STRUCTURING HUMAN AUGMENTATION WITHIN PRODUCT DESIGN

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ABSTRACT

Human augmentation is a thriving research field that aims to amplify human abilities through the development of technological improvements as an integral part of the human body. Human augmentation products may be made for anyone, ranging from healthy users wanting to enhance their human abilities to users who face temporary or permanent disabilities, physical impairments, or perilous situations that oblige them to use these products.
This article attempts to introduce readers to the domain of human augmentation by providing a thorough formulation of the concept and its related terms to develop a more solid structural basis. Additionally, a categorical and dimensional classification of the field was given. Based on these findings, we then proposed a novel framework in the form of a diagrammatic presentation of both classifications, which could enable product designers to better understand and characterize the type of human augmentation product they are designing by determining its location in the diagram. Finally, the proposed framework was evaluated by introducing and classifying several significant human augmentation products most of which have proven to successfully exceed human abilities.

Keywords: Human augmentation, Research methodologies and methods, Visualisation, Product structuring

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1 INTRODUCTION

Human augmentation is generally used to refer to technologies that amplify and improve the human ability to do work (Sankai, Hasegawa and Suzuki, 2013; Alexander et al., 2016; Daily, Oulasvirta and Rekimoto, 2017; Matariæ, 2017; Oertelt et al., 2017; Pirmagomedov and Koucheryavy, 2019; Raisamo et al., 2019; Xie, Mitsuhashi and Torii, 2019). Attempts to recover or improve human abilities began in ancient times (Alicea, 2018). The majority of these attempts aimed at replacing a lost body part with an artificial one, such as a leg or arm prosthesis. However, some fervent inventors aimed to go beyond the natural capabilities of the human organism by developing 'upgrades', for example wings for flying (Huber et al., 2018). Thus, human augmentation products may be made for anyone, ranging from healthy users wanting to improve their human abilities to users who face temporary or permanent disabilities, physical impairments, or perilous and unhealthy situations that oblige them to use these products. The extensive field of human augmentation therefore comprises many different types of apparatuses such as prostheses, orthotics and other physical assistive devices that replace missing or lost functions, exoskeletons that extend physical abilities, and head-up displays using augmented reality (AR) or virtual reality (VR).

As a research field, human augmentation is still so young that there is no detailed description of what it includes or excludes, although the number of articles and books on the topic is increasing. When it comes to tools, the boundaries may have already become unclear. A vacuum cleaner, for example, can improve our ability to clean floors but is not considered to be augmentation. This leads to the question of whether an exoskeleton is not just another, more advanced tool. According to Jeff Alexander et al. (2016), the line between a tool and an augmentation is drawn when a product is so integrated into the user's life that it becomes an extension of them. A vacuum cleaner is only significant to your life when you need it, but an exoskeleton could become as integral to your life as your ability to run. On this basis, we may conclude that for a product or a technology to be considered an augmentation it needs to be an extensional and intuitive part of a person's life, while a tool does not become an integral part of an individual's self.

Against this background, this paper intends to provide a thorough outline of human augmentation and its related terms based on a review of the literature. In addition, we offer a classification of human augmentation into four categories (sensory, physical, cognitive and social augmentation) and three dimensions (replicating, supplementing and exceeding human ability). We will present this classification framework in a diagram as the key contribution of this paper, which will facilitate new insights and opportunities from the design perspective. Finally, we will evaluate our proposed framework by introducing and classifying several successful human augmentation examples based on a clear description of their functionalities.

2 AIM

The aim of this article is to introduce the reader to the growing research field of human augmentation by addressing the following research questions:

1. How can human augmentation and related terms be defined/framed?
2. How can human augmentation be classified?
3. Is there a way to visualize this classification, and which design opportunities arise from it?

Accordingly, this article provides a comprehensive understanding of human augmentation and its related terms as a structural foundation, for a classification of the field into different categories and dimensions. We then explore a novel way to transpose both classifications into a diagram, which could provide novel design perspectives relevant to product designers developing human augmentation products.

