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Adoption of Human Augmentation Technologies for Non-Medical Applications: A Systematic Review of Empirical Literature

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Abstract

The digitalization of society is driving adoption of human augmentation technologies beyond medical applications. While market size and public interest grow, empirical research on the adoption of non-medical augmentation technologies remains fragmented. This systematic review analyzes 61 empirical studies following PRISMA guidelines, using the TCM-ADO framework to map theoretical, contextual, methodological characteristics and research findings. Based on Diffusion of Innovations theory, we propose an integrated framework capturing the functional, affective, ethical, technological, and societal factors that influence the adoption process. Findings reveal contrasts between current and prospective users. Current users, often highly educated and aligned with the transhumanist movement, view augmentation technologies as tools to advance human evolution. In contrast, prospective users face barriers including limited access, regulatory uncertainty, and ethical concerns, with some expressing value-based opposition grounded in religious beliefs. This systematic review of empirical studies provides guidance for future research on non-medical human augmentation and their adoption.

Keywords: Human Augmentation, Systematic Literature Review, Technology Adoption, Empirical Studies

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1 Introduction

As non-medical Human Augmentation (HA) technologies evolve in the context of a rapid digitalization of societies [63], this systematic review presents the first comprehensive mapping of empirical research on their adoption, addressing a critical gap [21] in this novel interdisciplinary research field [41]. Human augmentation technologies are ubiquitous computing devices such as wearables, subcutaneous microchip implants, and Brain-Computer Interfaces (BCIs) [78] that extend cognitive, physical, and sensory functions of the human body [45] through digital capabilities [13] including AI features [104]. Non-medical applications of augmentation technologies are disruptive [36] and innovative [22], forming a significant component of the global human augmentation market, which is expected to reach USD 725 billion by 2030 [12]. Possible non-medical applications of these technologies can enhance multiple aspects of life, from work productivity to physical and cognitive capabilities [96]. Despite limited accessibility of non-medical HA technologies to the general population, studies show that across different countries the public is increasingly aware of and interested in them. In the U.S.A., 25% of the population was aware of augmentation technologies in 2018 [128]. While less than 1 in 10 respondents had used them, up to 34% expressed interest in trying augmentation technologies [128] to improve personal abilities beyond normal ranges. Similarly, a survey of the German population reveals that one third of the respondents were aware of non-medical cognitive augmentation technologies in 2021, and 57% were open to using them if they became available [111]. Lastly, a 2025 survey of the UK population shows that 80% of the respondents believe that non-medical augmentation technologies will be widely used by the population within a span of 10 years [32]. However, despite growing interest, significant privacy, safety, and cybersecurity concerns have emerged in recent research. A [58] survey across multiple countries and a 2023 survey of the Swiss population [64] report that approximately 80% of respondents are concerned about cybercrime and safety related to augmentation technologies. These studies collectively demonstrate growing interest across different countries, tempered by concerns about security and safety. In response to the growing prominence of HA technologies and their potential impact on individuals and society, we carry out a systematic review of empirical literature on the adoption process of non-medical human augmentation technologies. This review maps the existing empirical literature to structure the research field and encourage further contributions. We provide a comprehensive overview of studies on the adoption of non-medical human augmentation technologies, identifying key influencing factors and gaps in the empirical evidence. This systematic review aims to inform future research and foster interdisciplinary dialogue among scholars, developers, and policymakers.

We contextualize the adoption of human augmentation technologies within the broader process of digitalization. Digitalization is conceptualized as a threefold socio-technical transformation, encompassing the datafication of life domains (where increasing aspects of human life become sources of data collection), the algorithmization of decision-making processes (through automated analyses), and the platformization of markets [63]. The platformization of human body functions [91] exemplifies this transformation, as digital augmentation devices are integrated with or within the body to monitor, collect, and analyze data on bodily functions and activities. This trend is highlighted in scholarly literature under various terms. The notion of the Internet of Bodies (IoB) refers to a network of connected devices that are worn, implanted, or integrated into the human body to monitor, collect, and exchange data about bodily functions and activities [67]. Similarly, human-technology integration [74] and cyborgization [44] describe the integration of digital technologies with the human body in order to extend human capabilities beyond natural limits. Social phenomena like biohacking [134] and the Quantified Self movement [66] exemplify community-driven practices that involve monitoring and enhancing human functions through augmentation technologies, including digital devices. The systematic literature review focuses on digital technologies for non-medical human augmentation, identifying their increasing adoption as integral part of current trends of digitalization.

Throughout this review, we use the term "adoption" as an umbrella term to refer to the innovation-decision process outlined in Rogers' Diffusion of Innovations (DoI) theory [105]. This is a multi-stage process that encompasses initial individual awareness and attitude development, followed by an adoption decision that, if positive, culminates in the actual use of the technology. This adoption process is influenced by individual characteristics, societal context, and technological attributes, which affect how innovations are adopted over time moving from innovators and early adopters, to early and late majority, and finally to laggards [105]. By framing the adoption process within the context of the DoI theory, we emphasize the pivotal role of individual decision-making in understanding how non-medical human augmentation technologies transition from the innovation stage to widespread societal integration. This process can be observed through empirical adoption studies, which provide a critical angle of analysis for technological innovations, as demonstrated by extensive research across diverse domains e.g., [84, 61, 83, 133]. This focus guides our interest towards empirical studies that examine individual attitudes, intentions to use, motivations for the actual use, and the factors influencing the adoption process of non-medical augmentation technologies.

Although various terms are used to describe augmentation technologies, we favor the term "human augmentation technologies" [6] because it is the most widely used across disciplines to refer to digital technologies that enhance human capabilities [37, 45, 98]. Other terms found in the literature include embeddable or cyborg technologies [13] and technologies for human-computer integration [73]. From a device perspective, existing literature identifies a broad range of digital augmentation technologies that can operate both external and internal to the human body, in order to restore or expand human functionalities [13]. We refer to external and internal devices as wearables and insideables [11] respectively. Insideables can be further classified as subcutaneous microchip implants and Brain-Computer Interface (BCI) technologies [13, 73]. These technologies will be the focus of this article, and we will collectively refer to them as Human Augmentation technologies.

While initially focused on medical uses e.g., [72, 133, 132], non-medical applications of augmentation technologies are increasingly commercially available. Examples of non-medical applications of Human Augmentation technologies include the improvement of work-related performance [39, 51], the facilitation of task-specific activities like personal identification and payments [56], and augmentation for entertainment or personal enjoyment, such as sensory enhancement [16, 38, 34]. In niche markets, technology enthusiasts in biohacker and transhumanist communities experiment with wearables and subcutaneous implants to enhance their human capabilities for non-medical purposes [16, 127]. More advanced non-medical augmentation technologies, such as BCI implants [22], are not yet available to the public, but highly anticipated in initial adopter communities [113] and public discussions [111]. As the range of applications for non-medical augmentation expands, HA technologies hold transformative potential and spark discussions on individual and societal implications deriving from their widespread use.

The adoption of non-medical augmentation technologies has profound individual and societal implications. Ontologically, these technologies challenge traditional definitions of what it means to be human by blending biological and technological elements, suggesting a shift toward hybrid entities [44]. In response to this, the field of Human-Computer Interaction expanded to include Human-Computer Integration [73], suggesting the emergence of a new paradigm in which technologies are inherently entangled with humans [33]. The merger of human and machine fuels critical debates about personal autonomy and safety of the individual [59]. Personal autonomy can be affected by the use of augmentation technologies [14]. For example, placebo effects of cognitive enhancement result in increased risk taking and altered decision-making [123]. Individual safety is hindered by the technological challenges of integrating these devices with the human body, biocompatibility issues, and vulnerability to hacking and data breaches [59, 73, 115]. At a societal level, the uneven availability of these technologies results in the risk of deepening existing inequalities, as it creates a divide between augmented and non-augmented individuals [7, 14, 98]. The relevance of these debates increases as non-medical augmentation technologies evolve and become increasingly accessible to the general public, turning the theoretical discussions into pressing practical consequences that require empirical insights.

Despite the growing variety of non-medical augmentation technologies, empirical research on their adoption was largely overlooked until 2016 [103], after which a booming interest emerged [21]. The impact of this oversight is noted in the existing literature. Scholars point out that the limited availability of empirical studies makes current debates surrounding augmentation technologies too theoretical rather than grounded in public opinion and attitudes [17, 109]. Béland et al. [18] highlight that debates between competing philosophical positions, such as transhumanist enthusiasm for technological augmentation, and humanist caution regarding its societal risks, fail to progress due to their speculative nature. In order to solve this stalemate, [39] emphasizes the need to rely on empirical research to complement theoretical discussions. Empirical studies are also relevant for the development of technologies, as experts focusing on responsible technological innovation call for the inclusion of public perspectives to develop technologies that align with societal values and expectations [31]. So far, public involvement in the design and testing of augmentation technologies has been limited to experimental efforts [99], highlighting that end-user concerns and expectations are overlooked in the development of augmentation technologies. Overall, the body of empirical research on the adoption of non-medical augmentation technologies remains fragmented and lacks a comprehensive synthesis, despite initial non-systematic literature reviews [21, 130] that stress the need to comprehensively examine available research in the field.

This study addresses this research gap by focusing on empirical literature related to the adoption of digital augmentation technologies for non-medical purposes. The contributions of this article are threefold. First, we present a systematic review that maps characteristics and findings of existing empirical literature on the adoption of non-medical augmentation technologies. Second, we develop an integrated framework based on Rogers' Diffusion of Innovations model and innovation-decision process [105] to characterize the adoption of non-medical augmentation technologies, identifying and categorizing the influential factors. Finally, we propose future research directions based on the gaps identified in the current literature. By aggregating existing empirical research, this review aims to offer insights to stakeholders in the field, and can foster and structure further research and development on the adoption of non-medical augmentation technologies.

