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Multimodal thinking in the process of designing inclusive products

Dominique Adam [1]

Abstract: The concept of accessibility or the approach of inclusive design in the process of designing product interfaces is a premise that has been considered to propose more comprehensive solutions that meet the needs of a larger number of people, ensuring a satisfactory user experience. In order for the interaction experience to be minimally positive, it is interesting to consider aspects of multimodality in the industrial design process, shaping solutions that value different perspectives, abilities, and human sensory preferences. Thus, through a bibliographic and exploratory research with professionals specialized in appliances development and people with visual impairments, concepts of perception and information processing considering multimodality were mapped to support design choices to favor accessibility in the appliance development process. From the studies conducted, it was possible to identify the potential of multimodality as a technology to be considered from the beginning of the development process of an appliance solution in order to enable autonomy in accessing products and make the use of the solution more intuitive with less cognitive effort, regardless of users' abilities.

Keywords: Accessibility - Multimodality - Visually impaired - Appliances - Interfaces

[Resúmenes en castellano y en portugués en la página 205]

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Introduction

The search for accessibility in home appliances is widely discussed worldwide by the visually impaired and their representatives. In agreement with WHO (2019), visual impairment is a condition that affects a large part of the world's population, affecting tasks that are part of daily household routines, regardless of the frequency of performance. According to the latest census published by IBGE (2010), 3.4% of the Brazilian population -around 6.5 million people- were considered having severe visual limitations or blindness. In Brazil, some movements on the topic were advocated by the Human Rights and Participative Legislation Commission (CDH) Senado (2019), based on the request of the visually impaired and their representatives in accordance with the Brazilian Law of Inclusion of Persons with Disabilities (2015), which advocates that all people should have the same opportunity to access information.
Considering the universe of home appliances, the interfaces of products are usually not designed with accessibility thinking, that contains elements or features that benefits an efficient interaction for people, especially those with disabilities Adam (2022). Narrowing down the concept of accessibility for the visually impaired, it is evident that there is a need to consider in the product design process panels and interfaces that allow more autonomous use of the products, such as raised markings on buttons, auditory and tactile feedback in addition to visual cues. The lack of addressing these issues directly impacts the user experience, and consequently the autonomy of the person with a disability in the domestic context.
As reported by Martín; Ramírez (2003), a person is considered visually impaired when assistive resources, such as corrective lenses and magnifying glasses, for example, are not sufficient to correct visual loss. Both blindness and low vision are severe ocular anomalies that influence individual performance. According to the authors, an individual is considered blind if they have lost light perception up to total absence of it, requiring tactile or auditory resources to access information. On the other hand, an individual with low vision is able to perceive light, but with limitations that may interfere with their understanding, requiring assistive resources. As a result, they have difficulties in perceiving three-dimensional representations, depth, perspective, details, and objects with poor lighting Martín; Ramírez (2003). When these individuals are provided with appropriate sensory stimulation, they have the ability to use other senses to perceive information, such as smell, taste, hearing, and touch to compensate for the lack of vision. Relating these abilities to cognitive processing, Freeman *et al*. (2017), Park; Alderman (2018) mention that sensory stimuli that provide conditions for visually impaired individuals to interact with the world depend on the stimulation and development of other senses, such as auditory, tactile, and multisensory. Auditory feedback (using resources like screen readers, speech synthesizers); haptic/vibrotactile feedback (vibrotactile sensors), thermal feedback (different temperatures), gesture recognition systems, and multisensory interaction, combining different feedbacks-multimodal Oviatt (2003).
In this scenario and considering technological progress, physical design solutions are encompassing functionalities that are increasingly close to human behavior, through the automation of activities and actions. With the democratization of artificial intelligence

and smart products gaining ground in Brazilian context, home appliances are increasingly being considered as desired assistants in home environments for their facilitative role and for enhancing satisfaction in performing a task with greater autonomy and agility (Adam, 2022). Given the various options of solutions available, what criteria can we consider to select one that best meets the demands of users with or without visual impairments in terms of efficiency and user satisfaction? The answer, according to Adam (2022) is that all solutions should be considered. The positive acceptance of a product, in this case a home appliance, depends on the individual and their perceptual and cognitive issues, the product and its practical, aesthetic, or symbolic functions, and the context, considering the domestic environment *(See Figure 1).*

