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THE AESTHETICS OF PROSTHETIC DESIGN: FROM THEORY TO PRACTICE

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1. Introduction

Aesthetics of prosthetic device design is an emerging field of research; this study investigates both the theoretical and the practical aspects of this subject. Our belief is that prostheses, perceived by users as attractive, can enhance a positive feeling, promote their psychological acceptance of the "new limb" and, in general, their well-being. "Prosthetic" is a term that refers to devices designed to replace a missing part of the body. This definition applies to devices that replace a limb segment rather than externally-applied devices which are referred to as "orthotics". For example, we can classify an artificial arm, leg, or finger as a prosthesis, whereas external entities such as a dental brace, insoles or a pair of glasses are orthotics. Specifically, this field of research is currently focusing on below-knee prosthetic devices.

A fundamental research question is "what are the characteristics that make a prosthetic device look and feel aesthetically attractive?" What we want to explore are the aesthetic expectations of prosthetic users for their ideal devices and how wearing them could positively affect their self-confidence. In order to investigate this field in a wider perspective, an interdisciplinary approach was set up to include product design (with relevant consideration for natural-inspired design), prosthetic design, emotional design, psychology, and fashion trends. These instances contributed to this research in terms of providing a theoretical framework.

The specific purpose of this paper is to show how design information and knowledge of aesthetics of prosthetic devices is gained. This work highlights the initial problems encountered during the research, the theoretical framework process, and how this theoretical framework translated into new prosthetic designs (Figure 1). Specifically, the paper will focus on our understanding of "concinnity" for prostheses, and will propose a set of guidelines regarding prosthetic elements and principles to be applied to the aesthetic design of prosthetic devices and, potentially, to product design in general.

2. Aesthetics of prosthetic devices: a new concern

The limited literature on the aesthetics of prosthetic devices demonstrates that this field is still in its infancy and that most of the work to date has focused on technical improvement of the devices [Cheetham et al. 2011, Hahl et al. 2000]. Our search found few academic studies discussing cosmetic devices (i.e. realistic-appearance aesthetics – and mainly in upper limb designs) [Davies et al. 1977, Ferrone 2001], in parallel with a considerable number of companies (i.e. Procosil, Touch Bionics, The Alternative Limb project, Ottobock) and associations (i.e. Amputee Coalition, Amputee prosthetics,

Westcoast Brace and Limbs) that deal with the production and/or advertisement of highly realistic limbs.

