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Explaining Accessibility: Possible Variables in Users' Abilities, Tasks, and Contexts in IT Artefact Use

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Abstract:

The interconnection between the two information technology (IT) artefact qualities, accessibility and usability, is challenging to define. Efforts to design and develop accessible IT artefacts should encompass the broadest range of user abilities in identified tasks and contexts. We lack sufficient research on information systems and human-computer interactions that presents a comprehensive model to explain what variables these key components of accessibility contain and how they interconnect. To address this gap in the literature, I draw on theories beyond human-computer interactions, tasks, and contexts to posit the influence of human abilities on IT use by referring to the International Classification of Functioning, Disability, and Health (ICF) framework that the World Health Organization developed. In this paper, I theoretically describe accessibility, its components, and their relationships in the IT use context based on which I present an accessibility model. Furthermore, I argue that accessibility is a moderating variable between system features and usability. Therefore, accessibility is a major determinant of user acceptance.

Keywords: Accessibility, Accessibility Theory, IT Artefacts, User Abilities

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1 Introduction

Both the Association for Information Systems (AIS) and the Association for Computing Machinery (ACM), two major scientific societies, state in their code of ethics: "Technologies and practices should be as inclusive and accessible as possible, and scholars and computing professionals should take action to avoid creating systems or technologies that disenfranchise or oppress people" (Association for Computing Machinery, 2021; Association for Information Systems, 2021; Hanson, 2017). The majority of accessibility-related studies and approaches describe accessibility on a continuum. For example, studies often refer to the well-known International Organization for Standardization (ISO) Standard 9241-171:2008, which defines accessibility as the "extent to which products, systems, services, environments and facilities can be used by people from a population with the widest range of user needs, characteristics and capabilities to achieve identified goals in identified contexts of use" (ISO, 2018). To this extent, accessibility has three aspects (human abilities, identified goals (i.e., user tasks), and use context) that one can retrieve and interpret as an accessibility component. Accessibility problems may occur at the individual, technological, or organizational level (the core focus areas in IS research) or somewhere in between (Myers, 1997). Understanding the variables in human abilities helps researchers identify possible human ability-related obstacles in using information technology (IT), and that identification enables people to perform tasks to create business value (vom Brocke et al., 2012). Furthermore, accessibility constitutes a critical factor in IT adoption and user acceptance, which represent central concerns in IS research (Venkatesh & Davis, 2000). Models that describe user acceptance behavior, such as the technology acceptance model (TAM) (Davis et al., 1989), posit perceived usefulness and perceived ease of use. TAM sees individual differences as having an effect on user behavior (Davis et al., 1989). However, one cannot easily describe and explain the possible variables in users' abilities, tasks, and contexts in the HCI process when these descriptions largely remain holistic and, thus, vague. Researchers have conducted many studies to explain the relationship between human cognition and technology (Germonprez et al., 2007). Schomaker et al. (1995) described the interaction process between humans and computers, while Gerlach and Kuo (1991) and Norman (1986) elucidated user task performance behaviors in human-computer interaction (HCI). The vague way in which researchers have described accessibility has led to constant debates about the difference and overlap between accessibility and usability and whether accessibility should include usability or not in its definition (Aizpurua et al., 2016; Petrie & Kheir, 2007; Santana & Baranauskas, 2015; Sauer et al., 2020; Yesilada et al., 2015). As a result, the many definitions and perspectives for "accessibility" have made it difficult for scholars and practitioners to interact and gain a deeper understanding of the topic (Yesilada et al., 2015). Practice indicates that there is an interconnection between accessibility and usability as they overlap substantially. Accessibility primarily focuses on people with disabilities, while usability focuses on overall improvement (Web Accessibility Initiative, 2021). For researchers, the ambiguous connection between the two concepts may affect their ability to discriminate between their features during evaluation (Aizpurua et al., 2016).

Due to the complex nature of human abilities, we need research that theoretically describes the components of accessibility and their relationships with usability (Santana & Baranauskas, 2015). In this paper, I contribute a richer theory that explains the variables in users' abilities and IT artefact (e.g., websites, Web applications, and user interfaces (Alter, 2008)) use contexts and tasks. In addition, I show what factors influence users' access to information. In particular, I address the following research questions (RQ):

RQ1: What are the boundaries of the concept of accessibility and how does the concept relate to usability?

RQ2: What components does accessibility include, what possible variables do they possess, and how do the components relate to one another?

RQ3: How does accessibility relate to user acceptance?

In this paper, I "disassemble" accessibility's definition (ISO 9241-171:2008) into three main components that influence product (IT artefact) use: 1) human abilities, 2) identified goals (i.e., user tasks), and 3) use context (see ISO, 2018; Petrie et al., 2015). Then, I review kernel theories related to these components, their constructs, and statements of relationships to address the research questions. I synthesize and "reassemble" four theoretical streams to describe accessibility: 1) theories of human abilities, 2) task theories, 3) theories that describe the use context, and 4) human-computer interaction theories. I use the "structural components of theory" (Gregor, 2006) as a lens to extract possible theory components, constructs, statements of relationships, and scope. However, I did not conduct a systematic or comprehensive review. First, the proposed accessibility model (AM) draws on the theories of human abilities: the International Classification of Functioning, Disability, and Health (ICF) that the World Health Assembly agreed on in 2001 (World Health Organization, 2013) and Cattell-Horn-Carroll's (CHC) theory of intelligence in cognitive abilities (McGrew, 2009). Second, it draws on Norman's (1986) well-known task performance theory. Third, it draws on theories that describe use context (McKay, Marshall, & Hirschheim, 2012). Finally, as a starting point for theory development, it draws on the theory of human behavior with a computer: Schomaker et al.'s (1995) basic model of human-computer interaction.

In this theory-development paper, I focus on describing accessibility in a more detailed way. I do not attempt to redefine accessibility or its desired extent but to explain its "anatomy" and, thereby, help IS and HCI researchers 1) recognize the relationship between the components in the concept, 2) define and align their intended research focus—related to human ability—with a clear picture of accessibility for them to see the related factors, and 3) understand the variables in human abilities related to interactions with IT and the varieties in task characteristics and use context that both affect the interaction.

According to Weick (1995), a variable list does not represent a well-developed theory but can still convey the relationship and causation between items. Therefore, I not only list variables but also describe the relationship between constructs.

This paper proceeds as follows: in Section 2, I address RQ1 by presenting prior definitions for accessibility and its interconnections to usability. In Section 3, I describe theories about accessibility's components as prior knowledge for addressing RQ2. In Section 4, to answer RQ1 and RQ2, I synthesize this knowledge and the relationships between the components in an accessibility model (AM). Furthermore, to address RQ3, I demonstrate how one can use the AM by juxtaposing it to well-known technology acceptance models (TAMs) and discussing its relationship to usability. I also evaluate the AM by comparing it to other models that describe accessibility. In Section 5, I discuss the implications for research and practice and highlight the limitations of this study. Finally, in Section 6, I conclude the paper.

2 Definitions and General Discussion of Accessibility

In this section, I present prior knowledge to understand accessibility's boundaries and how it relates to usability (RQ1). I first discuss how literature and practice have conceptualized and explained accessibility, usability, and the related concept of universality. Then, I demonstrate how the varying ways the literature has defined accessibility and usability and, to a lesser extent, describe accessibility as a construct.

2.1 Definitions and Explanations of Accessibility and Related Concepts

Persson et al. (2014) derived various accessibility-related approaches, such as barrier-free design, design for all, universal design, inclusive design, accessible design, universal access, and cooperative design. They also considered accessibility legislation and standards to combine the goals in these approaches and defined accessibility as:

> *The extent to which products, systems, services, environments and facilities are able to be used by a population with the widest range of characteristics and capabilities (e.g., physical, cognitive, financial, social and cultural, etc.) to achieve a specified goal in a specified context.*

The United Nations (2006) considers accessibility as a human right. Indeed, it has stated that parties should promote information accessibility early on in the information and communication technology (ICT) designing processes and focus on producing IT artefacts (e.g., websites) that the broadest number of users can access.

As for usability, ISO 9241-11:2018 defines usability as the extent to which specified users can use a system, product, or service to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified use context. According to these definitions, usability entails measurable goals (effectiveness, efficiency, and satisfaction) that one can use to design or evaluate a system's usability quality. In contrast, accessibility only indicates the use state (is accessible or has accessibility issues). Moreover, the ISO definition for usability explicitly states "specified users", which leaves the decision to specify the target audience open. Among the most cited usability theories includes the definition that Nielsen (1993) provides for the concept in positing it as a key factor in acceptability (23,068 citations on Google Scholar as of 2021). Nielsen (1993) divided usability into five attributes: easy to learn, efficient to use, easy to remember, contains few errors, and subjectively pleasant.