2 Related Literature Reviews

Despite growing interest in human augmentation technologies, literature reviews of empirical studies on their adoption for non-medical purposes remain scarce. We provide an overview of literature reviews that examine the adoption of enhancement technologies, including nanotechnology, biotechnology, information technology, and cognitive sciences. These fields form the NBIC convergence, driving the development of various enhancement technologies [63]. We start with relevant literature reviews from related fields, and then narrow the focus to studies that cover human augmentation technologies, highlighting the relevant findings and the research gap that our systematic review addresses.

Dijkstra and Schruiff ([29]) conduct a systematic review of public opinion on biotechnologies for non-medical human enhancement, covering 36 articles on biotechnologies such as CRISPR gene editing, reproductive technologies, and pharmaceutical cognitive enhancements. Although non-digital enhancement technologies like biotechnologies are outside the scope of our review, Dijkstra and Schruiff's findings [29] provide valuable insights on the urgency of systematically analyzing empirical literature. Their findings reveal that, contrary to optimistic theoretical perspectives, empirical studies suggest general public skepticism towards non-medical applications of biotechnologies. Furthermore, Dijkstra and Schruiff [29] identify critical limitations of current empirical research. They find that existing empirical studies have a limited scope, since they focus on Western countries and often address individual biotechnologies in isolation, rather than capturing broader attitudes towards non-medical biotechnologies as a whole. The authors point out that an increased focus of the research community on empirical studies could mitigate the gap between negative public attitudes towards biotechnologies and optimistic theoretical debates.

Two studies partially address empirical research on the adoption of digital augmentation technologies. Wolbring et al. [130] conduct a systematic review in 2013, evaluating the applicability of standard technology acceptance models for innovative technologies, focusing on social robots, brain-computer interfaces (BCIs), and pharmaceutical cognitive enhancements. While their study includes digital augmentation technologies alongside other types of innovative technologies, their primary focus is on assessing the suitability of acceptance models, rather than synthesizing empirical findings on adoption itself. Wolbring et al. [130] highlight that existing acceptance models are insufficient for capturing the unique factors influencing the adoption of enhancement technologies, as the inclusion of additional dimensions like psychological traits and social context is necessary to characterize the unique aspects that affect the acceptance of these innovative technologies. Consequently, Wolbring et al. [130] suggest that it is necessary to design extensions to traditional technology acceptance models to fill this gap.

Chaudhry et al. [21] present a non-systematic review of technology acceptance models specific to non-medical human augmentation technologies, analyzing 16 articles published from 2016 to 2023. Their review highlights the unique challenges of studying the adoption of non-medical augmentation technologies. Chaudhry et al. [21] argue that, while society accepts augmentation technologies for medical purposes (e.g., cochlear implants), the adoption process for non-medical augmentation technologies is more nuanced. They find that acceptance models for non-medical augmentation technologies incorporate diverse factors, from psychological to technological and societal. Based on their findings, Chaudhry et al. [21] emphasize the need to broaden the focus of empirical research on non-medical augmentation technologies, extending beyond traditional technology acceptance theoretical models to include theories from social sciences and psychology. Additionally, they note that while their literature review focuses on quantitative technology acceptance research, qualitative studies could provide valuable insights into the novel dimensions that contribute to the process of technology adoption in the case of non-medical augmentation technologies.

Our systematic review addresses the research gaps highlighted in prior studies. Given the need to systematize empirical research in this area, we carry out a systematic review of empirical studies on the adoption of non-medical digital augmentation technologies.

3 Objectives

With this systematic literature review we focus on the following research questions concerning the adoption of human augmentation technologies for non-medical purposes:

- RQ1: What are the characteristics of empirical research on the adoption process of human augmentation technologies for non-medical purposes?
- RQ2: Which factors influence the adoption process of human augmentation technologies for non-medical purposes, and how?
- RQ3: What future research directions emerge from empirical literature on the adoption process of human augmentation technologies for non-medical purposes?

The contribution of this systematic literature review is threefold: Firstly, we examine both meta-level characteristics of empirical research, and related findings. Meta-level characteristics include an overview of populations and technologies, bibliometric trends, key publication venues, theoretical frameworks, and methodological approaches used in the studies. Findings highlight the key factors influencing the adoption of non-medical augmentation technologies.

Secondly, we design an integrated framework that maps empirical findings on the process of adoption of non-medical augmentation technologies, unifying them according to Diffusion of Innovation theory [105]. Consistent with Rogers' [105] innovation decision process, we distinguish between antecedent factors, decision-related aspects, and outcomes to identify the most relevant factors and their role within the adoption process. The integrated framework provides a structured overview of the state-of-the-art findings from research in this field.

Finally, we identify gaps in the current literature and propose future research directions to address them. These insights are intended to structure the research field, and guide researchers and other stakeholders by identifying actionable areas for further exploration.

4 Methodology

4.1 Rationale

To this date, there is no systematic review of studies on the adoption of human augmentation technologies for non-medical purposes. Literature reviews are fundamental for the development of research fields, and systematic review methodologies strengthen the relevance of their findings [86]. Although 'literature review' serves as an umbrella term that encompasses various research approaches such as narrative, scoping, systematic and meta-analysis reviews, scholars highlight that the design of a review should align with the objectives of the study and fit the characteristics of the research field [43, 95]. Systematic reviews, in particular, are distinguished by their structured and transparent methodology, including predefined inclusion criteria, comprehensive search strategies, and rigorous data analysis [95].

We choose a systematic mapping approach for this literature review, to prioritize the characterization of existing knowledge and the identification of research gaps rather than focusing on selectivity or quality appraisal based on predefined guidelines [43]. This approach is appropriate because the adoption of augmentation technologies is an emerging field of research. In the absence of a systematic characterization of the guiding theories and methods in this area, it would be impractical to use approaches such as method-based or theory-based reviews, which include methodological or theoretical criteria in the study selection process [88]. Furthermore, the diverse range of research topics and methodologies in this field limits the applicability of standard quality appraisal checklists [95], as they are designed for studies using specific methodologies.

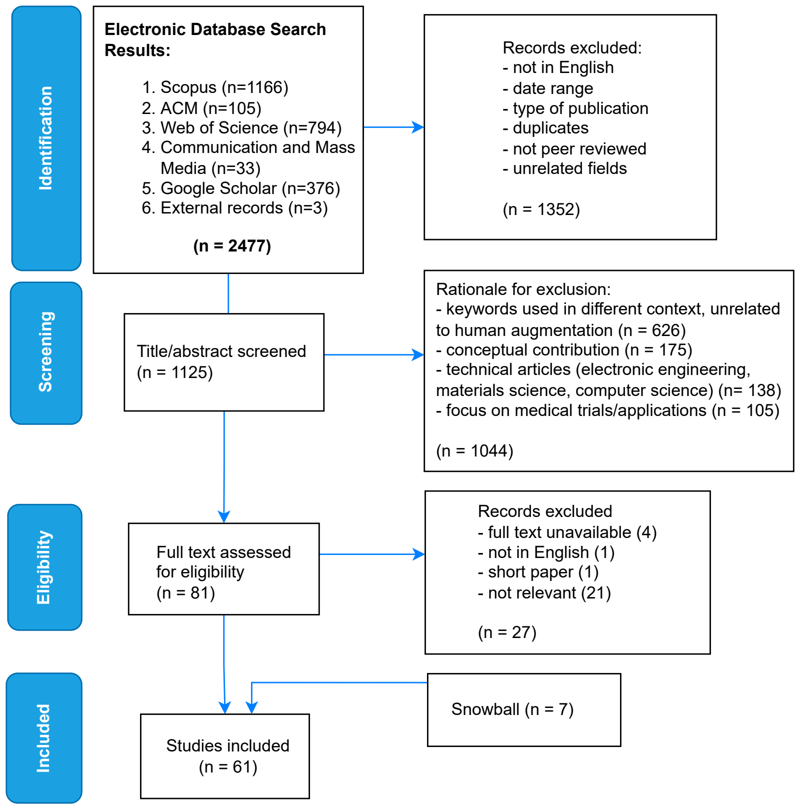
To ensure methodological rigor, this review follows a systematic approach through established processes and frameworks to document the study selection, and guide the analysis. We adhere to PRISMA guidelines [70] to document the selection process, and apply the Theories, Context, Methods - Antecedents, Decisions, Outcomes (TCM-ADO) framework [65] to structure the analysis. The TCM-ADO framework provides a structured approach to examine both "what we know" and "how we know" about the factors influencing adoption, thereby offering a comprehensive and systematized view of the current state of knowledge on non-medical human augmentation technology adoption.

4.2 Selection Process

We adhere to the PRISMA guidelines to document the identification, screening, and selection of relevant studies [70], detailing the rationale and significant steps in the selection process to ensure repeatability. The selection process involved the collaboration of the authors to refine search strategies, adjust query keywords and inclusion/exclusion criteria, and validate the selected set of studies. A PRISMA flow diagram (Figure 1) illustrates the selection process.

Database and Sources Selection A broad coverage of academic databases is necessary to collect relevant material for a systematic review. We conducted a thorough search across five academic databases and archives to cover a broad range of disciplines, including social sciences, economics, and computer science. The selected databases were ACM Digital Library, Scopus, Web of Science, Communication and Mass Media Complete, and Google Scholar.

Figure 1: PRISMA graph for the selection of articles for the systematic review. Created by the authors.



Google Scholar was included to locate gray literature and relevant peer-reviewed material which is not indexed in the selected databases [46]. Additionally, relevant institutional reports were included when encountered. Due to the fragmented nature of the field and the use of specialized terminology across subfields, constructing a comprehensive database query posed significant challenges. Consequently, to ensure that all relevant studies were included, a complementary snowballing technique was employed [129]. This involved screening the reference lists of the articles selected through database search, in order to locate additional relevant studies.