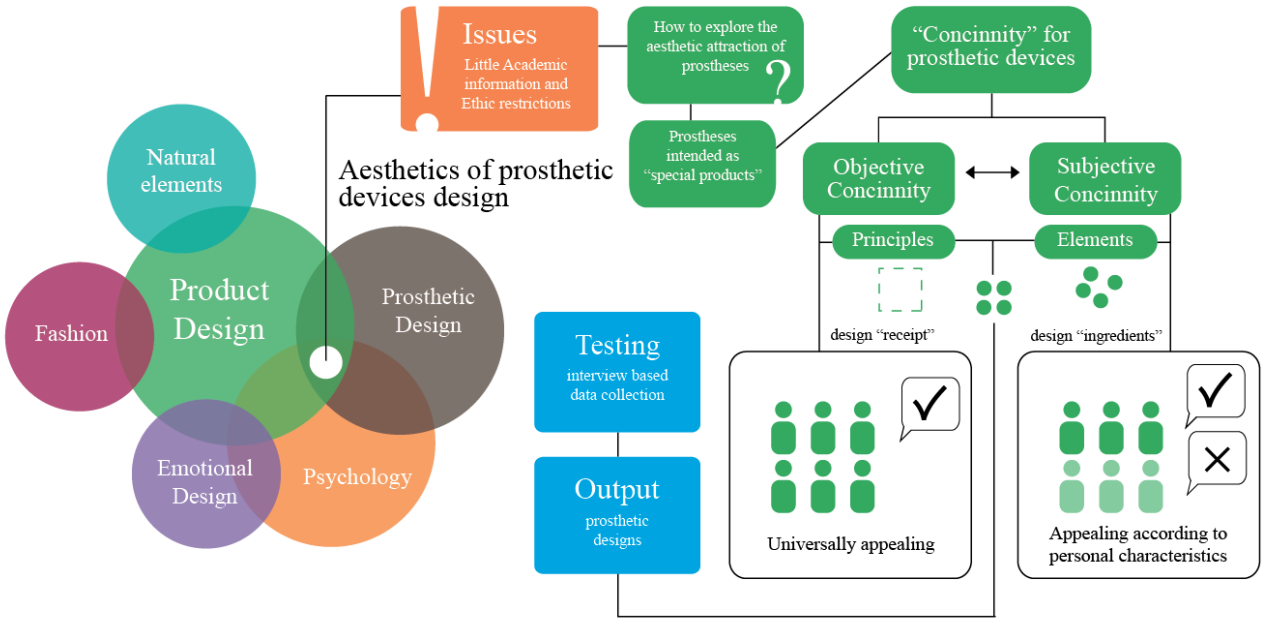


Figure 1. Representation of the fields covered in "Aesthetics of prosthetic devices design" and the research process presented in this paper

We found little literature investigating the aesthetics of non-cosmetic devices (i.e. non-realistic designs). Capestany and Esparza [2001] described a case study of an amputee who required the design of a personalized golf-prosthesis. In a similar manner, Plettenburg [2005] designed a prosthetic prehensor (a design similar to a wrench) for children, by using a combination of solid design and an appealing colourful style. Similarly, Hilhorst [2004] described his non-conformist-styled design applied to prostheses for children, personalizing them for each person's unique identity. Non-cosmetic designs provide good examples of co-design, accounting for the emotional side of the wearers. In a similar manner, as the examples proposed, this research is interested in the investigation of non-cosmetic devices and, in addition to the work of other researchers, we aim to add more to the field by understanding the subject in a wider perspective by establishing both an interdisciplinary theoretical and practical approach.

3. Methodology

3.1. Revision of the meaning of Prosthetic Device

There are different theories regarding the meaning of prosthesis. The science "Prosthotology" [Bache 2008] refers to a new science that interprets this medical product as a new proper part of the body, and not as an external entity. A similar approach is found in the Gestalt's visual psychology rule of the "totality concept" [Giannini et al. 2011], where an entity is perceived as a whole figure rather than a sum of visual stimulus (i.e. the parts of the figure). According to these two points of view, we would relate both realistic and non-realistic looking prosthesis as equal to the other parts of the whole human body (i.e. limbs, head, bust) and not a section to be perceived as separated.

However, some prosthetic users could have a different point of view. The amputee model Aimee Mullins states that a prosthetic limb no longer represents the need to replace loss. The prosthesis can stand as a symbol where the wearer creates him/herself like an architect and continuingly changes

identity [Vainshtein 2011] (Figure 2a). A point of view aligned with this statement is offered by the orthotic designer F. Lanzavecchia [Vainshtein 2012], which interprets her orthotic products (Figure 2b) as extensions of the body and aims to achieve comfort for the wearer in different situations. In a similar matter, simple everyday orthotic products, such as eye-wear glasses (Figure 2c) are no longer considered a disability, but rather as fashion icons [Pullin 2009]. Our hope is to discover whether the principle of conceiveing and using a medical product as an appealing work of design (instead as a product to "hide") can be extended to prosthetic devices.

Figure 2. (a) The set of prosthetic legs of the amputee top model Aimee Mullins (source: www.pixeldiva.co.uk), (b) a neck brace designed as a metallic necklace (F. Lanzavecchia) (source: from Vainshtein 2012) , and (c) an orthotic product (D&G glasses) advertised as a fashion product (source: www.shadestation.co.uk)

In a similar manner to Bache [2008] and Aimee Mullins [Vainshtein 2011], the aim of this research is to revise the traditional meaning of prostheses and go beyond the conventional vision of replacing support. A prosthesis should be conceived as a special and intimate product (maybe perceived as a bridge between a product and a real limb), with which the user establishes an effective relationship. Our point of view is that the aesthetics of prostheses plays an important role in positive acceptance by the users and we believe that perceived attractive aesthetics of the product by the users can enhance their psychological wellbeing.