If we combine accessibility and usability as defined in ISO standards, they describe the ideal state of IT use when users, regardless of their capabilities, disabilities, impairments, or disabling conditions, perceive use as effective, efficient, and satisfying with or without assistive technology (AT). In practice, one needs to successfully incorporate both accessibility and usability into IT artefacts (Aizpurua et al., 2016). Researchers have used the term “universal usability” to refer to the extent to which usability appeals to all users during any task in any context (Aberg & Shahmehri, 2001; Henry et al., 2014; Petrie & Kheir, 2007; Shneiderman, 2000). Meiselwitz et al. (2010) included varieties in technological diversity (hardware, software, and network), user diversity (impairments, learning disabilities, low literacy level, age, gender, socio-economic status, cultures, etc.) and context (environmental factors, such as location, time, device type, and users’ current cognitive or psychological state) in universal usability. However, in discussions about universal usability, Henry et al. (2014) recommended that, when discussing accessibility, one should focus on user diversity rather than situational limitations that result from the context because design strategies and solutions for people with disabilities and people with situational limitations significantly overlap. Concepts under the universal accessibility domain attempt to cover all diversity in users’ abilities in various contexts (Obrenovic et al., 2007; Savidis & Stephanidis, 2004). In this paper, I exclude issues such as the availability of suitable technology, financial means to ensure access to ICT for all people, education, ICT literacy and skills, culture, age and language from universal accessibility because they often relate more to concepts such as inclusion or digital division (Abascal et al., 2016; Web Accessibility Initiative, 2021).

Overall, accessibility represents a complex concept (Persson et al., 2014) that one can divide into three layers: 1) computer accessibility (interaction and access between software and hardware), 2) browser accessibility (browser features and user agents, assistive technology, and Web navigation technology), and 3) Web accessibility (Web content and structure that users perceive and interact with) (Sevilla et al., 2007). Meanwhile, Culnan (1984) divided accessibility into physical accessibility of system use and information accessibility, which includes three dimensions: 1) physical (using a computer), 2) interface (a user’s interaction with “non-natural language”), and 3) informational (a user’s ability to retrieve information independently). According to Culnan (1984) and further investigations from Loiacono et al. (2013), one can divide information accessibility into three dimensions that influence users’ intention to use a system:

1) Perceived convenience (users perceive access to information as convenient, which influences their intention to use the system and their perception of ease of use)
2) Perceived reliability (users perceive that they can access the system in a reliable, dependable, and failure-free manner; perceived reliability influences users’ intention to use the system, how easy they perceive the system to use, and how useful they perceive the system), and
3) Perceived ease of use (users perceive the system as user-friendly, flexible, and forgiving).

Notably, information accessibility has a significant impact on perceived usefulness and perceived ease of use in users’ acceptance process (Djamasbi & Tullis, 2006; Loiacono et al., 2013).

An accessible IT artefact also allows people to use assistive technology, such as screen readers, screen magnifiers, voice recognition, alternative devices, and displays to access system elements and, thus, ensures equitable access for people with disabilities (Babu et al., 2010; Lazar et al., 2004; Petrie et al., 2015). Assistive technology renders content decoding to multi-modal channels (visual, auditory, tactile), which facilitates users’ interaction with information (Watanabe, 2017). However, due to assistance technology, potential accessibility barriers become even more complex to understand (Vollenwyder et al., 2019). To attain access for all, such as in the European Union, Directive 2016/2102 compels public digital services, websites, and mobile applications to be accessible. Similarly, in the private sector, the European Accessibility Act requires all digital products established after June 2025 to be accessible (Directive 2016/2102 (European Parliament, 2016) of the European Parliament and of the Council of 26 October 2016, 2016; European Telecommunications Standards Institute, 2015). These directives require compliance with the Web Content Accessibility Guidelines (WCAG) (which the Web Accessibility Initiative (WAI) from the World Wide Web Consortium (W3C) publishes) at the mid-range conformance level. However, although ISO standards and the WCAG receive many citations and represent the de facto standard in accessibility, scholars often claim that even full compliance with these standards and guidelines does not guarantee good accessibility or usability when websites remain unsatisfying (Aizpurua et al., 2015; Babu et al., 2010; Berget et al., 2016; Lazar et al., 2004; Leuthold et al., 2008; Martins et al., 2017; Vollenwyder et al., 2019). For example, among the accessibility problems that blind people encounter, WCAG covers only around half (Aizpurua et al., 2015, 2016; Giraud et al., 2018; Petrie et al., 2003).

To better understand how people interact with IT artefacts when accessing information, accessibility scholars often investigate certain target populations and their needs for a successful interaction. For example, Martins et al. (2017) recommended defining a specific scope, such as using accessibility guidelines or characterizing the target population with attention to users' capability limitations and other attributes when evaluating accessibility.

2.2 Discussions between Accessibility and Usability

Some prior studies emphasize the importance of including usability inaccessibility. According to Link et al. (2006), users should perceive accessible IT artefacts as easy to learn and use. Similarly, Cairns et al. (2019) argued that accessibility in user interface (UI) interactions no longer simply concerns whether people can perceive and operate a UI. Thus, IT artefacts should provide usability to as many people as possible regardless of their ability (Giraud et al., 2018; Leuthold et al., 2008; Link et al., 2006; Martins et al., 2017; Ruiz et al., 2011; Vollenwyder et al., 2019). However, Petrie et al. (2015) analyzed 50 definitions of Web accessibility in books, papers, standards, guidelines, and online sources and found that only 30 percent mentioned usability. Moreover, Yesilada et al. (2015) confirmed that the Web accessibility community thinks that accessibility and usability relate highly to each other.

Petrie et al. (2015) provided a unified definition for Web accessibility that includes usability as follows:

> *All people, particularly disabled and older people, can use websites in a range of contexts of use, including mainstream and assistive technologies; to achieve this, websites need to be designed and developed to support usability across these contexts.* (p. 3)

This definition posits accessibility as a necessary precondition for usability, and only after people successfully interact with IT artefacts can the artefacts gain other qualities such as usability and user experience (UX) (Cairns et al., 2019; Davis et al., 1989; Iwarsson & Ståhl, 2003; McKay et al., 2012; Meiselwitz et al., 2010). However, in their study with blind and sighted participants, Petrie and Kheir (2007) found that accessibility problems do not encompass all usability problems and usability problems do not encompass all accessibility problems. Thus, accessibility does not automatically make content on websites usable (Leuthold et al., 2008). For example, according to Leuthold et al. (2008), content that adheres to WCAG does not result in significant differences in efficiency, errors, or satisfaction in website usage among blind users. Hence, once accessibility has been achieved, the interaction design should provide good usability, which means people with disabilities should be able to exploit interfaces equally, efficiently, effectively, and safely; they should perceive the interaction as satisfying and a good experience with a reasonable amount of time and effort (Cairns et al., 2019; Giraud et al., 2018; Leuthold et al., 2008; Little et al., 2005; Santana & Baranauskas, 2015). Similarly, Aizpurua et al. (2016), Giraud et al. (2018) and Santana and Baranauskas (2015) stated that accessibility and usability play a significant role in attaining a successful system so that one should consider and address these elements together. According to Aizpurua et al. (2016), accessibility also correlates with 27 of 35 UX attributes (mostly with hedonic UX qualities). Therefore, one needs to deeply focus on and appropriately consider accessibility. Otherwise, IT artefacts would exclude a significant group of potential users whose ICT use relies on appropriately provided accessibility (Aizpurua et al., 2016). In addition, Yesilada et al. (2015) found that accessibility applies to everyone and not just to people with disabilities.

Although accessibility and usability have proven difficult concepts to define with clear distinctions between their qualities, one evidently needs to integrate them properly; otherwise, websites, for example, would be inaccessible but usable or accessible but not usable (Aizpurua et al., 2016). Moreover, websites could become useless for people with disabilities and lack usability for all (Santana & Baranauskas, 2015).

In summary, despite the variation in definitions, prior accessibility research agrees that making accessibility improvements, such as using universal design principles for a website, makes them more effective (Djamasbi & Tullis, 2006). Past studies on accessibility have formulated accessibility theories often by referring to the desired extent stated in focal accessibility definitions, such as in ISO standards. Although confusing accessibility and usability can cause concerning consequences, studies that attempt to describe the relationship between accessibility and usability build their models on a holistic picture of interaction and do not clearly articulate the difference between these qualities. For example, Sauer et al. (2020) examined the meaning of the concepts of accessibility, usability and UX and their relationship with one another. They proposed a new higher-level concept called "interaction experience" as an umbrella term that more holistically encompasses the experience gained in interactions with IT artefacts. Obrenovic et al. (2007) described the fundamental connection between universal accessibility and multi-modal interface design.

They presented a framework to identify whether an interface's design is appropriate for a particular situation and how one interaction modality affects users' abilities. For example, hand movements during an interaction require users' motor, perceptual, and cognitive abilities (Obrenovic et al., 2007).

Overall, these findings represent a good starting point to frame the components of an accessible IT artefact to construct a descriptive explanation of the process of accessing information by users.

