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Applications for the social inclusion of people with disabilities and reduced mobility: A systematic literature review

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ABSTRACT
Information and Communication Technology (ICT) can potentially enhance the independence of people with disabilities using mobile applications. Comparing the results of various applications in the literature can be challenging. This systematic literature review reveals the development of applications on mobility, spatial orientation, obstacle prevention, and access to urban information. The findings highlight the complexity involved in the development and the relevance of these tools in promoting the independence of users with disabilities, as well as collaborative efforts. Developing such applications is a complex task due to the heterogeneity of the end-users, requiring the identification of the necessary resources for each group. Innovations in modifying the urban environment allow everyone to enjoy life in the city. Conclusion: Social inclusion demands collaborative action from professionals from diverse fields, the general population, and the government in developing applications that meet the needs of all.

Keywords: Mobile Device, Application, Assistive Technology.

1 INTRODUCTION

The global population of individuals aged 60 years and older has doubled since 1980, and it is projected to reach 2 billion by 2050 [1]. People with disabilities account for approximately 650 million individuals, representing 15% of the world's population. Consequently, public authorities are striving to implement policies that effectively and adequately serve this segment of the population. By 2025, it is anticipated that 5.9 billion, or 71% of the world's population, will have access to mobile services. Information and Communication Technology (ICT) comprises a suite of integrated resources employed in various sectors, including education. ICT, particularly through mobile applications, has the potential to enhance the independence of individuals with disabilities [2].

A mobile application (App) is a program designed for mobile devices, tailored to execute specific functions. Mobile device-based assistive technology, featuring Apps, can significantly enhance autonomy and overall quality of life for individuals with disabilities and the elderly [3]. The interactions and collaborations of experienced users can further assist others, thereby fostering the creation of new services and tools capable of addressing the accessibility and information challenges arising from shared data [4].

The existing body of literature contains numerous research studies focused on developing mobile Apps catering to individuals with disabilities or limited mobility. Nevertheless, comparing the outcomes across different platforms and applications is challenging. A Systematic Literature Review (SLR) has been conducted with a specific focus on mobility, spatial orientation, obstacle prevention, and access to urban information.