3.2. Concinnity: attraction in prosthetic devices

The product's form is an important aspect designed to attract the consumers' attention, interest, desire and action [Chang et al. 2007]. Crilly [2004] and Bloch [2003] distinguish the impressions occurring during the process of product perception: aesthetic impression, semantic interpretation, and symbolic associations are the dynamics that are verified during the cognitive process of the observer (Figure 3).

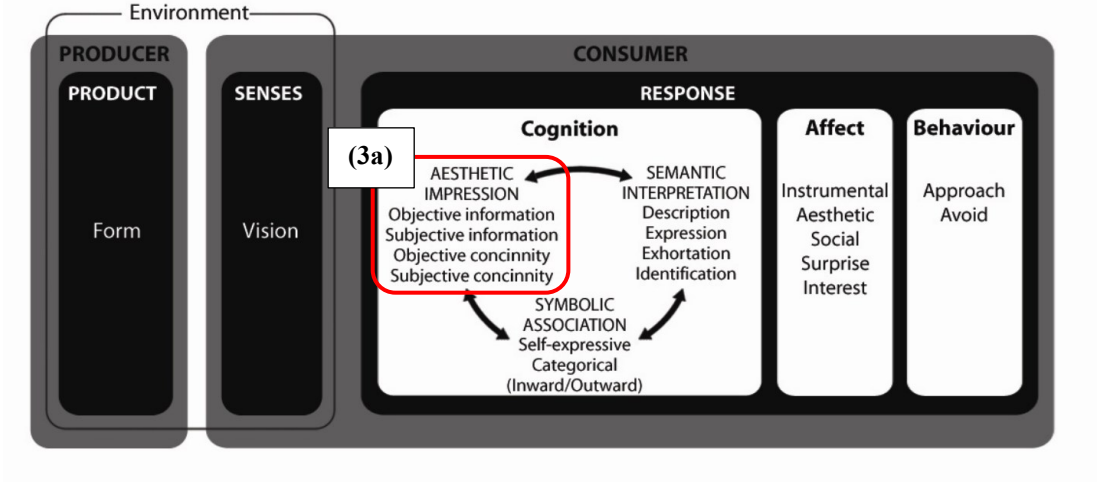


Figure 3. Framework for design as a process of communication with expanded cognitive response [Crilly et all. 2004] – our field of research explored in this paper includes the section "aesthetic impression"

"Semantic interpretation" refers to the "function, performance, efficiency and ergonomics" of products [Crilly et al. 2004]. More directly related with our work is the concept of "Symbolic association", which attempts to communicate meanings linked to the observer's interpretation and can be reconnected to 1) some personality characteristics perceived in the design (i.e. cheerful, serious) 2) practical issues (i.e. cheap) and 3) styles of cultures or periods (i.e. 90's style) [Özgen 2008]. This issue will be further explored in a future investigation and will not be analysed in this paper.

"Aesthetic impression" is particularly relevant to this work as it represents what our research is currently exploring. Coates [2003] offers an overview of this topic by formalizing the components influencing attraction towards objects in the concepts of "Objective Concinnity" (Figure 4) and "Subjective Concinnity". In terms of what is meant by objective concinnity, the author claimed that a well-designed object "never gains or loses objective concinnity during the time, as this property is universally perceived and is not subject to fashion, cultural or personal trends". Subjective concinnity, on the contrary, represents the perception of "novelty" of the viewer and stands on the subjective taste of the observers and is driven by their own life experience, as supported by the studies of Proshansky [1970] and Tractinsky [2006]. Aligned with this point, Norman [2004] states that the subjective background of people (i.e. the memories of a person) greatly influences their aesthetic taste towards objects.

