Human by Design: Integrating Human-Centred Principles in Augmentation Technologies

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Abstract Human augmentation technologies (HAT) are rapidly advancing, promising to extend physical, sensory, and cognitive capabilities. However, their development often remains technology-driven, overlooking the human, social, and ethical dimensions critical to real-world integration. This paper argues for a human-centred design (HCD) approach to HAT, one that foregrounds lived experience, contextual awareness, and inclusive participation. Through a review of the current HAT landscape and a case study of the Second Skin project, which engaged manual workers in the co-design of a wearable augmentation prototype, the paper demonstrates how embodied, participatory methods can reveal user insights and challenge dominant narratives around efficiency and surveillance. Building on this foundation, the paper proposes a set of design principles tailored to the complex demands of augmentation emphasising empathy, ethical reflection, adaptability, and systemic awareness. By reorienting design processes around human values and societal context, this work contributes to shaping augmentation futures that are not only innovative but also equitable, sustainable, and attuned to the realities of those they aim to serve.

Keywords: Human Augmentation Technologies, Human-Centred Design, Inclusive Design, Ethical Technology, Wearable Technology

1 Introduction

Human augmentation technologies (HAT) encompass a broad range of innovations designed to extend or enhance human physical, sensory, or cognitive capabilities, either temporarily or permanently. These technologies include wearable devices such as exoskeletons, sensory aids like advanced prosthetics and implants, and even emerging gene-editing techniques that modify biological functions (De Boeck and Vaes 2024; Human Augmentation Initiative 2021). As the boundary between humans and machines increasingly blurs, HAT promises profound impacts on health, productivity, and everyday life.

While human augmentation technologies (HAT) hold transformative potential, their development has largely followed a technocentric path, one that prioritises technical innovation and performance over the nuanced realities of users and the complex systems they inhabit. This trajectory is not unique to HAT but reflective of a broader pattern in emerging technologies, where engineering-led solutions often underemphasise social, ethical, and experiential dimensions (Anastassova, Mégard, and Burkhardt 2007; Greenhalgh et al. 2017; Vallor 2016). As a result, augmentation systems are often designed *for* users rather than *with* them, risking poor adoption, exclusion, and unintended consequences (Raisamo et al. 2019).

Such challenges call for a reorientation towards human-centred design (HCD) principles, an approach that prioritises users lived realities, values inclusivity, and embeds ethical reflection throughout the design process.

This paper investigates the question: *How can Human Centred Design (HCD) principles be effectively applied to the development of human augmentation technologies to ensure they are ethical, inclusive, and contextually relevant?* This emerges from the growing concern that augmentation technologies are being developed in isolation from the users they aim to support (De Boeck and Vaes 2024; Raisamo et al. 2019). By examining a real-world case study, the paper explores how embedding user insight into the design of wearable systems can lead to more responsible and human-aligned technological futures that are not only innovative but also sustainable, ethical, and socially responsible. By adopting a holistic perspective that considers the dynamic interplay between humans, technology, and environment, designers and developers can better anticipate challenges, foster equitable access, and ensure that augmentation technologies genuinely enhance human well-being in ways they want.

In the sections that follow, the article outlines the current landscape of HAT, the necessity of human-centred design, and key principles to guide future development.

2 Landscape of Human Augmentation Technologies

The concept of human augmentation has long captured the imagination of popular culture, featuring prominently in science fiction media such as *Cyberpunk 2077*, *Star Wars*, *The Expanse*, and *Neuromancer*. These narratives often explore technologically enhanced bodies, envisioning scenarios where implants, prosthetics, or exosuits push humans beyond natural limitations. Far from mere entertainment, such depictions play a significant role in shaping public expectations and influencing the trajectory of technological development. Scholars have noted that speculative fiction acts as a form of "design fiction" (Bleecker 2009), creating imaginaries that inform both public discourse and the ideation phase within innovation and design communities (Haraway 1991; Suchman 2007).

While these cultural imaginaries may seem distant from reality, advances in wearable technologies, neural interfaces, and bioengineering are steadily narrowing the gap between fiction and practice. Already, exoskeletons are being adopted in industrial and rehabilitative contexts, such as in logistics and physiotherapy (de Looze et al. 2016), while sensory augmentation tools like cochlear implants and haptic feedback systems are increasingly integrated into everyday assistive technologies. Although the mainstream visibility of more radical augmentations such as robotic limbs with AI-driven feedback loops or mechanical tails for balance is still limited, early-stage research and niche applications suggest that wider adoption may not be far off (Makin and Orlov 2020; Villa et al. 2023).