3 METHODS

We used the following academic databases to obtain relevant studies for the present article: Web of Science, ScienceDirect (Elsevier), Scopus (Elsevier) and Google Scholar. Studies referring to an augmented human as a person who is able to use AR effectively were excluded from this review. When using the term 'augmentation', we found various papers concerning aesthetic surgical operations, such as dental implants, facial reconstruction or breast augmentation. These studies were also excluded.

4 RESULTS

4.1 Terminology

The term 'human augmentation' has a few related concepts. To clarify and avoid confusion, these terms are defined in this section and illustrated with examples in Figure 1. Firstly, *assistive augmentation* refers to rehabilitative technology for people with disabilities or the elderly. The Tech Act of 1988 (Code United States, 2020) defines an assistive technology device as 'any item, piece of equipment, or product system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve functional capabilities of individuals with disabilities'. The Assistive Technology (AT) Act of 2004 uses essentially the same definition as the Tech Act, with an exception that excludes surgically implanted medical devices. As a field, it is concerned with the development and study of technology that substitutes for, recovers or empowers physical, sensorial or cognitive capabilities, depending on specific user needs (Huber et al., 2018).

Secondly, *human enhancement* refers to a similar but broader field than human augmentation, covering several disciplines from mechanical to genetic engineering. Human enhancement encompasses solutions which require medication (e.g. chemical stimulants that can be used to improve intelligence, concentration or memory), surgical operations (e.g. organ transplants or implants (Kobayashi, Yoshinaga and Ohtsuka, 2012) or even genetic modification (De Araujo, 2017). According to Walter Anderson (2003), these methods fall under the definition of 'human enhancement' but are not considered human augmentation. While they may alter human characteristics and capacities, Anderson claims that human enhancement concerns creating abilities that are biologically inherent in the phenotype, in contrast to human augmentation. Some augmentations may have profound effects on a person's sense of self and may strengthen the ego but cannot alter it. Moreover, augmentation tends to be device-based and temporary, while enhancement may be permanent. For example, spectacles fall under assistive augmentation, while lenses are considered human augmentation and laser eye surgery as enhancement (see Figure 1).

Finally, *human augmentation* or *augmented human* refer to technologies that enhance human productivity or capability, or that add to the human body or mind in some manner. Raisamo et al. (2019) discussed the field of human augmentation and proposed the following definition be adopted by the entire research community, which we chose to do in this paper:

> Human augmentation is an interdisciplinary field that addresses methods, technologies and their applications for enhancing sensing, action and/or cognitive abilities of a human. This is achieved through sensing and actuation technologies, fusion and fission of information, and artificial intelligence (AI) methods.

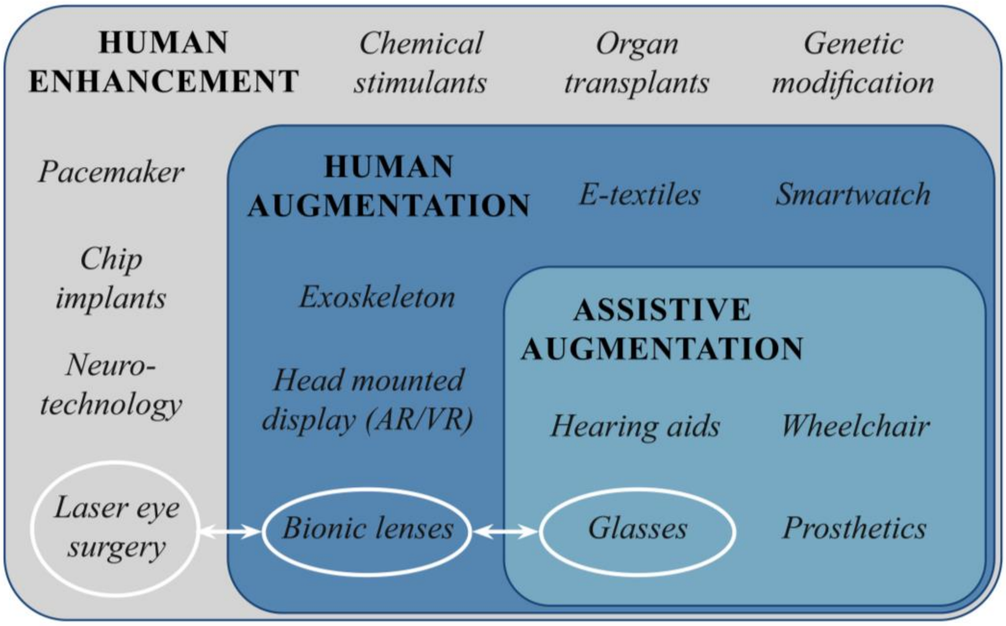

Figure 1. Visualization (with examples) of human augmentation and its related terms