3 Theory Overview: Accessibility's Components

To address RQ2, I draw on the prior basic theories related to each component of accessibility. I retrieved these focal components from the definition for the term that ISO 9241-171:2008 provides, which I simplify as follows: **people with various abilities** can **interact** with **IT artefact features** to use **information** for an identified **task** in an identified **use context** (International Organization for Standardization, 2018; Persson et al., 2014; Petrie et al., 2015). The extracted focal components constitute "accessibility" constructs (i.e., user abilities, interactions, product features, tasks, and use contexts). I scoped out technological components such as a computer (interaction between software and hardware), browser features, user agents, and AT because these components influence the interaction, and I focused on describing only the interactions between users and IT artefacts.

Table 1. Summary of the Components of Accessibility

Component	Theories reviewed	Summary of the possible variables	References
User abilities	International Classification of Functioning, Disability, and Health (ICF); Cattell-Horn-Carroll's (CHC) theory of intelligence	User sensory perception, cognition, and human functional operation	Berget et al. (2016), Carroll (1993), Lee & Nass (2003), McGrew (2009), Nass et al. (1994), Sevilla et al. (2007), World Health Organization (2002, 2013, 2021)
Interaction (using computers)	Basic process of human-computer interaction (Schomaker et al., 1995)	User perception, cognition and action (human input and output channels) Computer output media and computer input modalities	Babu et al. (2010), Gerlach & Kuo (1991), McGrew 2009), McKay et al. (2012), Schomaker et al., (1995)
Product features	The model of user experience (Hassenzahl, 2003); WCAG	Content, presentation style, functionality, interaction style and structure	Hassenzahl (2003), W3C (2018)
Task	Seven stages of action (Norman, 1986)	Task characteristics, user's mental and physical activities: establishing the goal; forming the intention; specifying the action sequence; executing the action; perceiving the system stage; interpreting the state; and evaluating the system state with respect to the goals and intentions	Carroll (1993), Gerlach & Kuo (1991), Norman (1986)
Use context	Universal usability (Shneiderman, 2000), socio-technical model (Lyytinen & Newman, 2008)	Environmental factors, socio-cultural factors, cultural, political and sociological factors, history of that context, context of IS, socio-technical components	Lyytinen & Newman (2008), McKay et al. (2012), Meiselwitz et al. (2010), Sharp et al. (2020), Shneiderman (2000), World Health Organization (2013)

3.1 User Abilities

To classify a person's functional abilities in this paper, I used the ICF, which the World Health Assembly agreed on in 2001 (World Health Organization, 2002). Despite its potential, the ICF rarely sees use in IS or HCI studies, though disability experts in governments and other sectors commonly use it (World Health Organization, 2013). Cinquin et al. (2019) recommended that system or feature design should consider ICF, such as in learning activities. To understand and follow the large scale of human psychological and physical differences, I used the ICF framework to identify human factors. The ICF framework presents possible disabilities in a person's interactions with the social, physical, and digital environments (Cinquin et al., 2019). The ICF is a tool to measure functioning in a society with a focus on health, functioning, and a person's abilities rather than disabilities that may risk separating people into different categories (World Health Organization, 2002). Thus, the ICF helps one understand human diversities and collects knowledge about individuals' basic needs based on impairments or complex disorders (World Health Organization, 2013).

The ICF proposes two conceptual disability models. First, the medical model defines disability as a feature of a person caused by disease, trauma, or other health conditions that require medical treatment to "heal" the individual (World Health Organization, 2013). Second, the social model sees disability as a socially created problem in which society creates an unaccommodating environment by neglecting the rights of persons with disabilities (World Health Organization, 2013). Finally, the ICF provides an integrated disability model that considers both the medical and social models and that includes biological, psychological, and social perspectives. This more familiar biopsychosocial disability model has two parts: 1) functioning and disability, which includes body functions and structures in addition to activities and participation; and 2) contextual factors, which include environmental factors and personal factors (World Health Organization, 2021, 2013). In this paper, I adopt the ICF but consider only the factors related to human-computer interactions, such as user sensory perceptions, cognition, and functional operations.

3.1.1 User Sensory Perception

The ICF classifies human sensory functions as follows: seeing and related functions, hearing and vestibular functions, taste function, smell function, proprioceptive function, touch function, sensory functions related to temperature and other stimuli, and pain (World Health Organization, 2002) (see Appendix A).

3.1.2 Cognition

Cognitive ability and possible patterns of cognitive deficits differ for each individual (Berget et al., 2016; Sevilla et al., 2007). Therefore, when analyzing issues relating to cognitive deficits, one needs to consider each specific cognitive deficit rather than considering cognitive matters as a whole (Sevilla et al., 2007). According to the CHC theory of intelligence, interpreting and organizing perceived data constitute a cognitive process that involves cognitive abilities such as reasoning, comprehension, short-term and long-term memory, reading and writing, and visual and auditory processing, which refer to the ability to generate, store, and retrieve visual information and analyze, manipulate, and comprehend auditory information (McGrew, 2009). Carroll (1993) defined ability as an attribute of an individual that refers to the possible variations in the liminal levels of task difficulty (or in derived measurements based on such liminal levels) at which, on any given occasion where all conditions appear favorable, individuals successfully perform a defined class of tasks. ICF does not definitively list human cognitive deficits but describes the brain's functions as mental functions, such as attention functions, memory functions, thought functions, mental functions of language, calculation functions, psychomotor functions, a mental function of sequencing complex movements, emotional functions, higher-level cognitive functions, and experience of self and time functions (see Appendix A for specific mental functions). Moreover, ICF provides the following abilities for applying knowledge: focusing attention, thinking, reading and writing, calculating, problem-solving, and making decisions (see Appendix B) (World Health Organization, 2021).

To conclude, one needs awareness of individuals' cognitive abilities to perform tasks and to adopt this knowledge when designing IT artefacts to create a successful interaction.

3.1.3 Human Functional Operations

Human outputs or actions in IT use such as typing with a keyboard and using pointing devices, touch screens, and so on require at least one human functional ability (Carroll, 1993). ICF classifies human functional abilities as follows: voice and speech functions (voice functions, articulation functions, fluency and rhythm of speech functions, alternative vocalization functions) and neuromusculoskeletal and movement-related functions (joint and bone functions, muscle functions, movement functions) (see Appendix A) (World Health Organization, 2021). As one can also consider human-computer interactions social interactions (Lee & Nass, 2003; Nass et al., 1994), human abilities for social interaction, such as abilities for interpersonal interactions, relationships, and communication (receiving and producing, conversing, and using communication devices and techniques) (World Health Organization, 2021), can affect social interactions in a digital environment. Therefore, one should consider them in designing for accessibility. ICF divides the abilities for interpersonal interactions and relationships into abilities for basic and complex interpersonal interactions, relating with strangers, formal relationships, and informal relationships (see Appendix B) (World Health Organization, 2021).

3.2 Interaction

Human interaction with an IT artefact involves three basic user processes: perception, interpretation (i.e., cognition), and action (Babu et al., 2010; Gerlach & Kuo, 1991; McKay et al., 2012). The communication between humans and IT artefacts starts with a user's perception and continues with the user's interpreting perceived data (Gerlach & Kuo, 1991). Human perception receives information generated through the body positions and senses, such as sight, hearing, and touch. Humans have varying abilities to perceive data. Once they have perceived data, the interpretation process starts. Schomaker et al. (1995) described human-computer interaction as having two actors: the human and the computer. Both actors receive outputs and send inputs to each other. The computer output is an input for humans. Human output is an input for computers. The interaction refers to exchange between these actions. Each actor has a cognition process between received input and sent output: the mental process involved in gaining knowledge and comprehension for humans (McGrew, 2009) and data processing for computers.

