

## **A NEW DESIGN SYSTEM OF BELOW-LIMB PROSTHESES - THE ROLE OF A VISUAL PROSTHETIC DESIGNER**

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### **Abstract**

This paper analyses the model of prosthetic design in the context of the public prosthetic centres in the UK, and proposes a new system of design including the role of the visual prosthetic designer. The visual aspect of prosthesis can favour a positive body image in the users; however they are often not advised or provided with models responding to their needs. We claim that the visual designer would improve the process for the appearance of the prosthesis, provide the amputees with visual solutions and support the prosthetists in the design process. The aim of this research is to highlight that more attention is needed for the visual needs of prosthetic users and that a change is needed in the current design approach of public prosthetic centres.

**Keywords:** Product-service systems (PSS), Design costing, Design process, User centred design, Visualisation

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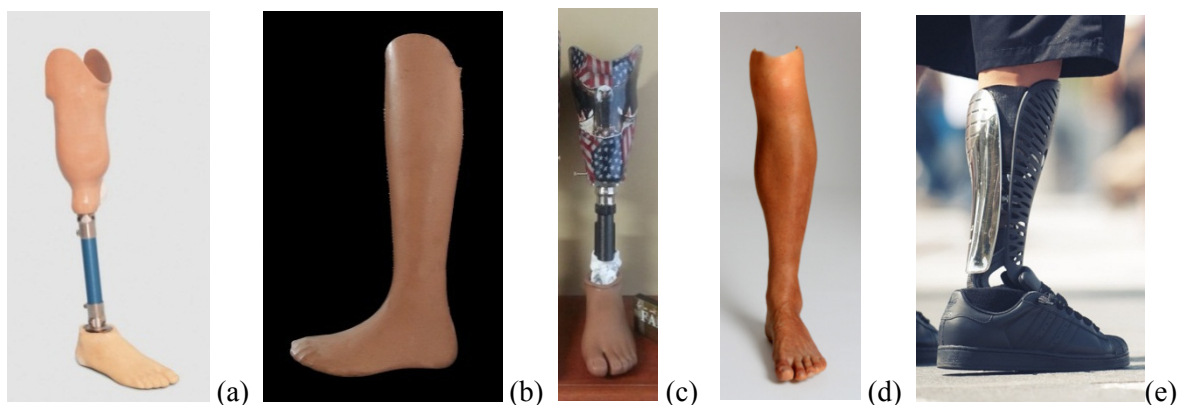
# 1 INTRODUCTION

‘Prosthetics’ is a term that refers to devices designed to replace a missing part of the body, this definition applies to devices such as artificial arms, legs, or fingers. Specifically, our research focuses on the aesthetic appearance of below-knee prosthetic devices and connects this factor to the psychological well being of prosthetic users.

The visual choices currently offered in a public prosthetic centre are limited to only what is considered essential for the patients and little is accounted for the appearance of the devices. These options include the uncovered ‘skeleton’ device (Figure 1a), and a basic foam covered ‘cosmetic’ prosthesis (Figure 1b). The only alternative providing minimum aesthetic elaboration is the uncovered prostheses with graphic decorations on the socket (Figure 1c).

In private clinics and prosthetic companies however, additional designs such as high definition cosmetic (Figures 1d) or robotic prostheses (Figure 1e) are offered.

We identify the restricted range of aesthetic options offered by public clinics of the UK as an issue, and respond to this problem by proposing a new system of prosthetic design accounting more importance to the aesthetic aspect of the devices.