Research Query The choice of appropriate query strings and research filters is crucial to the success of a systematic literature review. An initial review of literature in the field allowed us to identify the appropriate time span, relevant fields of research, as well as the most relevant keywords. Paul et al. [86] point out that systematic literature reviews should consider a time span of at least 10 years for relevant publications. We limited the search to the years 2000-2025, a time frame in which technologies for human augmentation were in development and potentially available to the public. An initial non-systematic review of relevant studies allowed us to identify keywords that are frequently found in the context of adoption of technologies for human augmentation. For the purposes of this review, we use the term "adoption process" as conceptualized in Rogers' Diffusion of Innovation theory [105], as an umbrella term encompassing attitudes, acceptance, and experiences related to augmentation technologies. It is important to note that studies in the field rarely address adoption holistically, instead they typically focus on individual aspects of the adoption process, corresponding to a diverse range of keywords. We identified common keywords related to technologies (e.g., human augmentation, cyborg, microchip implant, Brain-Computer Interface), specific aspects of adoption (e.g., acceptance, perception, attitudes, opinions) or lastly present findings from reports and interviews of initial adopters (e.g., interview, biohacker). The final search query aggregates relevant keywords to capture a wide spectrum of studies related to the adoption of technologies for human augmentation. A final query update was executed in the selected databases and Google Scholar on April 10, 2025.

> **Title-Abstract-Keyword** *("human enhancement technolog*" OR "augmented human*" OR "human augmentation*" OR "human* 2.0" OR cyborg* OR "implant* technolog*" OR "microchip implant*" OR "biohack*" OR "brain-computer interface" OR "bci")* AND **Title-Abstract-Keyword** *(perception* OR view* OR acceptance* OR debate* OR opinion* OR trust OR attitude* OR interview OR survey OR expectation* OR report)*

Screening and Eligibility The selection process involved multiple phases to identify the final set of studies. All the databases were scraped evaluating the query for matches in the Title, Abstract, and article Keywords. The initial query results were filtered to include only peer-reviewed, final-version articles, in order to ensure the reliability and consistency of the findings. Following recommended heuristics on the use of Google Scholar for systematic literature reviews [46], we included the first 250 results, sorted by relevance, in the screening phase. In the final database search conducted before submission, 126 additional articles were identified through Google Scholar and added to the screening phase. All identified records were exported to Zotero to remove duplicate, and filter irrelevant and inaccessible results. Despite the initial large dataset, most of the search results were irrelevant to our research interest and were excluded because the keywords were used in different contexts, unrelated to technologies for human augmentation (626 records excluded). We adhered to the following criteria to ensure relevance of the remaining studies to our research questions:

- C1: The study must include empirical data on the personal use (current or prospective) of technologies for human augmentation for non-medical purposes.
- C2: The study must not exclusively focus on technical details of the technologies for human augmentation.
- C3: The study must not exclusively focus on (but can include information about) medical or specialized applications of technologies for human augmentation, that exclude the use among the general public.

Based on these criteria, 81 studies were selected for full-text analysis, and 7 additional studies were identified through snowballing. Ultimately, at total of 61 studies were included, which is a suitable number for a systematic literature review [86]. Figure 1 summarizes the steps of the selection process, including the rationale for exclusion of the remaining articles.

4.3 Analytical Framework

Choice of the Framework We adopt the TCM-ADO framework [65] for this systematic review because it enables a comprehensive analysis of research characteristics, and a structured organization of findings. This choice is also driven by the importance of repeatability in impactful systematic literature reviews [87]. A variety of analytical frameworks are available for systematic literature reviews, including TCCM (Theories, Context, Methods, Characteristics) [90], ADO (Antecedents, Decisions, Outcomes) [85], TCM (Theories, Context, Methods) [89] and TCM-ADO [65] (a combination of the previous two frameworks). Since this review aims to explore both the characteristics of the research landscape and the main findings of the selected studies, TCCM and TCM-ADO frameworks were identified as suitable options. Examples of systematic literature reviews on the adoption of emerging technologies can be found for both the TCCM e.g., [61, 83] and TCM-ADO framework e.g., [9, 24, 55]. However, the two frameworks provide different level of granularity for analysis. TCCM defines "Characteristics" as the "elements of a construct and their relationship with other variables of interest" [87], offering an unstructured category to map findings. However, Paul et al. [87] note that TCCM does not offer sufficient depth to structure and analyze a complex network of concepts. We therefore favor the TCM-ADO framework, that structures findings into a process-oriented framework of Antecedents, Decisions and Outcomes, offering a more granular approach to organize concepts [65]. Applying the TCM-ADO framework in this systematic review enables a comprehensive analysis of research characteristics, and structures the findings in alignment with our definition of the adoption process of human augmentation technologies according to Diffusion of Innovations [105]. This approach allows us to identify antecedent factors, characterize the decision-making process, and structure the resulting outcomes. While the framework's comprehensive nature is challenging for systematic reviews with large sample sizes [87], it is well-suited for our review of 61 studies.

Coding and Dataset The TCM-ADO framework offers a structure to code and analyze the selected studies, guiding the creation of the initial codebook. The initial codebook was further developed through an inductive-deductive approach. Based on the findings, further categories of codes were defined to distinguish between individual, technological and societal antecedent factors, as well as different aspects related to the decision process for the adoption of augmentation technologies. The analysis was conducted using the MaxQDA24 [122] software to ensure systematic and comprehensive coding of the data.

During the coding process, we identified six studies that use the same cohort population. In line with established guidelines for handling duplicate cohort data in systematic reviews [131], we included all studies in the content analysis while ensuring that duplicate findings were not reported multiple times. This approach captures the full range of insights provided by these studies without skewing findings due to duplicate counting. To focus on the most salient factors, we adopted frequency-counting practices used in prior reviews [42, 4, 83] and limited our discussion to factors reported in at least three different studies. The coded list of articles is available as supplementary material. This approach ensures methodological rigor while accurately reflecting the scope and characteristics of the available research.

5 Results and Discussion

This section presents the findings of our systematic review on the empirical research on the adoption of human augmentation technologies for non-medical purposes, guided by the TCM-ADO [65] analytical framework. The finding are organized and discussed at two levels of abstraction: (1) meta-level characteristics of the research, and (2) empirical findings on key factors influencing the adoption process., Additionally, this section provides an overview of future research directions in this field. The TCM portion of the framework (Theories, Context, and Methods) guides the content analysis and discussion of RQ1, focusing on meta-level characteristics of the research. This includes contextual aspects such as bibliometric information (publication trends, venues, and leading authors), study populations, technologies examined, theoretical foundations, and research designs and methods used. To synthesize the findings for RQ2, we present an integrated framework based on Diffusion of Innovations theory [105], using the ADO structure (Antecedents, Decisions, Outcomes). This framework maps key factors influencing the adoption of augmentation technologies. Finally, RQ3 addresses future research directions, synthesizing promising insights from the current literature and highlighting knowledge gaps suitable for further exploration in order to further develop the field.

5.1 RQ1: What are the characteristics of empirical research on the adoption of Human Augmentation technologies for non-medical purposes?

This research question seeks to identify the meta-level characteristics of empirical studies on the adoption of non-medical augmentation technologies, guided by the TCM analytical framework (Theories, Context, and Methods). We structure the discussion as follows: first, we examine key contextual characteristics, focusing on the populations studied, including distinctions between current and prospective users, as well as the types of technologies investigated. Contextual information on published research includes an overview of bibliometric information, highlighting publication trends, prominent publication venues, and the leading authors in the field. We also provide an overview of the theoretical and conceptual frameworks employed, along with the research methods used in the studies.

Our findings indicate that empirical research on non-medical HA technologies is an emerging interdisciplinary field with a growing theoretical and methodological foundation. At first focused on small niches of adopters, the field has expanded to include broader population samples expanding its methodological and theoretical foundations. The recent emergence of mixed methods and experimental designs indicates the maturation of the field, suggesting a shift toward more structured and sophisticated research approaches. Nevertheless, limitations can be found in the lack of population representativeness, a Western-centric scope, and limited integration across disciplines. Overall, the characteristics of empirical research in this field reflect its formative status, marked by an emerging theoretical and methodological foundation that can benefit from further research efforts.

5.1.1 Context of Research

The TCM-ADO framework broadly defines context as "circumstances shaping the research setting" [87]. For our purposes, we consider the following aspects to be relevant contextual information: populations and technologies examined in the studies, as along with bibliometric information, including publication trends over time, key publication venues and leading authors. Analyzing these elements allows us to understand the research landscape, assess the development of the research field over time, and identify potential gaps or trends that may inform future research directions.

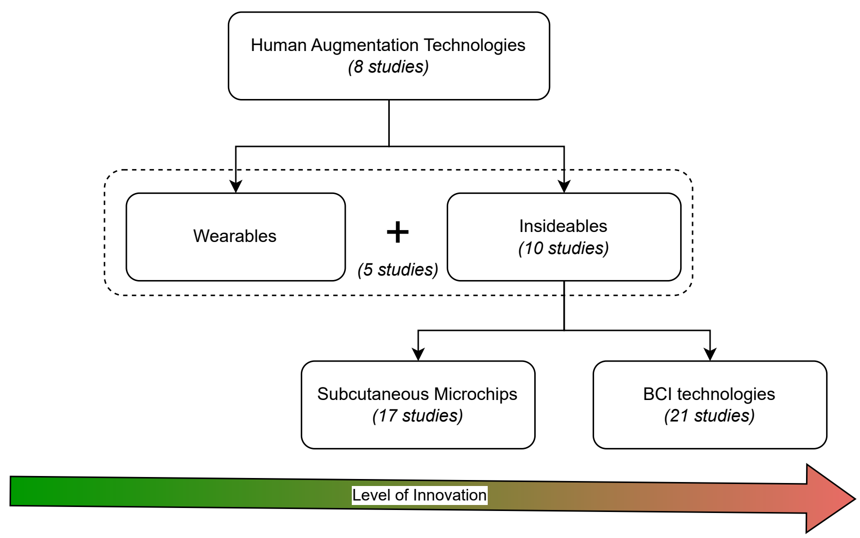
Populations Context The empirical literature on the adoption of non-medical human augmentation technologies distinguishes two primary populations: current and prospective users.

