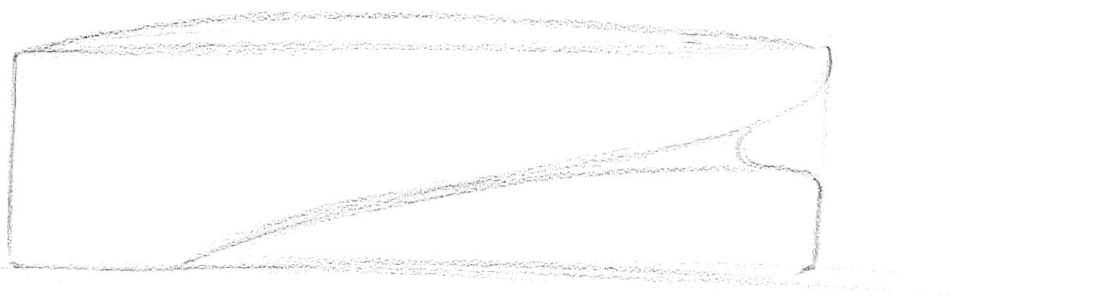
Fit between buttons + body is fine, but fit between body + base is very tight. Strange, because tolerance is the same, probably part has 'warped'. Connex 500 parts seem to suffer a lot from this (compared to nylon parts anyway