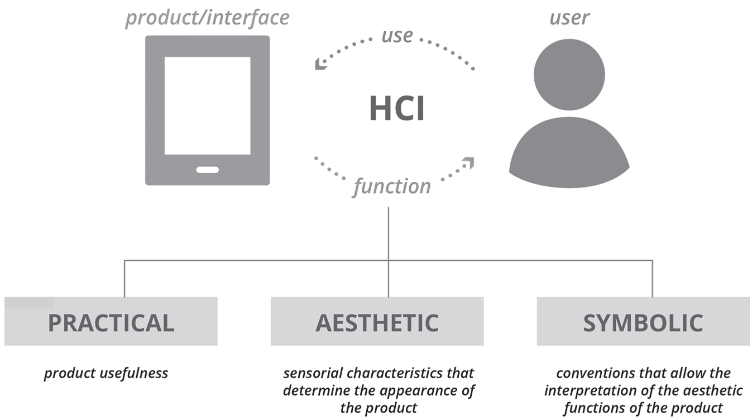

Figure 1. Product's functions (Source: Based on Lobach, 2001).

According to Lobach (2001), the 'practical' function refers to the utility or functionality of the solution[1] considering the objective it aims to achieve. The 'aesthetic' function, on the other hand, represents the appearance of the solution, presenting the physical, digital, and sensory characteristics that contribute to the user's perception during use. Finally, the symbolic function is constructed by beliefs, user's background, social, and cultural aspects that guide information processing.

Considering the scenario of accessibility in the development of home appliances, several studies foster the discussion about the rights of people with disabilities to autonomy in the use of these products Aguiar (2004); Turunen *et al.* (2010); Coelho; Duarte (2011);

Rezende (2014); Fagundes (2015); Raposo (2015); Oliveira (2018). For this, they consider the concepts underlying Interaction Design and Usability Norman (1988); Maguire (2001); ISO 9241:210 ISO (2019), e.g., visibility, good conceptual model, good mappings, feedback, consistency, and affordance, are related to accessibility and multimodality.
Thus, it is possible to visualize the interaction agents and associate the best accessible experience with the concepts of Multimodality W3C (2003); Ernst; Bülthoff (2004); Duarte; Carriço (2006); Shimomura; Thora (2010); Freeman *et al*. (2017); Park; Alderman (2018), Inclusive Design, and Usability Keates (2005); Clarkson *et al*. (2015); Lim (2019).
By dividing the information processing into stages, it is possible to understand that design can influence all of them, using structured stimuli based on users' previous experiences, also considering their needs to promote intuitive, efficient, and satisfactory use, aiming to minimize cognitive effort during interaction.

1. Multimodality and Information Processing

Human interaction with the universe is multisensory. Each individual is unique and capable of developing differentiated abilities and acquiring experiences from their relationship with their surroundings. Vision, touch, hearing, smell, and taste are sensory modalities responsible for interaction with the physical and virtual world, facilitating communication with the environment and materializing learning and experiences Ernst; Bülthoff (2004). Perception of these modalities is based on behavioral, motivational, and cultural aspects. In an iterative manner, it relates stimulus to the user and enables processing, encoding, and response *(See Figure 2).*