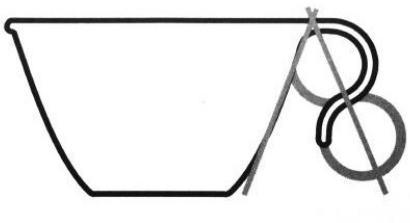


Figure 4. Objective Concinnity example: repeatability of elements and symmetry in a cup design [Del Coates, 2003]

According to the principle of concinnity, we agree on the idea that objects are endowed by both objective characteristics that make an object feel "just right" and subjective characteristics that might appeal to the observers for the "novelty" presented by the design of a product. Our understanding is that a prosthetic design concept should represent characteristics that make it feel "objectively" attractive (i.e. proportion referred to human leg shaping) as well as elements giving a touch of "novelty" and "personality" (i.e. reminding the shape of a natural element).

What this research aims to achieve is a detailed understanding of the dynamics ruling "objectivity" and "novelty" in design, and to attempt to apply these instances to prosthetic design. In order to achieve this goal, literature has been reviewed and led this study to investigate the assumption that "principles" are associated with objective concinnity and "elements" are associated with subjective concinnity in design. The next section describes this topic in detail.

3.3. Concinnity represented in Aesthetic Design Principles and Elements

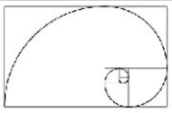
Faimon and Weigand [2004] introduce the concept of "elements" and "principles" as matters for attention to achieve a good design. This concept can be expressed by comparison of food preparation. Preparing a good dish requires: good-quality "ingredients" and the appropriate "receipe" to follow. In a similar matter, a good design requires a balance between the "ingredients" (elements: i.e. parts of the design) and the right "recipe" (principles of design: i.e. rules guiding the structure) in order to obtain a visually-successful product.
Design elements are the parts of the design (i.e. the semi-spherical shape of the handle of a cup –

Figure 4) and the principles are the framework rules that order them (i.e. the repeatability of elements following two spheres and the symmetry – Figure 4).We would like to attempt a parallelism between "principles" and "objective concinninity", and between "elements" and "novelty" and to create a list of guidelines for each instance.

Prior to forming the list of principles and elements in design, an extensive literature review was undertaken [Clay 2009, Faimon and Weigand 2004, Hekkert 2006, Lidwell et al. 2010, Macnab 2011, Palmer 1989, Sudjic 2009] in order to gain a wider perspective of the subject from the point of view of other designers. The literature search shows that these two issues are not conceived as standard, and even if designers agree on most of the principles (i.e. unity, variety, rhythm etc.) each of them has a personal understanding of the classification of elements.
The selection of the entities of both categories has been performed using a summary approach and tended to include principles and elements that 1) were found along most of the sources 2) could be applied to products similar to prostheses (i.e. exclusion of design principles more pertinent with landscape design or architecture) and 3) were aligned with our understanding of the subject according to our experience of designers. Consequently, the design guidelines classification (Table 1) has to be conceived in general terms and as work filtered by our personal understanding of the subject as graphic designers.

Our speculation is that the principles stand by themselves and, if properly applied, allow the designer to create a "just right" design perception, as this framework-aspect of the design should not be affected by the subjective taste of the observer. Furthermore, according to the belief of Chakrabarti [2011], the elements of the design perceived as "good looking" (according to factors related to the personal background of the observer) are subjective and vary from person to person, and are essential as they represent the "innovation" in prosthetic design.
For instance, a prosthesis which best represents all the principles of objective concinnity is a human likeness device (i.e. a model resembling a real-leg interface), which gains approbation by the observers by simply emulating a real-leg appearance. However, this model does not show any innovation and simply represents a standard design that does not require creativity.

Table 1. Elements and principles list to be applied to aesthetics of prosthetic devices

Design Principles	Examples	Design Elements	Examples
Unity		Natural patterns	
Grouping		Archetypes	
Rhythm and Pattern		Colours	
Contrast		Scultural properties	
Balance		Fashion	
Placement		Meaning	
Proportion			

What about a device adding new elements that differ i.e. in color, shape, and symbols? This device would have a higher level of "novelty", and by developing this design the risk of the observer to feel repulsion has to be faced, as the novelty proposed might not be accepted. In a similar matter, the observers might have a high level of acceptance for the "novelty" represented and positively accept the originality offered by the design. In this example, it is made clear how principles of design are based on objective concinnity, whereas elements of design introduce the aspect of subjective concinnity to a prosthesis.