*Figure 1. The basilar NHS uncovered skeleton device (a), the NHS cosmetic foam covered device (b), a decorated skeleton device (c), a device with an high level of human resemblance (d) and a robotic device (e) [sources: (a) [www.mirror.co.uk](http://www.mirror.co.uk), (b) personal archive, (c) **Farr Tech Fabrication Inc.** - [www.fartechfabrication.com](http://www.fartechfabrication.com), (d) *The Alternative Limb Project* - [www.thealternativelimbproject.com](http://www.thealternativelimbproject.com), and (e) *Bespoke Innovations* [www.bespokeinnovations.com](http://www.bespokeinnovations.com)]*

The subjects of our research are below-knee prosthetics users and the professionals who assist them in the choice of the visual aspects of the prosthetic device. A prosthetist is a professional who provides care for anyone requiring an artificial limb (prosthesis), advises users on rehabilitation, and selects the best possible prosthesis for their patient<sup>1</sup>. In the majority of the cases a prosthetic technician<sup>2</sup> is the person instructed by the prosthetist to manufacture the prosthetic device.

The process for amputees suitable for wearing a prosthetic device<sup>3</sup> is undertaken in a specialised clinic (i.e. a prosthetic rehabilitation centre), which “provides a service to people who have undergone amputation, those who may need an amputation and those with congenital limb loss”<sup>4</sup>. This service is “for life and includes the provision, maintenance and repair of artificial limbs together with a rehabilitation service provided by a multidisciplinary team”. The contexts considered within this research are the prosthetic centres of the National Health Service (NHS) of the UK.

<sup>1</sup> “Prosthetist and Orthotist”, from NHS Career (source: <http://www.nhscareers.nhs.uk/explore-by-career/allied-health-professions/careers-in-the-allied-health-professions/prosthetist-and-orthotist/>)

<sup>2</sup> “prosthetic technician”, from NHS Career (source: <http://www.nhscareers.nhs.uk/explore-by-career/wider-healthcare-team/careers-in-the-wider-healthcare-team/clinical-support-staff/prosthetic-technician/>)

<sup>3</sup> “Recovering after an amputation”, from NHS choices (source: [www.nhs.uk/Conditions/Amputation/Pages/Recovery.aspx](http://www.nhs.uk/Conditions/Amputation/Pages/Recovery.aspx))

<sup>4</sup> “Prosthetic Rehabilitation Unit”, from Royal National Orthopaedic Hospital NHS Trust (source: <https://www.rnoh.nhs.uk/clinical-services/prosthetic-rehabilitation-unit>)

The majority of academic literature research in prosthetic design focusses on medical and practical issues connected to, for instance, the comfort of the socket (Colombo, et al., 2010; Lineham, et al, 2014), functionality (Akarsu, et al, 2013), or prosthetic fitting (Webster et al., 2012).

In contrast, limited research has been found on the existing model of prosthetic design, and in particular the appearance of the devices. An example of research that can be found on the design of a prosthetic limb is Plettenburg (2005), this paper consisted of using colourful upper-limb prosthetic devices for children that aimed to achieve acceptance from the users and their parents. Similarly, Hilhorst (2004) presents his project on a brightly coloured hook prosthetic design for children which matches with the users' identity. Psychological aspects of prosthetic users have also been widely investigated and it has been reported that the amputation of a limb can generate unpleasant psychological consequences (Price & Fisher, 2007; Maguire & Parkes, 1998). It is apparent that body image perception and the appearance of prostheses for amputees are related issues.

The lack of interest in aesthetic below-knee prosthetic design is an issue that we propose to investigate in our research. Specifically, we would like to analyse the current prosthetic design system and to propose a new system integrating the role of a visual designer to improve the process.

## 2 METHOD

The data source consists of responses to open interviews with prosthetists and prosthetic users and of a comprehensive literature review. There were a total of 9 participants including 4 below-limb prosthetic users and 5 prosthetists. Amputee participants were volunteers recruited through an advertisement, and prosthetist participants were volunteers recruited at two different prosthetic centres.

The participants are a small target group of UK amputees and prosthetists involved (or previously involved) with a UK NHS prosthetic centre.

The interviews with prosthetists were based on a few open ended questions selected according to the aim of the study. The topics investigated included:

- The dynamics leading to the choice of the prosthetic device appearance
- The link between the emotional well-being of the user and the appearance of the device
- The proposal of implementing the work of an aesthetic prosthetic designer in the public system

The questions for the amputees were flexible, in order to allow them to answer the questions freely.