4.2 Classification of human augmentation

4.2.1 Categorical classification

Because human augmentation is a relatively new term, there is no definitive classification of terminology in the field. Nevertheless, our literature search revealed that similar categories have been identified. As shown in Table 1, four similar categories were found in five different papers, although not all of the categories were present in each paper. Nevertheless, we consider all four categories to be relevant to the purpose of this article.

Table 1. Different categories of human augmentation found in relevant articles

Article	**Categories**			
	Category 1	Category 2	Category 3	Category 4
IoT technologies for Augmented Human: A survey (Pirmagomedov and Koucheryavy, 2019)	Advanced sensing	Physical augmentation	Mental/ cognitive augmentation	/
Human augmentation: past, present and future (Raisamo et al., 2019)	Augmented senses	Augmented action	Augmented cognition	/
Assistive Augmentation (Huber et al., 2018)	Sensory substitution and fusion technology	/	Cognitive augmentation	Novel user input and interaction techniques
Technology for Human Augmentation (Daily, Oulasvirta and Rekimoto, 2017)	Advanced sensory capabilities	Enhanced muscle functioning and capabilities	Improved brain function	Augmented communication
Holistic quantified self framework for augmented human (Lee et al., 2018)	/	Body augmentation	Brain augmentation	Social augmentation

Category 1 - Sensory augmentation. The first category concerns augmentation of the senses, which can be achieved by interpreting the sensory information available and presenting feedback to the user through their senses.

Category 2 - Physical augmentation. The second category involves augmentation of the physical human body and aims at the improvement of an individual's ability to move and manipulate objects. One of the most common examples of physical augmentation is the exoskeleton (Kazerooni, 2005, 2008; Chen et al., 2019). Successful physical augmentation often requires human sensory feedback and information to be collected from the environment, in order to control action in an adaptive manner.

Category 3 - Cognitive augmentation. The category of cognitive augmentation encompasses data-processing assistance, facilitation of decision-making and assistance with memorization. Cognitive augmentation can be achieved by detecting the human cognitive state, making an accurate interpretation of it, and adapting feedback to match the current and predictive needs of the user.

Category 4 - Social augmentation. Finally, the category of social augmentation refers to techniques to enhance social ability by supporting empathy, interaction (both human-to-human and human-to-computer interaction), means of communication, and collaboration. For example, Ionut Damian et al. (2014) proposed a social augmentation concept using a head-mounted display (HMD) to augment the user's ability to sense and control their social behaviour, based on social signal processing and peripheral feedback. Furthermore, Cheng Zhang et al. (2017) presented an acoustic signal-based method using the human body as a communication channel to transmit information across different devices. The authors described how this capability can be used to transmit text through the human body, as well as communicating between humans using devices outside the body. Despite its significant future value, augmentation of social abilities has not been as thoroughly studied as the other categories mentioned above (Lee et al., 2018).

4.2.2 Dimensional classification

As with the classification into categories, different dimensions of human augmentation were also found in the literature. As shown in Table 2, three similar dimensions were found in three different papers. This dimensional classification refers to a continuum where the boundaries are less explicit and along which the concepts may be present at various levels. From left (Dimension 1) to right (Dimension 3), the continuum reflects increasing ability provided to users.

Table 2. Different dimensions of human augmentation found in relevant articles

Article	**Dimensions**		
	Dimension 1	Dimension 2	Dimension 3
Human augmentation (Alexander et al., 2016)	Replicating human ability	Supplementing human ability	Exceeding human ability
Designing Human 2.0 — Regenerative Existence (Vita-More, 2008)	The amended body	The extended body	The suspended body
IoT technologies for Augmented Human: A survey (Pirmagomedov and Koucheryavy, 2019)	Specific needs Substitute, recover	No specific needs Empower, augment	Super-human needs

Dimension 1 - Replicating human ability. The first dimension of human augmentation is the replication of a capacity that a typical person has. Replication provides assistance to individuals who are born with deficiencies, who suffered from a medical condition or who have experienced a tragic accident. Replication may also be used to counteract the natural process of aging. One of the most common examples is a prosthesis. In general, a natural human function is replicated for someone who does not have it.