The designs shown in the following section aim to mediate the two instances and generate attraction in observers by inserting innovative elements prior to application of the design principles. No speculation regarding the weight of influence of principles rather than elements for attraction on prosthetic users is attempted (i.e. under which percentage is a person affected by the "right shape" of a prosthesis rather than the "originality" factor?) as it is an issue that will be researched in a future investigation.

4. Output: design guidelines applied to aesthetics of prosthetic devices

The design of elements and principles has been used as a guideline for the design of new prosthetic device models. The design process finds inspiration from the work of designers such as Eiji Nakatsu and Janne Kyttanen [Macnab 2011] and some designs of Cyclus company. Their designs start from identifying an inspiring element coming from nature (i.e. a kingfisher, a beehive, and a pangolin) linked with an aesthetic that is intended to be represented in the design. Nakatsu, for instance, chose a kingfisher's head and beak in the act of gliding through the air and precisely diving into water to snag fish as an inspiring element representing the nose of the Shinkansen train [Sheppard, 2012]. In a similar matter, the starting point of our designs begins with defining the meaning that we want to suggest and, subsequently, in finding an element that could provide inspiration for the creation.

The importance of natural elements and energy in design is proposed by Macnab [2011] who states: "Learning the language of nature gives you tools to effectively communicate. A good design detective will 'capture' the energy of the communication to do much of the intuitive lengthwork in its understanding […]." [Page 112, Design by Nature]

By considering our case study 1 (Jellyfish model), the initial idea is to create some feeling of "energy distribution", an issue that was associated with the idea of a slow and lazy dance. After reconnecting this issue with both our memories – linked to our personal background - and a search over multiple visual sources, the natural inspiring element is identified in a jellyfish in the act of swimming. The steps thereafter are to 1) hand-sketch the idea 2) redefine the design by accounting for most of the design principles (only the design principles considered appropriate by the designer are chosen, for instance "pattern" might not suit the needs of "Jellyfish" design) 3) represent the final vectorial version compatible with the proportion of the human body.

4.1. Case study 1 "Jellyfish" model: from theory to practice

In the "Jellyfish" model (Figure 4a) the process of design consisted of (a) the identification of the inspiring element (i.e. an animal – jellyfish), (b) sketching a few proposals (c) creating a professional 2D representation of the model by accounting "principles" and "elements".

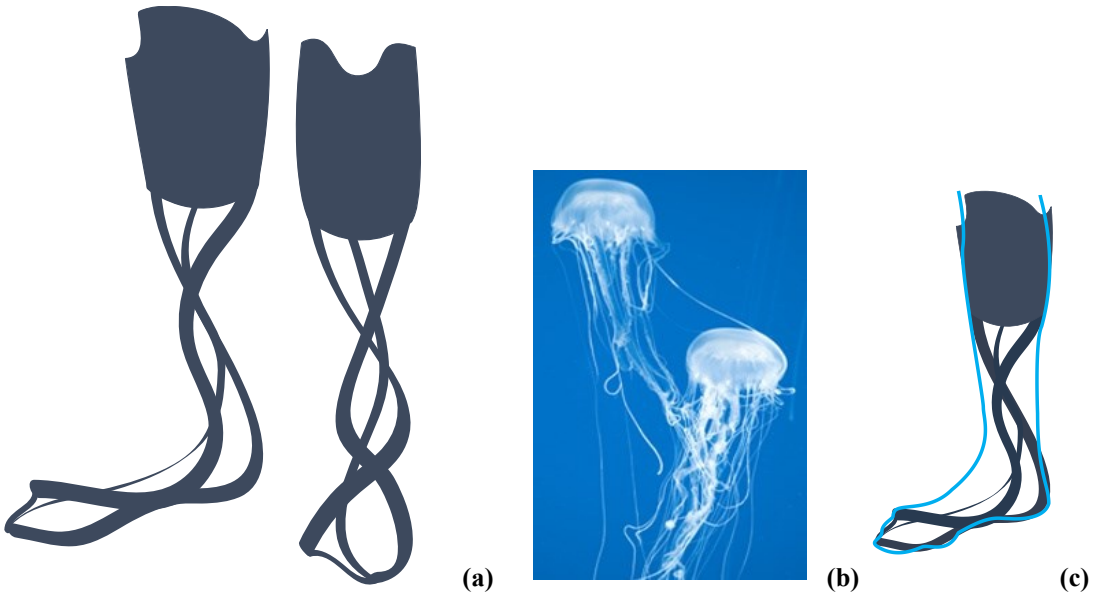


Figure 5. "Jellyfish" model (a), the inspiring natural element (source: www.science.howstuffworks.com) (b), and proportional correspondence to a human leg (c)