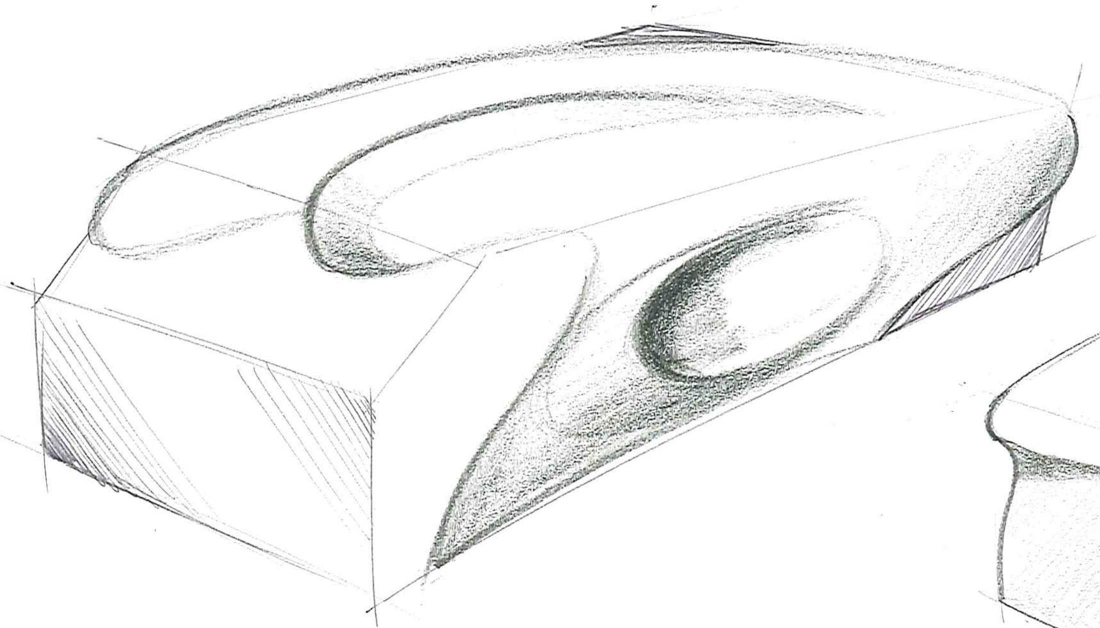


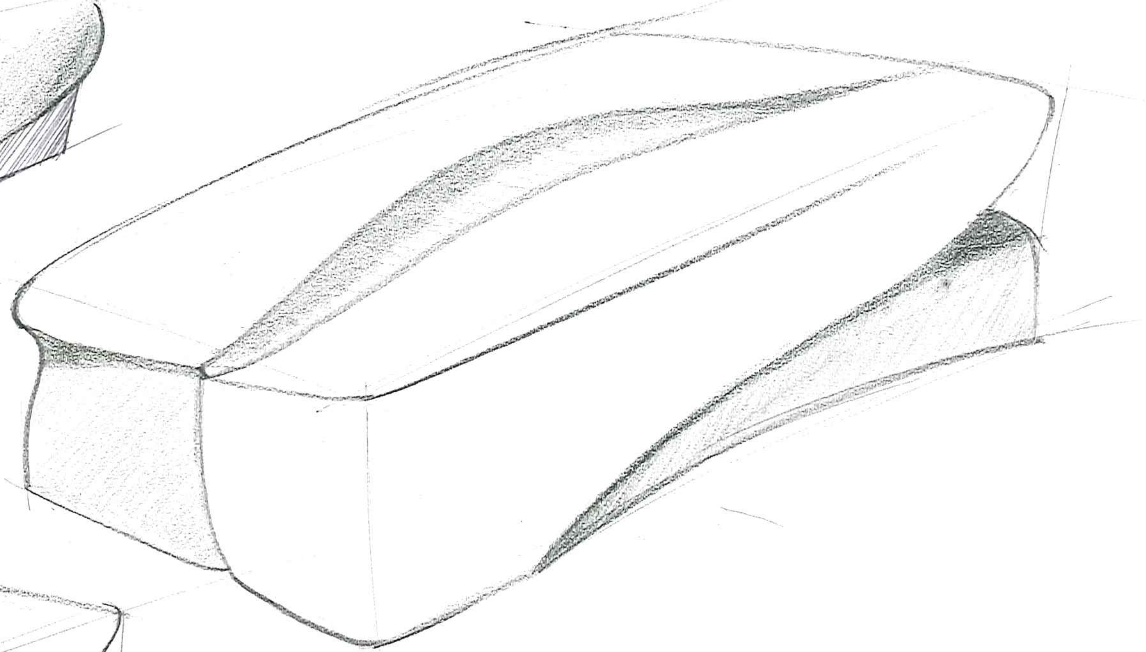




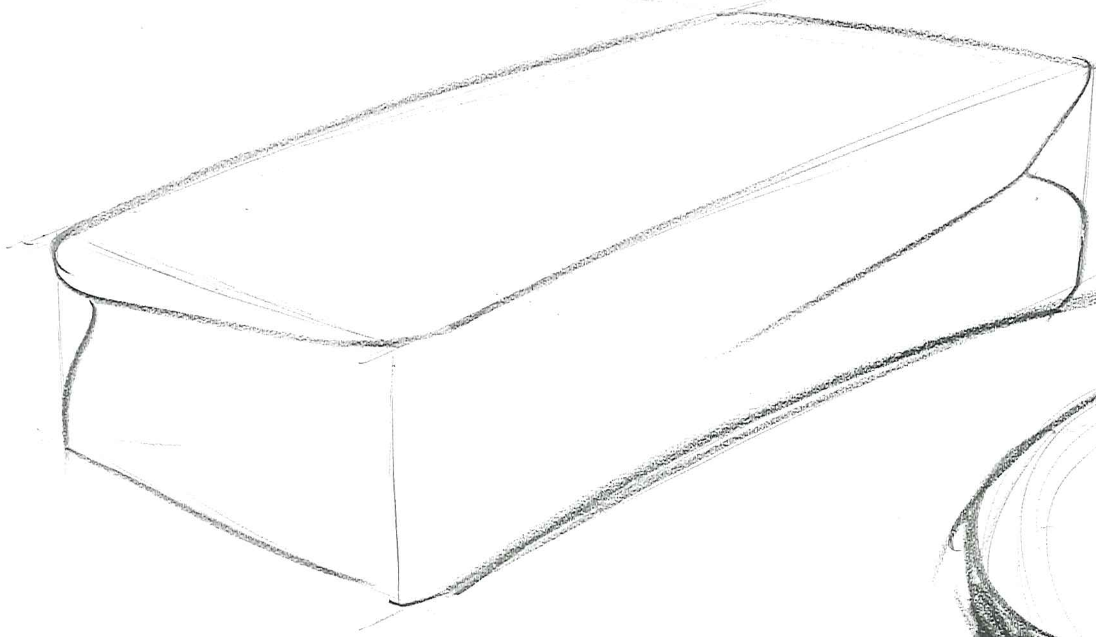


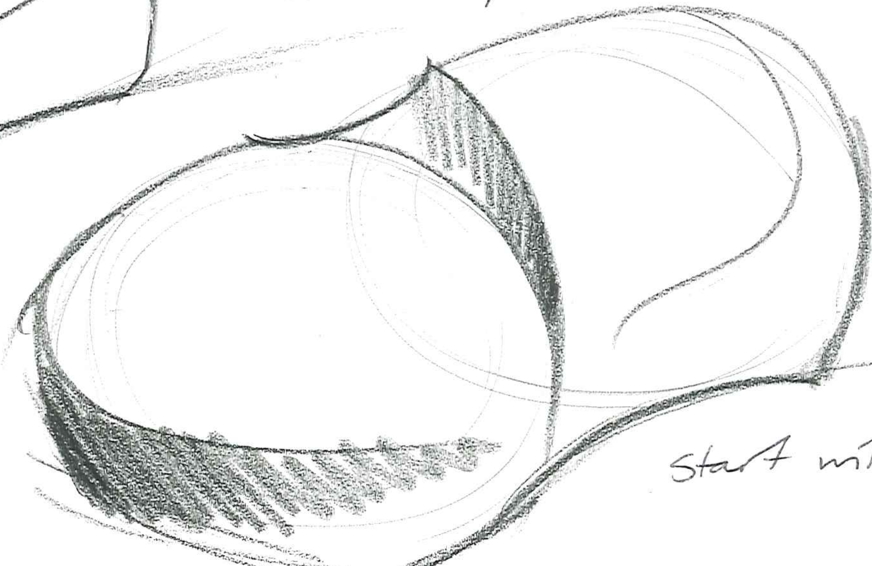




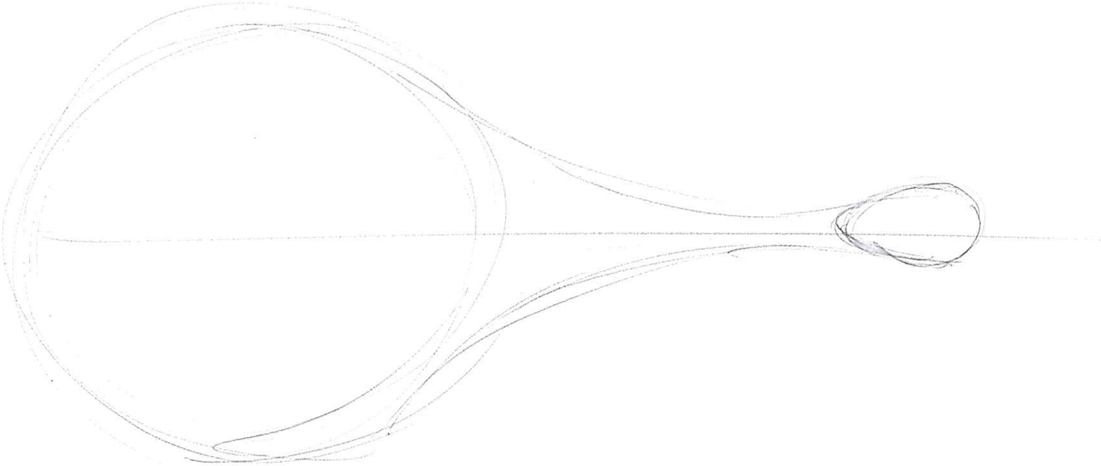


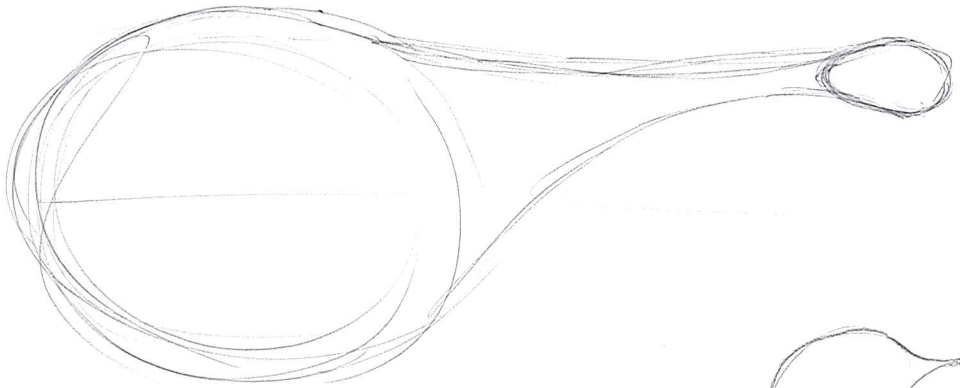
Still starting with basic shape
but no part reveals itself

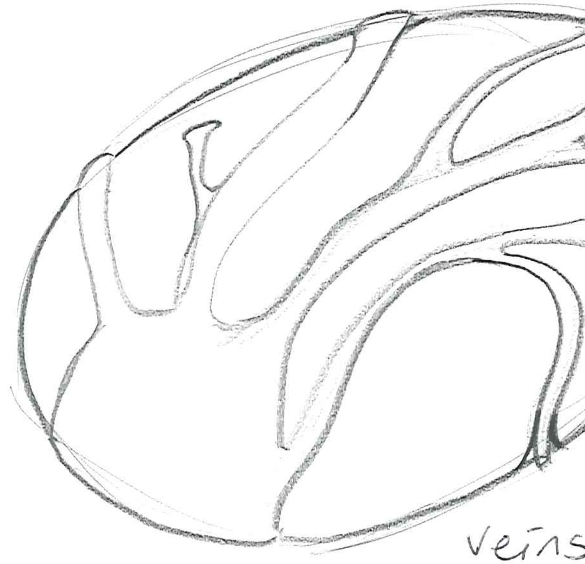




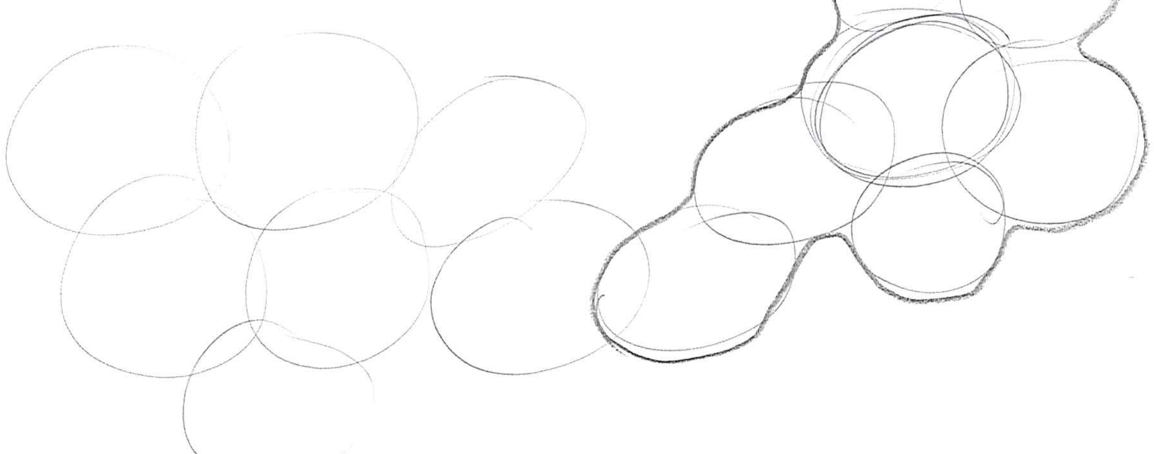
Start with spheres.