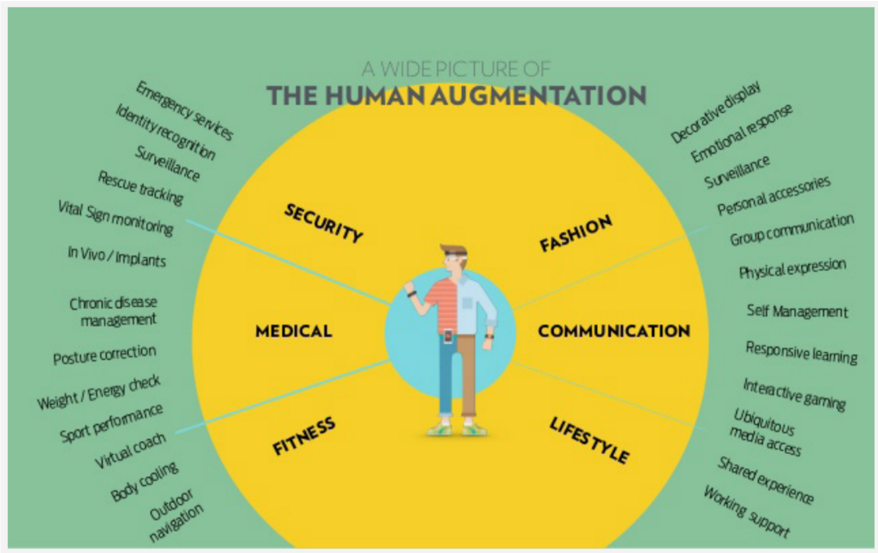

Fig 1. Different forms Human Augmentation can take in the future (Saracco, 2017)

As seen in Fig 1, these technologies encompass both lives altering clinical enhancements like disease management, to more expressional alterations for social enhancements like Botox. In both research and application, human augmentation technologies are often conceptualised across three interrelated domains: **sensory**, **motor**, and **cognitive** augmentation. Sensory augmentation involves enhancing perception, such as vision, hearing, or tactile feedback, through devices like visual prosthetics or sensory substitution interfaces. Motor augmentation targets physical movement and strength, evident in technologies like robotic limbs, exosuits, and supernumerary robotic limbs (Raisamo et al. 2019). Cognitive augmentation refers to the enhancement of memory, attention, or decision-making through tools such as neurofeedback systems, brain–computer interfaces (BCIs), or AI-assisted cognitive aids (De Boeck and Vaes 2024; Villa et al. 2023). Together, these categories help delineate the ways HAT can interface with the human body, enabling targeted innovations across healthcare, work, mobility, and beyond.

As Villa et al. (2023) argue, focusing solely on sensory–motor–cognitive capabilities risks reducing users to passive recipients of technological intervention rather than active agents embedded within complex social, cultural, and ecological networks.

To fully grasp the implications of human augmentation, we must go beyond the technological lens and examine how these innovations intersect with social values, power structures, and lived experience. As such, it becomes increasingly

important to frame the landscape of HAT not just in terms of capability expansion, but also in relation to societal norms, ethical imperatives, and the relational contexts in which technologies are adopted and experienced.
To move beyond these abstractions, it is crucial to examine a concrete example where human centred design methods are applied in situ. The following case study of the Second Skin project demonstrates how embedding user insight and embodied inquiry at every stage can yield augmentation solutions that resonate with the complex realities of physically demanding professions.

3 Case Study

The case explored in this paper is the Second Skin project, a thesis-led research and design initiative that examines how wearable augmentation technologies can support the embodied experiences of physically demanding professions. The project was selected as a case because it engages directly with the lived expertise of blue-collar workers, whose voices are often excluded from discussions on emerging tech. Their embodied knowledge and work routines present a unique and underrepresented perspective for designing augmentation systems that are ethical, inclusive, and practical.
The project employed a Human Centred Design (HCD) approach and a collaborative design process that brought together electricians, carpenters, university technicians and warehouse staff, whose bodily routines, safety needs, and sensory feedback loops were central to shaping the design.
The research began with contextual inquiries and observational studies in work environments where physical strain, repetitive motion, and environmental exposure were part of daily practice. Informal interviews and shadowing sessions revealed nuanced insights into how workers perceived fatigue, posture, pressure points, and sensory overload; factors that often go unaddressed in conventional wearable tech design. These early engagements informed the design brief and led to a participatory process where practitioners became co-creators rather than mere end users.
Workshops were conducted with these professionals to co-design concepts for the Second Skin prototype. Through bodystorming, sketching on the body, and rapid material prototyping, participants explored how wearables might augment awareness, offer feedback, or intervene during physically intensive tasks. Collaborators also tested early functional mock-ups, offering grounded feedback on comfort, flexibility, interference with workflow, and perceived usefulness.