Current users are the initial adopters of augmentation technologies, typically found in niche communities such as biohacker collectives [16, 38, 48, 49, 52, 53, 54, 68, 69, 82, 112, 113]. A defining characteristic of these users is their alignment with transhumanist ideals, which advocate for the improvement of human capabilities and the transcendence of biological limitations through technology [71, 62]. This ideological alignment is evident among current users included in the studies, as their use of augmentation technologies reflects both a philosophical commitment to these ideals and a practical exploration of the potential for human-technology integration e.g., [16, 52]. This characteristic positions them as influential actors in the adoption process, as their experimentation may influence societal attitudes and the broader acceptance of these technologies.

In contrast, studies on prospective users explore attitudes toward augmentation technologies among larger, more diverse population groups, investigating general public perspectives in populations where augmentation technologies are not widely accessible. Prospective user studies sample populations across various geographical and online contexts, with a notable concentration in European countries, particularly Spain e.g., [94, 93, 103, 27] and Germany [109, 110, 111]. Despite access to larger population samples, these studies rely on non-representative data, with the exception of six studies [35, 58, 97, 110, 111, 128]. Among the reviewed studies, two notable clusters reuse the same underlying datasets. One consists of four single-country studies that draw on the same dataset of 600 survey responses from Spain [79, 94, 93, 103]. The second cluster comprises six studies that rely on the same dataset of 1563 survey responses spanning seven countries: Chile, China, Denmark, Japan, Mexico, Spain and U.S.A [11, 10, 23, 26, 28, 92]. The reliance on non-representative data, combined with a limited geographic focus and the repeated use of the same datasets across multiple publications, may skew the understanding of general public attitudes and restrict the findings' applicability across cultural contexts.

Technological Context We define the technological context as the range of augmentation technologies examined in the studies. We also discuss how the types of technologies studied, as well as their levels of availability, may influence research designs and results. Figure 2 categorizes the main technologies discussed, also highlighting their degree of innovation and commercial availability. The empirical studies explore diverse human augmentation technologies, including external devices(i.e. wearables), and internal devices (i.e. insideables), which are further divided into subcutaneous microchip implants and BCI implants. We distinguish between the two categories as commercially available technologies (wearables) and innovative technologies (insideables), which define the contextual limitations of the studies. This systematic review spans 17 years of technological development, with the focus of the articles reflecting the evolving novelty and availability of specific technologies. In earlier years, microchip implants were considered innovative technologies e.g., [53, 54]. More recently, there has been a shift toward BCI implants e.g., [57, 106, 111, 113], signaling advancements in the development of augmentation technologies. Recent publications have introduced a novel focus on AI-based augmentation, including AI for cognitive enhancement and BCI implants, reflecting a growing interest in the role of Artificial Intelligence in human augmentation, especially in light of the increased attention to generative AI [104, 80, 81].

Figure 2: Taxonomy of augmentation technologies that define the technological context of the articles. Article count for each technological context is included. Created by the authors.



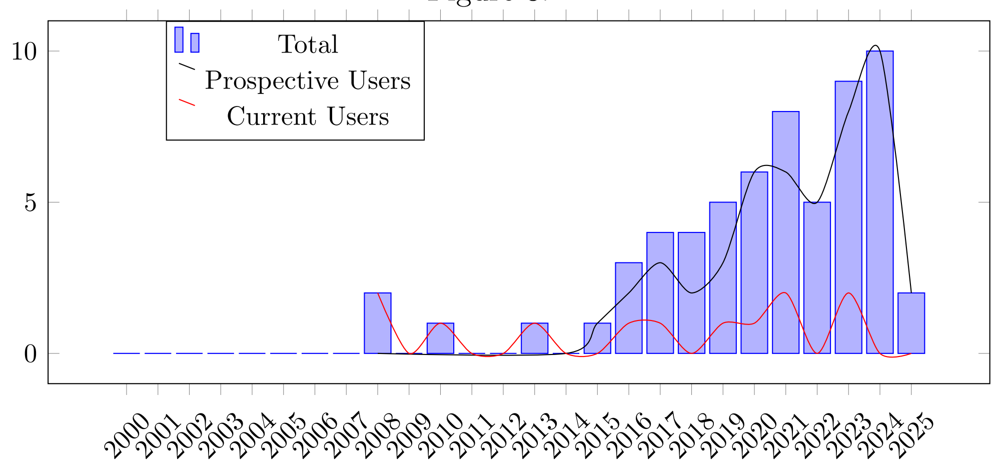
The studies in our systematic review focus on these technologies in two distinct ways. The first group of studies (8 in total) adopts a technology-agnostic approach, broadly examining user attitudes toward augmentation technologies without focusing on particular devices [16, 58, 97, 116, 124, 125, 128, 135]. The second group of studies, comprising the majority of our sample, is device-specific. Seventeen studies focus on subcutaneous microchip implants [30, 38, 48, 49, 52, 54, 53, 68, 69, 77, 79, 82, 107, 114, 126, 137, 136], which, despite being available for applications like payment and identification in countries like Sweden [5], have yet to achieve widespread adoption. Ten studies expand from subcutaneous implants to include insideables in general e.g., [10, 28, 35]. Five studies [11, 23, 26, 75, 100] specifically examine the differences in the adoption process between insideable technologies and commercial options such as wearables. Research on experimental technologies, including BCI implants (twenty-one studies in total e.g., [2, 19, 57], highlights emerging trends and potential future applications. However, these technologies remain largely inaccessible to the public.

Similarly to the findings of Dijkstra and Schruiff [29] on biotechnologies, empirical research on augmentation technologies predominantly examines devices in isolation, rather than considering them as part of a cohesive trend toward non-medical human augmentation. This isolated approach limits the ability to comprehensively characterize the adoption process of non-medical augmentation technologies. First, it hinders the understanding of the factors that cause differing adoption rates across technologies. Second, it makes generalizing findings across augmentation technologies difficult, as it overlooks the broader technological trend of non-medical augmentation that ties these devices together. However, the focus on individual devices aligns with their varied stages of development and market availability, as wearables are widespread across the population while other types of augmentation technologies remain less accessible [11]. The limited availability of non-medical augmentation technologies has profound implications for research design and methodology. Since most augmentation technologies beyond wearables remain inaccessible to the general population, researchers studying prospective users are constrained to measuring attitudes and intentions rather than actual adoption behaviors. This technological context creates a fundamental methodological divide in the field. While studies of current users can examine real-world adoption and continued use, studies of prospective users must rely on hypothetical scenarios. This constraint not only limits the types of outcomes that can be measured to attitudes and intention to use, but also raises questions about the future validity of findings, as intentions formed without direct experience may differ substantially from actual adoption decisions when technologies become available. This context adds complexity to the research landscape, while reflecting the evolving nature of the field as augmentation technologies become more accessible.

Publication Trends The evolution and increased interest in this area of research are illustrated in Figure 3, which shows the number of publications per year and highlights a notable increase in output, especially in the last decade. We distinguish between research clusters focused on current users (2008-present) and prospective users (2016-present) to highlight the increasing relevance of research on augmentation technologies for the general population. This shift from niche research on the biohacker community to broader studies of the general public reflects the rising importance of augmentation technologies, as they gain potential for widespread social adoption and impact. Notably, the surge in research since 2016 coincides with a growing interest from the business and marketing sectors e.g., [94, 93, 10, 11], which focus on identifying market segments for the adoption of augmentation technologies. This heightened interest aligns with both Gartner's identification, in 2019, of human augmentation technologies as an upcoming disruptive innovation [36], as well as the 2023 market projections of a significant increase in market capitalization for augmentation technologies [12], reinforcing their growing relevance and potential for widespread adoption.

Leading Authors and Publication Channels An overview of contributing disciplines and publication venues (Table 1) reveals a concentration of research within specific regions and author groups, alongside a diverse but compartmentalized disciplinary interest in non-medical augmentation technologies. Data on author affiliations and research domains show that publications in the field are concentrated in a few key research centers. In particular,

Figure 3:



active research groups are prominent in Europe, particularly in Spain and Germany e.g., [10, 11, 57, 94], in Asia, including Malaysia [2, 3, 1, 108] and Japan e.g., [75, 76], as well as in Australia e.g., [53, 68], the USA [128, 114], and South America, specifically Chile and Colombia e.g., [107]. Despite the strong growth in publication output since 2016, a limited number of authors and research groups account for the most publications. For instance, Pelegrin-Borondo co-authors 12 of the 61 publications included in this review, and in general European authors are frequently listed as first authors.

Table 1: Overview of the main contributing disciplines where research is disseminated. Created by the authors.

Main Contributing Disciplines	**Count**	**Examples of Venues (and Articles)**
Interdisciplinary	16	International Symposium on Technology and Society [68], Technology in Society [39]
Psychology and Cognitive Sciences	14	Human Behavior and Emerging Technologies [27], Computers in Human Behavior [23], Current Psychology [3]
Informatics	12	CHI [124], Informatics [114]
Business and Economics	10	International Journal of Consumer Studies [136], Developments in Marketing Science [77]
Social Sciences and Humanities	5	Media, Culture and Society [69], Science, Technology and Human Values [109]
Independent Reports	3	AARP [128], Kaspersky [58], SIENNA project [97]
Medical Sciences	1	JMIR Formative Research [8]

This concentration of publications not only highlights the reliance on a few leading contributors, but also reflects a skewed disciplinary focus of the field. Contributions from Business, Psychology, Informatics, and Social Sciences are notable, with particular emphasis on Business and Psychology. Much of business research focuses on market segmentation and consumer behavior e.g., [94, 93, 10, 11], while psychology-related studies often address personality traits that influence user acceptance and attitudes [2, 3, 1, 116]. Although the field is expanding across various academic disciplines, there is a noticeable lack of interdisciplinary collaboration, with most studies addressing discipline-specific concerns rather than integrating diverse perspectives e.g., [106].

The analysis of publication venues reveals the interdisciplinary nature of the field, with the 61 publications included in this review distributed across 45 different channels. Only four venues (CHI, Computers in Human Behavior, Human Behavior and Emerging Technologies, and Technology in Society) host more than one publication (examples are shown in Table 1).