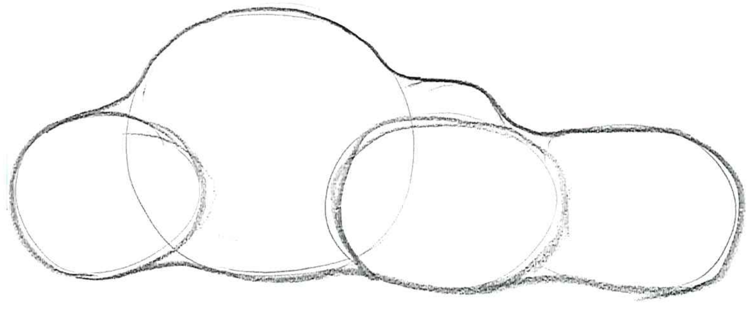


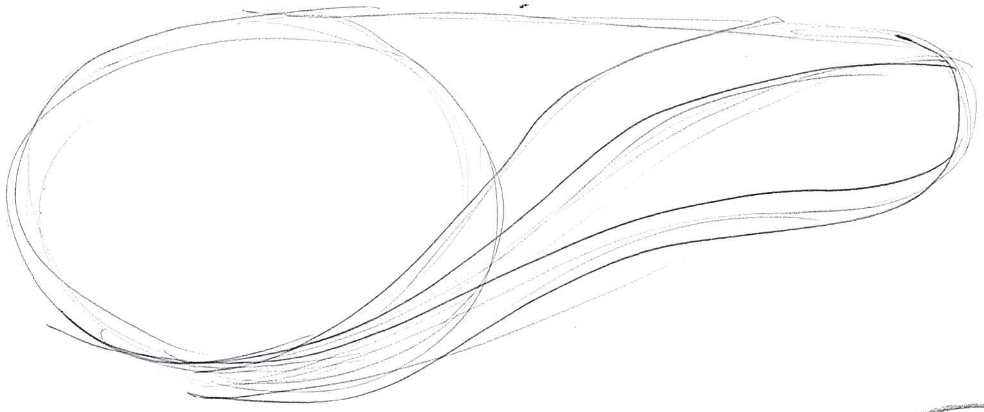


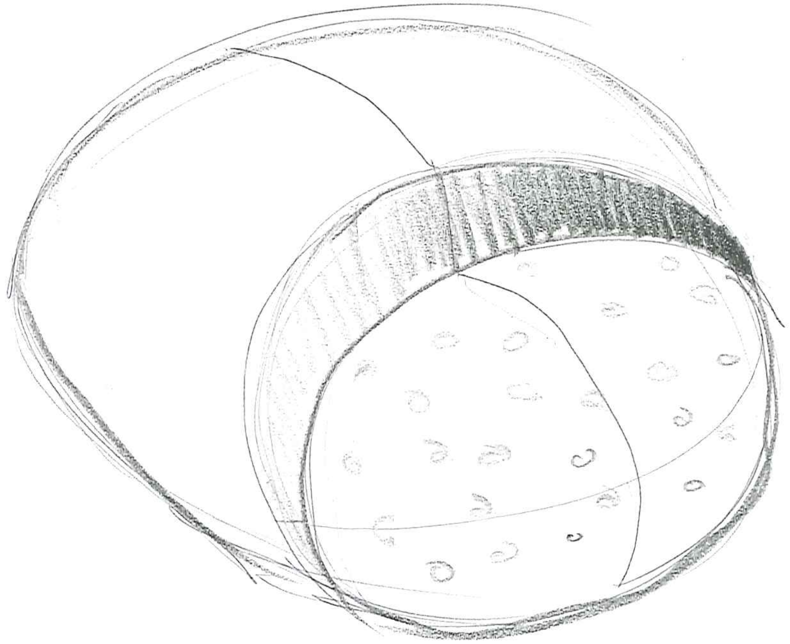


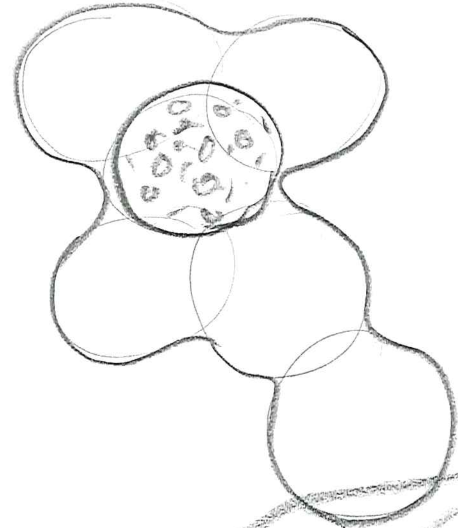
veins.

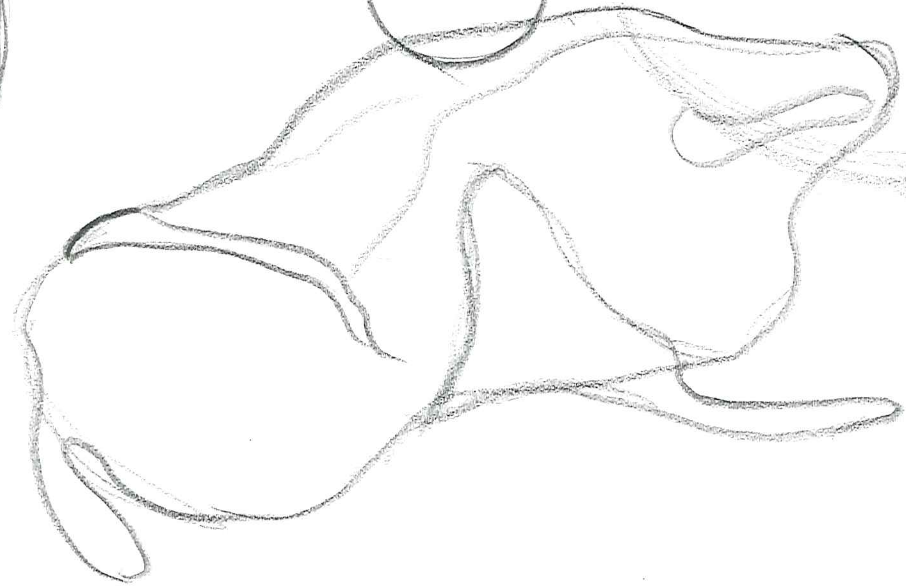


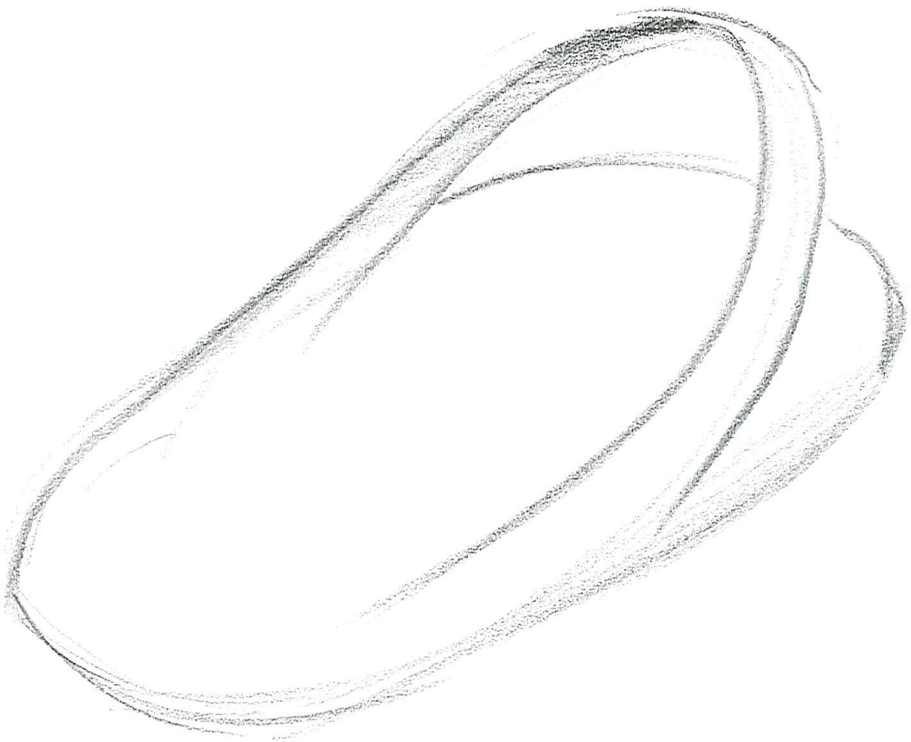
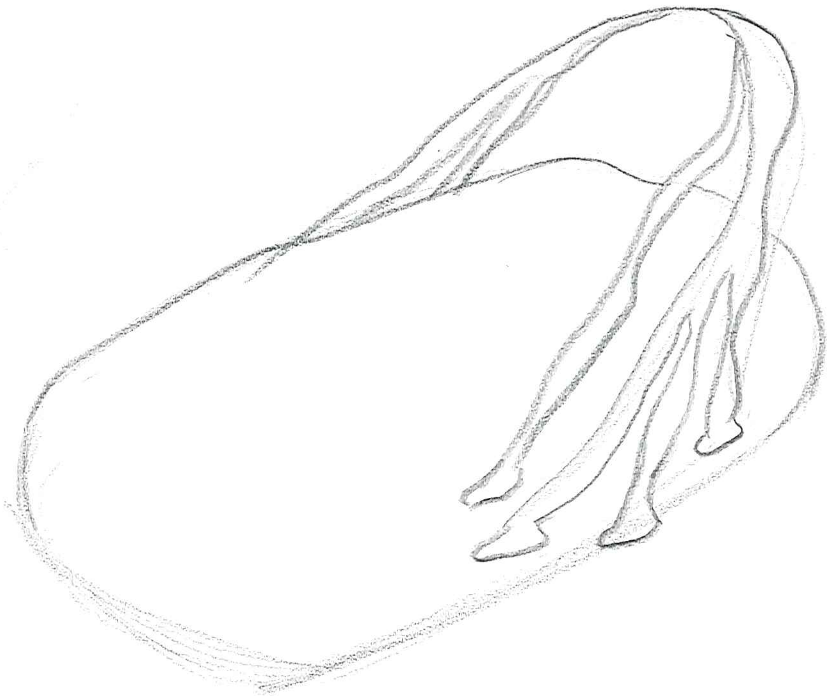
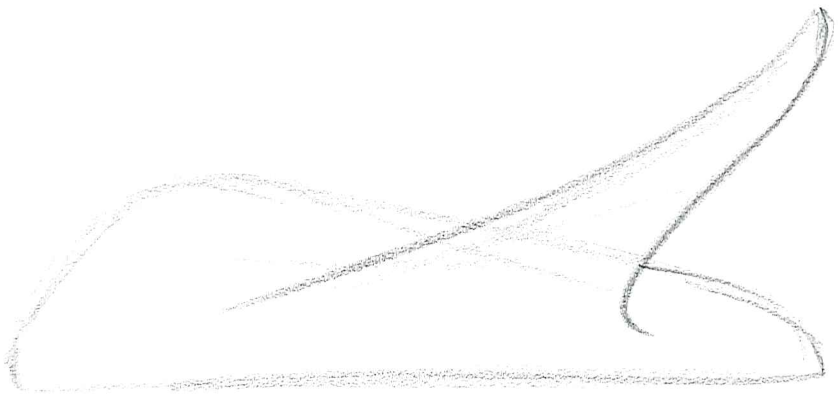
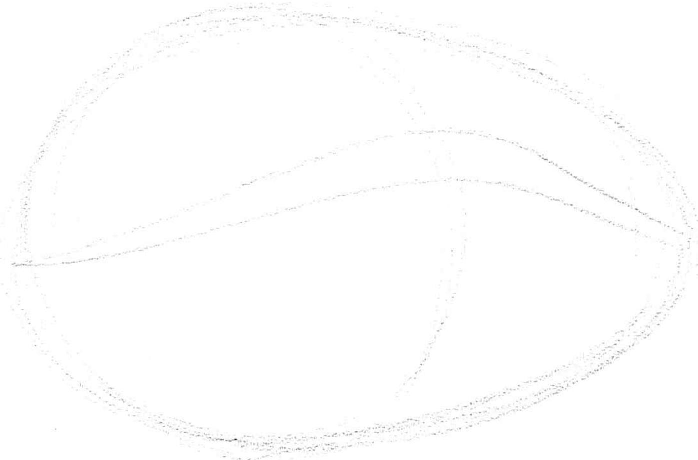