Traditional HCD methods were adapted to foreground experiential and embodied knowledge, allowing for design decisions to emerge not just from dialogue, but from hands-on interaction and bodily intuition. For instance, an electrician's feedback on toolbelt usage and cold temperatures influenced material choices and sensor placement. A warehouse worker's insight into shift-based fatigue cycles shaped the logic behind passive versus active haptic alerts.

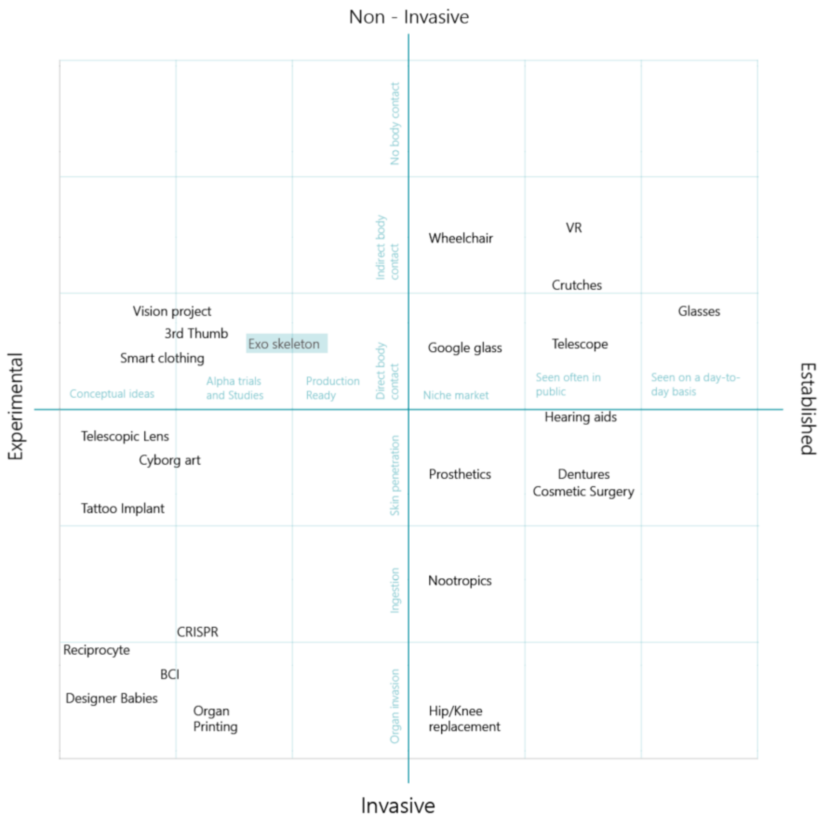

Fig. 2. Relationship between Established and Invasive nature of HAT

Existing HATs, all in various stages of development, were mapped in accordance with the "closeness" to the body and close they are to be market ready (Fig 2). While many are in their nascent stages, either as college project (Vision Project) or might still be at an experimental research stage (3^{rd} Thumb), many have entered the market without us directly labelling them as augmentation technologies, like Telescopes or Prosthetics.

Exo-skeletons stood out as one such technology that is being rapidly adopted in workplace environments to help assist with load, transportation and support (de Looze et al., 2015; McFarland & Fischer, 2019; Jurczak, 2019). Its main application for now is seen in medicine for rehabilitating patients after hip/knee surgery or partly restoring limb functions for people who use wheelchairs, or in the military. In order to understand gaps in relation with the body itself, several of the examples from Figure 2 were mapped to a human body parts, establishing relationships between specific body functions, the type of HAT and number of affected areas.