The issues explored were:

- The level of satisfaction with the appearance of the prosthesis
- The dialogue with their prosthetis and visual choice for their prosthetic device
- The proposal of being advised in the visual choice of their device (within the prosthetic centre and in addition to their prosthetist) by an aesthetic prosthetic designer and being provided with more options

## 3 RESULTS

The data collection showed three main topics that were raised during the interviews with prosthetists (Table 1), and analogous topics identified during the interviews with prosthetic users (Table 2).

*Table 1. Summary of the responses of prosthetists*

	(1) Cost-related issues as influencing factors when advising the users	(2) Extra visual option offered to users for their prostheses without NHS	(3) Proposal of implementing a visual prosthetic designer to the prosthetic design model
Prosthetist A	YES	YES	NO
Prosthetist B	YES	YES	YES
Prosthetist C	YES	NO	YES
Prosthetist D	YES	NO	YES
Prosthetist E	YES	NO	YES

By considering the results of the interview with prosthetists (Table 1), when observing topic (1) it can be noticed that all prosthetists identified the cost as the major issue preventing them to offer more visually elaborated prosthetic solutions to users (e.g. high definition cosmetic or robotic device). The

issue is connected to the limited amount of money allocated by the NHS. Regarding question (2), when asked about offering other visual options to users (i.e. by referring to an external company and/or web site), respondent A stated that they would have done it if they thought that the amputee could have had afforded it. Similarly prosthetist B, which stated the importance of alternative visual solutions, occasionally offered extra options by showing website sources. Respondents C, D, and E stated that both a robotic and a highly realistic device would take too long to be produced, would cost too much money and therefore they do not advise the users about these options.

Concerning question (3), when proposing to the prosthetists the idea of a new prosthetic design system implementing a visual prosthetic designer supporting the prosthetists, three of the respondents welcomed the idea, where prosthetist A found this new professional role “not necessary”.

*Table 2. Summary of the responses of prosthetic users*

	(1) Extra visual options offered by their NHS prosthetist	(2) Desire to have been offered other prosthetic visual options without NHS	(3) Proposal of implementing a visual prosthetic designer to the prosthetic design model
Pro-user S	NO	NO	NO
Pro-user J	NO	YES	YES
Pro-user D	NO	YES	YES
Pro-user E	NO	YES	YES

The responses of users (table 1) showed that, for what concerns question (1), the responses of prosthetists are aligned with the statements of all the users, which stated that they have never been offered any other visual solutions, and that in one case the device was directly chosen by the prosthetist without asking the opinion of the user.

By considering question (2), three out of four users stated the desire to be offered alternative visual designs for their prosthesis. The exception is found in the user S, who is happy with the cosmetic prosthesis that is going to be provided.

With regards to question (3), three prosthetic users stated that having the advice of a visual designer that would advise and provide them with new solutions for below-limb devices would have been beneficial.

## **4 PROSTHETIC USERS AND AESTHETIC NEEDS FOR THEIR PROSTHESES**

### **4.1 Personal preference for the level of visual realism in prosthesis**

What is intended by pleasing aesthetic appearance for prosthetic users? By taking as true the proverb “the beauty lies in the eye of the beholder” (Theocritus, The Idyll) for prosthetic devices, it can be stated that the taste of users significantly differ from person to person. The results of a recent research on the visual attraction for prostheses (Sansoni et al., 2015) found that the first factor influencing the aesthetic preference for a prosthetic device is the level of realism of the device. The results suggest that realistic devices are perceived as appealing to some observers, where people attracted to robotic devices identify realistic devices unattractive (i.e. Figures 1c and 1e).

Therefore, we believe that the category of users preferring realistic devices might choose realistic solutions such as the foam device (Figures 1a) or a highly detailed device (Figure 1b). Differently, the category of users preferring robotic devices may have more varied taste, as the dynamics of preference should follow design principles and subject to individual taste (Sansoni et al., 2014).