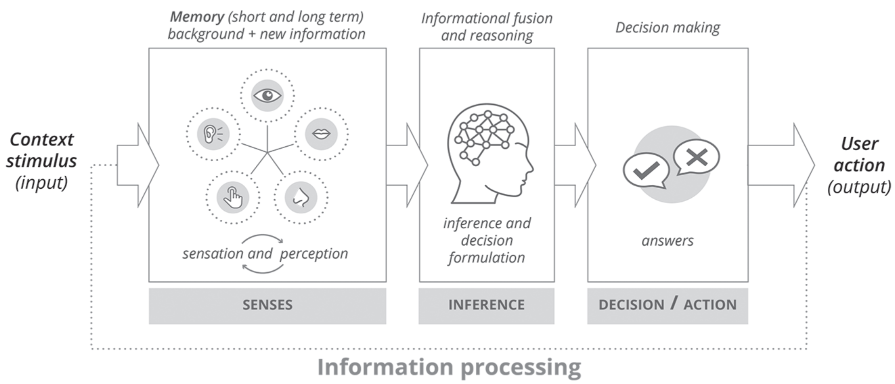

Figure 2. Information processing in Human-Computer Interaction (Source: Based on Sumari; Ahmad, 2013).

The input of information (stimulus) is perceived and interpreted by the senses (sensory registration = sensations + perception). Through memory, perceived information is compared and associated to initiate information processing. Sensation is considered the stimulus from the environment; perception as the organization of sensations and actions resulting from the stimulus. Memory, on the other hand, consists of the human ability to store and recall specific information, whether short or long-term. The archived information is associated, and informational fusion enables reasoning (cognition) so that action possibilities are inferred (organized, selected, and chosen) as responses (action) to the presented stimulus Sumari; Ahmad (2013).
According to Chang; Nesbitt (2006), Salvendy (2012), and Park; Alderman (2018), it is essential to consider the perceptual process in the context of developing design solutions with the purpose of informing, guiding, and reinforcing information to guide users' decision-making. As a consequence, multimodality can enhance accessibility in various contexts through different types of interactions (e.g., visual, auditory, haptic/vibrotactile, gestural, among others) W3C (2003); Ernst; Bülthoff (2004); Shimomura; Thora (2010); Freeman *et al*. (2017). Related to the context of home appliances' interfaces, the user-solution contact surfaces, can consider perception and multimodality to meet the basic criteria for accessible interaction, as it is possible to develop compatible stimuli, such as colors, textures, shapes, materials, sound stimuli, tactile stimuli, etc., that can be perceived by the audience Aguiar (2004); Iida (2005); Duarte; Carriço (2006); Ratzka (2008, 2013); Miñón *et al*. (2014); Coelho; Duarte (2011), Park; Alderman (2018).
Based on the above and following Adam (2022), it is possible to associate information processing with multimodality in the context of interaction with home appliances since it expands the interaction possibilities of people with sensory limitations with products, providing alternative and complementary means of perception for those who do not have these limitations.

2. Design process of inclusive products

When discussing about design process, it is essential to consider, in addition to the solution to be designed, the factors that motivate this development: the needs of users and the context in which they are inserted. In view of this, Norman; Draper (1986) disseminated in the Design field the term "User-Centered Design" (UCD), which was popularized as a design approach that highlights user needs in the design process Norman (1988); Maguire (2001); ISO 9241:210, ISO (2019). The process, which previously unfolded in a linear manner, over time adopted a user-centered and/or stakeholder-centric, iterative (cyclical), or participatory approach, emphasizing empathy Schlemmer; Padovani (2022).
However, considering the user in the design process is not a simple task due to various limitations in the development context Norman; Draper (1986). According to Ideo (2011), the user-centered design process is based on a strategic challenge of interpolating user desires with the technical and financial feasibility of the solution. Considering this approach, the process of listening, creating, and implementing the solution can concretely identify

field research observations, followed by compilation and analysis of the information to generate informational structures to guide the design process, resulting in alternatives and potential solutions to be tested with a group of users. Finally, the last phase aims to implement the solutions, considering feasibility, costs, and technical-design requirements *(See Figure 3)*.