Objective concinnity (Design principles):

- **Unity** of the prosthesis with a human leg (Figure 5c) is obtained by creating the feeling of anatomical human outline of the leg – upper muscles, ankle, and feet shape represented in the metal rods curvatures. In this model, as well as in other models we designed, the anatomical proportion of the picture of a male leg has been used as guidance. Additionally, according to some past research findings [**Ref deleted**], we speculate that by modifying a few characteristics of the anatomical shaping of the leg, some categories of observers may state higher attraction. For example, in previous research we tested the validity of the commonplace belief that see female targets as more attracted to graceful designs whereas male targets for masculine stylish design. The assumption is that a higher level of appreciation may be obtained if creating a thinner and more graceful prostheses for females and a thicker and masculine one for males.
- Even if **repetition** usually refers to regular patterns, we applied this design principle within

this kind of design. The aim of repeating three similar shapes (rods) is to create a sense of "**grouping**" and to make the observer perceive the model as a global homogeneous entity

- The **Connection** (referred to **"grouping"**) between socket and feet is clear as the elements are part of the whole continuous design and there is no separation. Specifically, the Gestalt principle of "closure" [Giannini et al.2011] is reminded, in order to allow the human eye to close the elements of the design and perceive them as a unique entity
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Subjective concinnity (Design Elements):

- Design of the natural pattern "**meandering"** (freely inspired by the swimming movement of a jellyfish – Figure 4b)
  The sinuous meander gives the idea of "lazy movement" and as a way of representing good distribution of energy because it does not exhaust it with intensity.
- The principal **variety** of the "product" is about the **sculptural property** and consists of designing a "non-concrete stylish" shape and includes cavity elements inside the model. The innovation of this design should make it more active looking and more interesting to observers
- The metallic color differs from the skin color of the wearer and attempts to transmit stability (suggesting the strength of iron or inox)

The model represented is supposed to inspire the "objective concinnity" attraction by the application of the "objective" design principles as in the examples shown above. However, the attraction of the design element "meandering" is subject to the personal taste of the observer. Consequently, we attempt to say that the framework rules guiding the design should universally attract observers (in that all people should perceive a sense of right shape /right proportion in the model) where the innovation of the design might generate attraction, or not, according to personal taste ofobservers that cannot be predicted.

4.2. Case study 2 - "Feather" model

The "Feather" model (Figure 6a) is proposed as a second example for illustrating the application of principles and elements.