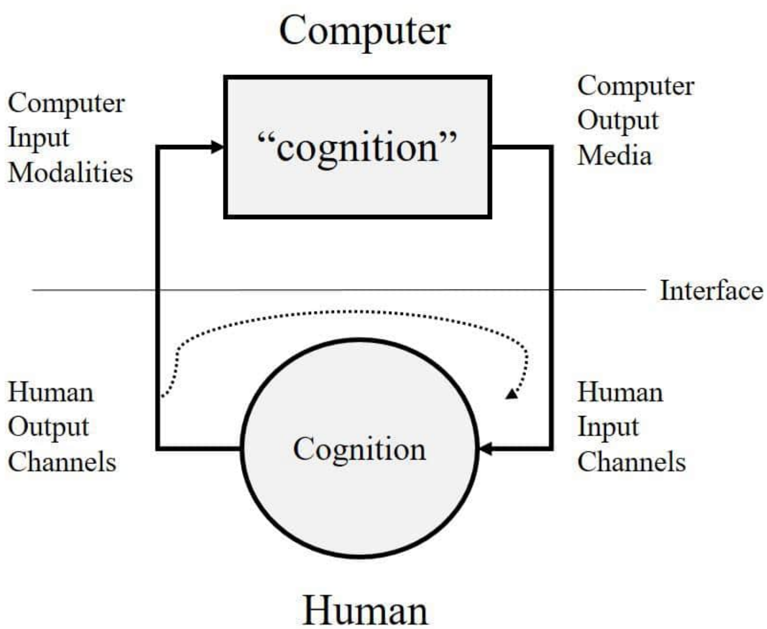

Figure 1. Basic Process of Human-Computer Interaction (Schomaker et al., 1995)

3.3 Product Features

As the term "IT artefact" may have different meanings, I define it here as an application (e.g., Web application, website, UI, etc.) or an IS component that enables or supports some tasks embedded in the structure in some context (Alter, 2008; McKay et al., 2012). IT artefacts have certain features, such as content, presentation style, functionality, interaction style, and structure whereby users interact to use information (Hassenzahl, 2003; W3C, 2018). According to Hassenzahl (2003), individuals construct their own conceptual version of an artefact's character based on personal judgment (emotional consequences such as pleasure, satisfaction, and so on and behavioral consequences such as increased time spent with the artefact). Notably, regardless of the design process or method, the construction process results in only one design solution for an IT artifact (McKay et al., 2012).

3.4 Tasks

User tasks refer to the processes that users have or should be able to do with IT artefacts (Savidis & Stephanidis, 2004). Performing any task usually requires more than one ability. For example, a simple task that asks the user to select "yes" or "no" in response to a presented question requires the ability to see, recognize, and read the words; to understand what the words mean; to evaluate the oppositeness of the answers and understand the consequences; and, finally, the ability to make a selection physically with the device (Carroll, 1993). Norman (1986) described a user's mental and physical activities in performing a task using seven stages:

1) Establishing the goal
2) Forming the intention
3) Specifying the action sequence
4) Executing the action
5) Perceiving the system stage
6) Interpreting the state, and
7) Evaluating the system state with respect to the goals and intentions.

Therefore, task performance requires cognitive and physical activities from a user.

Gerlach and Kuo (1991) suggested that an HCI design should include two main elements: 1) the conceptual aspect (e.g., task analysis and design) and 2) the physical aspect (e.g., designing action and presentation style that enables the user to communicate with a system). Designing tasks and dividing complex tasks into smaller, precisely defined tasks has a positive effect on motivation and engagement (Jackson et al., 2015; Sprinks et al., 2017; Tinati et al., 2017), which, for example, gamification and game elements can strengthen (Prestopnik et al., 2017; Tinati et al., 2017; Zhou et al., 2017).

3.5 Use Context

The ISO standard states that one should address design according to its identified use context. However, identifying the use context's scope may be challenging. According to Meiselwitz et al. (2010) and the World Health Organization (2013), one needs to consider environmental factors such as location, time, device type, and the user's current emotional state (cognitive or psychological state) when designing for context. In addition, Sharp et al. (2020) stated that one needs to understand socio-cultural factors, such as customs, traditions, and beliefs that drive users' thoughts, feelings, and behaviors to understand genuine accessibility problems. Moreover, McKay et al. (2012) described the use context to comprise the properties of interactions among technical, human, and organizational elements and noted that a context's cultural, political, sociological, and historical aspects influence users. Actual computer use context includes perception, interpretation, and use (McKay et al., 2012). McKay et al. (2012) suggested having a socio-technical viewpoint that includes human-centered design knowledge and construction-centered design knowledge for designing artefacts for use context to meet both approval and use requirements. If we consider IT artefacts IS artefact components (McKay et al., 2012), one needs to understand the IS context. The socio-technical model (Lyytinen & Newman, 2008) helps one identify possible imbalances or gaps as critical incidents between the following socio-technical components: actors, technology, task, and structure. Therefore, in the use context of a socio-technical system, a user may face problems in operating, understanding, and/or accepting tasks, structures, and/or technology, which may occur in three simple conditions: the user 1) does not understand, 2) cannot operate, or 3) does not accept the tasks, structure, or technology (Lyytinen & Newman, 2008). Moreover, individual characteristics and abilities, task characteristics, the external environment, and supporting systems influence these conditions (Bostrom & Heinen, 1977).

4 Synthesizing Knowledge of the Accessibility Components into a Model

I present the accessibility model I developed after synthesizing prior theories related to the components of accessibility in Figure 2. The model explains the "accessibility" construct and includes its components, variables, processes, and their relationships. I developed the model for IS and HCI researchers to align their identified research problem with the picture of accessibility to see related variables and relationships between the components of accessibility in the problem domain.

Figure 2 presents a conceptual case whereby a user interacts with IT features to access and use information (see the explanations in Table 2). The first column in Table 2 includes the components of accessibility as stated in the simplified definition. The second column includes each listed component's possible variables and processes (if any).

In the accessibility model, the interaction flow illustrates the information-exchange cycle between the user and the computer. It should rotate as long as the user reaches the information. If this rotation ends or a mismatch between the UA and COM or CIM interrupts it, the ITAF or the information becomes inaccessible.

I next describe the components and their variables in Table 2 in detail. Figure 2 shows the abbreviations for the components, variables, and processes.

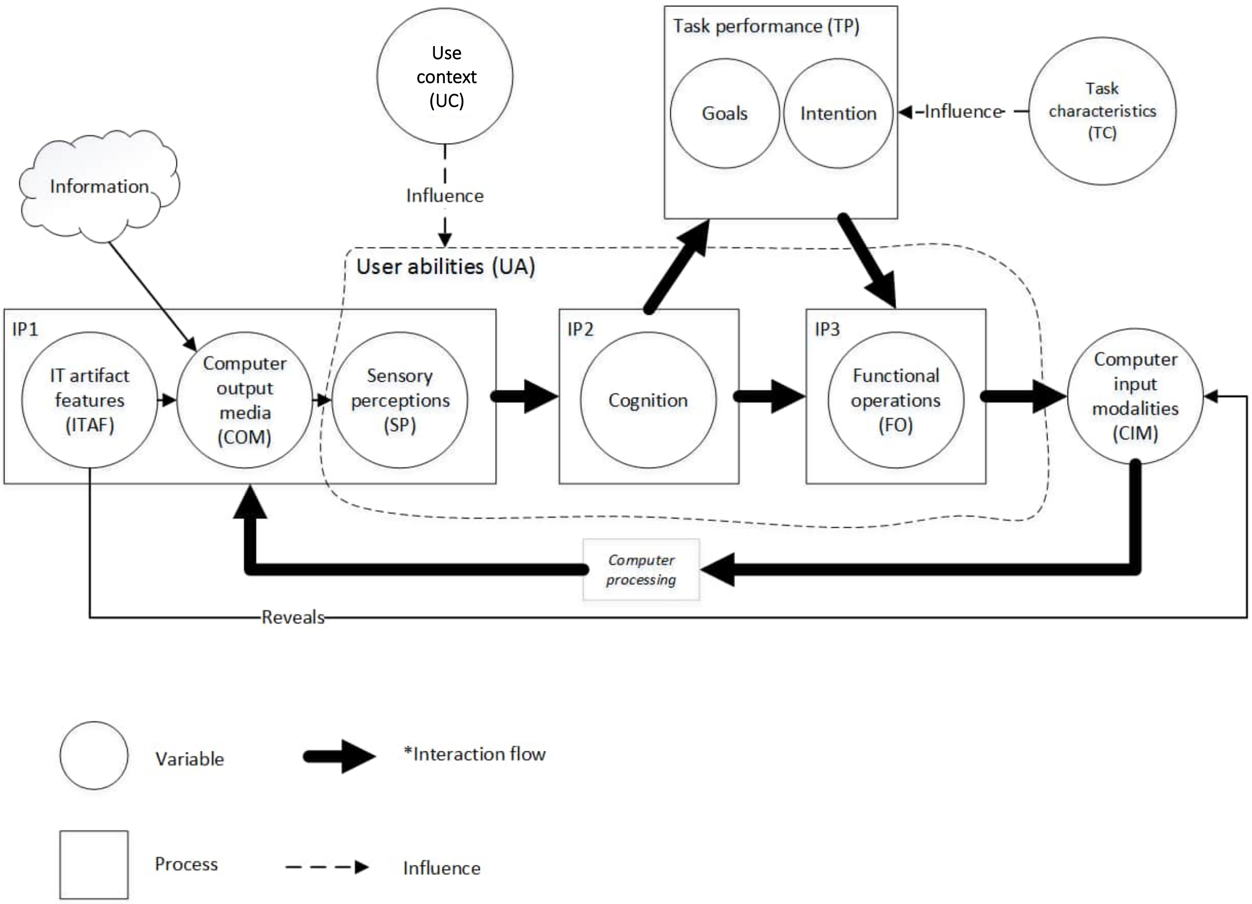

Figure 2. Accessibility Model (AM)

The range of ***user abilities*** (UA) varies. Similarly, users' sensory perceptions (SP) differ with respect to their *sight, hearing, touch, smell, taste, and balance* abilities (Schomaker et al., 1995; World Health Organization, 2021, 2013). One can classify and unify the domains of users' cognitive abilities based on the CHC theory (McGrew, 2009) and the ICF classification of human ability to apply knowledge as follows: focusing attention, memory, thinking and processing speed, reading and writing, mental functions of language, calculating and quantitative knowledge, solving problems, making decisions and reaction speed, psychomotor functions and sequencing complex movements and speed, emotional functions, perceptual functions, higher-level cognitive functions and domain-specific knowledge, experience of self and time functions, and comprehension knowledge (see Appendix C for detailed descriptions). Users' functional operations (FO) related to human-computer interactions vary in terms of their *movement, voice, and sight* abilities (McKay et al., 2012; Sevilla et al., 2007).