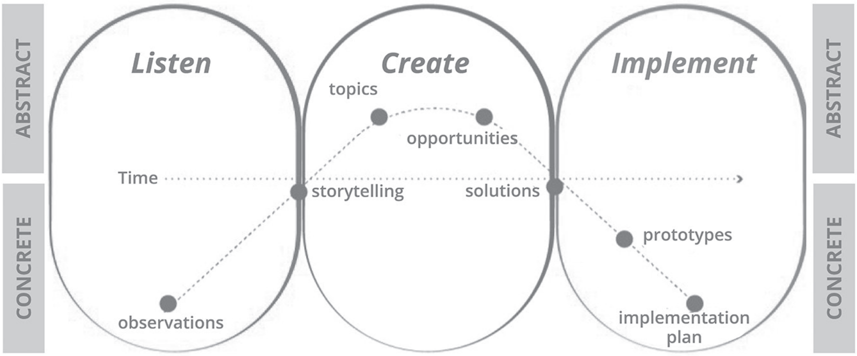

Figure 3. User-Centered Design Process (Source: Based on Ideo, 2011).

When relating the design process to the concept of Inclusive Design, it is possible, according to Clarkson *et al.* (2015), to establish macro phases that encompass the process (need, understand, define, ideate, prototype) from a non-linear sequential framework *(See Figure 4)*.

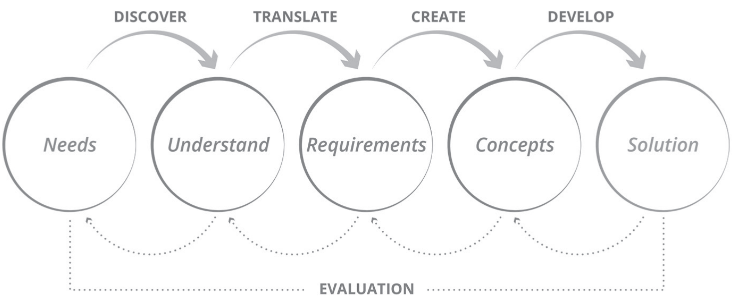

Figure 4. Inclusive Design Process (Source: Based on Clarkson *et al.*, 2015).

Iteratively, users' needs within a specific context are mapped and converted into design requirements. These provide information for defining the functional, aesthetic, and symbolic aspects of the product based on usability, accessibility, and inclusivity[2] indices. With this understanding, the creation process begins. Methods, techniques, and tools are defined to aid in converting requirements into design concepts. Solution development commences based on these definitions, aiming to make them tangible while considering current technological and market limitations and possibilities. It is suggested that all stages be evaluated with a user-centered approach to reduce informational gaps guiding product development. It's worth noting that inclusive products should not completely alter the established production scope, but their insertion and validation require process adaptations. The solution, however specific it may seem, is not exclusive. By identifying requirements and functions that meet the inclusion demand, it's possible to increase the number of benefited users, consequently expanding market demand Norman (1988); Maguire (2001); Clarkson *et al*. (2015), ISO 9241:210, ISO (2019).

3. Multimodal Interfaces

The development of physical products' interfaces goes beyond understanding user needs and platform or technological limitations. For their development, in addition to understanding the user profile, it's essential to comprehend the elements that influence its structuring, as well as how they are arranged and organized Oakley *et al*. (2000); Han *et al*. (2001); W3C (2003); Park; Alderman (2018). According to Garrett (2003), to better understand interfaces' behavior, it's possible to fragment them into five informational levels (strategy, scope, structure, skeleton, and surface). From abstract to concrete, these levels represent characteristics stemming from identified problems (strategy) and presented solutions (surface). With interdependent behavior, the levels that interpolate these extremes present design decisions that elevate the detailing of interface components, whether in functionality or informational content.
Associating this concept with the theory of multimodality, Duarte; Carriço (2006) discuss the behavior of multimodal inputs/outputs in an interface, namely, how is the behavior of visual, auditory, haptic/vibro-tactile elements can assume different functions in the interface Iida (2005); Oliveira, (2018); Qian *et al*. (2011); Turunen *et al*. (2010). *Figure 5* illustrates a relationship between the structure of an interface and the presentation of multimodal information.