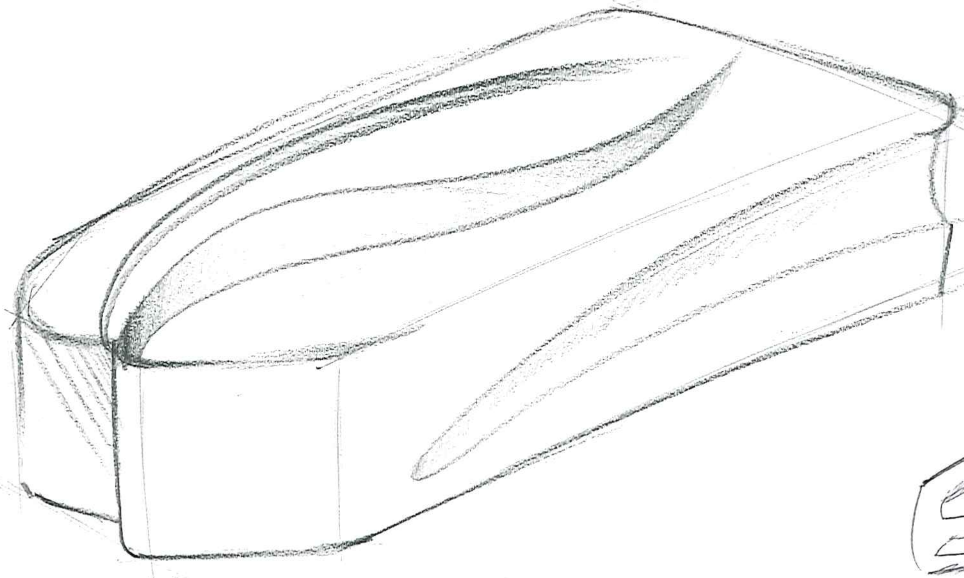




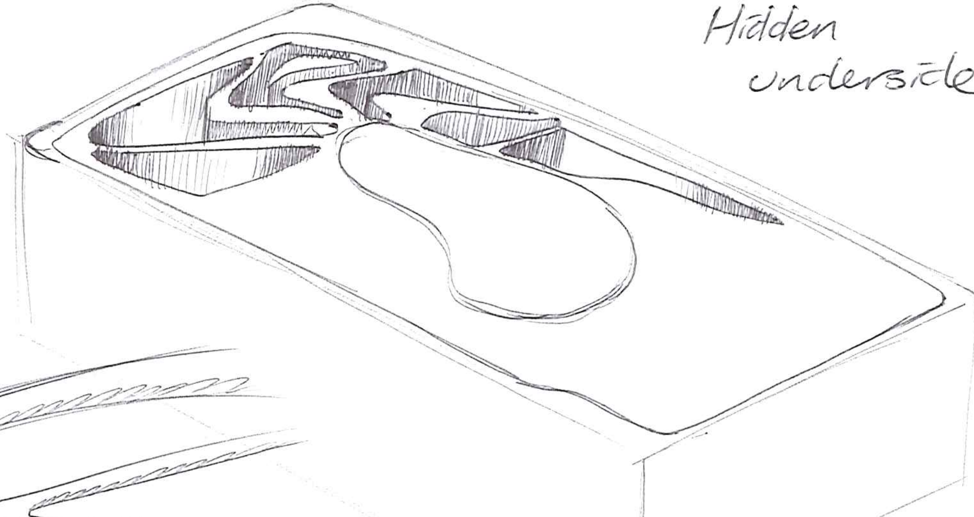




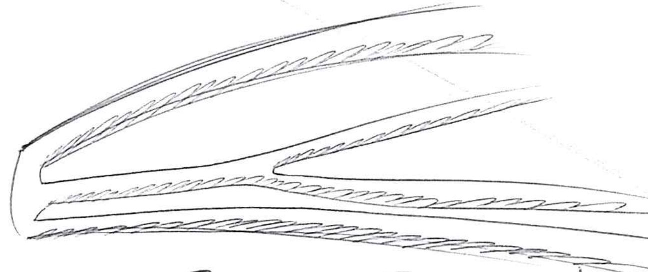







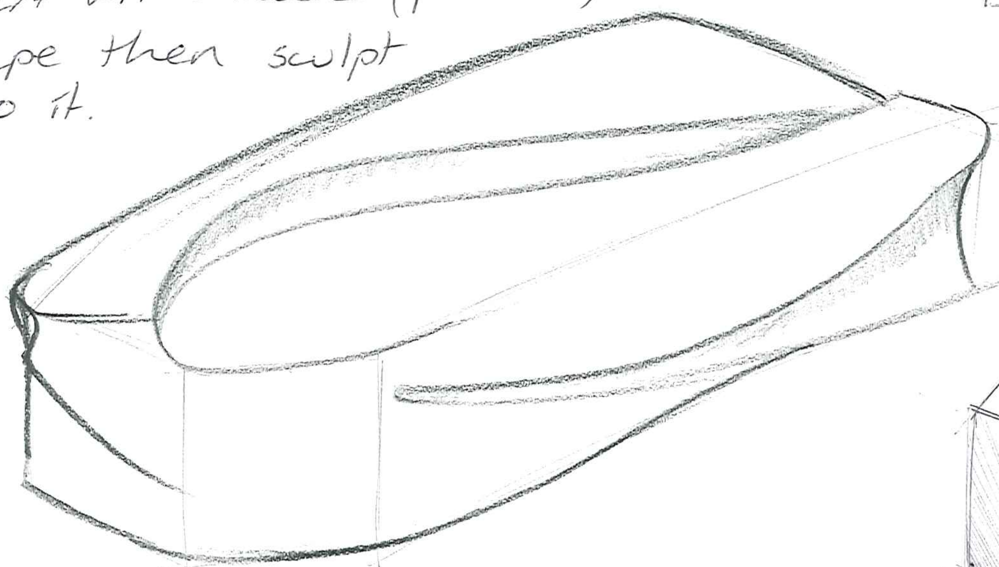
Start with basic (primitive) shape then sculpt into it.