Overall, while research on the adoption of augmentation technologies is expanding across disciplines, the field remains in its early stages of definition. Interdisciplinary collaboration is limited, and much of the published research is driven by a small number of contributors.

5.1.2 Theoretical Frameworks

The TCM-ADO framework defines theories as "theoretical underpinnings and paradigms used to explain the inter-relationships between constructs" [87]. This definition, with its focus on quantitative, model-oriented structures, does not fully capture the variety of theoretical approaches observed in the empirical literature on non-medical human augmentation technologies. To better reflect the diversity of the literature, we categorize the studies into three overarching theoretical approaches: (1) exploratory and theory-building approaches, (2) behavioral description and prediction approaches, and (3) interpretive approaches through critical theories.

Exploratory and Theory-Building Approaches This category encompasses studies that do not explicitly adopt established theoretical frameworks but instead aim to generate preliminary insights and develop foundational understanding, often serving as a basis for future research. The absence of a theoretical framework in a study means that the research does not explicitly draw upon or align with an established set of concepts, paradigms, or models to guide its design, analysis, or interpretation of findings. In our sample, we identify 15 articles that do not specify a theoretical framework [48, 49, 53, 54, 69, 77, 97, 112, 111, 113, 58, 124, 128, 8, 32]. These studies provide preliminary insights into user attitudes, concerns, and expectations on technologies for human augmentation, but lack the structured guidance of established theories. As a result, their conceptual definitions and rationales are often under-specified, increasing the difficulty to compare findings across studies. Among these, research by [112] stands out by employing a grounded theory approach, aiming to build a theory on the motivations that drive users of non-medical augmentation technologies. However, the other studies in this category do not aim at constructing new theoretical frameworks. Instead, they focus on descriptive and exploratory objectives, offering valuable insights into key areas of interest such as user preferences for different applications of augmentation technologies [48, 97] and related societal concerns [58, 128]. These studies serve as useful groundwork for generating more hypotheses, providing direction for future research that can incorporate more robust theoretical frameworks.

Behavioral Description and Prediction Approaches This category covers 42 studies that aim to understand how individuals form preferences, attitudes, and intentions toward adopting human augmentation technologies. While traditionally rooted in theoretical technology acceptance models like TAM [25], TAM2 [120], UTAUT [121], and Diffusion of Innovation [105], this category also includes studies that apply psychological, sociological and ethical theories or concepts to explore behavioral drivers. These theories are frequently used to extend technology acceptance models to examine the process of adoption of augmentation technologies, and collectively contribute to understanding the influential factors, including demographic, contextual, and individual differences.

Psychological theories are used in studies that focus on the influence of personality traits, emotions and personal values on the use of augmentation technologies. The Self-Discrepancy Theory [50] is incorporated to explain how discrepancies between an individual's actual self and their ideal self can drive the desire to use augmentation technologies, explaining the role of personality traits like perfectionism and competitiveness in the adoption of augmentation technologies [2, 108, 3, 1]. Furthermore, affective influences, such as users' emotional responses, and environmental factors, including social norms, have been shown to significantly impact users' adoption decisions for augmentation technologies [28, 94, 93, 92, 106]. Similarly, value-based psychology constructs demonstrate that personal values influence the adoption process of augmentation technologies e.g., [79, 114, 116].

Theories that consider individual ethical judgment play a crucial role in expanding technology acceptance models, particularly in research focused on market segmentation. For example, the Multidimensional Ethics Scale [101] has been successfully used to identify different market segments based on the perceived ethical judgement of augmentation technologies. This research reveals how varying perceptions of fairness, autonomy, and societal impact shape the adoption process [2, 10, 23]. Moreover, ethical considerations are critical in specific applications, such as the use of augmentation technologies in the workplace where concerns about employee privacy and safety are highlighted [39], and in relation to BCI technologies [57, 109], which introduce unprecedented risks due to the sensitive nature of brain-related data.

Interpretive Approaches through Critical Theories Critical theoretical approaches offer a nuanced lens for examining the adoption of augmentation technologies. Despite being the smallest category of our sample, comprising only 4 studies, we identify two key research foci that relate to the individual experience and societal impact of non-medical augmentation technologies.

Phenomenological research investigates how individuals experience the integration of augmentation technologies with their bodies. [38] and [82] examine how users perceive the transformation of their bodies as they adopt augmentation devices, and offer insight into the lived experience of integrating with technology in what the articles refer to as the "cyborg" body. [38] shows that users of augmentation technologies conceptualize the cyborg body as a site of integration between human identity and technological innovation. [82] highlights that the cyborg body becomes a vehicle for self expression and for challenging biological limitations of the human body.

The second research focus examines the societal and political impact of augmentation technologies. The feminist Science and Technology Studies perspective, drawing on Haraway's work [47], is used to analyze how non-medical augmentation technologies can impact marginalized groups, examining the effect of augmentation technologies on issues related to gender and disability [16]. [52] and [38] examine the political activism enabled by augmentation technologies. Users of these technologies conceptualize them as tools to resist anthropocentric worldviews, and use them to foster deeper connections with nature and to challenge traditional human-centered perspectives of the world.

5.1.3 Research Methods

The studies in this systematic review employ diverse research methods to explore the adoption of non-medical human augmentation technologies. We categorize the methods into qualitative, quantitative, mixed, and computational methods, detailing the associated data collection and analysis methods within each category.

Qualitative Methods Qualitative methods are predominantly used in studies focusing on current users of augmentation technologies. These studies aim to provide in-depth insights into the motivations and experiences of initial adopters, and rely on methods such as case studies [38, 39, 52, 68], interviews [48, 53, 54], and ethnographic research [16, 82, 113] for data collection. The data analysis process is guided by grounded theory [117, 20] or thematic analysis [15]. [40] examine the prospective users' ethical judgment of augmentation technologies using a qualitative Q-study methodology.

Quantitative Methods With the expansion of research to include the general population, a significant shift toward quantitative methods is evident. Studies that rely on quantitative methods typically employ survey-based methods to collect data from larger sample sizes, allowing for statistical analysis and generalization of findings. Within this category, some studies present descriptive statistics for their data analysis, mapping attitudes and perceptions toward augmentation technologies (e.g., [30, 124, 58]). Other studies (based on Technology Acceptance Models) rely on regression or Structural Equation Modelling [119] to assess the validity of models and relationships between constructs that have been adapted to fit the specific context of human augmentation e.g., [2, 108, 3, 1, 94, 93, 92]. Our article sample includes three experimental studies [19, 110, 135], which focus on the acceptance and intention to use cognitive enhancement technologies. The limited use of experimental research designs in research on the adoption of human augmentation technologies can be ascribed to the emerging nature of the field, but should be encouraged as this approach is particularly useful for isolating specific factors that influence adoption decisions, providing evidence of causality.

Mixed Methods Although relatively recent in this field, mixed-methods research on non-medical augmentation technologies emerged in 2021 [49, 114, 124, 27], allowing researchers to corroborate quantitative data with qualitative insights, and enhancing both the reliability and depth of findings.

Computational Methods Another methodological approach is found in [77], [80] and [8], all using computational techniques to analyze large datasets of online data. [77] and [8] use topic modeling to analyze online user attitudes toward microchip and BCI devices on X (Twitter). [80] propose a data analysis framework to examine public perceptions of BCI devices, integrating multiple computational methods.

5.2 RQ2: Which factors influence the adoption of Human Augmentation technologies for non-medical purposes, and how?

This section presents findings related to research question RQ2, focusing on the factors that shape the adoption process for non-medical human augmentation technologies. We use the ADO (Antecedents, Decisions, Outcomes) portion of the TCM-ADO framework to guide content analysis. The field's methodological diversity, encompassing ethnographic studies, experimental designs, large-scale surveys, and phenomenological investigations, reflects the complexity of the adoption process. Therefore, our analysis focuses on thematic aggregation of factors rather than effect sizes, providing a comprehensive map of influential factors across diverse methodological approaches. This thematic synthesis approach allows us to identify patterns while acknowledging the field's methodological pluralism.

We structure this section by first presenting a categorization of factors within a taxonomy of antecedents, decision-related aspects, and outcomes according to the ADO framework. Using practices seen in previous systematic reviews on similar topics [42, 4, 83], we only discuss factors that appear in at least three different studies. A coded table of articles is available as supplementary material. We begin with an introduction of the measured outcomes that can be highlighted in the empirical literature reviewed, we then discuss findings related to how antecedent factors and decision-related aspects affect the outcomes. Finally, these factors are mapped in an integrated framework, based on Rogers' [105] Diffusion of Innovations process, that aggregates findings and offers a unified perspective on the categories of factors shaping the adoption of non-medical augmentation technologies.

5.2.1 Outcomes

We frame outcomes using Rogers' [105] Diffusion of Innovation model, which conceptualizes adoption as a multi-stage process. Following the ADO framework's definition of outcomes as "consequences arising from performance or non-performance of a behavior" [87], our content analysis identified three measurable outcomes in augmentation technology adoption studies: attitudes, intention to use, and current use. These outcomes represent sequential stages in Rogers' adoption process.

Definition and Categorization of Outcomes We code as "Attitudes" all the outcomes that the studies identify as attitudes, opinions, concerns and expectations. Attitudes represent the first evaluative stage in the adoption process, corresponding to the Knowledge and Persuasion stages in the DoI model [105]. We code as "Intention to Use" the individual's active evaluation of their personal willingness or intention to use augmentation technologies. Intention to Use is the result of the Decision stage identified by [105], where potential adopters consider different aspects related to technology adoption, resulting in an intention to use augmentation technologies. Among prospective users studies, Intention to Use is the most advanced stage in the adoption process. Finally, we code as “Current Use” all reported cases of individual use of augmentation technologies. Current Use corresponds to Rogers' [105] Implementation and Confirmation stages, which represent continued use of the technology.