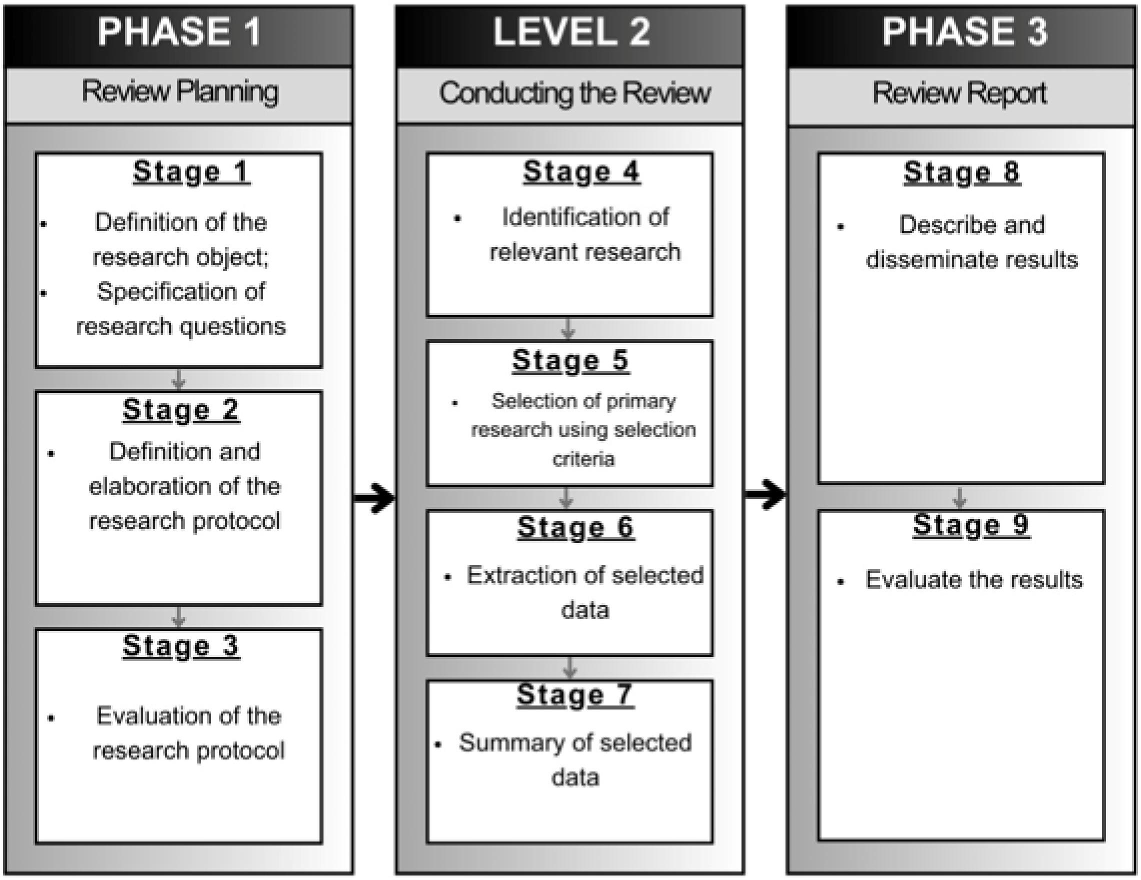
2 METHODOLOGY

In this Systematic Literature Review (SLR), three research questions were delineated to guide the inquiry:

1. What technologies have been employed in mobile applications designed to assist individuals with disabilities or reduced mobility?
2. What were the challenges encountered during the development of these applications, and what solutions were implemented to address them?
3. In what manner has the collective collaboration system been harnessed in the development and maintenance of these applications?

Following the methodology devised by Brebeton, the SLR was partitioned into three distinct phases: planning, execution, and the compilation of the review report (Figure 1) [5]. These phases offer a comprehensive framework for conducting the review, enabling a systematic and rigorous approach to sourcing and analyzing relevant literature concerning the development of mobile applications for individuals with disabilities or reduced mobility. They also ensure that the review is carried out transparently and thoroughly documented, facilitating the presentation of reliable and pertinent outcomes.

Figure 1 – Phases of the Systematic Literature Review



Source: The authors

In Phase 1 of the systematic literature review (SLR) planning, a research protocol was established to delineate the search criteria for studies published in the English language between 2008 and 2021. The search was conducted across the following databases: Scopus, SpringerLink, ScienceDirect, and the Integrated Digital Library of the Institute of Space Technology, using specific search strings.

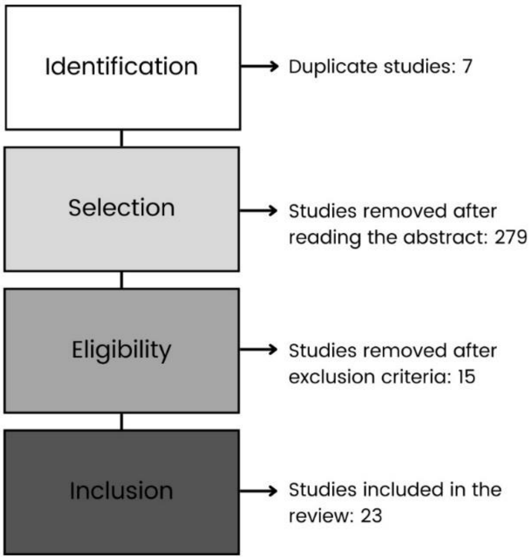
Phase 2 of the SLR execution comprised four stages: identification, selection, extraction, and synthesis of studies. In this phase, relevant studies were identified through the search process, repeated studies were excluded, and those meeting the inclusion criteria were selected.

Phase 3 entailed the synthesis of the selected studies to address the research questions. In the study selection process, inclusion and exclusion criteria were defined. Excluded were studies lacking data to address the research questions (such as editorials, abstracts, book chapters, and studies presented at events), and only primary studies that underwent peer review and fully or partially addressed the research questions were selected.

3 RESULTS

A total of 23 studies were selected to form the SLR. Figure 2 illustrates the study selection process based on the inclusion and exclusion criteria established in the protocol. Across all databases, an initial set of 324 studies was selected, of which 7 were excluded due to duplication in more than one database. Following the review of titles and abstracts, 279 studies were excluded in adherence to the exclusion criteria. The remaining studies were examined in their entirety, and after this step, an additional 15 studies were excluded.