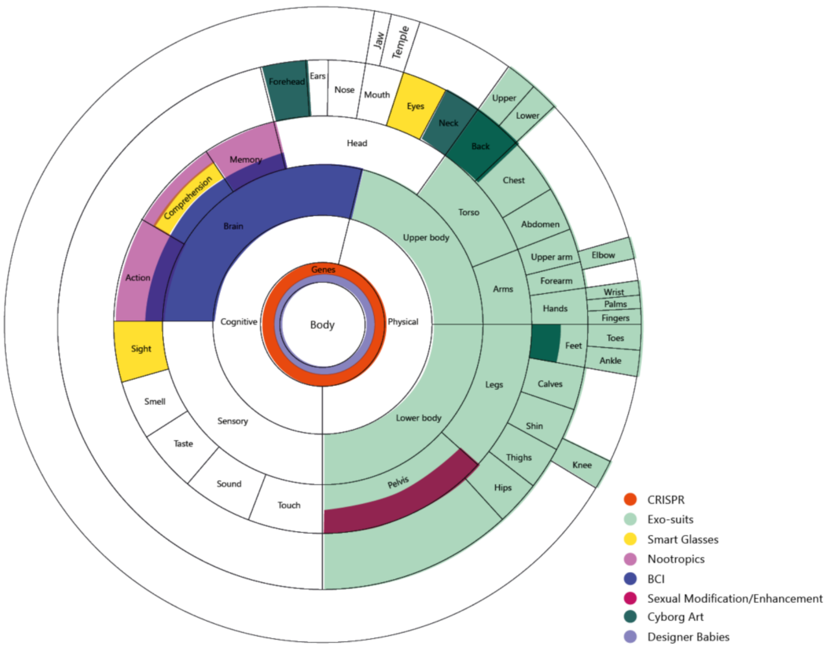

Fig. 3. Overlay of existing devices—commercial (blue) and research prototypes (orange)—reveals underserved regions in the augmentation design space.

Figure 3 builds on this by overlaying existing commercial and research prototypes, illustrating coverage gaps but also the large coverage area by exo-suites. For these reasons exo-suits as a HAT showed promise in workplace application. It also connects with most of the body to provide strength, support and rehabilitation. Following this structured approach within a design framework and outlook helped narrow down an area of intervention that had strong conceptual foundation and impact on the user's body. In both research and application, human augmentation technologies are often conceptualised across three interrelated domains: sensory, motor, and cognitive augmentation (Raisamo et al.

2019). **Figure 2** maps these domains onto the human body, highlighting which regions are most addressed and, by contrast, which remain under-served.

By grounding the intervention in both biomechanical need and user context, the exo-suit not only delivered strength and support but also set the stage for richer conversations about the worker's experience. These findings helped further interactions with blue-collar workers which revealed that workers did not want to be "fixed" or monitored, rather they wanted a partner in their labour.

One of the most profound insights gained from this collaborative process was the importance of dignifying physical labour through design. Rather than framing wearable tech as a tool to correct or monitor behaviour, participants viewed it as a partner in their daily rhythms, a perspective that only emerged through deep engagement and mutual respect. This challenged dominant narratives of efficiency and surveillance in wearable design, and emphasized augmentation as a means of support, awareness, and care.

For the Interaction Design community, the Second Skin project underscores the value of including skilled manual workers and frontline practitioners as design collaborators, not just as test subjects. It also demonstrates how HCD can evolve to include embodied, context sensitive, and socially grounded practices. Ultimately, the project advocates for a more inclusive and responsive design ethic; one that listens to the body, honours lived expertise and creates with rather than for those who wear our technologies.

The Second Skin project served as both a proving ground and a provocation for revealing the potential of wearables to support embodied labour, and the limitations of traditional HCD frameworks when applied to complex, emergent domains like human augmentation. Insights from this collaboration informed a deeper examination of how interaction design methods might be reoriented to better address the ethical, experiential, and systemic dimensions of augmentation. Drawing from this experience, the following section outlines key principles and process considerations for designing HAT in ways that are attuned to lived realities, bodily nuance, and social responsibility.

4 Principles and Processes in Human-Centred Design for HAT

Human-centred design (HCD) has matured significantly, providing structured, evidence-based approaches to developing technologies that truly meet human needs. The value of systematic design processes in conceptualising and creating future technologies has been well documented (Ritter, Baxter, and Churchill 2014; Grinyer 2001). Yet, current frameworks often lack the breadth needed for emerging fields like human augmentation technologies (HAT), which require designers to balance complex human, technological, ethical, and environmental factors.

To navigate the unique demands of human augmentation technologies (HAT), this checklist draws on both established and emerging frameworks in interaction design, including ISO 9241-210 principles (Ritter, Baxter, and Churchill 2014), sustainable and appropriate design methodologies (Sianipar et al. 2013), and value-sensitive design (Greenhalgh et al. 2017; Vallor 2016). These principles are not arbitrarily selected but reflect recurring priorities across HCD literature, such as context-awareness, iterative development, inclusivity, and ethics, that are critical when designing for the body and identity. Their value was demonstrated in the Second Skin project, where practitioner engagement, prototyping, and environmental considerations led to more grounded and respectful design decisions (Jacob 2023).