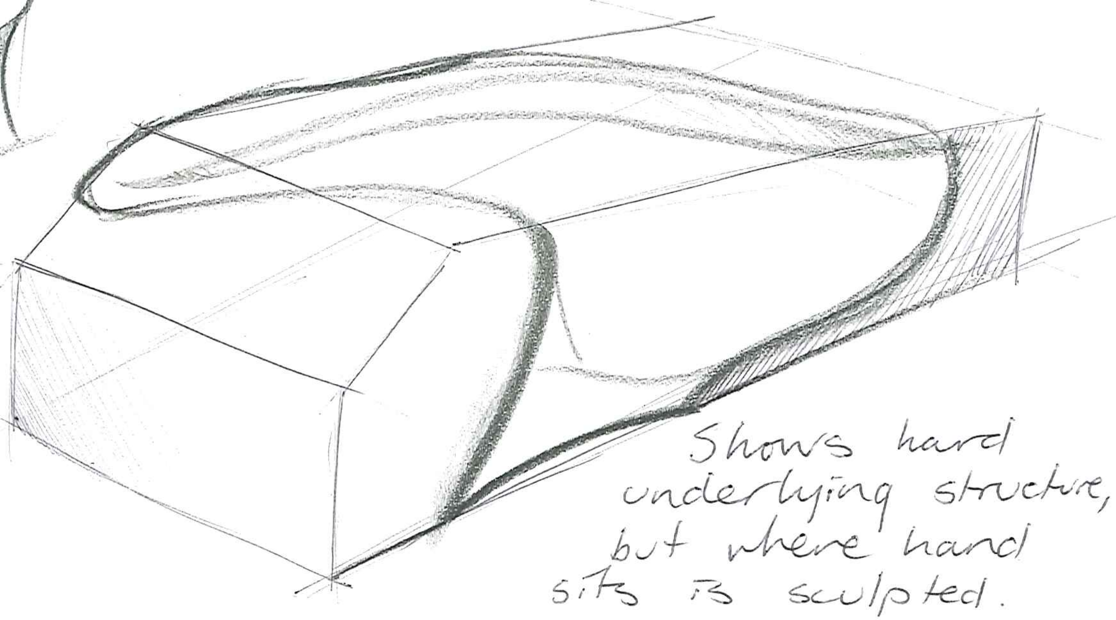


Hidden underside

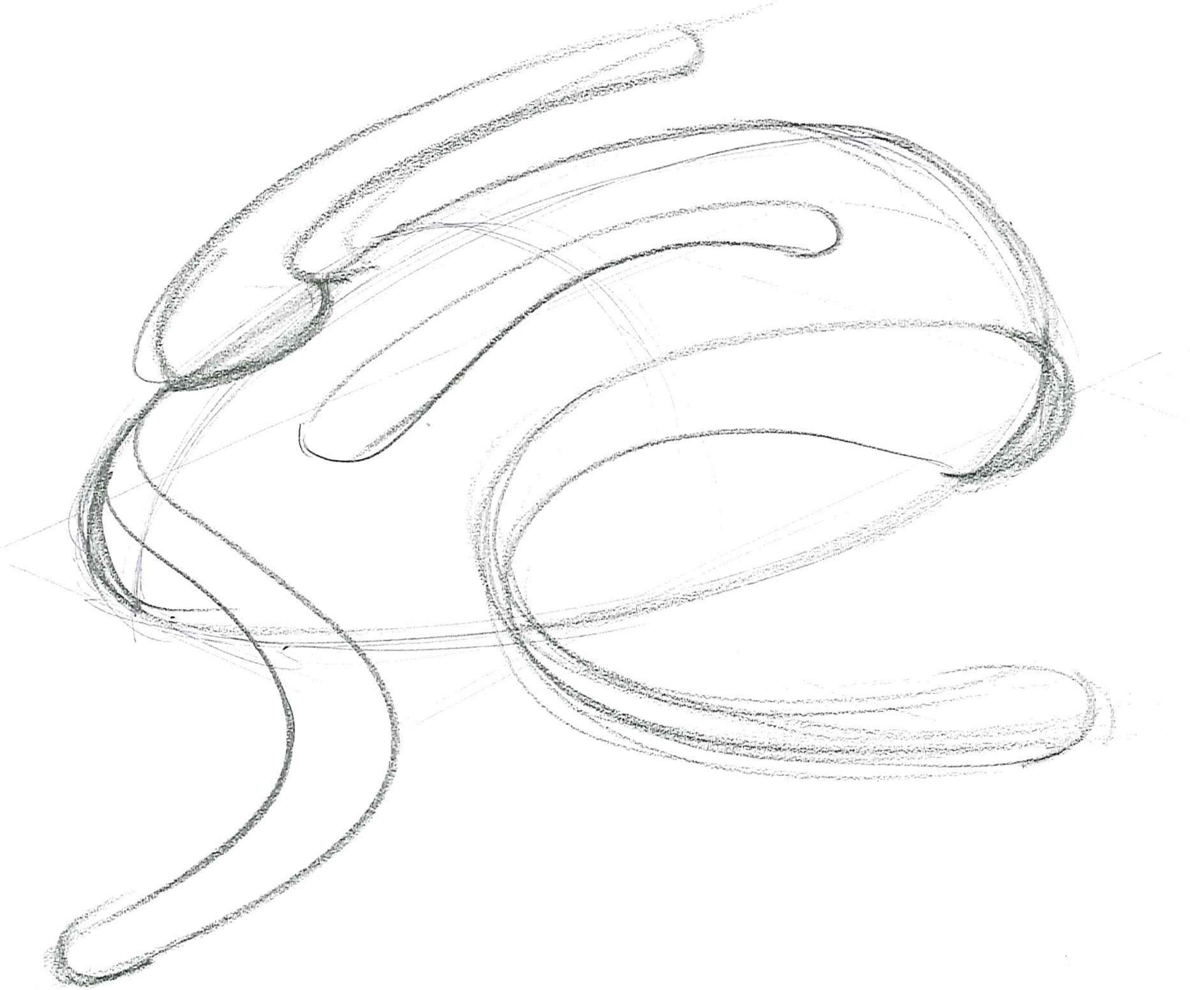


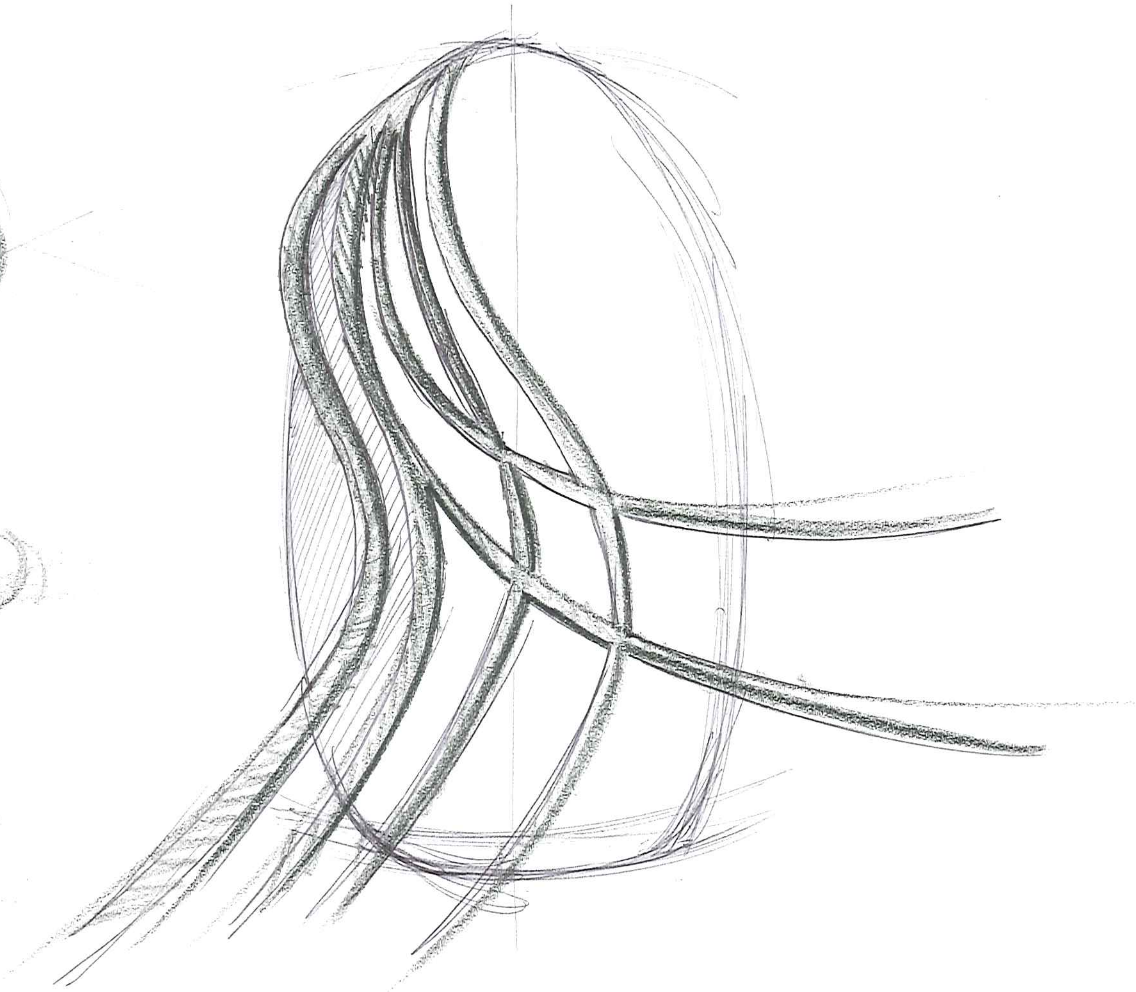
Bone or coral-like growths.