### **4.2 Desire of users for visually-appealing devices**

As highlighted by the work of Shairer (2011) and Nielsen et al. (1989), lower limb amputees have different priorities for their device. Specifically, according also to statement of prosthetist B, it appears that all users have as first priority the factor of comfort. However, where some of them express as a second priority the need of functionality, and pleasant appearance as third requirement (User group 1- Figure 2), other users rate appearance at the second place, even in spite of a lower level of functionality (User group 2 - Figure 2). Accordingly, Pillet and Didierjean-Pillet (2001) highlight the fact that all amputees have special personal requirement and that “nowadays, function is not sought at

any cost, especially not at the cost of sacrificing the appearance of the hand”. Some categories of users, more functional-orientated, attribute little or no importance to the look of their device (Users group 3 - Figure 2). The user groups considered as the focus of this paper are 2 and 1.

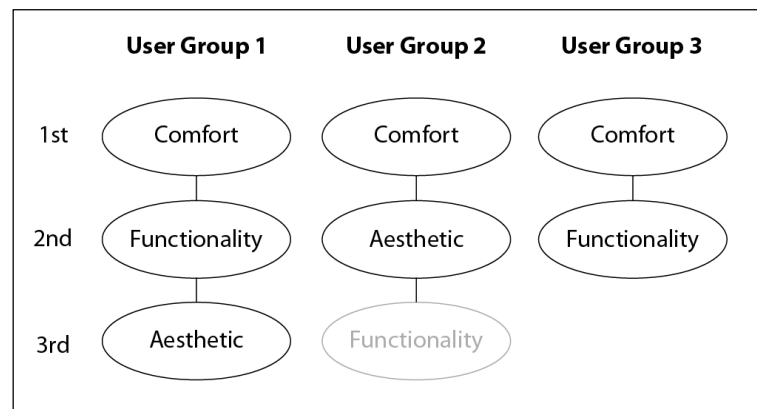


Figure 2. Representation on the priorities for the issues of comfort, functionality and aesthetic in prosthetic devices by below knee prosthetic users

Our data collection showed that, three of the four users rated importance to the visual aspect of the device, as well as two of them stated strong dissatisfaction for their current device and one medium level of dissatisfaction. For instance, user J states not to like at all his uncovered device and aims for a robotic model, and also emphasises the fact that sadly, three years after the amputation, they have not found any visual choice that satisfies their aesthetic requirements. Similarly, user E stated to find robotic looking devices with artificial patterns very attractive, and that they would be happy to wear them in front of i.e. family members and whilst wearing shorts on the street. Specifically, when being shown some alternatives, they stated to desire a robotic model, but was never informed about other options apart the standard ones proposed by his prosthetist.

According to our findings, the literature offers examples of amputees highlighting the importance of the appearance of their device. Nguyen (2013) claims that a female user “requires a prosthesis that aligns aesthetically with her body image just as much as she requires comfort and functionality” and adds in regards to prosthetic design, “Embracing latent, aesthetic needs early in the prosthesis design process can help lead prosthetists to more informed design decisions and increased prosthesis user satisfaction”. The amputee top model Aimee Mullins states that her several prosthetic artificial legs can stand as a [aesthetic] symbol where the wearer creates him/herself like an architect and continually changes identity (Vainshtein, 2012). Similarly, in “Design Meets Disability”, Pullin (2009) claims that, as well as many other orthotic products (i.e. eye-wear glasses), prosthetic products should no longer stand for disability, but rather be considered as fashion icons.

### 4.3 Aesthetic of prosthesis and user’s psychological well-being

According to a study focused on psychological well-being in below knee prosthetic users, it was claimed that the factor of aesthetic of prosthesis and psychological well-being of users are two issues strongly connected, and that failure or success to address this issue can derive distress or well-being in the users (Sansoni et al., 2014). Cairns et al. (2013) argue that the appearance of the prosthesis affects acceptance of the device and that there is a link between the perception of its negative aesthetics and a negative self-body image. In the context of lower limb cosmetic devices, it is stated that the improvement of the aesthetics of the prosthesis can consequently help to improve the self-body image and psychological wellbeing of the wearer.