Human-computer ***interaction*** (IP) involves three basic human processes: sensory perception (IP1), cognition (IP2), and functional operation (IP3) (Babu et al., 2010; Gerlach & Kuo, 1991; McKay et al., 2012; Schomaker et al., 1995). In the sensory perception process (IP1), users detect an **IT artefact's features** (content, presentation style, functionality, interaction style, and structure) with SP (Hassenzahl, 2003; W3C, 2018). Some computer output media (COM) modalities (*visual, auditory, tactile, olfactory, gustatory or vestibular*) (Schomaker et al., 1995) can reveal these features. In the cognition process (IP2), human cognition interprets COM and guides human body functions (i.e., FO) (Babu et al., 2010; Gerlach & Kuo, 1991; Schomaker et al., 1995). In the functional operation process (IP3), human FO work with computer input modalities (CIM) (Babu et al., 2010; Gerlach & Kuo, 1991; Schomaker et al., 1995).

Information is a conceptual component that contains a message that a provider wants to convey. The provider can express information via COM modalities (*visual, auditory, tactile, olfactory, gustatory, or* *vestibular)* (Schomaker et al., 1995). In practice, messages are expressed either via texts, images, videos, graphs, charts, tables, shapes, and so on that may manifest differences in their presentation style. For example, using colors, font size, shapes, and other elements involves accessibility features, which means that they have quality. Overall, information quality can comprise availability, relevancy, response time, accuracy, completion, up-to-dateness, transparency, reliability, convenience, ease of use, and, most importantly, accessibility itself (Alkhattabi et al., 2011; Culnan, 1984; Delone & McLean, 1992; Djamasbi & Tullis, 2006; Liang et al., 2017; Loiacono et al., 2013). Information quality in terms of accessibility means that one who provides information considers users' SP and cognitive abilities. Good information quality enhances the extent to which users perceive benefits and mitigates the extent to which they perceive fake information risk (Liang et al., 2017). Information quality also has a positive impact and relationship to the actual use state and user satisfaction (cf. the IS success model (Delone & McLean, 1992)). Moreover, information convenience and reliability—information quality features—have a positive impact on perceived ease of use, perceived usefulness, and intention to use (cf. the TAM by Davis et al., 1989) (Loiacono et al., 2013).

Accessibility features can help improve information perception, which means that one can improve information quality by implementing accessibility features. For example, one can improve intrinsic, contextual accuracy, and completeness with context-sensitive design and factors related to information architecture. According to Liang et al. (2017), disability level affects how a user perceives information quality and system quality. As an example, Liang et al. (2017) argued that people with severe disabilities did not notice a significant difference in the risks posed by fake websites that provide high-quality information versus those that provide low-quality information. However, both high and low system quality had a strong positive effect on the likelihood that people with severe disabilities detected fake websites. Misinterpreting system quality can be dangerous because, for example, fake websites can easily create the impression that they possess high system quality, which users rely on to assess risk (Liang et al., 2017). System quality is a multidimensional factor, but, from an accessibility perspective, accessibility itself predicts system quality more strongly than any other feature (Liang et al., 2017). Furthermore, one can improve other system quality factors, such as fastness, navigability, and content readability, through accessibility features. For example, one can improve fastness by reducing cognitive load and improving remembering (Sayago & Blat, 2010; Sharlin et al., 2009). One can improve navigability with several accessibility factors related to, for example, navigation linearity (Vigo & Harper, 2013), customization (Harper & Bechhofer, 2007), and naming (Aizpurua et al., 2016). One can improve content readability with the bilingual approach and factors related to information architecture (Aizpurua et al., 2016; Berget et al., 2016; Hammami et al., 2019; Sayago & Blat, 2010).

To support users' task performance (TP), one should design ***tasks*** in a way that considers users' abilities to perceive and recognize the system stage, interpret and understand what messages mean, evaluate the system stage and understand the consequences with respect to the established goals and intentions, and physical activities (Carroll, 1993; Gerlach & Kuo, 1991; Norman, 1986). Moreover, one should break down complex tasks into smaller chunks with precisely defined tasks and gamification elements that characterize the tasks to increase motivation and engagement. Thus, task characteristics influence users' goal-setting and intention to perform tasks (Jackson et al., 2015; Prestopnik et al., 2017; Sprinks et al., 2017; Tinati et al., 2017; Zhou et al., 2017).

Use context (UC) may vary due to environmental factors, such as the context's cultural, political, sociological, and historical aspects and users' emotional state (Lyytinen & Newman, 2008; McKay et al., 2012; Meiselwitz et al., 2010; Sharp et al., 2020; World Health Organization, 2013). The Use context influences users' abilities. Moreover, users' expectations based on past experiences, prejudices, evoked memories, unmet expectations, and confidence strongly affect how they perceive and experience websites with respect to accessibility (Aizpurua et al., 2015). One can interpret expectations as part of context history (e.g., users' feelings of dread).

Table 2. Variables and Relationships between Components of Accessibility

Components	Variables and processes	References
Users with various abilities can	Users' abilities (UA) vary in terms of: 1) Sensory perceptions (SP): *sight, hearing, touch, smell, taste, and balance;* 2) Cognition: *focusing attention, memory, thinking and processing speed, reading and writing, mental functions of language, calculating and quantitative knowledge, solving problems, making decisions and reaction speed, psychomotor functions and sequencing complex movements and speed, emotional functions, perceptual functions, higher-level cognitive functions and domain-specific knowledge, experience of self and time functions, comprehension-knowledge;* and 3) Functional operations (FO): *movements, voice, and sight.*	Berget et al. (2016), Carroll (1993), McGrew (2009), Schomaker et al. (1995), Sevilla et al. (2007) World Health Organization (2021, 2013)
Interact with	The interaction process (IP) includes the following UA: (IP1) = SP receives ITAF via COM and transmits information to IP2; (IP2) = Cognition interprets and organizes perceived data from IP1 and guides IP3; and (IP3) = Receives information from IP2 and directs FO for actions with computer input modalities (CIM) (*movements, force, sound, images)* revealed by IT artefact features (ITAF).	Babu et al. (2010), Gerlach & Kuo (1991), McKay et al. (2012), Schomaker et al. (1995)
IT artefact features to use	IT artefact features (ITAF) include: *content, presentation style, functionality, interaction style* and *structure.* These features are revealed through computer output media (COM): *visual, auditory, tactile, olfactory, gustatory, or vestibular.*	Hassenzahl (2003), Sevilla et al. (2007), W3C (2018)
Information identified	Information is a conceptual component presented with some of the COM modalities.	Culnan, 1984), Djamasbi & Tullis, 2006), Loiacono et al., 2013), Schomaker et al. 1995), W3C, 2018
Task identified	Task performance (TP) includes the following IP: the user evaluates the results of IP1 and IP2 with respect to *goals* and *intentions*, whereupon the user proceeds to IP3. Task characteristics (TC), such as *complex, motivating, and engaging,* influence TP.	Carroll (1993), Jackson et al. (2015), Norman (1986), Prestopnik et al. (2017), Sprinks et al. (2017), Tinati et al. (2017), Zhou et al. (2017)
Use context	Use context (UC) varies in terms of *environmental factors, users' emotional state, socio-cultural factors, and socio-technical factors wherein the cultural, political, sociological, and historical aspects of that context influence the user.*	Lyytinen & Newman (2008), McKay et al. (2012), Meiselwitz et al. (2010), Sharp et al. (2020), World Health Organization (2013)
Texts in *italics* indicate possible variables		

4.1 Positioning the Accessibility Model for Technology Acceptance

Accessibility is a fundamental factor in technology acceptance (Culnan, 1984; Djamasbi & Tullis, 2006; Loiacono et al., 2013), so I next juxtapose the AM to well-known technology acceptance models (TAMs) (Davis et al., 1989), and discuss its relationship to usability (i.e., address RQ3).