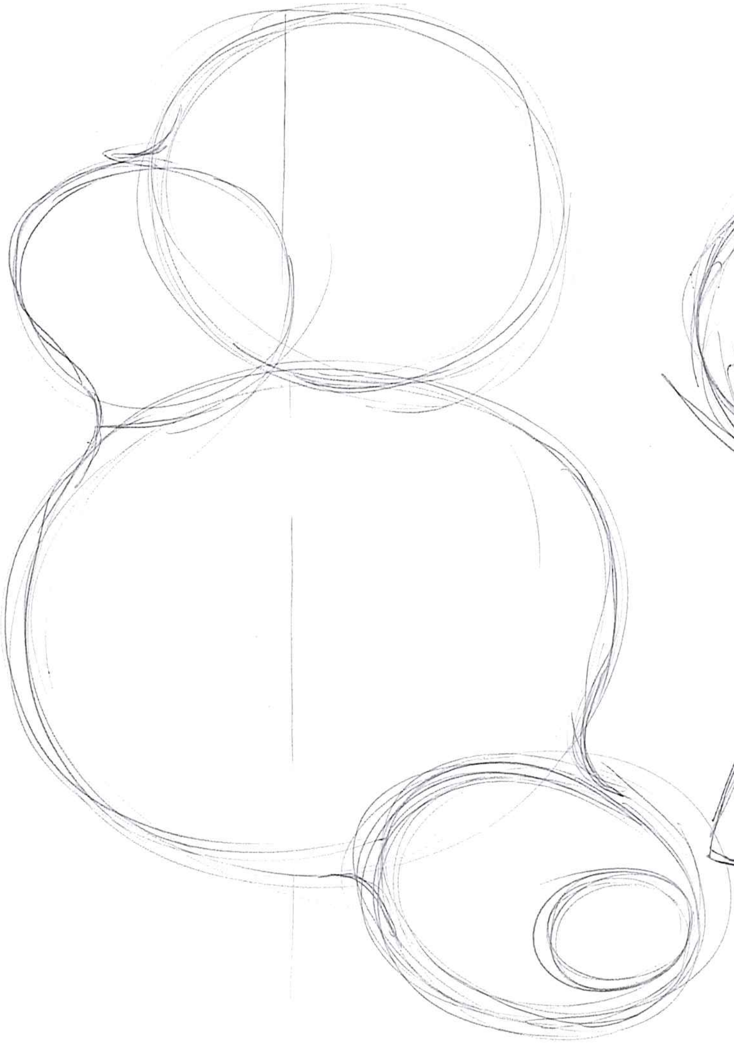


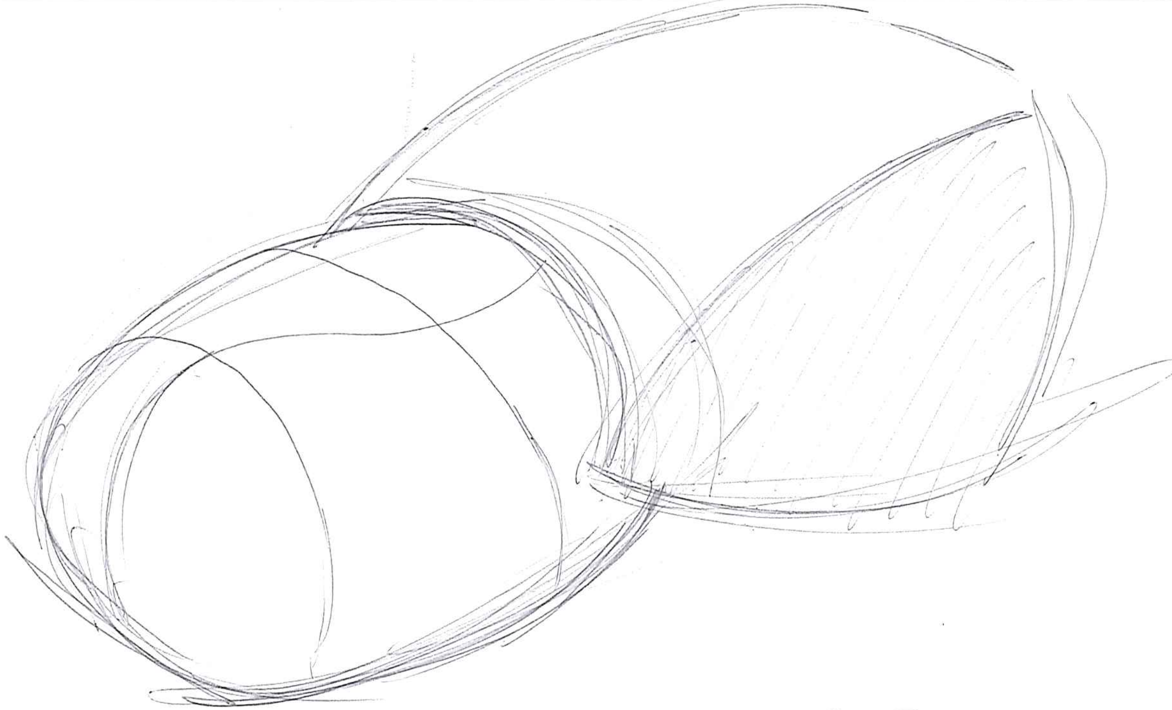


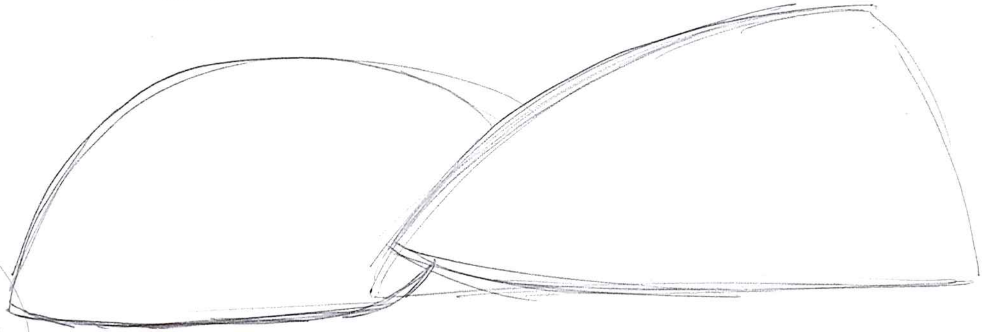
Shows hard underlying structure, but where hand sits is sculpted.