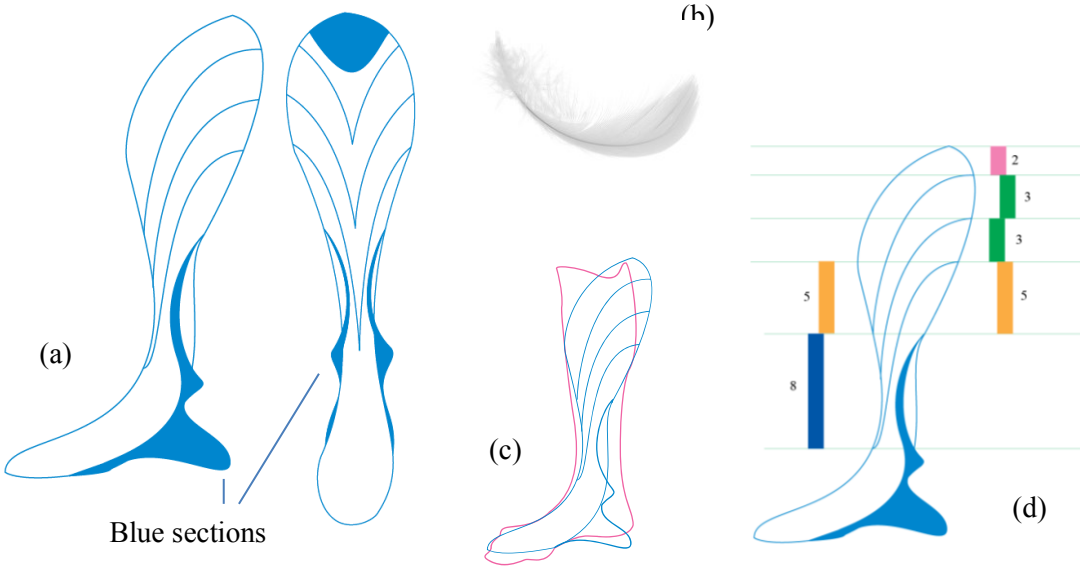

Figure 6. "Feather" model (a), the inspiring natural element (b) (Source: www.science.howstuffworks.com), human proportion reminded by same below-knee and foot length (c), and proportion between elements and Fibonacci's series (golden ratio) (d)

Objective concinnity (Design principles):

- **Unity** with a traditional prostheses is obtained by reproducing human length of the below knee section and of the knee (Figure 6c)
- The **connection** between socket and feet is continuous as the shape of the ankle and feet follow the shape border of the socket
- The **proportion** between elements is obtained by proposing Fibonacci's proportional (Golden ratio) distances between the lines crossing the design (Figure 6d)
- A sense of **contrast** is obtained by the use of two colours and overall by the dynamic shape of the leg. The placement of the structure and lines is not static but curved and moves in a diagonal direction: it should be remembered that 'kinetic energy' (a feeling of "excitement" and "dynamic design") is sought
- The use of an angular intersection (front side) should give a touch of 'aggressiveness' in order to **balance** the general "softness" of the design

Subjective concinnity (Design Elements):

- Element reminded: natural element **"feather"** (Figures 6b)
- The main **Novelty** factor of the product involves "sculptural" shaping and consists of: 1) amplification of the volume of the upper section of the prototype 2) emphasis of the diagonal lines resembling the texture of a feather 3) deformation of the sections corresponding to the ankle and the feet
- **Colours:** the combination of blue and white is associated with "purity" and "cleanness"; these hues are also supposed to represent a feeling of "lightness"
- **Meaning:** this prototype should resemble the shape of a feather (front side), and the opened wings of a bird (i.e. a swan - from the lateral point of view). The aim of this model is to transmit a feeling of lightness, gentleness and at the same time, dynamicity, as if the prostheses could be "moved" by the wind. The delicate feeling that we tried to create with the design should appeal more to female observers for potential use

5. Next stage: interview-based experiment

The next stage of the research will be a semi-structured interview aimed to collect feedback from participants by both showing them a set of prosthetic models designed by the researcher and by asking aesthetic-related questions. The questions will aim to discover at which level people are affected by both objective and subjective (novelty) concinnity. Additionally, the goals of this investigation will be to test if the "novelty" elements of the designs will be accepted as attractive or not. Furthermore, we aim to test if the aesthetic taste of participants for prostheses is specifically influenced by personal issues such as age, gender, nationality, etc. This experiment will take place in the next stage of the research and aims to test the response of prosthetic users to our theoretical and design work in relation to aesthetics of prosthetic devices.

6. Conclusion

This paper represents only a portion of the research track and summarizes our design philosophy. The work aims to show recent research progression and to inform people of the existence of the emerging field of aesthetics of prosthetic devices. We attempt to show our research methodology responding to initial research issues and to develop both a strong theoretical framework and a practical design application of our arguments. It is hoped that the work presented hererepresents a starting point to fill the gap of knowledge and research in relation to aesthetics of prosthetic device design. .

Our belief is that prosthetic users, wearing prostheses perceived as aesthetically attractive, are more confident with their personal body perception and, consequently, gain psychological well-being. However, many users are unsatisfied with the aesthetics of their prostheses. With our research, we hope to improve future prosthetic devices and positively impact the emotional aspect of users of prosthetics.

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