The TAM and its variations (Davis et al., 1989) provide theories to explain and predict user acceptance to expand the knowledge of why people accept or reject new technology. The original TAM posits two primary relevance for technology acceptance; namely, perceived usefulness (PU) and perceived ease of use (PEU), which both influence users' attitudes towards use (Davis, 1993; Davis et al., 1989). The TAM considers internal beliefs, attitudes, and intentions as external variables and sees individual differences as impingements on user behaviors (Davis et al., 1989). It considers system features for improving usability as external variables that influence *perceived usefulness* and *perceived ease of use*. Venkatesh and Davis (2000) expanded TAM with a cognitive instrumental process that impacts *perceived usefulness*. The cognitive instrumental process includes job relevance, output quality, result demonstrability, and *perceived ease of use* (Venkatesh & Davis, 2000). Venkatesh and Bala (2008) also extended the original TAM by defining the determinants for *perceived ease of use* (computer self-efficacy, computer anxiety, computer playfulness, and perceptions of external control). However, neither these extensions nor the original TAM consider possible users' disabilities (Djamasbi & Tullis, 2006). However, computer self-efficacy in Venkatesh and Bala's (2008) extension does consider users' differences in terms of individuals' beliefs about their ability to use the system. Furthermore, objective usability represents one of the system's characteristics related to adjustments and, by using the system, users learn how to use it (Venkatesh & Bala, 2008). Venkatesh and Bala (2008) considered usability an anchor of *perceived ease of use*, whereas Nielsen (1993) believed that all usability features promote usefulness. Meanwhile, Lin (2013) tested the relationship between TAM and usability and found no significant causality between *perceived usefulness* and usability (effectiveness and efficiency). Instead, they found a correlation between *perceived ease of use* and usability attributes of learnability and memorability.

The unified theory of acceptance and use of technology (UTAUT) (Venkatesh et al., 2003) considers age, gender, experience, and voluntariness of use as moderating variables between effort expectancy (dependent variable) and behavioral intention (independent variable). Effort expectancy refers to how easy people find using a system and contains *perceived ease of use* (Venkatesh et al., 2003). In UTAUT, all moderating variables that refer to individual differences influence the relationship between effort expectancy and behavioral intention. However, from these individual differences, one can consider only age as a factor in accessibility when ignoring other individual differences.

In conclusion, the usability features that affect *perceived ease of use* include learnability and memorability, which both require users' cognitive effort (Cinquin et al., 2019; Davis, 1993; Nielsen, 1993). Moreover, users should be able to accomplish tasks without much cognitive effort to gain efficiency in use (Leuthold et al., 2008). In this case, cognitive effort focuses on users' cognitive abilities and, thus, accessibility. Therefore, appropriately adjusting system features, such as usability features, to meet users' abilities can make *perceived usefulness* and *perceived ease of use* more possible for people whose abilities one considers in the IT artefact design process. Thus, one can consider accessibility a moderating variable between systems features (independent variable) and *perceived usefulness* and *perceived ease of use* (dependent variables). Considering IT artefact features as independent variables may present all the features that IT artefacts comprise. In fact, according to the accessibility model, IT artefact features reveal the COM and CIM.

5 Discussion

In this paper, I explain the concept of accessibility, its underlying constructs, and their relationships. Moreover, I discuss the interconnection of accessibility to usability in the model I propose. I developed this model to help increase the rigour of accessibility-related research.

5.1 A Richer Description of Accessibility

The literature largely agrees on the aims of accessibility. In fact, studies rely on the definitions stated in the ISO standard and in accessibility approaches, such as universal design and design for all (Persson et al., 2014). According to Sevilla et al. (2007), one can divide accessibility into interaction and access between software and hardware; browser features and user agents, AT, and Web navigation technology; and user interaction with Web content and structure. Culnan (1984) described accessibility in dimensions as computer use (physical dimension), a user's interaction with "non-natural language" (interface dimension), and a user's ability to retrieve information independently (informational dimension). I embedded these dimensions in the accessibility model and describe them as follows. The physical dimension represents FO that interact with CIM. Meanwhile, the interface dimension represents interaction processes: the sensory perception process (IP1), the cognition process (IP2), and the functional operation process (IP3). Finally, the informational dimension represents varieties in users' abilities (UA). The accessibility model focuses on describing user abilities in human-computer interactions, so it ignores interactions between software and hardware, which includes assistive technology's interaction with a computer. However, the accessibility model explains the relationship among user abilities, ITAF, COM, and CIM and, thereby, reveals the connection between these domains. The accessibility model extends the HCI model (Schomaker et al., 1995) with the CHC theory (McGrew, 2009) and ICF classifications (World Health Organization, 2021) of cognitive abilities. Moreover, the accessibility model considers task performance and related processes. Gerlach and Kuo (1991) described similar user task performance behaviors in HCI but did not describe all variables in user abilities, tasks, or contexts.

A challenging task in accessibility design is setting the COM to match users' varying abilities in SP and setting the CIM to match the user's FO channels. In addition, probably the most challenging task is providing information through COM in such modalities that match the users' varying cognitive abilities. Therefore, as an ideal script for information accessibility, one should design the COM first such that users perceive them with any variable in their SP. In addition, one should design the COM such that it also matches the variables in users' cognitive abilities. The accessibility model considers information as a conceptual component that ITAF can present and COM can reveal. Information quality comprises availability, relevancy, response time, accuracy, completion, up-to-dateness, transparency, and, most importantly, accessibility itself (Alkhattabi et al., 2011; Culnan, 1984; Delone & McLean, 1992; Djamasbi & Tullis, 2006; Liang et al., 2017). Then, one should design CIM such that they can receive possible human outputs such as movement, force, sound, or image that input devices (pointing devices, keyboards, microphones, cameras, sensors, etc.) can measure (Schomaker et al., 1995).

5.2 Relationship between Accessibility and Usability

The relationship between accessibility and usability in prior studies is holistic and, thus, vague. For example, researchers have presented concepts that integrate accessibility, usability, and UX in one experience (e.g., Sauer et al., 2020). Some prior studies emphasize the need to jointly consider and address usability and accessibility to provide usability to as many people as possible regardless of their abilities (Aizpurua et al., 2016; Cairns et al., 2019; Giraud et al., 2018; Leuthold et al., 2008; Link et al., 2006; Martins et al., 2017; Ruiz et al., 2011; Santana & Baranauskas, 2015; Vollenwyder et al., 2019). On the other hand, some prior studies consider accessibility as a precondition to usability (Davis et al., 1989; Iwarsson & Ståhl, 2003; McKay et al., 2012; Meiselwitz et al., 2010). In contrast, I developed the accessibility model to more rigorously describe the interconnection between accessibility and usability. According to Lin (2013), the usability features that affect *perceived ease of use* include at least *learnability* and *memorability*, both of which require users' cognitive effort (Davis, 1993; Nielsen, 1993). Moreover, efficient use means that users should accomplish their tasks without much cognitive effort (Leuthold et al., 2008). The requirements for cognitive effort relate to accessibility. Hence, the accessibility model provides a more in-depth description: adjusting usability features to meet individual requirements makes *perceived usefulness* and *perceived ease of use* more possible for people whose abilities one considers in the IT artefact design process. Thus, accessibility is a moderating variable between IT artefact features (independent variable)—in this case, usability—and *perceived usefulness* and *perceived ease of use* (dependent variables).

Prior studies recommend multimodality as a step towards universal access (see Alghabban et al., 2017; Barreto et al., 2007; Cairns et al., 2019; Ferres et al., 2013; Giraud et al., 2018; Raisamo et al., 2019; Ruiz et al., 2011; Sevilla et al., 2007). I agree with these studies. The accessibility model describes multimodality in COM and CIM similar to Schomaker et al., (1995), but it also presents variables related to user abilities to illustrate the fit between user abilities and multimodality. For example, Obrenovic et al. (2007) presented a framework to identify if the designed interface is appropriate for a particular situation and how one interaction modality affects a user's abilities, such as cognitive factors as a whole. However, according to Berget et al. (2016) and Sevilla et al. (2007), one needs to consider issues related to cognitive deficits as specific individual cognitive deficits rather than cognitive matters as a whole. Therefore, the accessibility model presents possible variables in cognition and does not consider it as a whole. As a contribution to the universal aspect, the accessibility model shows accessibility's constructs, variables in cognition, and their relationship to each other. With the accessibility model, researchers can identify variables in user abilities, interaction processes, tasks, and contexts more accurately. By identifying variables, accessibility and usability of IT artefacts can also be evaluated more accurately (Aizpurua et al., 2016). As IT adoption and user acceptance represent central concerns in IS research (Venkatesh & Davis, 2000), researchers can apply the accessibility model to understand the variables in human abilities in the IS use context. In practice, by doing so, researchers can identify and address possible human ability-related obstacles in IT use and create interaction paths, which enable users to perceive information and perform tasks. Based on this study's results, I claim that, in practice, one cannot easily access and use information concerning all variations in user abilities in any task and context using just one solution even though it remains possible at a theoretical level.