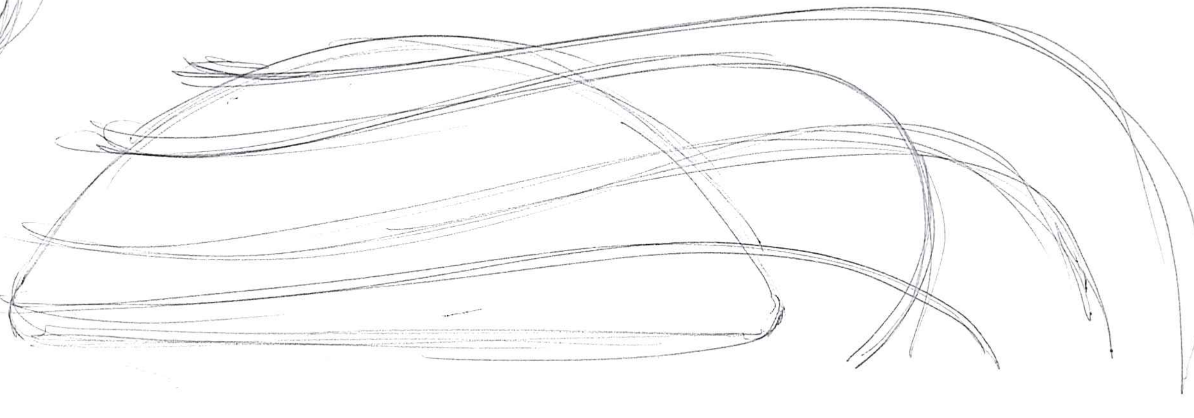


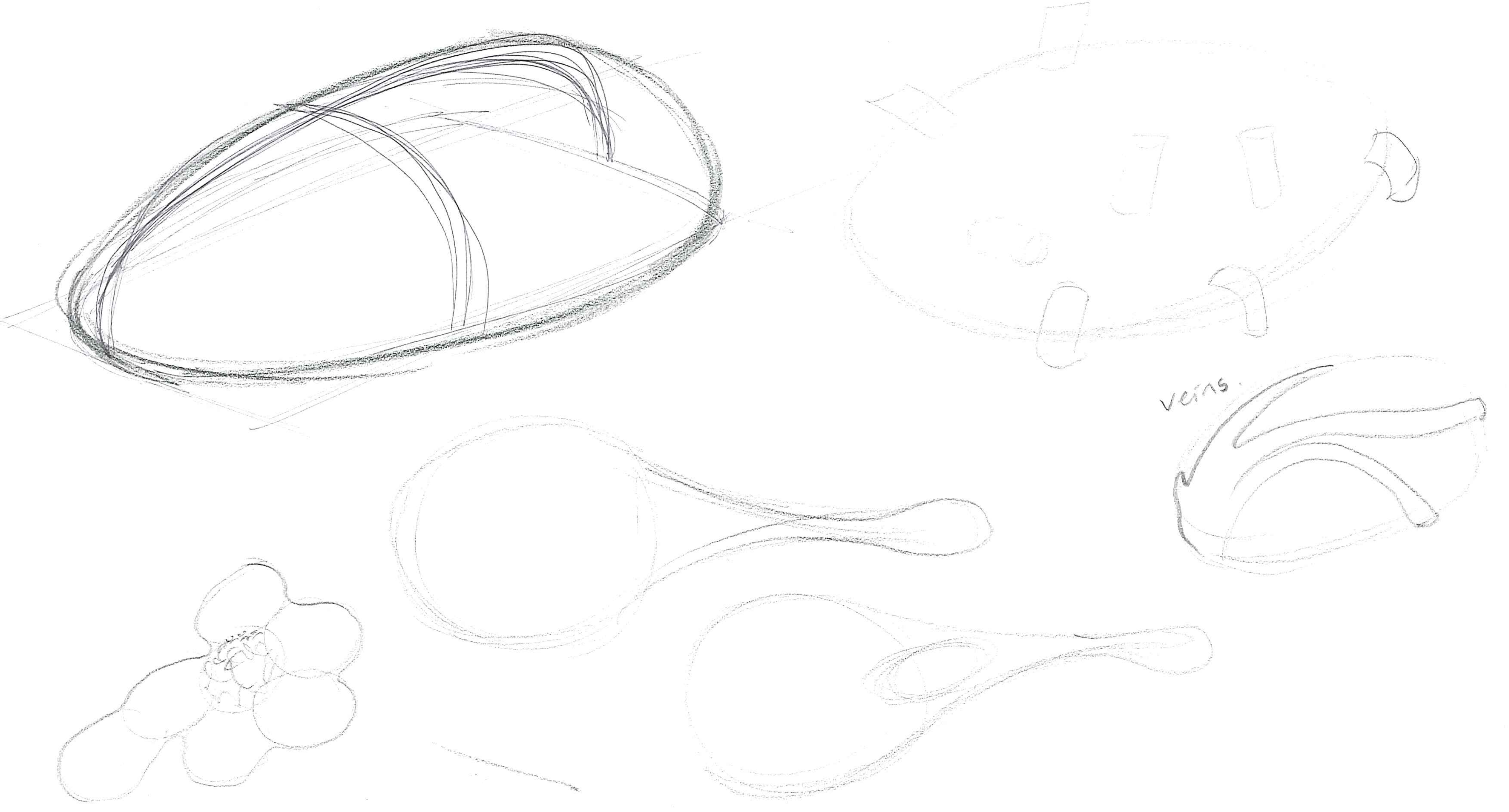


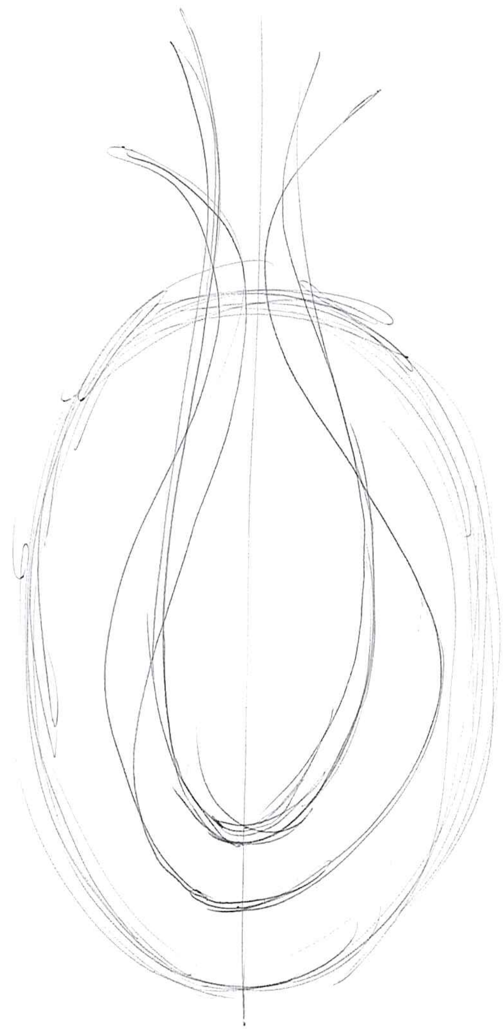









veins.



APPENDIX 10.4 Cosmic Blobs Diary Entries

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Summary of day's activity

Date	Software	Description of Activity
Week 1		
26/04/11	Cosmic Blobs	Tutorials + First Experiments
27/04/11	"	"
28/04/11	"	"
29/04/11	"	Modelling Experiments
30/04/11	"	"
Week 2		
02/05/11	"	Modelling Experiments
Week 3		

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 26/04/11	Software Cosmic Blobs.

Description of Activity

Software has been installed on my (old) machine for some time, installed off CD, no problems. Can't transfer to newer machine because it won't (reliably) run on Windows Vista.

This software is no longer available or supported. There's a link (within the program) to the Cosmic Blobs homepage but this is no longer active.

No tutorial content either within the program or supplied as documentation. Help functionality is limited, it seems like the intention is for the user to just play around.

The program runs sluggishly on my machine, not sure why this is, the machine is (3½ years) old but will run Solidworks okay.

Immediate impressions are obviously concerning 'child-like' aesthetic and lack of adherence to existing paradigms. Not sure what was the exact target age, so can't comment on whether it works or it's patronising. I suspect children would already know how to right-click (not supported). Forces you to investigate though. No File-Edit-etc menu structure. All tools have sounds, kind of annoying, but also actually helps to remember what each tool does.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 26/04/	Software Cosmic Blobs

Description of Activity

Found a number of video tutorials (http://s101.photobucket.com/albums/m47/TMeeks/CosmicBlobs Tutorials/?start=all)
Unfortunately they're for 'Deluxe' version (1.3.6380), I have 'Lab Rat' version (1.3.3010). Not sure how much difference there is functionally. Video version has tool tips for example (my version doesn't)
Can use undo even on saved + closed models. When reopened can still step back - makes it 'easy' to learn how other people have made models (similar to stepping through history in a parametric model).
Cosmic Blobs is a boolean (only) modeller.
No way to accurately align objects (by measurement) can only do it by eye.
No way (as far as I can tell) to import or export other formats. CB uses a proprietary format for its models.

Design Diary

Analysis of Consumer-oriented CAD Software

Detail of day's activity

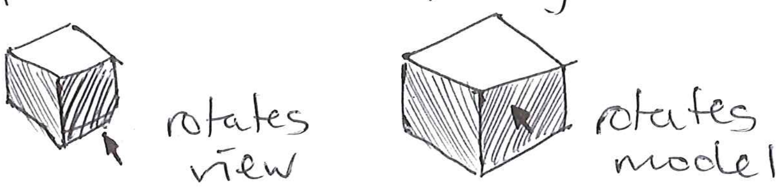
Date 27/04/11	Software Cosmic Blobs.

Description of Activity

Watched tutorials + experimented with some of the features covered

Is possible to turn a triangular mesh display on, this shows any problems with integrity of model. Not sure, but it seems there ~~ex~~ is a limit on number of triangles - model can become very messy around small details.

Can use mmb to zoom, rmb to rotate. This rotates view rather than actual model. Using rotate tool rotates view if click + drag outside model, rotates model if click + drag on model - v. confusing w/ no explanations



It is possible to create a vrml file (contrary to what I wrote previously). No way to control accuracy / no. of triangles though.

Modelling method (from what I can tell so far) is entirely about modifying shapes (distorting, cutting, joining etc).

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 28/04/11	Software Cosmic Blobs

Description of Activity

Previously I said Cosmic Blobs was a boolean modeller, not really true – operations like combine, cut, intersect don't exist. There is a 'glue' command but this is more like 'group' in other programs – when a glued model is exported as vrml, comes in ~~as~~ to SW as separate entities.

There is a 'join' command, but this works by creating a 'bridge' connector between parts:

Difficult to control, not sure how useful

- Created a model (of birds head) and exported as .wrl file. Imported to Solidworks with no errors. However scale (which can't be controlled accurately in CB) was huge, approx 3metres long.

Can draw lines/curves on surface to push or pull

Cannot find a way to import a .wrl (or any other) file to Cosmic Blobs

Can draw lines in space + push to deform objects.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 29/04/11	Software Cosmic Blobs

Description of Activity

Having exhausted the Cosmic Blobs tutorials (searched for a while but couldn't find anything), decided to try + create models of 'real' products. For some reason Ron Arad chairs came to mind, so searched for images + tried to model some.

Very frustrating session, not really able to get anywhere close to what I'm aiming for. Called it a day after about 3 hours. I'm wondering if the problem is my mindset - trying to set things up in advance rather than just jumping in and playing around.

Program seems to crash quite often. Autosaves after every operation, so annoying, but no work lost.

Frustrated by mirror function, seems inconsistent as to when it works + with which tools.

Tried opening an existing model + stepping back through to learn techniques. Problem is this doesn't show what tools were used, or how. So not that useful.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 30/04/11	Software Cosmic Blobs

Description of Activity

After unsuccessful day previously, decided to try modelling a character, since this is more in line with what the program is intended to do. Chose Munny character.

Exercise was a lot more successful, got a reasonably recognisable model. Lack of fillet or 'blend' command means joining (glueing) parts together is always crude (for example legs to bodies). Alternative is to 'pull' a leg out but difficult to control.

Still not fully understanding mirror command. No way to pre-select an object so mirror refers to it, always seems to reference older objects rather than newly created ones. (boolean)

Lack of 'cut' function is a big hole, would it really be so difficult for kids to understand this functionality.

Also find the crowded workspace annoying, especially graphic elements which have no modelling function. Get in the way of what you're trying to do.

Design Diary

Analysis of Consumer-oriented CAD Software

Loughborough University

Detail of day's activity

Date 02/05/11	Software Cosmic Blobs

Description of Activity

Went back to trying to model a piece of furniture, chose something (again by Ron Arad) that I thought would be easier. Can't say it was entirely successful, but at least it was 'recognisably' the object I was trying to model. I think the problem is that I'm in the mindset of wanting to be able to model 'accurately', whereas the best that CB will ever achieve is 'approximately'. Annoying thing (for me) is that accuracy could be improved hugely with a few minor additions - being able to constrain an object to one plane when rotating for example.

Very difficult to model symmetrical objects. No way to constrain to a line or plane, so cannot create or imply tangency at the mirror plane. ~~Crea~~ Modelling on either side of an object won't be accurate as no way of inputting dimensions.

APPENDIX 10.5 Moments of Inspiration (MoI) Software Report

Moments of Inspiration (MoI)		
Quality of User Experience		
	Details	Score (0-5)
Cost	£67.95	2
Platform	PC (Windows XP, Vista, 7)	3
Ease of Installation	13.6Mb, approx 17 secs to download. Standard Windows installation wizard. Approx 3 minutes total installation time.	4
Documentation	Online user guide, command reference manual, overview and tutorials (accessed through application Help). PDF gives printable version of overview and reference.	4
Tutorials	Official: 3 video tutorials, very basic and not very representative of software's capabilities. Website also links to: Community: large number of tutorials, both video and 'written'. Varying quality, but some are very good.	3
Bugs	Edges often display 'through' an object. Boolean operations are temperamental if parts touch rather than intersect.	2
Support (Company)	Hosted forum with MoI developer interaction on some topics.	3
Support (Community)	Forum for problems, tips & discussions.	