Considering the role of hand prostheses, Pillet and Didierjean-Pillet (2001) argue that the device can be the “answer” to overcoming the issues encountered when taking part in social activities. Regarding the use of digital cosmetic prostheses (i.e. devices with a high level of limb-like realism – Figure 1a), Carrol and Fyfe (2004) state that in contrast to the basic prosthesis, the improvement of realism of devices can reduce the level of anxiety and depression and enhance the well-being of the users.

According to these examples, we believe in a connection between the aesthetic of prosthetic devices and psychological well-being of users.

## 5 LITTLE IMPORTANCE TO AESTHETIC OF PROSTHETIC DEVICES

According to the statements provided by prosthetists, users and the “NHS procedures of service” (NHS, 2013), we can represent the system of rehabilitation of the user as a set of interactions between the user, prosthetist, prosthetic technician, prosthetic components supplier, clinical psychologist, prosthetic users association, rehabilitation physician, physiotherapist, and occupational therapist.

Specifically, the people involved in the prosthetic design process are the user, the prosthetist and the prosthetic technician. Figure 3 represents the dynamics of interaction between the parts in the processes of rehabilitation and, as informal source of information, we can also include the prosthetic user group. The interactions between the people listed work as following.

The prosthetic user is in direct contact with the prosthetist and has an optional contact with the clinical psychologist (i.e. they might not need emotional support or the therapist might not be present in the centre), and group/association of prosthetic users. The official source of information regarding the visual options for the prosthesis comes from the prosthetist, where the clinical therapist does not play a direct role in advising a design that can help the prosthetic user to regain a positive body vision. An informal source of information about prosthetic designs often comes from the informal dialogue between users (Schairer, 2011).

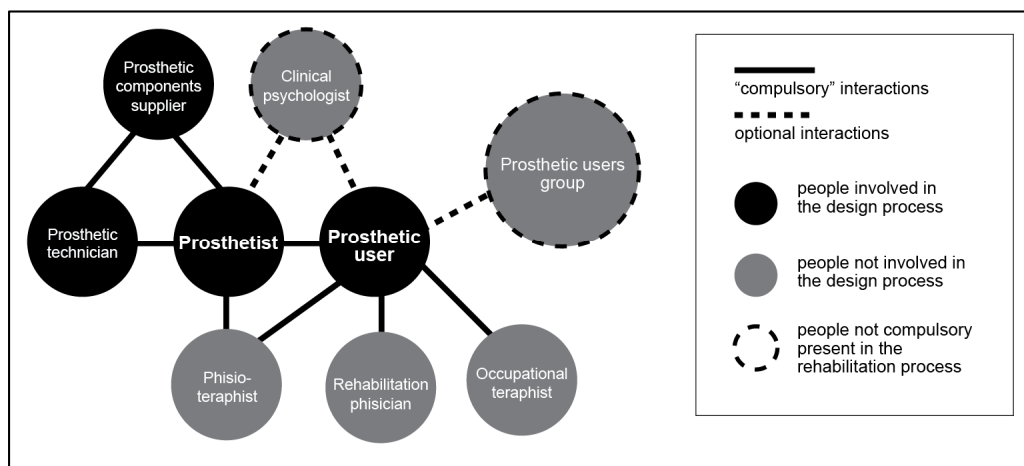


Figure 3. Current system of rehabilitation of the prosthetic user, where the darker parts are involved in the process of design of the prosthesis

When observing this procedure, it can be noticed that the planned steps provide good technical support to patients as well as informative and emotional support. However we can notice as a weak point that, regarding the prosthetic design system, no expert of visual design is involved.

### 5.1 Limited availability of prosthetic aesthetic designs

Our interviews showed that the visual options provided to users by prosthetist are strongly bounded by a) budget restriction and b) the few options that, as part of the NHS, the prosthetist can offer. On the NHS web site it is stated that “a prosthetic limb should feel and look like a natural limb”. This statement highlights the assumption that a device should look like a foam device or an uncovered device (where only the foot looks natural).