5.3 Limitations and Future Research

As with any study, this study has several limitations. First, in constructing the accessibility model, I relied on certain studies from which I extracted theories and integrated them into the model. These prior theories represent constructs (i.e., building blocks) that I relied on to create the accessibility, and one can consider them samples. Therefore, the accessibility model does not comprehensively cover all prior theories related to accessibility. However, the references I used to construct the accessibility model appear in highly reputable IS or HCI journals or have become well-known in practice. Second, I have not empirically tested the accessibility model, so I cannot claim that it represents the best solution. However, I hope that the model will help researchers understand user abilities, their relationships with interaction, and usability and will help them define and communicate their research and its relationships more rigorously. The accessibility model is explanatory in nature. Thus, it describes what accessibility is and explains how something should or could be done. However, it is a conceptual model. For example, it explains how one can design COM using visual, auditory, tactile, olfactory, gustatory, or vestibular presentational styles to meet user abilities (sensory perceptions, cognition, and functional operations). Practical methods and techniques to say how to actually perform such designs in practice warrant more research.

The next avenue for accessibility and multimodality research should address ability level and how far we can develop technology to support users with severe disabilities and their autonomous IT use. I call for a research stream for universal accessibility. Using the accessibility model, researchers can investigate the desired extent of universal accessibility, including any changes in user ability and context, as follows:

- How should one formalize COM to match users' varying abilities in SP?
- How should one design CIM to match users' varying FO channels?
- How should COM express information so that users with varying cognitive abilities can understand and use it?

6 Conclusion

Due to the complex nature of human abilities, not all users can access all IT artefacts. Describing accessibility theories can help researchers align their intended research focus with accessibility more fully. If we can develop a rich understanding of accessibility, which includes aspects of human abilities, task, and context, we can develop IT artefacts that all or the widest range of users can adopt. Thus, researchers should identify variables and relationships related to human abilities, tasks, or use contexts in order to find and investigate solutions for accessible interaction. Few publications in IS and HCI field have discussed these variables and relationships. In this paper, I describe accessibility's constructs. I illustrate possible variables in human abilities, tasks, and use contexts and how their relationships form. Finally, I discuss the difference between accessibility and usability in user acceptance and argue that accessibility is a moderating variable between IT artefact features (in this case, usability, and perceived usefulness and perceived ease of use). In this way, accessibility is a major determinant of user acceptance.

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Appendix A: ICF Classification of Human Body Functions (World Health Organization, 2002, 2013, 2021)

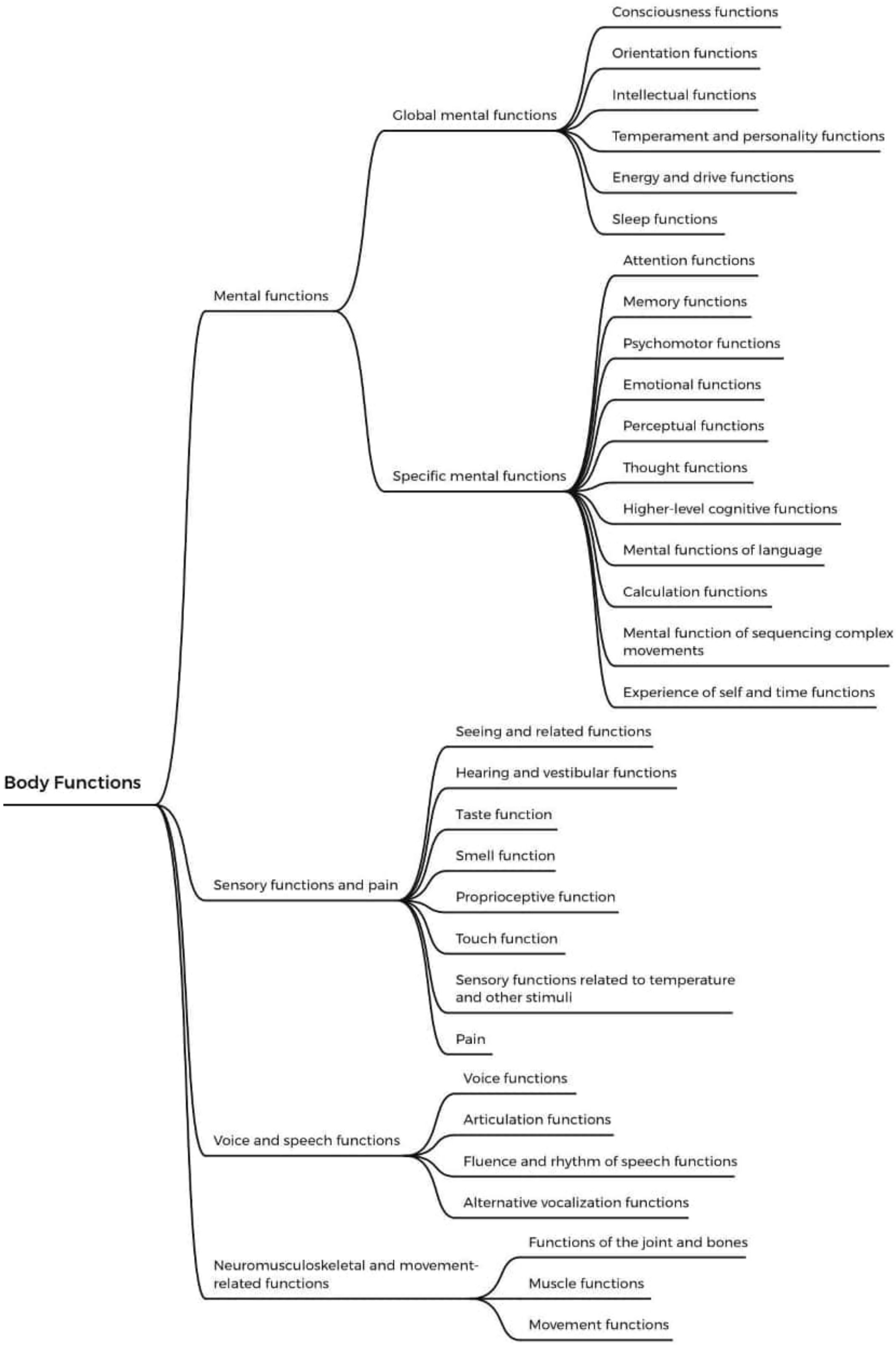

Figure A 1. ICF Classification of Body Functions Taxonomy

Appendix B: ICF Classification of Human Abilities for Activities and Participation (World Health Organization, 2002, 2013, 2021)