Dimension 2 - Supplementing human ability. This dimension concerns the extended body, which improves our ability to do something. It enables us to better perform tasks that are already humanly possible. This includes, for example, devices that artificially increase our strength, such as exoskeletons, improve our memory or increase our concentration while driving.

Dimension 3 - Exceeding human ability. Finally, the third dimension concerns augmentation that allows us to do things that we are not able to do in a natural way. Therefore, this dimension is also referred to as that of superhuman abilities: here augmentation turns the user into a superhuman with capabilities that are not naturally human but well beyond the ordinary. Examples include products enabling the user to fly, or to breathe underwater, turn invisible, see ultraviolet or infrared light, or smell chemicals not currently detectable by the human sense of smell.

While replication of human abilities refers to assistive augmentation (which is a subpart of human augmentation, see Figure 1), the other two dimensions concern the field of human augmentation. There is even a unique competition called Cybathlon (Hoy, 2019) for people with disabilities, in which they compete against each other while testing the usefulness of assistive technologies in performing everyday activities – and thus replicating human abilities. These pilots evaluate the performance of devices such as advanced stair-climbing wheelchairs, prostheses and rehabilitation robots.

4.3 Diagram of human augmentation classifications

Having expounded the different categories and dimensions of human augmentation found in the literature, we now explore a novel way to visualize both categorical and dimensional classifications in a diagram. The diagram is shown in Figure 2, in which corresponding examples are given. Evidently, a human augmentation product may be situated in multiple dimensions and/or categories, depending on its functions. A clear description of product functions is therefore needed to determine its correct location or locations within the diagram.