5.2.2 Antecedent and Decision-Related Factors

We categorize factors affecting adoption outcomes based on Rogers' innovation-decision process [105], and differentiate between preexisting antecedents and factors related to evaluative decision using the definitions of the TCM-ADO framework [87]. Antecedents are ”drivers behind involvement or non-involvement in a behavior,” existing independently of the adoption process. Decisions are defined in the TCM-ADO framework as “types of behavioral performance/dimensional structure of a construct” [87]. In this context, decision-related factors are different aspects of decision-making that emerge during the individual's adoption decision. Our analysis accounts for duplicate findings from repeated population samples [131], which could artificially inflate the importance of certain factors.

Categorization of Antecedents We identify three primary categories of antecedents affecting non-medical human augmentation adoption: individual, technological, and societal. Each of these categories includes relevant sub-categories based on thematic overlap. Individual antecedents include socio-demographic factors and personal characteristics (Table 4). Technological antecedents cover device type, augmentation type and goal, and lastly the cost of the device (Table 2). Societal antecedents encompass social context, regulatory frameworks, and country differences. Table 3 presents the complete categorization of related findings.

[**Insert Table 4 approx. here**]

Overall, findings on antecedent factors suggest that, beyond basic sociodemographic characteristics like age and gender, additional antecedent factors such as technological expertise, personality traits and social influences (e.g., belonging to biohacking communities) are crucial in shaping the individual adoption process. Despite contextual, theoretical and methodological differences, findings are largely consistent across studies. The association between age, gender, and technology adoption is consistently confirmed e.g., [35, 110], with younger males emerging as the most supportive demographic. Technological expertise is also associated with positive attitudes towards adoption of non-medical augmentation technologies e.g., [118]. Furthermore, the relevance of individual beliefs and social context is confirmed across current and prospective user populations. First, while progressive personal beliefs are associated with technology use [76, 52], religious beliefs are linked to negative attitudes towards augmentation e.g., [128, 109]. [40] further confirm this contrast, showing that progressive and religious beliefs respectively drive acceptance and rejection of non-medical augmentation technologies. Second, the effect of a supportive social context is highlighted in both prospective user studies e.g., [94, 93, 102] and current user studies which highlight the supportive role of biohacking communities e.g., [16, 113], which also facilitate access to augmentation technologies [113]. Current users appear undeterred by regulatory gaps e.g., [16], while prospective users view limited regulation as a barrier e.g., [111, 114].

Table 2: Categorization of Technological Antecedent Factors. The table includes information on the associated findings (numbered) and relevant reference count for each finding. Created by the authors.

Antecedent	**Findings**	**Count**
Type of Device	External devices (wearables): (1) Relate to better attitudes (2) Generate higher intention to use (3) Invasive devices are preferred by current users, due to their convenience and the association with cyborg identity	(1) N=3 (2) N=5 (3) N=2
Type of Augmentation	(1) The type of augmentation (cognitive, sensory, physical) influences attitudes towards HA technologies (2) The type of augmentation (cognitive, sensory, physical) influences the intention to use HA technologies	(1) N=3 (2) N=1
Goal of Augmentation	The goal of augmentation (medical, task-specific or superhuman): (1) Influences user attitudes (2) Influences intention to use (3) Motivates current users to adopt HA technologies	(1) N=9 (2) N=5 (3) N=2
Cost of Device	(1) The cost of the augmentation device affects attitudes towards HA technologies	(1) N=3

The main inconsistent results relate to the effect of the individual health status. Although two studies suggest that lower health status may positively impact individual attitudes [109, 114], Whitman [128] shows the opposite effect. The comparison between these studies is difficult since they are based on population samples of different countries (USA, Canada, Spain and Germany), and use quantitative [109, 128] and qualitative [114] methods, so further research is needed to explore the inconsistency. While the lack of further inconsistencies is encouraging, the limited number of studies on the topic, and their theoretical, methodological and contextual characteristics, warrants caution. For example, the reliance on non-representative student populations can significantly skew findings toward younger, higher educated individuals. Further contextual variations between studies arise from the different types of augmentation technologies examined, as highlighted in RQ1. The focus on different technologies across the selected studies implies that the influence of specific technological characteristics cannot be explicitly quantified.

Table 3: Categorization of Societal Antecedent Factors. The table includes information on the associated findings (numbered) and relevant reference count for each finding. Created by the authors.

Antecedent	**Findings**	**Count**
Social Context	Social context: (1) Affects attitudes towards HA technologies (2) Affects the intention to use HA technologies (3) Belonging to biohacking communities facilitates the use of HA technologies	(1) N=3 (2) N=8 (3) N=4
Regulatory Framework	(1) Prospective and current users believe augmentation technologies should be regulated	(1) N=9
Country or Regional Differences	(1) Attitudes toward HA technologies vary across countries and regions (2) Intention to use HA technologies differs by country	(1) N=7 (2) N=2

These findings collectively show that individual, technological, and societal antecedent factors all contribute to shaping the adoption process of augmentation technologies.

Categorization of Decision-Related Considerations We identify five categories of decision-related considerations that influence the adoption of non-medical augmentation technologies: functional, affective, ethical, technological, and societal. These categories are derived from thematic overlaps across studies. Detailed findings for each category are reported in Table 5. Functional considerations relate to perceived usefulness and ease of use. Affective considerations involve emotional responses, including excitement, enjoyment, fear, and discomfort. Ethical considerations reflect individual judgments on fairness, responsibility, and moral acceptability. Technological considerations concern risks associated with the technology itself, such as privacy, security, invasiveness, and health. Societal considerations include perceptions of broader societal impact, trust in regulation, and concerns about stigma or dehumanization.

[**Insert Table 5 approx. here**]

This categorization of decision-related aspects aligns with Chaudhry et al.'s [21] taxonomy of technology acceptance models for augmentation technologies, confirming the presence of cognitive, affective, ethical, technological, and societal considerations in the adoption process. While their work focuses solely on technology acceptance models, our review includes both acceptance studies and exploratory or qualitative research involving current and prospective users. This broader scope reinforces the validity of the categorization by showing that similar considerations emerge across diverse user groups and research designs.

Functional considerations on usefulness and ease of use remain central to adoption decisions, consistent with traditional technology acceptance models e.g., [25, 121]. Current users particularly emphasize the comfort and convenience of augmentation technologies compared to external devices like ID cards or credit cards e.g., [53, 54]. For prospective users, perceived usefulness varies significantly by application domain, with medical and task-specific enhancements viewed more favorably than superhuman augmentations e.g., [110, 128]. However, the adoption process also incorporates novel dimensions beyond functionality, including affective, ethical, technological and societal considerations.

Affective considerations reveal that prospective users often experience a mix of excitement, curiosity, fear, and discomfort, reflecting both the allure and uncertainty of augmentation technologies e.g., [103, 93]. In contrast, current users describe their adoption experiences as enjoyable and fulfilling, often emphasizing the personal satisfaction derived from technological integration, regardless of its utility e.g., [53, 54].

Ethical considerations shape the adoption process differently for prospective and current users. Prospective users express concerns about fairness and the potential misuse of augmentation technologies e.g., [23, 75]. On the other hand, current users often frame their adoption as an expression of autonomy and empowerment, with beliefs in individual control over their bodies serving as a significant motivator e.g., [16, 82].

Technological considerations, such as concerns about invasive implant procedures and privacy risks related to continuous data collection, present significant barriers for prospective users e.g., [57, 137]. This contrasts with the experience of current users, who report an easy integration of augmentation technologies into daily life [38, 48, 53].

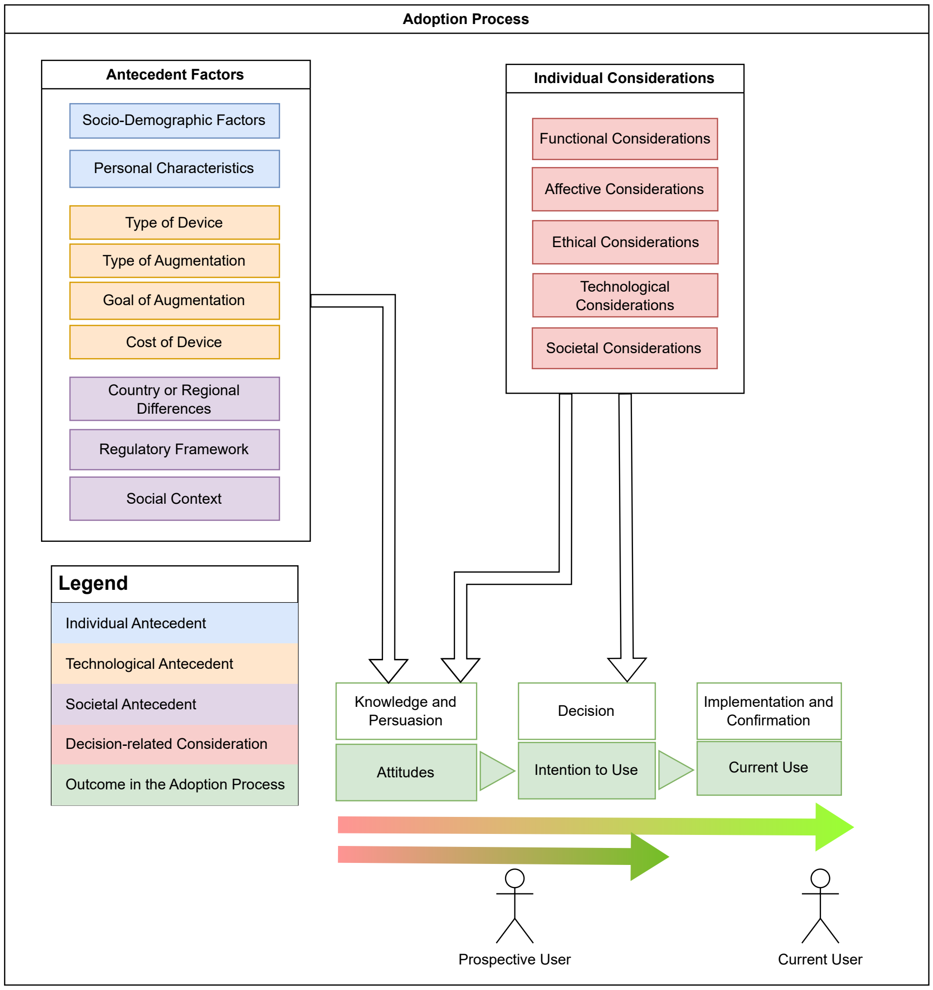
Finally, societal considerations highlight the tension between personal gains and collective implications of augmentation technologies. Prospective users voice fears about inequality, misuse, social exclusion and discrimination e.g., [58, 114, 124, 125, 135]. Current users on the other hand have a more optimistic perspective, viewing augmentation technologies as tools for societal improvement and progress e.g., [52, 38], and as a way to achieve the next step in human evolution [16, 48].