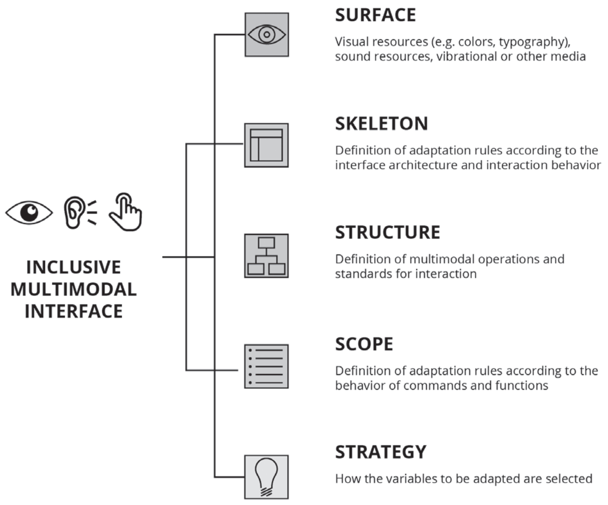

Figure 5. Inclusive multimodal interface structure (Source: Adam (2022) Based on Garrett (2003); Oviatt (2003); Duarte; Carriço, 2006).

When considering the development of an inclusive multimodal interface, and the mentioned structure, Adam (2022) in accordance with Garrett (2003), Oviatt (2003), and Duarte; Carriço (2006) comments that is also necessary to understand the elements or perceptual variables that make the interaction experience tangible. *Table 1* presents the stimuli and sensory dimensions that should be considered, from an accessibility perspective, in any interface design process.

Table 1. Stimuli and sensory dimensions (Source: Based on Park; Alderman, 2018).

Stimuli	**Dimension**	**Perceptive characteristics**
Visual	Bright	Words, images, shapes, colors, contours, movement
	Color	
	Visual	
	Visual acuity	
Sound	Frequency	*Hero sounds, synthesized voice, earcons, ornamental sounds*
	Amplitude	

Haptic / vibro tactile	Temperature	*Size, shape, orientation, position, movement patterns, frequency, amplitude, rhythm, wavelength*
	Pressure/force	
	Vibracional frequency	
	Texture	

The basic elements of visual communication, such as color, shape, dimension, and movement, are characteristics that can be represented by verbal elements (typography). According to development and design resources –About sound– Material Design Google (2020), sound elements can be designed as alert feedback and/or notifications, representing command activation, start and end of actions, errors, among others. Presentation forms vary between hero sounds (musical ringtones, expressive and playful), synthesized voice, earcons (brief sounds/'beeps'), ornamental sounds (music) as reinforcement for visual information. Meanwhile, haptic/vibro-tactile elements can be categorized according to Oakley *et al.* (2000) into touch sensation (temperature, pressure, pain) and kinesthetic (physical response to tactile stimulus – vibration, movement). These elements can be activated through different gestures, such as a single tap, double tap, two-finger tap, swipe, among others. Thus, the combination of these elements can influence Human-Computer Interaction (HCI) given the potential to represent a hierarchical structure of information, enhancing the user experience in an interaction (Han *et al.*, 2001).

Method

This study aimed to identify the potential of multimodality in the process of designing appliance interfaces from the perspective of the literature, considering the experiences of blind individuals, accessibility experts, and appliance development specialists *(See Figure 6)*.

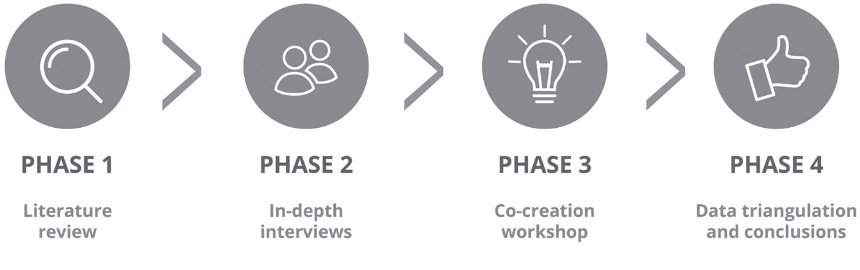

Figure 6. Methodological procedures (Source: The author, 2021).