According to the statements of the prosthetic user E, they have always accepted the skeleton prosthesis offered by his prosthetist (Figure 1c), and “never been offered any other option” of device appearance. However, when being shown some aesthetically elaborated robotic prosthesis, they immediately stated that they would be much happier to wear and to show to others a robotic device like that rather than his current one. Similarly user J, who directly expressed to the prosthetist the desire to have a robotic device, was not informed about any visual solution by his prosthetist, neither advised about the existence of external companies/designer that could had provided this service privately.

Aligned with the statements of the users, the web page “Premium Prosthetics”<sup>5</sup> published a post referred to the work of American company “Genesis Prosthetic Arts” for below-knee prosthetics, which states:

"Sad but true, appearance is the last thing on your prosthetists mind. And there is a reason. It is really not in his skill sets [...]. But that pipe you were walking on needed a lot more than a foam cover, and you waited for more. At least you can cover it with pants, right? [...]"

In this chapter our intent is not to blame the work of the prosthetist. It is our belief, indeed, that their work is successful in terms of making people walk again and making them feel comfort when using the socket; basically for what concern their area of work, and that being an expert of prosthetic appearance is not a task within their working duties. Our argument is directed on a larger scale to the system of prosthetic design offered to prosthetic users within the public prosthetic centres, as according to our opinion, the gap of service regarding the visual aspect of the devices should be filled.

## 6 A NEW MODEL OF PROSTHETIC DESIGN

### 6.1 Low cost visual solutions for below knee devices

Prosthetists confirmed that they are prevented to offer more aesthetically elaborated options for a matter of cost, as it is believed that an option outside the standard basic models could cost a significantly higher amount of money. It is considered that more advanced prostheses can be very expensive (i.e. high definition cosmesis and bionic prostheses), however it is also true that appealing robotic cover devices can be accessible for a reasonable amount of money.

For instance, the designer Jonathan Bradshaw, who “wanted to provide amputees with an affordable way of reflecting their sense of style”, applied a research approach in which he considered appearance to be as important as comfort in the context of prosthetic design (BBC, 2013). The student created a set of low-cost prosthetic covers to wear according to the preference of the user (Figure 4a) by stating that a similar option is currently “out of reach of the NHS and most people”. The US company Unyq<sup>6</sup> proposes a wide range of aesthetically elaborated carbon fibre prosthetic covers for an affordable amount of money (price range £300-£500 - Figure 4b). A suitable example is also the project developed by industrial design students, which aimed to create prosthetic limbs at the cost of \$30 for children from underdeveloped countries (Reichert & Speer, 2014). During the concept/prototype phases, visual design inspiration (including culture/aesthetic) was included in order to create prostheses that could be visually pleasing for the users (Figure 4c). The project, named Simple Limb Institute<sup>7</sup>, aims for “good and appropriate design solutions that meet the cultural, emotional, and functional needs of the amputee”.

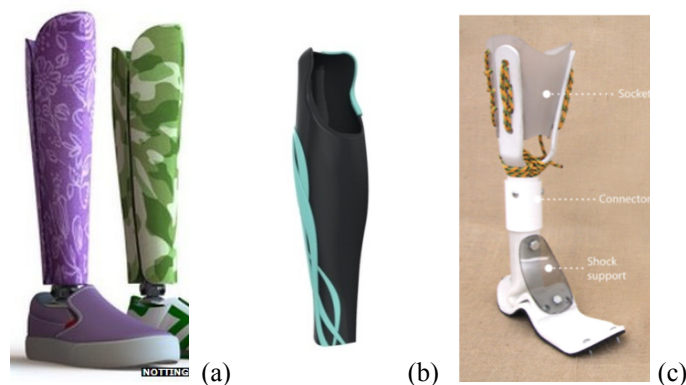


Figure 4. Robotic cover devices designed by Jonathan Bradshaw (a) and Unyq company (b) [sources: (a) [www.bbc.co.uk](http://www.bbc.co.uk) - (b) [www.unyq.com](http://www.unyq.com)], and full robotic devices of a below limb device part of the Simple Limb Institute project (c) [source: [www.simplelimb.com](http://www.simplelimb.com)]