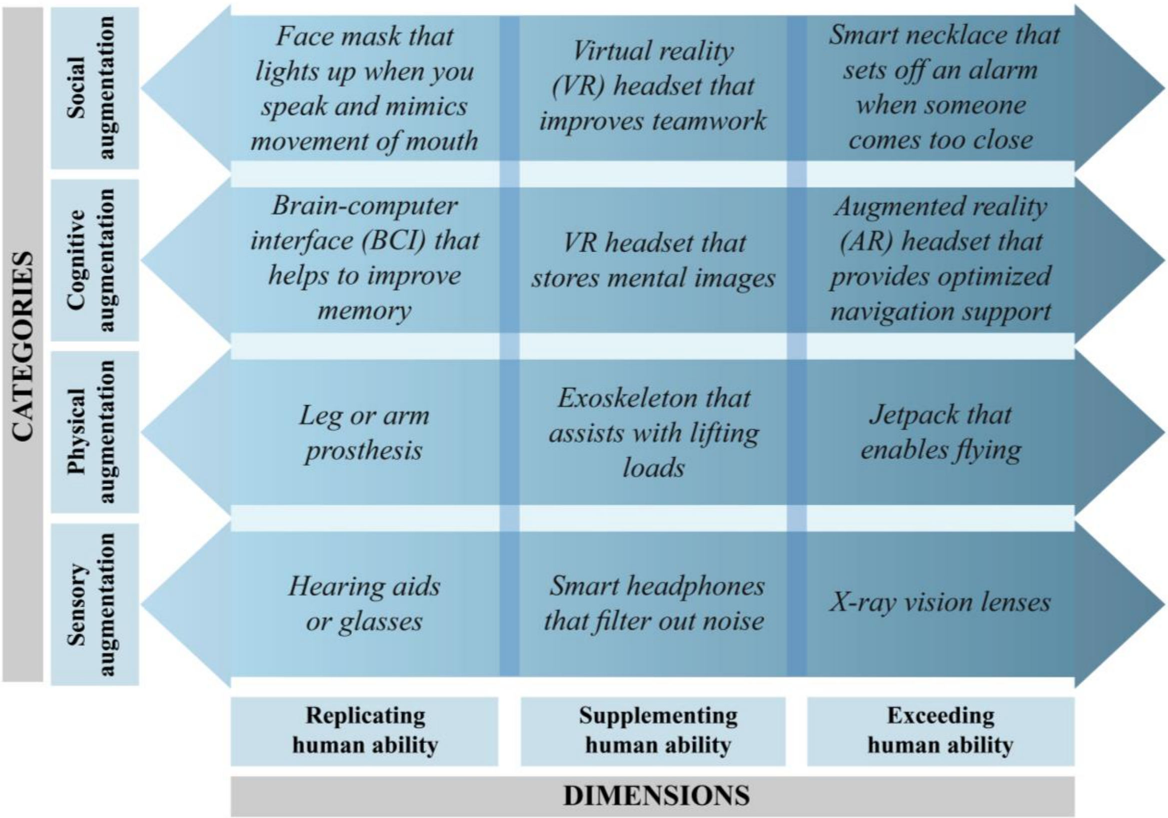

Figure 2. Visual diagram of potential human augmentation combinations

For product designers who develop human augmentation products, this diagram could assist them in a wider reflection on their (yet to be developed) product by considering its location in the diagram. It might also suggest alternative directions to them that could lead to new perspectives or opportunities. For example, a prosthesis designer who focuses solely on replicating an amputee's ability to walk could explore new opportunities, such as enabling the wearer to jump exceptionally high, or enabling them to change the colour of the prosthesis. When exploring other categories such as sensory augmentation, Petrini et al. (2019) have shown that sensory feedback can be integrated to provide real-time tactile feedback through nerve stimulation. While most of these advanced technologies still need time to mature, many of them can already be integrated into products to further augment primary human abilities.

4.3.1 Evaluation of the proposed framework

To evaluate our proposed framework, below we will introduce several successful human augmentation products and classify them based on a clear description of their functionalities.

The first human augmentation product we will discuss is the (Flex-Foot) Cheetah, which is a prosthetic leg developed by biomedical engineer Van Phillips, who lost his leg at the age of 21. The Cheetah (shown in Figure 3) is a carbon-fibre running blade inspired by the hindquarters of the cheetah, which is able to store kinetic energy as potential energy, like a spring. Advances in prosthetic technology have led to widespread debate about whether amputee athletes may have an advantage over able-bodied athletes (Zettler, 2009). Although the Cheetah is considerably lighter than a human limb, amputees wearing them must still expend a similar amount of energy as able-bodied people when running (Nolan, 2008). Therefore, we can classify the Cheetah as **physical augmentation** that **replicates human abilities**. However, if future versions of Cheetahs were shown to enable amputee users to run significantly faster than able-bodied athletes, they would be situated within the dimension of supplementing human abilities. Recently, Össur – the company that produces the Cheetah and other prosthetic products – announced a next-generation mind-controlled leg prosthesis with bionic features (Össur, 2015). In addition, it is even possible to integrate electronic skin (e-skin) that changes the colour of the prosthesis (Chou et al., 2015). Such advances in technology indicate that exceeding human ability is just around the corner for prosthetic users.

Figure 3. The Flex-Foot Cheetah, here worn by athlete Aimee Mullins: an example of physical augmentation that replicates human abilities

Second, we consider the Hövding, invented by Anna Haupt and Terese Alstin, which is an airbag for urban cyclists that is worn around the neck (see Figure 4). The airbag deploys when the accelerometers in it detect unusual movement patterns that match the profile of a crash. The Hövding can be worn as part of an outfit and offers protection that is up to eight times better than traditional bicycle helmets (Hövding, 2021). We classify the Hövding as **physical augmentation** that **exceeds human ability**.

Figure 4. The Hövding, invented by Anna Haupt and Terese Alstin: an example of physical augmentation that exceeds human abilities

Third, we discuss the Spider Dress, created by Anouk Wipprecht, which is a 3D-printed dress equipped with sensors and motorized, extendable limbs that defend the wearer's personal space (see Figure 5). The limbs extend when someone comes too close, restoring the wearer's comfort zone. Although the dress is a conceptual design exploring what clothing could be, it shows how human augmentation products can take social experience to a new level by sensing and responding to the wearer and their surroundings (Wipprecht, 2016). We classify the Spider Dress as **social augmentation** that **exceeds human ability**, as we do not have additional limbs that can extend when they sense a person coming too close.