To better understand accessibility from the perspective of multimodality, a methodological sequence was established to conduct a literature review aimed at understanding information processing considering multimodality to aid in the development of appliances under the approach of Inclusive Design Keates (2005); Clarkson *et al*. (2015); Lim (2019). Following the state-of-the-art review on the topic, interviews were conducted with blind individuals to immerse in appliance accessibility (washing machine), and finally, a co-creation workshop was conducted with accessibility experts and appliance development professionals to understand how multimodality can influence the design process to enhance appliances' accessibility. Data triangulation confirmed the potential of multimodality for developing inclusive multimodal interfaces for appliances.

Phase 1 involved a literature review, analyzing documents and publications on accessibility, appliances, and how information processing focusing on multimodality can contribute to a better perceptual experience of information from an interface. The objective of this phase was to gather information to compose a theoretical framework for the development of inclusive multimodal interfaces based on Garrett (2003), Oviatt (2003), and Duarte; Carriço (2006) *(See Table 2)*.

Table 2. Phase 1: Literature review (Source: The author, 2021).

Themes	Concepts
Inclusive Design	Universal Design, accessible design, design for all, visually impaired
Interaction Design	Usability, user experience, accessibility, interface development
Home appliances' development	Methods, techniques, and tools, design process, user-centered design
Human perception	Information processing, perceptual theories
Multimodality	Multimodal interaction, sensory compensation, guidelines and recommendations on multimodal interfaces

Phase 2 aimed to understand, from the perspective of blind individuals, the perception and information processing, as well as the user experience with appliances (focusing on washing machines). Based on in-depth interviews, personas were developed, which are fictional characters representing user behaviors in a given segment/context Martin; Hanington (2012). These personas were created to support the next phase of the research: co-creation of an inclusive process under the multimodal approach from the perspective of blind individuals using washing machines *(See Table 3)*.

Table 3. Phase 2: In-depth interviews (Source: The author, 2021).

Participant	Gender	Visual perception
P1	Female	Congenital blind
P2	Female	Aquired blind
P3	Female	Aquired blind
P4	Male	Congenital blind
P5	Male	Congenital blind
P6	Male	Congenital blind

Phase 3 aimed to conduct online workshops to map the development process of inclusive products by associating design attributes and multimodality through the theoretical framework to guide the interface development process proposed in Phase 1. From the perspective of experts and based on the creation of personas with visual impairments[3], two workshops were conducted with two distinct pairs: A and B. Each pair consisted of 1 accessibility expert and 1 professional expert in appliance development. The workshops aimed to stimulate design thinking from the perspective of multimodality and accessibility, considering the pillars of product, user, and context of use. The selected product was the washing machine, as it is an interface with high information density and inaccessible to blind individuals. The personas developed from Phases 1 and 2, representing blind users of washing machines in the domestic context, informed the dialogue between the experts *(See Figure 7).*

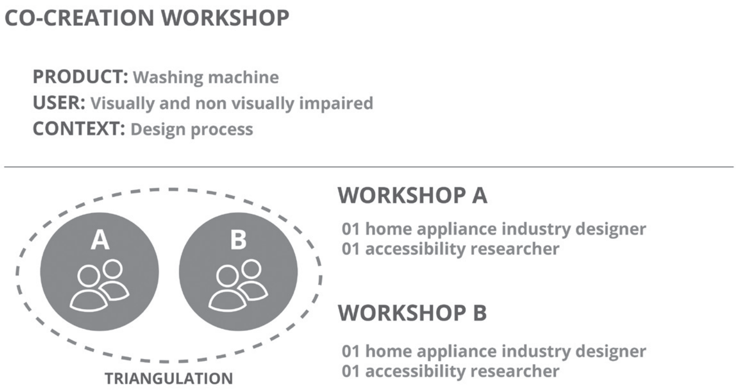

Figure 7. Phase 3: Co-creation workshop (Source: The author, 2021).