	3rd party scripts complement official ones to extend functionality.	3
Comments, Total Score	Official support is very good. Lack of official tutorials is a problem - never sure that community generated tutorials demonstrate 'best practice'	24
Ease of Use		
Presentation	4-view (3 orthographic + perspective) or single-view screen. Pale grey background (can be changed), objects display rendered (no wireframe) with hidden detail option. Icons are unfussy.	4
UI Structure	Non-standard File-Edit menu structure. Tools divided into 'Draw', 'Edit' and 'Construct/Transform'. Scene browser allows filtering of object display (by colour, by layer, by type, etc). Tool bar can be repositioned but not floated, no customisation. Command icons often expand to show more options (eg 'Construct Boolean' - 'Difference', 'Union', 'Intersect', 'Merge').	4
Adherence to Existing Conventions	Click-drag L-R & R-L selection. Undo/Redo.	3
Divergence from Existing Conventions (minus score)	Right-click re-selects previous tool/operation. Shift does not constrain eg rectangle to square.	-2

	Guides disappear after geometry is created. Can use sketches in boolean operations. Sketches are not dimension/constraint driven.	
Notable Features and Methods	Most tools work in both 2D and 3D (eg fillet). Impressive surfacing capabilities (eg G3 fillets). Possible to set up 'Incremental Save' to give model 'history'. 'How to use' dialogue for each tool at top of toolbox Scripts and 'hidden' commands (mapped to shortcut keys) extend functionality Copy-Paste places parts, surfaces, etc exactly.	3
Ease of View	MM-scroll to zoom, MM-click to pan, RMB to rotate. Rotate action can be customised. Icons to named views, double click to reverse (eg one click for 'Right', double click for 'Left'. View icons inside window allow pen & tablet, but very sensitive with mouse. At high zoom display of edges is not accurate.	3
Repetition	'Draw Solid' replicates sketch then extrude/revolve/etc	5
Redundancy	'Select All' and 'Deselect All'	5

Learning Curve	Basic Skills: moderate Advanced Skills: moderate	2
Model Accuracy and Integrity	Sketches can be dimensioned and measured. 'Shell' 'Offset' and boolean commands mean internal surfaces can be easily modelled. Hidden command (Display Edges) shows unstitched surfaces.	5
Comments, Total Score	Hidden commands mean some functionality is easily missed (eg show points will create points on surface - not in documentation).	32
Communication with External Environment		
Tools Required	One button mouse, two button with scroll preferred. Pen and tablet is an alternative option.	5
Imports non-native file formats?	iges, sat, step, ai, png, tif, jpg, gif, bmp	3
Exports non-native file formats?	iges, sat, step, obj, stl, 3ds, lwo, fbx, skp	4
Exports AM data formats?	stl, but no option to set number of triangles	4
Comments, Total Score	Missing stl input Greater control over stl output accuracy would be beneficial	16

APPENDIX 10.6 Sculptris Software Report

Sculptris		
Quality of User Experience		
	Details	Score (0-5)
Cost	Free	5
Platform	PC (Windows XP, Vista, 7), Mac (OSX 10.5+)	4
Ease of Installation	Automated download link (from email) did not work, needed to type address manually. 19.2Mb, approx 20 secs to download. Standard Windows installation wizard. Approx 3 minutes total installation time.	4
Documentation	No in-application Help. PDF Instruction and Reference manual included in download. Pixologic (Sculptris publisher) forum includes some unofficial guides.	4
Tutorials	Official: Website has 'Features' page which looks like it should host 12 tutorials, but only 6 videos provided. Videos are basic, last 1/3 of each given over to Z-Brush (commercial upgrade). Community: Some available on Pixologic forum, also (now closed) Sculptris forum and YouTube. Majority are time-lapse videos of sculpture being created rather than real tutorials.	2

Bugs	Inflate tool causes creased surfaces/zero thickness objects. Plane object only renders one side.	1
Support (Company)	Hosted forum but no Pixologic employee interaction. Email contact to support desk.	3
Support (Community)	Forum for problems, tips & discussions.	2
Comments, Total Score	Lack of tutorials is biggest problem	25
Ease of Use		
Presentation	Single view, perspective only. Rendered model with option to show triangles, in current material. Dark grey faded background, icons are small and unobtrusive on modelling area, animate and highlight on roll-over/selection.	5
UI Structure	No File-Edit menu structure. Tools divided into 'Sculpt', 'Utility' and 'Open/Save/Import/Export'. Each Tool has options for size, strength, detail etc, operated by sliders but also shortcuts. Each tool can be inverted (Alt key) or changed to 'Smooth' tool (Shift key) Tool bars cannot be repositioned or customised.	5
Adherence to Existing Conventions	Undo (11 times)	3

Divergence from Existing Conventions (minus score)	No right-click menu. No measurement or align tools, no indication of size. No Redo. No Boolean operations. No layers or 'Lock Object' option.	-2
Notable Features and Methods	'Reduce' (Triangles) and 'Reduce Region' to lower file size. 'Bake' clay before painting (one-way operation). Symmetry 'On' reflects existing features. Tool size is not absolute (depends on zoom level). Realtime rendering is excellent.	3
Ease of View	MM-scroll to zoom, MM-click or RMB to rotate, MM-click + Shift to pan, RMB+shift snaps to closest orthographic view. Rotate action can be customised. Perspective can be adjusted. Very smooth rotation, zoom a little less so.	4
Repetition	All tools have 'inverse' mode, so (eg) 'Draw' tool can become 'Crease' and vice-versa. But don't work identically.	2
Redundancy	Paint Mode	3
Learning Curve	Basic Skills: steep Advanced Skills: moderate	1
Model Accuracy and Integrity	Impossible to dimension or measure size or position of model.	

	No recognition of invalid volumes (in particular zero-thickness regions). But most models are fully enclosed volumes.	1
Comments, Total Score	Reducing number of triangles but keeping smooth surface is extremely difficult. Other software performs this (re-topologizing)	25
Communication with External Environment		
Tools Required	Two button mouse with scroll preferred. Pen and tablet is preferred option.	4
Imports non-native file formats?	obj (with limits)	1
Exports non-native file formats?	obj	1
Exports AM data formats?	No.	0
Comments, Total Score		6

APPENDIX 10.7 Cosmic Blobs Software Report

Cosmic Blobs		
Quality of User Experience		
	Details	Score (0-5)
Cost	No longer available	n/a
Platform	PC (Windows XP)	3
Ease of Installation	Installs from CD via standard installation wizard. Not sure of time (installed some time ago)	3
Documentation	No written or electronic documentation on disc. In-application Help tries to connect to website but no longer active. In-application 'Instructor' Contextual help shows 'storyboard' of how to use tools, but very difficult to understand.	1
Tutorials	Official: None available. Unofficial: Only one source - videos by Tom Meeks on Photobucket; these are 'introductory' rather than 'advanced'.	1
Bugs	Occasional crash-to-desktop. Mirror function is unpredictable.	2
Support (Company)	None available	0
Support (Community)	None available	0
Comments, Total Score	Software is no longer available; the level of	

	documentation, support etc provided when software was current cannot be ascertained.	10
Ease of Use		
Presentation	Childlike, bright colours, animated icons. Cartoon sound effects. No ability to customise. Wireframe view is possible but *very* difficult to enable.	2
UI Structure	No File-Edit menu structure. Functions spread all around screen borders with unclear grouping. Each Tool has options for size, strength, detail etc, operated by sliders. No tool-tips.	2
Adherence to Existing Conventions	Undo/Redo	1
Divergence from Existing Conventions (minus score)	No copy-paste. No right-click menu. No measurement or align tools, no indication of size. No possibility to choose plane of symmetry. Move and Rotate move either view or model, depending on whether model is clicked (very poor). Models are auto-saved after every step.	-5
Notable Features and Methods	Can use 'Undo' on saved and closed models, allows user to step back through (another user's) modelling process.	

	Pick tool - modify - (slider) adjust (with direct visual feedback) process is very easy to use.	4
Ease of View	MM-scroll to zoom, RMB to rotate. No pan via mouse. Menu to orthographic views. Perspective always engaged.	2
Repetition	Many tools have 'inverse' button, so (eg) 'Pull' tool can become 'Push' and vice-versa. But don't work identically.	2
Redundancy	Animation. Decoration.	3
Learning Curve	Shallow	5
Model Accuracy and Integrity	Impossible to dimension or measure size or position of model. Software automatically sub-divides surfaces, but relatively crude (model quickly loses smoothness). No recognition of invalid volumes (in particular zero-thickness regions).	0
Comments, Total Score	No possibility of creating dimensionally accurate models of any kind	16
Communication with External Environment		
Tools Required	One button mouse, two button with scroll preferred.	4
Imports non-native file formats?	No.	0

Exports non-native file formats?	vrml	2
Exports AM data formats?	vrml, but without units	1
Comments, Total Score	Can output an AM data format, but requires use of additional modelling software to adjust scale, check for errors etc.	7

APPENDIX 10.8 Costs of AM parts used to assemble mouse models.

	Part Identifier	Material	Cost
SketchUp	Mouse Bottom	White, Strong and Flexible*	$33.33
	Mouse Middle	Frosted Ultra Detail**	$85.03
	Mouse Top	White, Strong and Flexible	$28.25
			$146.61
Moments of Inspiration	Mouse Bottom	White, Strong and Flexible	$22.98
	Mouse Middle	White, Strong and Flexible	$21.67
	Mouse Top	White, Strong and Flexible	$43.64
			$88.29
Sculptris	Mouse Bottom	White, Strong and Flexible	$22.70
	Mouse Middle	White, Strong and Flexible	$34.60
	Mouse Top	White, Strong and Flexible	$14.23
			$71.53

* Laser Sintered Nylon PA 2200

** Ultra-Violet cured Acrylic