Figure 5. The Spider Dress, created by Anouk Wipprecht: an example of social augmentation that exceeds human abilities

Fourth, we have the Cyborg Antenna, created by Neil Harbisson, which is a device attached to the head that turns colours into audible frequencies. Initially, it was intended for colour-blind people, but in theory, it can also be worn by people with normal colour vision. As shown in Figure 6, the Cyborg Antenna has been permanently attached to Harbisson's head since 2004. He is even legally recognized as a cyborg by the government (Landres, 2015). As the Cyborg Antenna enables its wearer to also hear colours that are invisible to the human eye such as infrared and ultraviolet, it can be classified as **sensory augmentation** that **exceeds human ability**.

Figure 6. The Cyborg Antenna, worn by Neil Harbisson: an example of sensory augmentation that exceeds human abilities

Fifth, we consider Duoskin, which is an on-skin user interface enabling human-computer interaction and is based on the aesthetics found in metallic jewellery-like temporary tattoos. The customizable interface (see Figure 7) enables three types of interaction modalities: sensing touch input, displaying output and communicating wirelessly with other devices (Kao et al., 2016). Therefore, we classify Duoskin as **social augmentation** that **exceeds our human abilities**.

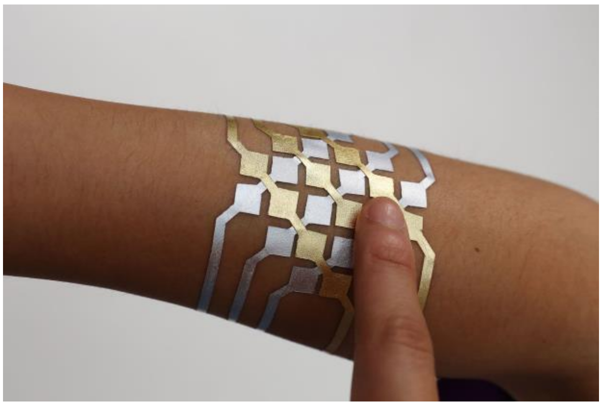

Figure 7. Duoskin, a wearable on-skin user interface enabling human-computer interaction: an example of social augmentation that exceeds human abilities

Finally, we discuss mixed reality headsets that can offer improvements in learning outcomes by significantly increasing training efficiency (Hsieh and Lee, 2018). The HoloLens, for example (see Figure 8), has been shown to be useful as an anatomy application, allowing medical students to view a 3D representation of a human body and even display, enlarge, turn and rotate realistic-looking anatomical parts (Microsoft, 2021). As the HoloLens can simplify complex disciplines such as anatomy and molecular chemistry through spatial visualization and thereby enable students to learn faster and retain knowledge better, we can classify it as **cognitive augmentation** that **exceeds our human abilities**.

Figure 8. Students wearing the HoloLens glasses during medical education: an example of cognitive augmentation that exceeds human abilities

5 DISCUSSION

Human augmentation is a thriving research domain that can be defined as encompassing any attempt to overcome the current limitations of the human body through technological means. This article attempts to introduce readers to the concept of human augmentation by first providing a thorough formulation of human augmentation and its related terms to develop a more solid structural basis. Furthermore, a classification of the field into four categories (sensory, physical, cognitive and social augmentation) and three dimensions (replicating, supplementing and exceeding human ability) was given. Despite its significant potential value, we have discovered that social augmentation has not been as thoroughly studied as the other categories, which future research should bear in mind.

Additionally, we proposed a novel framework in the form of a diagrammatic presentation of both classifications, which could enable product designers to better understand and characterize the type of human augmentation product they are designing by determining its location in the diagram. Potentially, this may also provide a wider scope of design opportunities. The proposed framework was evaluated by introducing and classifying several significant human augmentation products most of which have proven to successfully exceed human abilities.

Having formulated a solid conceptual framework for the growing research domain, we conclude this article with a brief indication of the next research steps. These comprise experimental research through several use cases, with the aim of deriving design directions that could be useful during the design of human augmentation products. Moreover, future research will discuss why it is essential that, not only engineers and medical specialists but also product designers should be part of any development team working on human augmentation products.

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