Finally, in **Phase 4**, data from the previous dynamics and phases were triangulated, identifying the potential of multimodality for the development of inclusive multimodal interfaces for appliances from the perspective of literature, blind individuals, and experts.

Results and discussion

Through the methodological procedures, it was possible to map perceptions about multimodal thinking in the design process of appliance interfaces, from the perspective of literature, blind individuals, accessibility experts, and appliance development experts. The following are the results found in each phase, aligned with the research objective.

Phase 1 - literature review: Multimodality and design process foundation
From the literature review, it was possible to identify studies that underpin the topic in question considering information processing Ernst; Bülthoff (2004); Chang; Nesbitt (2006); Salvendy (2012); Park; Alderman (2018); Sumari; Ahmad (2013). Research discussing terminologies regarding Inclusive Design (e.g., Universal Design, Accessible Design) Keates (2005); Clarkson *et al*. (2015); Lim (2019) and the User-Centered Design approach (UCD) Norman; Draper (1986) in the context of appliance interaction and development, focusing on usability, accessibility, and user experience Norman (1988); Maguire (2001); ISO 9241:210, ISO (2019) by visually impaired Han *et al*. (2001); W3C (2003); Park; Alderman (2018). Finally, studies advocating the potential of multimodal technology and exploration of individuals' perceptual abilities to foster inclusion in product, system, or service development were identified W3C (2003); Ernst; Bülthoff (2004); Duarte; Carriço

(2006); Shimomura; Thora (2010); Freeman *et al.* (2017); Park; Alderman (2018). *Table 4* synthesizes the main topics and authors mapped in the research.

Table 4. Synthesis of concepts (Source: Adam (2022).

	Concepts	Main references
TERMINOLOGIES	Inclusive Design	Keates (2005); Clarkson et al. (2015); Lim (2019)
	Universal Design	Mace et al. (1996); Shneiderman; Plaisant (2005)
	Accessible Design	IEC GUIDE 71:2001(E) - ISO (2001)
MULTIMODALITY	Interface	IEC GUIDE 71:2001(E) - ISO (2001); Oviatt (2003); W3C (2003); Caragea et al (2009); Giudice et al. (2012); Oliveira (2018); Park; Alderman (2018); Khan; Khusro (2019); Hussain et al. (2019)
	Development/ design	Aguiar (2004); Iida (2005); Duarte; Carriço (2006); Shimomura et al. (2010); Ratzka (2008, 2013); Miñón et al. (2014); Coelho; Duarte (2011)
	Perception, sensory compensation	Ernst; Bülthoff (2004); Iida (2005); Körding et al. (2007); Spence (2011); Sullivan; Sahasrabudhe (2017)
ACCESSIBILITY, USABILITY AND USER EXPERIENC	User-Centered Design	Norman; Draper (1986); Maguire (2001); Merino (2016); ISO 9241:210 (ISO, 2019)
	Home appliances'perspective	Han et al. (2001); Aguiar (2004); Fagundes (2015); Osisanwo et al. (2015); ISO 20282-1 ABNT (2016); ISO 9241-171, ABNT (2018); Oliveira (2018); Park; Alderman (2018)
	Usability and user experience	Maguire (2001), Krippendorff (2005); Cybis et al. (2010); ISO 9241-11 ABNT (2011b); ISO 9241-210 ISO (2019)
	Interaction Design	Norman (1988); Mace et al. (1996), Nielsen (1994) e Shneiderman; Plaisant (2005), Rogers et al. (2013) Shaer (2009)
	Accessibility of interaction (visual impairment)	Shimomura et al. (2010); Turunen et al. (2010); Coelho; Duarte (2011); Raposo 2015); ISO 9241-171 ABNT (2018); W3C (2003); Oliveira (2018); Khan; Khusro (2019)