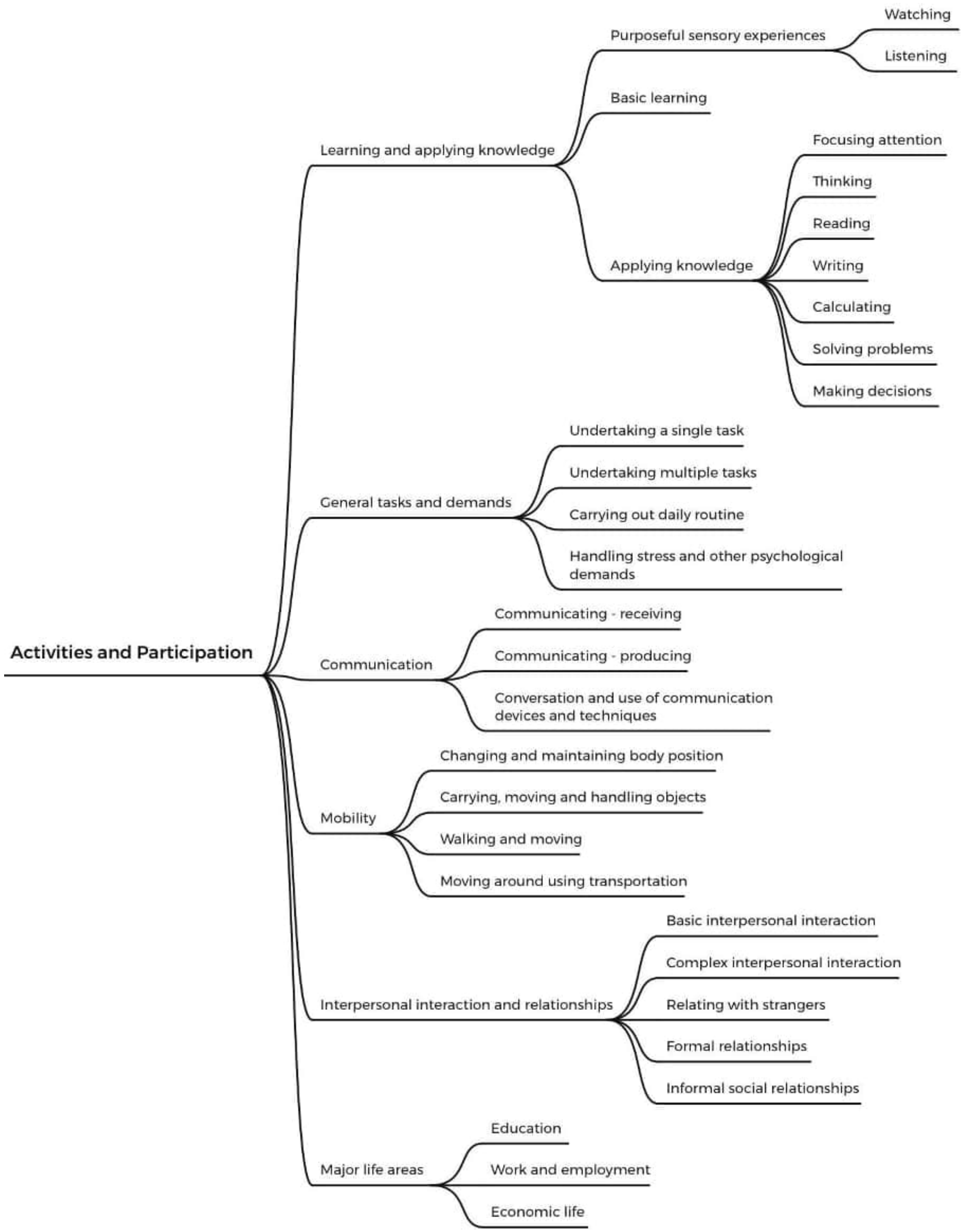

Figure A 2. ICF Classification of Activities and Participation Taxonomy

Appendix C: Unified Classification of Human Cognitive Abilities

Table A1 presents the Cattell-Horn-Carroll (CHC) theory of cognitive abilities with the original codes (McGrew, 2009) and domains in ICF mental functions and in ICF applying knowledge and their original ICF browser codes from the International Classification of Functional Abilities (World Health Organization, 2021).

Table A 1. Unified Classification of Human Cognitive Abilities

Cattell-Horn-Carroll (CHC)	ICF mental functions	ICF applying knowledge	Unified classification of cognitive abilities	Description (quotations of related ability)
-	Attention functions (b140)	Focusing attention (d160)	Focusing attention	"Specific mental functions focusing on an external stimulus or internal experience for the required period of time" (b140). "Intentionally focusing on specific stimuli, such as by filtering out distracting noises" (d160).
Short-term memory (Gms) Long-term storage and retrieval (Glr)	Memory functions (b144)	-	Memory	"The ability to comprehend and maintain awareness of a limited number of elements of information in the immediate situation (events that occurred in the last minute or so)" (Gms). "The ability to store and consolidate new information in long-term memory and later fluently retrieve the stored information (e.g. concepts, ideas, items, names) through association" (Glr). "Specific mental functions of registering and storing information and retrieving it as needed" (b144).
Processing speed (Gs)	Thought functions (b160)	Thinking (d163)	Thinking and processing speed	"The ability to automatically and fluently perform relatively easy or over-learned elementary cognitive tasks, especially when high mental efficiency (i.e. attention and focused concentration) is required" (Gs). "Specific mental functions related to the ideational component of the mind. Inclusions: functions of pace, form, control and content of thought; goal-directed thought functions, non-goal-directed thought functions; and logical thought functions, such as pressure of thought, flight of ideas, thought block, incoherence of thought, tangentiality, circumstantiality, delusions, obsessions and compulsions" (b160). "Formulating and manipulating ideas, concepts and images, whether goal-oriented or not, either alone or with others, such as creating fiction, proving a theorem, playing with ideas, brainstorming, meditating, pondering, speculating or reflecting" (d163).
Reading and writing (Grw)	-	Reading (d166); Writing (d170)	Reading and writing	"The breadth and depth of a person's acquired store of declarative and procedural reading and writing skills and knowledge" (Grw). "Performing activities involved in the comprehension and interpretation of written language (e.g., books, instructions or newspapers in text or Braille) for the purpose of obtaining general knowledge or specific information" (d166). "Using or producing symbols or language to convey information, such as producing a written record of events or ideas or drafting a letter" (d170).

-	Mental functions of language (b167)	-	Mental functions of language	"Specific mental functions of recognising and using signs, symbols and other components of a language. Inclusions: functions of reception and decryption of spoken, written or other forms of language, such as sign language; functions of expression of spoken, written or other forms of language; integrative language functions spoken and written, such as those involved in receptive, expressive, Broca's, Wernicke's and conduction aphasia" (b167)
Quantitative knowledge (Gq)	Calculation functions (b172)	Calculating (d172)	Calculating and quantitative knowledge	"The breadth and depth of a person's acquired store of declarative and procedural quantitative or numerical knowledge" (Gq). "Specific mental functions of determination, approximation and manipulation of mathematical symbols and processes. Inclusions: functions of addition, subtraction and other simple mathematical calculations; functions of complex mathematical operations" (b172). "Performing computations by applying mathematical principles to solve problems that are described in words and producing or displaying the results, such as computing the sum of three numbers or finding the result of dividing one number by another" (d172).
Fluid reasoning (Gf)	-	Solving problems (d175)	Solving problems	"The use of deliberate and controlled mental operations to solve novel problems that cannot be performed automatically" (Gf). "Finding solutions to questions or situations by identifying and analysing issues, developing options and solutions, evaluating potential effects of solutions, and executing a chosen solution, such as resolving a dispute between two people. Inclusions: solving simple and complex problems" (d175).
Reaction and decision speed (Gt)	-	Making decisions (d177)	Making decisions and reaction speed	"The ability to make elementary decisions and/or responses (simple reaction time) or one of several elementary decisions and/or responses (complex reaction time) at the onset of simple stimuli" (Gt). "Making a choice among options, implementing the choice, and evaluating the effects of the choice, such as selecting and purchasing a specific item, or deciding to undertake and undertaking one task from among several tasks that need to be done" (d177).
Psychomotor abilities (Gp); Psychomotor speed (Gps)	Psycho-motor functions (b147); Mental function of sequencing complex movements (b176)	-	Psychomotor functions and sequencing complex movements and speed	"The ability to perform physical body motor movements (movement of fingers, hands, legs, etc.) with precision, coordination or strength" (Gp). "The ability to rapidly and fluently perform physical body motor movements (movement of fingers, hands, legs, etc.) largely independent of cognitive control" (Gps). "Specific mental functions of control over both motor and psychological events at the body level. Inclusions: functions of psychomotor control, such as in psychomotor retardation, excitement and agitation, posturing, catatonia, negativism, ambitendency, echopraxia and echolalia; quality of psychomotor function" (b147). "Specific mental functions of sequencing and coordinating complex, purposeful movements. Inclusions: impairments, such as ideation, ideomotor, dressing, oculomotor and speech apraxia" (b176).

-	Emotional functions (b152)	-	Emotional functions	"Specific mental functions related to the feeling and affective components of the processes of the mind. Inclusions: functions of appropriateness of emotion, regulation and range of emotion; affect, sadness, happiness, love, fear, anger, hate, tension, anxiety, joy, sorrow; lability of emotion; and flattening of affect" (b152).
Tactile abilities (Gh); Kinaesthetic abilities (Gk); Olfactory abilities (Go)	Perceptual functions (b156)	-	Perceptual functions	"Abilities involved in the perception and judging of sensations that are received through tactile (touch) sensory receptors'" (Gh). "Abilities that depend on sensory receptors that detect bodily position, weight or movement of the muscles, tendons and joints" (Gk). "Abilities that depend on sensory receptors of the main olfactory system (nasal chambers)" (Go). 'Specific mental functions of recognising and interpreting sensory stimuli. Inclusions: functions of auditory, visual, olfactory, gustatory, tactile and visuospatial perception, such as in hallucinations or illusions" (b156).
General (domain-specific) knowledge (Gkn)	Higher-level cognitive functions (b164)	-	Higher-level cognitive functions and domain-specific knowledge	"The breadth, depth and mastery of a person's acquired knowledge in specialised (demarcated) subject matter or discipline domains that typically do not represent the general universal experiences of individuals in a culture" (Gkn). "Specific mental functions, especially dependent on the frontal lobes of the brain, including complex goal-directed behaviours such as decision-making, abstract thinking, planning and carrying out plans, mental flexibility, and deciding which behaviours are appropriate under what circumstances; these are often called executive functions. Inclusions: functions of abstraction and organisation of ideas; time management, insight and judgement; concept formation, categorisation and cognitive flexibility" (b164).
-	Experience of self and time functions (b180)	-	Experience of self and time functions	"Specific mental functions related to the awareness of one's identity, one's body, one's position in the reality of one's environment and time. Inclusions: functions of experience of self, body image and time" (b180).
Comprehension-knowledge (Gc)	-	-	Comprehension-knowledge	"The knowledge of the culture that is incorporated by individuals through a process of acculturation" (Gc).

About the Authors

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