<sup>5</sup> “Fit, function, appearance? It takes a prosthetists and an artist to get all three” (<http://www.premiumprosthetics.com/below-knee-prostheics.html>)

<sup>6</sup> <http://www.unyq.com/>

<sup>7</sup> <http://simplelimb.com/>

As illustrated by the previous examples, it is possible for prosthetic users to be provided with a robotic cover prosthesis that is visually pleasing to their needs. These models can be afforded by people with a lower income. Therefore, we believe that a system introducing personalised robotic designs would be possible to be proposed also to prosthetic users of public prosthetic centres. The missing key in the current prosthetic design process is the lack of a specialised expert in aesthetics of prosthetics to provide the users with the desired visual options. We identify this character under the name of “visual prosthetic designer”.

## 6.2 The role of the visual prosthetic designer

The prosthetic designer should have an active role in the process of prosthetic design within a prosthetic centre in order to understand and respond to the visual requirements of users for their prostheses. The designer should interact with the prosthetic user, the prosthetist, the prosthetic technician, and in specific circumstances also with external prosthetic companies and a clinical psychologist. Figure 5 briefly illustrates the set of interactions between the designer and other people.

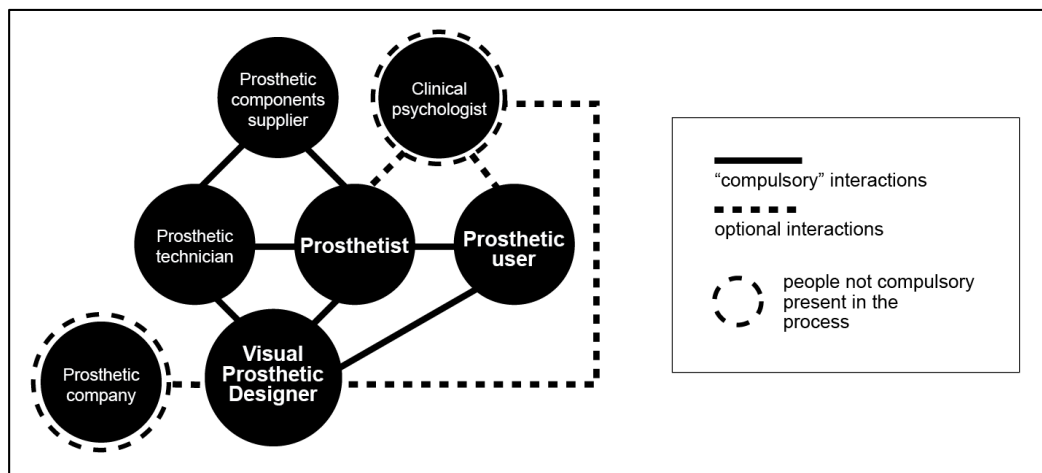


Figure 5. New system of interaction for prosthetic design, implementing a role for the visual prosthetic designer

### 6.2.1 How the designer can understand the visual needs of the prosthetic users?

The first step is to make the user aware of all options available. It often happens that a user opts for a certain design only because they are not aware of the existence of any alternatives, in particularly when they are in an early stage of post amputation. According to an interview with Steve Jobs, product users “don't know what they want until you show it to them” [*BusinessWeek*, May 25 1998].

The designer should guide the user to understand which device would suit them better. We recorded that all the users had a clear idea from the beginning of the interview about their preference for a cosmetic or an artificial looking model. Looking at our results we can see that users attracted to robotic devices prefer certain robotic patterns (i.e. shaping of the leg, elements) when being shown a full range of options. The suggested technique applied by the designer is the Repertory Grid Technique (RGT) (Fransella, 2004; Marsden & Littler, 2000), a technique used in the field of Personal Construct Psychology (Walker & Winter, 2007).