The literature review identified gaps regarding accessibility in appliances Aguiar (2004); Turunen *et al*. (2010); Coelho; Duarte (2011); Rezende (2014); Fagundes (2015); Raposo (2015); Oliveira (2018) and the lack of a systematized process guiding the development of these solutions based on knowledge of inclusive design and multimodality processes.
However, it provided theoretical support regarding concepts of accessibility, inclusive design, and Universal Design Keates (2005); Clarkson *et al*. (2015); Lim (2019), aligning with the use of multimodal technology for the development of physical product interfaces W3C (2003); Aguiar (2004); Ernst; Bülthoff (2004); Duarte; Carriço (2006); Shimomura; Thora (2010); Freeman *et al*. (2017); Park; Alderman (2018) and how it assists in information perception by individuals with different sensory abilities Ernst; Bülthoff (2004). These themes complement the experience and usability of appliances by considering the user (and their sensory abilities) for the development of more accessible and inclusive solutions Maguire (2001); ISO 9241-210 ISO (2019).
From this phase, it was possible to identify significant potential in exploring senses and providing complementary information to visual cues, such as auditory and tactile. This information was related to the structure of an inclusive multimodal interface based on Garrett (2003), Oviatt (2003), and Duarte; Carriço (2006) to contribute, alongside Phase 2, to a theoretical framework for the development of inclusive multimodal interfaces in appliances, serving as a guide for Phase 3: co-creation workshop.

Phase 2 – in-depth interviews: personas
The in-depth interviews mapped the strategies that blind users employ to minimally use appliances, focusing on washing machines. The interviewees contributed potential improvements for accessibility that can be integrated into the development process of washing machines as well as new products in general Adam (2022). Through this data collection technique, it was possible to confirm the lack of accessibility in most appliances, which limits or hinders their use with total autonomy and independence by this user profile. The basic elements of visual, auditory, and tactile communication that influence HCI lack accessibility and directly impact the inclusive experience Oakley *et al*. (2000); Han *et al*. (2001); W3C (2003); Park; Alderman (2018):

- Lack of accessible manuals or instructions;
- Complexity of the interface;
- Touchscreen displays;
- No tactile or auditory indication of positioning and function description;
- Overly sensitive touch buttons (immediate activation);
- Error prevention.

To overcome the lack of accessibility, according to Adam (2022), interviewees mentioned the following strategies:

- Asking for assistance from a sighted friends/ family to explain the interface and basic usage of the product;

- Assistance in affixing labels indicating main buttons (Braille or raised markings);
- Memorizing the sequence of basic or commonly used interactions (e.g., number of taps on each button);
- Memorizing the minimum functions to at least be able to turn off the product in case of emergency.

Possible accessibility solutions for the product align with the use of technology and artificial intelligence, providing speech feedback, voice commands, integration with accessible connected applications, and presenting visual information in a complementary manner, either through auditory or tactile means Oakley *et al*. (2000); Han *et al*. (2001); W3C (2003); Park; Alderman (2018); Adam (2022). Thus, the issues raised in the interviews directed the creation of personas *(See Table 5 and Table 6)* to represent visually impaired individuals (blind), their behaviors, and strategies performed during the laundry activity precisely to identify which design choices can provide a more accessible user experience Martin; Hanington (2012).

Table 5. Personas: Lucia-characteristics of blind washing machine users (Source: Adam, 2022).

Lucia: Totally blind. Lives with his mother. He is responsible for washing the clothes, but needs the help of other people to sort them. It has a front-load washing machine	
	- **Likes the auditory alerts**: *"The auditory alerts are good, I can tell when it's done, turned on, selected."* - **Dislikes the interaction mode**: *"I usually only use the quick wash function because I find the washing machine complicated - I have to press a sequence with 4 buttons, and if I make a mistake, I have to turn it off and start again."* - The washing machine has a rotary dial for selecting the wash program, but the sensitivity of the dial is not very sharp, and sometimes she is unsure if she has activated the function or not, so she chooses to use what she has already learned (button sequence). *"If the machine could speak or had the option of voice command interaction, that would be interesting. If it had Braille on the buttons, that would be interesting, but I would like a smart machine, with remote control or interaction via Alexa or Google platform."*