5.3 An Integrated Framework for the Adoption of Augmentation Technologies

Based on the findings of the studies included in this systematic review, we propose an integrated framework that synthesizes the main factors identified in the ADO analysis, integrates them in the context of Diffusion of Innovations, and adapts the innovation-decision process proposed by Rogers [105] to the adoption of non-medical augmentation technologies. The framework, depicted in Figure 4, integrates insights from our review across different technologies, user groups, and stages of adoption, providing a comprehensive overview of the factors influencing the adoption of non-medical augmentation technologies.

This integrated framework organizes factors in key categories of antecedent, decision-related considerations, and outcomes, mapping them in the process of adoption of non-medical augmentation technologies. Since the framework is an adapted version of Rogers' [105] innovation-decision process, we represent the outcomes from our ADO framework as sequential steps in the adoption process, with Attitudes, Intention to Use, and Current Use representing stages from initial awareness to technology use. The integrated framework illustrates how this progression is influenced by antecedent factors and decision-related considerations. A notable difference emerging from our integrated framework is the prominence of ethical, technological safety, privacy concerns at the individual and societal levels in the adoption process of non-medical augmentation technologies, adding nuance to the original

Figure 4: Integrated framework of factors affecting the adoption process of non-medical augmentation technologies. The adoption process is adapted from Rogers' innovation-decision model [105]. Created by the authors.

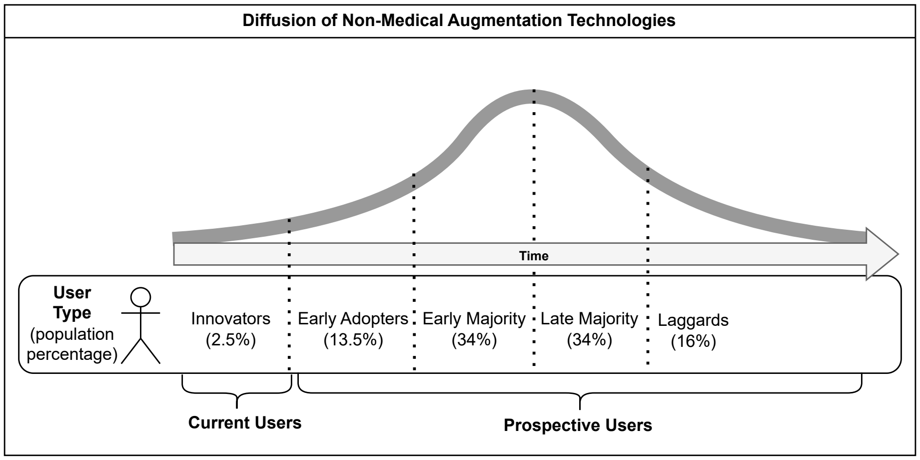


DoI innovation-decision process [105].

We distinguish between user groups and locate them across the DoI curve (Figure 5) based on their stage in the adoption process, as determined through the ADO analysis of empirical results. We classify current users within the "innovators" category based on empirical evidence that augmentation technologies remain predominantly adopted within specialized communities, representing the earliest phase of diffusion. These users display higher education levels, technical expertise, and worldviews aligned to transhumanist ideals. These users view augmentation as a desirable pathway to further human evolution and report fewer concerns over associated technological and societal risks, facilitating their transition to adoption and continued use.

On the other hand, prospective users, spanning early adopters, early majority, late majority, and laggards, express progressively more conservative and cautious attitudes toward

Figure 5: Diffusion of non-medical augmentation technologies across adopter categories, with distinction between Current and Prospective users. Adapted from Rogers' Diffusion of Innovation [105]. Created by the authors.



human augmentation technologies. For prospective users, unresolved ethical, technological, and societal considerations remain, and generate hesitations around privacy, technological safety, and societal consequences of the use of augmentation technologies. Importantly, our review suggests that some prospective users may never become adopters because of deep-rooted moral, religious, or philosophical opposition to the idea of augmenting the human body. For these individuals, non-adoption is not explained by the time-based diffusion of innovation model [105], but rather reflects a stable, value-based stance.

The integrated framework can be a valuable resource for academics, developers and regulatory actors. Its summary of current empirical evidence could serve as a guiding tool for future research, product development, and public policies. As the field of human augmentation continues to develop, this framework should evolve to represent the advances in our understanding of how non-medical augmentation technologies are adopted and integrated into society.

5.4 RQ3: What future research directions emerge from the literature on the adoption of Human Augmentation technologies for non-medical purposes?

Our systematic review identifies several critical areas where further research is needed to advance the understanding of the adoption process for non-medical human augmentation technologies. This section aggregates and discusses the future research directions highlighted by the studies included in our systematic review. Adhering to the TCM-ADO framework of analysis, the discussion is divided into two main perspectives. The TCM perspective refers to overarching characteristics of the research including theoretical foundations, research methodologies, and research context (i.e. populations and technologies). The ADO perspective addresses future research directions related to empirical findings. In addition, we include future directions concerning Research and Development (R&D) and regulation.

5.4.1 TCM Perspective

Theoretical Foundations The surveyed studies reveal promising directions and important gaps related to theoretical foundations. First, studies suggest that further research is needed for the development of technology acceptance models that are tailored to incorporate unique aspects of augmentation technologies such as ethical considerations, personal traits, and societal impact considerations [35, 40, 94, 93]. Second, while technology acceptance models provide valuable insights into the adoption of augmentation technologies in the general population, a separate approach could be used to characterize motivations of early adopters. While much of the existing research on this group has been ethnographic, exploratory, or descriptive e.g., [38, 53, 113], further investigation and theorization of early adopters' motivations and their evolution over time could enhance our understanding of the adoption process.

Research Methodologies The surveyed studies identify several considerations that could improve research methodologies. The predominance of cross-sectional designs is frequently cited as a limitation of current findings e.g., [2, 3, 1], leading researchers to recommend experimental approaches to better establish causal relationships between factors [100, 106]. Similarly, based on the evolving nature of augmentation technologies, researchers propose longitudinal studies to capture changes in attitudes and behaviors over time, particularly as HA technologies become more accessible [1, 80, 100, 108]. The reliance on self-reporting scales across the field also presents challenges, as authors highlight that these scales are susceptible to biases and potential inconsistencies based on how participants interpret questions [57, 60, 104]. To address this issue, researchers have suggested exploring alternative or supplementary methods of data collection. Both qualitative and quantitative studies suggest exploring mixed-method approaches to compensate for their shortcomings. For example, Gauttier et al. [40] suggest validating their framework, developed through qualitative research, through quantitative approaches. Conversely, Koverola et al. [60] suggest using in-depth qualitative research to explore individual motivations for cognitive enhancement, based on their quantitative findings. Finally, three studies [77, 80, 8] exemplify the value of deploying computational research methods, which could be further used to garner insights from online discussions and discourse around augmentation technologies, to e.g. explore online discussions using topic modeling [77, 8] or to profile users through clustering algorithms [80].

Population Contexts Existing research highlights limitations that derive from the selection of populations in empirical studies, suggesting opportunities for a broader representation in future studies. The majority of studies included in this review present results based on young, digital-native populations (usually university students), and recommend diversifying samples across age groups, educational backgrounds, and economic conditions in future research e.g., [3, 10, 11, 76, 107]. Additionally, researchers emphasize the importance of addressing the Western-centric scope of current research by incorporating perspectives from underrepresented cultural contexts e.g., [57, 109, 137]. Comparative analyses across countries and cultural contexts have also been suggested to explore the impact of local factors on technology adoption [102, 110]. Given the observed influence of religious beliefs on technology adoption e.g., [110, 81], Zhang et al. [135] propose investigating the role of Eastern philosophies and religions, which feature distinct conceptions of bodily integrity, in shaping attitudes toward augmentation technologies. In addition to these considerations, a methodological limitation lies in the frequent reliance on repeated cohort studies, which can constrain the generalization of findings. Expanding research to include new survey samples, rather than reusing prior respondent data, could provide new insights and strengthen the reliability of findings.

Technological Context Research on human augmentation highlights opportunities to explore the adoption process of individual technologies, such as Brain-Computer Interfaces or subcutaneous microchip implants [10, 11, 23]. Examining individual technologies may help clarify how features like invasiveness and usefulness shape user attitudes and behaviors. Additionally, authors suggest comparing technologies at different stages of diffusion [23, 26, 93].

5.4.2 ADO Perspective

Our proposed integrated framework (Figure 4) maps the factors currently known to be influential in the adoption of augmentation technologies, but additional key directions for future research can reinforce it by (1) consolidating research on individual factors and (2) examining interrelationships between them.

First, while many factors have been identified, their impact remains underexplored. For example, the exploration of the role of personal beliefs surrounding free will and determinism is recent, with authors recommending a more in-depth characterization of this role [1]. Interestingly, concerns about the cost of augmentation technologies, which might be expected to play a prominent role in adoption decisions, do not appear in the quantitative predictive models included in this review. However, such concerns are mentioned in exploratory and qualitative studies [114, 124, 32], particularly in discussions about the accessibility of augmentation technologies. Consequently, researchers interested in examining the influence of technology pricing on the adoption of augmentation technologies could explore whether cost serves as a potential barrier to adoption, particularly as these technologies move toward broader commercialization.