The RGT is a semi-structured interview in which respondents are asked to choose and relate a triad of elements by describing the way two of them are alike and thereby different from the last one (Hassenzahl & Trautmann, 2001). The similarities and differences described by the respondent are the constructs. The central points of the technique are the 1) elements (in our case, models or visual representations of prosthetic devices) and 2) constructs (i.e. the personal interpretations of the patterns of the prosthetics) (Coshall, 2000; Hankinson, 2004).

By applying this technique, the designer can propose a set of visual options to the user and detect a) if any device matches the taste of the user or b) if patterns on different prosthetics are identified as attractive. For instance, the user can state attraction for the organic shape of prosthetic A, for the cavity elements of prosthetic B and the colours of prosthesis C. According to the feedback gained, the designer can gain a clearer understanding of the needs of the user and create a personalised solution.



This technique can be implemented by a set of questions aimed to further explore the visual taste of the user, including: a) taste for clothing and accessories b) opinion regarding the current fashion trends c) level of influence of others in the dressing choice d) attachment to any cultural dressing code e) self-perception when wearing the prosthesis f) level of introverted\extroverted personality.

According to the literature, in some cases users can suffer from psychological distress after amputation (Atherton & Robertson, 2005; Whyte & Niven, 2001) and have a negative opinion of their body (Coffey, Gallagher, Horgan, Desmond, & MacLachlan, 2009). In these cases, the dialogue between the prosthetic designer and the clinical psychologist can be very important in this stage of decision making of the design. The clinical psychologist can identify in which phase of the grieving process a post amputation prosthetic user is in, and advise the prosthetic designer on the suitable design meets the requirements of the patient. For example, according to our previous work (Sansoni, Wodehouse, & Buis, 2014), prosthetic users with a low level of acceptance for their limb loss may better benefit in using a realistic limb (i.e. cosmetic device), where users that start to gain acceptance are advised to use an artificial looking device (i.e. robotic model). The dialogue between designer and clinical psychologist would be necessary only in the cases where users have difficulties to freely express their needs.

### **6.2.2 Visual needs and design process**

The designer should propose to the users a set of options within the technical and financial possibilities of each case. Communication between the designer, the prosthetist and the prosthetic technician is essential in order to understand the resources and technical issues (Figure 5).

A detailed description of the manufacturing process is not provided in this paper, as it still needs further exploration and will be part of our future work.

The following offers a brief description of the procedure of prosthetic design.

For prosthetic users requiring a medium-realistic device, the designer can simply introduce the foam-covered devices normally provided by the prosthetic technician at the centre. The designer can support when the users require skin-tattoo graphics on a device.

When a robotic device is required, the designer has an active role in designing and manufacturing the customised model required. The cost of the materials and manufacturing the device can be covered by both the prosthetic centre and a facultative contribution provided by the user.

When a more elaborated device is desired (i.e. high definition cosmetic or bionic prostheses), a higher budget is usually required. Therefore, the prosthetic designer should provide the information to the users and connect them to a private prosthetic company and be an intermediary between the two parts.

## **7 CONCLUSION**

This paper revises the prosthetic design model in the UK public prosthetic centres, and proposes a new system focusing on the aesthetic aspect of the prosthetic devices. This system includes the work of a visual prosthetic designer, who should be assigned to understand the visual needs of prosthetic users, to guide them in the choice and to provide prosthetic designs. This research aims to respond to the problem of underestimation of the visual aspect of the prosthesis, and to the users' visual dissatisfaction for their devices. This work discusses the importance of the aesthetics of prosthetic devices to promote a positive body image in the user and highlight that robotic-cover devices can be designed with a low money budget.

We hope to raise awareness on the fact that a change is needed in the NHS prosthetic centres in order to allow a wide range of prosthetic users to access visually pleasing devices.

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