By offering a synthesised yet actionable framework, the checklist functions both as a conceptual tool and a practical guide for navigating the socio-technical complexity of HAT development for future designers and engineers.

4.1 User-Centred Design

This principle encompasses multiple components essential for grounding design in real human experiences:

- **Empathy and understanding** through immersive research methods, such as ethnography and interviews, to capture the nuanced lived realities of users (Ritter, Baxter, and Churchill 2014). In *Second Skin*, shadowing electricians revealed critical posture and repetitive movement discomforts that shaped sensor placement (Jacob 2023).
- **Participatory Research Methods** that actively involve users and stakeholders in the early research phase, gathering diverse perspectives without necessitating direct involvement in design decisions (Sanders and Stappers 2008). People often suggest innovative ways they have used to solve specific problems for themselves, which in turn can be distilled into useful features rather than going off assumptions.
- **Iterative Testing and Feedback** to refine prototypes based on actual user interaction and evolving needs, ensuring responsiveness and usability over time (Kelley 2021). *Second Skin* underwent four in-situ prototype cycles, each improving upon materiality or comfort (Jacob 2023).

4.2 Contextual and Environmental Awareness

Designers could consider the social, cultural, and physical environments in which HAT will be deployed. This understanding supports solutions that are appropriate for local contexts and sustainable within their environmental settings (Sianipar et al. 2013). In *Second Skin*, extreme cold temperatures led us to select a combination of phase-change materials and battery-powered heating elements while also providing adequate insulation (Jacob 2023). **Figure 3**'s overlay of exo-skeletons in relation with multiple body parts underscores the importance of assessing environmental fit which drives context aware design.

4.3 Iterative Prototyping

Repeated cycles of design, testing, and refinement allow early detection of usability issues, enhance stakeholder engagement, and mitigate risks associated with complex technologies. Through iterative prototyping, designs evolve based on authentic user feedback, resulting in products that better meet user expectations and adapt to real-world conditions (Kelley 2021). For example, early *Second Skin* mockups created with cardboard and fabric quickly revealed arm girth differences between workers, prompting a switch to modular Velcro attachments and stretchable fabric (Jacob 2023).

4.4 Ethical Reflection and Responsibility

Ethics should be embedded throughout the design process, with proactive attention to privacy, equity, autonomy, and potential societal impacts (Hansson 2017; Vallor 2016). In *Second Skin*, participants collectively rejected continuous data logging in favor of event-triggered haptic alerts, demonstrating how early ethical discussions guided the choice to preserve worker autonomy (Jacob 2023).

4.5 Flexibility and Adaptability

Given the diversity of human bodies, behaviours, and contexts, HAT should be designed with modularity and adaptability in mind, capable of evolving alongside users and their changing needs (Roper, Micheli, and Love 2016). This would work not only for the product itself, but also for the eco-system created around it.

4.6 Inclusive Design

Technologies must be accessible and usable by people across varied abilities, ages, genders, and socio-economic backgrounds. Inclusive design aims to reduce barriers and prevent technology from reinforcing existing inequalities (Greenhalgh et al. 2017). A later trial of *Second Skin* with female warehouse staff confirmed that adjustable straps and non-gendered sizing are critical for universal adoption (Jacob 2023).

4.7 Inclusivity Beyond the Human

Designers should extend ethical considerations to the environment, animals, and ecosystems affected by technology development and deployment, acknowledging humans' interconnectedness with broader ecological systems (Sianipar et al.

2013). In the *Second Skin* project, all materials were chosen for recyclability and low-impact manufacturing, aligning with sustainable design goals (Jacob 2023). Furthermore, finding inspiration from nature has led to great advancements in design, like the front shape of Shinkansen has been inspired from the Kingfisher bird.

5 Conclusion

Human augmentation technologies hold transformative potential to extend human capabilities, but they also raise complex ethical, social, and environmental questions. Moving beyond a purely technology-driven approach, human-centred design places empathy, inclusivity, and ethical reflection at the core of development. This shift ensures that augmentation technologies align with real human needs, respect dignity and autonomy, and consider broader systemic impacts.

By engaging diverse stakeholders and understanding context, designers can create adaptable, equitable solutions that anticipate unintended consequences and foster sustainable innovation. As the line between human and machine blurs, a human-centred design ethos becomes essential to guide augmentation technologies toward enhancing human well-being in just and compassionate ways.

The choices made today in designing these technologies will shape the future of humanity. Embracing responsibility with critical insight and care is key to realizing augmentation's promise as a positive force for society.

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