Second, in addition to examining the influence of individual factors in the adoption process, researchers suggest analyzing how these factors interact and influence each other through moderating effects [19, 94, 106]. For example, existing literature suggests that age and gender influence attitudes and intentions to use augmentation technologies e.g. [35, 57, 100]. However, further research is needed to explore how these demographic factors interact with other variables. Correlations suggest that different age groups tend to prefer different types of augmentation [58, 128]. Additionally, women's attitudes toward augmentation technologies may be influenced by factors such as emotional responses, which affect genders differently [106], and the varying impact of perfectionism on men and women [108].

To facilitate more rigorous and comparable studies of these interrelationships, researchers could utilize recently developed measurement instruments. The validated scale proposed by

Villa et al. [125], as well as the questionnaire presented by [116], provide tools specifically designed to investigate the adoption of human augmentation technologies.

5.4.3 Research and Development

The systematic literature review identifies key areas for future work related to R&D, particularly in the areas of accessibility, security, and societal acceptance. First, since research highlights the importance of usefulness considerations in shaping adoption intentions, authors suggest that companies involved in the development of augmentation technologies could focus on clearly demonstrating the practical benefits of these technologies to appeal to a larger public [35, 93]. Second, the biocompatibility of materials, sustainable device upgrades and maintenance, rigorous safety testing, and cybersecurity emerge as critical factors in empirical studies [16, 30, 35, 49]. Lastly, findings in empirical literature highlight the user concern for social stigma and discrimination towards users of augmentation devices e.g., [19, 135]. Consequently, developers could focus on the design of technologies that integrate seamlessly with the human body, both functionally and aesthetically, if they want to mitigate user concerns and facilitate societal acceptance.

5.4.4 Regulations

The surveyed studies highlight several key directions for future research related to regulations. Findings suggest a need to conduct further research to understand the general public's support for different regulatory frameworks [19]. For example, Schmid et al. [112] find that, while the European Union currently lacks specific regulations governing the use of augmentation technologies by healthy individuals, this clashes with user expectations. This is consistent with other findings suggesting that the general public identifies the lack of regulations as a key barrier to adoption of augmentation technologies e.g., [114, 124, 128]. Researchers also highlight the importance of involving citizens in policy design to ensure that regulations align with public values and priorities [81]. Policies that promote education and public awareness about augmentation technologies are recommended to reduce misconceptions in the general public [81]. Sustaining innovation while maintaining public trust emerges as a central challenge, and greater collaboration between developers and policymakers is suggested to address this [80]. Furthermore, since most regulatory insights from existing literature are derived from Western contexts, policymakers seeking to understand regulatory preferences within different cultural settings should approach these recommendations with caution, as they may not fully represent priorities of non-Western contexts.

6 Limitations

This systematic review synthesizes empirical research on the adoption of non-medical human augmentation technologies, identifying key influencing factors and proposing a meta-framework for future research. As a rapidly evolving, interdisciplinary field, research in this area spans diverse terminologies and databases. Despite a comprehensive search strategy, relevant studies may have been missed due to variations in terminology and indexing. Snowballing helped mitigate this, though some omissions remain possible. The review reflects the state of the field up to the final database search, and recent studies may not be included. Additionally, while the analysis followed PRISMA guidelines and employed the TCM-ADO framework, the inductive-deductive coding process may reflect some degree of subjectivity. Despite these limitations, this review offers a foundation for ongoing research and discussion on the adoption of human augmentation technologies.

7 Conclusion

This systematic review of 61 empirical studies on non-medical human augmentation technologies makes three main contributions: (1) providing the first comprehensive mapping of research using the TCM-ADO framework, (2) synthesizing an integrated adoption framework based on Diffusion of Innovation theory, and (3) identifying future research directions. Our analysis reveals an emerging field characterized by limited interdisciplinary engagement, Western-centric focus, and non-representative sampling. This reflects a fragmented research landscape that requires broader, more representative, and theoretically diverse approaches. Through the ADO framework, we categorize antecedent factors into individual, technological, and societal antecedents, decision factors into functional, affective, ethical, technological and societal, and outcomes ranging from attitudes and usage intentions to current use. Our integrated framework, grounded in Diffusion of Innovation theory, synthesizes how these factors contribute to the adoption decision. The findings demonstrate that prospective users are hindered by unresolved ethical, technical, and societal concerns, while current users view augmentation technologies more positively, often embracing them as enablers of transhumanist ideals and human evolution. This highlights a significant divergence in risk and opportunity perception between user groups. By identifying key factors, research gaps, and possible future directions in the field of non-medical augmentation technologies, this review informs and guides future research and development efforts, ultimately facilitating the responsible development and integration of augmentation technologies into society.

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Long Tables

Table 4: Categorization of Individual Antecedent Factors. The table includes information on the associated findings (numbered), and relevant count of studies for each finding. Created by the authors.

Category	**Antecedent**	**Findings**	**Count**
Socio-Demographic	Age	(1) Young individuals have more positive attitudes towards HA technologies (2) Young individuals have higher intention to use HA technologies	(1) N=8 (2) N=5
	Gender	(1) Male individuals have more positive attitudes towards HA technologies (2) Male individuals have higher intention to use HA technologies	(1) N=8 (2) N=6
	Education Level	(1) Low education levels are associated with negative attitudes towards HA technologies (2) High education levels are associated with current use of HA technologies	(1) N=3 (2) N=3
Personal Characteristics	Health and Wellbeing	(1) Individuals with a lower health status, such as physical disabilities or high stress levels, have more positive attitudes toward HA technologies. *(**contradictory result)*	(1) N=4
	Technological Expertise	(1) High technological expertise is associated with positive attitudes towards HA technologies (2) High technological expertise is associated with intention to use HA technologies (3) High technological expertise is associated with current use of HA technologies	(1) N=3 (2) N=3 (3) N=3
	Personal and Religious Beliefs	(1) Religiosity is associated with negative attitudes towards augmentation technologies (2) Progressive beliefs are associated with positive attitudes towards HA technologies (3) Progressive beliefs are associated with intention to use HA technologies (4) Belief in free will (internal locus of control) versus fatalistic determinism (external locus of control) affects intention to use HA technologies (5) Transhumanist beliefs are associated with current use of HA technologies	(1) N=10 (2) N=1 (3) N=2 (4) N=2 (5) N=6

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Category	**Factor**	**Findings**	**Count**
	Personal Traits	(1) Perfectionism and competitiveness are associated with positive attitudes towards HA technologies (2) Perfectionism and competitiveness are associated with intention to use HA technologies (3) Personal innovativeness and curiosity are associated with intention to use HA technologies (4) Higher neuroticism trait is associated with intention to use HA technologies (5) Temporal orientation on present and future is associated with higher intention to use HA technologies (6) Personal habits affect the intention to use HA technologies (7) The desire to be a pioneer motivates current use of augmentation technologies	(1) N=1 (2) N=3 (3) N=3 (4) N=1 (5) N=1 (6) N=2 (7) N=3

Table 5: Categorization of decision-related considerations for the adoption of augmentation technologies. The table includes information on the associated findings (numbered), and relevant reference count for each finding. Created by the authors.

Category	Factor	Findings	Count
Functional	Usefulness Considerations	Usefulness considerations: (1) Affect attitudes towards HA technologies (2) Affect intention to use HA technologies (3) Affect the current use of HA technologies	(1) N=11 (2) N=13 (3) N=6
	Ease of Use Considerations	Ease of use considerations: (1) Affect attitudes towards HA technologies (2) Affect intention to use HA technologies (3) Affect current use of HA technologies	(1) N=6 (2) N=11 (3) N=3
Affective	Positive Emotional Response	Positive emotions (such as excitement and curiosity): (1) Affect attitudes towards HA technologies (2) Affect intention to use HA technologies (3) Affect current use of HA technologies (4) Personal enjoyment impacts intention to use HA technologies (5) Personal enjoyment impacts current use of HA technologies	(1) N=1 (2) N=6 (3) N=3 (4) N=4 (5) N=3
	Negative Emotional Response	(1) Negative emotions (such as fear and anxiety) affect attitudes towards HA technologies (2) Negative emotions (such as fear and anxiety) affect intention to use HA technologies	(1) N=2 (2) N=5
Ethical	Ethical Considerations	The individual's ethical judgment: (1) Affects attitudes towards HA technologies (2) Affects intention to use HA technologies ***duplicate results* (3) Activism in support for bodily autonomy motivates current users to adopt HA technologies	(1) N=12 (2) N=10 (3) N=7

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Category	Factor	Main Findings	Count
Technology-Related	Technological Risk Considerations	Concerns for invasive implant procedures: (1) Affect the attitudes towards HA technologies (2) Affect the intention to use HA technologies (3) Concerns for invasive implant procedures are acknowledged but dismissed by current users of HA technologies	(1) N=12 (2) N=5 (3) N=2
	Privacy Considerations	Concerns for cyberhacking or privacy infringement: (1) Affect attitudes towards HA technologies (2) Affect intention to use HA technologies (3) Are mentioned but dismissed by users of HA technologies	(1) N=16 (2) N=3 (3) N=5
Society-Related	Societal Impact Considerations	(1) Perceived societal impact of HA technologies affects attitudes towards HA technologies (2) Perceived societal impact affects intention to use HA technologies (3) Perceived societal impact motivates current use of HA technologies	(1) N=6 (2) N=1 (3) N=7
	Expectations of Negative Perceptions	Expectations of negative perceptions of augmented individuals (e.g., stigma, fear, dehumanization): (1) Affect intention to use HA technologies (2) Are highlighted by current users of HA technologies	(1) N=5 (2) N=1
	Personal Trust in Institutions	(1) Trust in institutions influences attitudes toward HA technologies (2) Trust in institutions influences intention to use HA technologies	(1) N=2 (2) N=3