Figure 2 – Studies Selection process

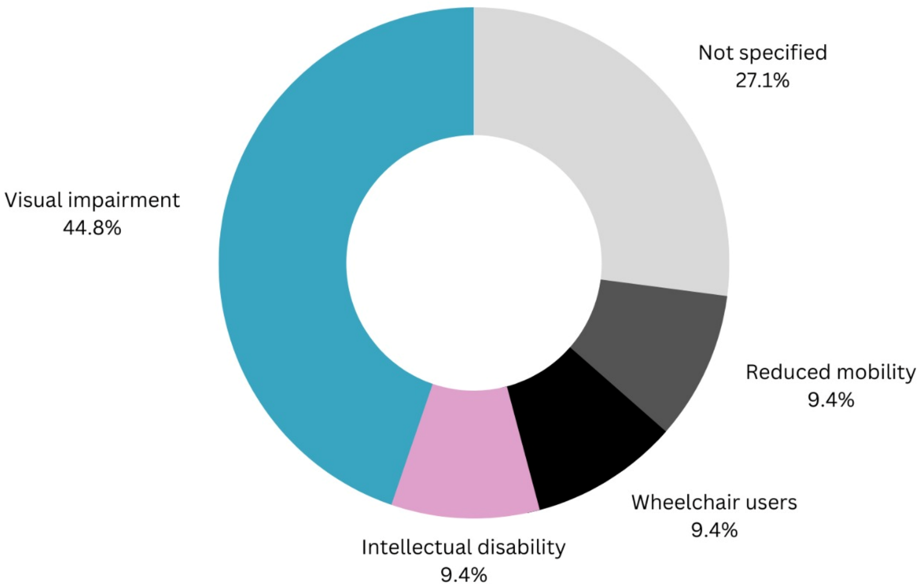


Source: The authors

The preliminary results of the search on the Scopus database using the search strings "(TITLE-ABS-KEY (application or app or 'mobile app' or health) AND TITLE-ABS-KEY (collaborative or collaboration or crowdsourcing) AND TITLE-ABS-KEY ('assistive technology' or 'assistive devices' or devices or 'adaptive technology') AND TITLE-ABS-KEY(Accessibility) WITHIN ARTICLE" returned 102 studies, with only 1 selected for inclusion. The search on SpringerLink with the search strings "(TITLE-ABS-KEY (mobile or smartphone) AND TITLE-ABS-KEY (collaborative crowdsourcing) AND TITLE-ABS-KEY ('assistive devices' or 'people with disabilities' or disabilities) WITHIN ARTICLE" yielded 49 studies, of which 6 were selected. The search on the ScienceDirect database with the search strings "(FIND ARTICLES WITH THESE TERMS (smartphone and 'people with disabilities' or 'assistive technology' and collaborative)" resulted in 53 studies, with 7 of them being selected. The search on the Integrated ITA database retrieved 120 studies, with 9 being selected. The applied search strings were: "('assistive devices' or 'people with disabilities' or disabilities) AND (mobile or smartphone or app) AND (collaborative or crowdsourcing or crowdfunding) AND (orientation or mobility) AND ('assistive technology' or 'assistive devices' or devices or 'adaptive technology')." In this database, the option "Peer-reviewed articles only" was selected.

Out of the 23 studies selected for the SLR, the results provided insights into the development of applications for individuals with various types of disabilities: visual (10), mobility impairment (2), cognitive disabilities and the elderly (3), wheelchair users (2), and 6 articles did not specify the type of disability (Figure 3). Six of the devices were designed for indoor environments, 11 for outdoor environments, and 6 for both outdoor and indoor environments. Table 2 outlines the objectives of the selected applications.

Figure 3 - Types of Disabilities Investigated in the App Development Studies



Source: The authors

Table 2 – Objectives of the selected applications

Objective	Reference	Application
Monitorem	[6] [9]	Ecaalyx
Mobility	[7]	PERCEPT
Orientation	[1] [8] [11] [13] [14][17][24][26-27]	IMAGO, ZebraRecognizer, All-SMAII
Information	[10][15]	SoNavNet, Ebsar
Assistance	[12]	-
Informação	[15-16][18-23]	SIMON, GAWA, AR Application
Auxílio	[18-23]	
Transporte	[25]	Tiramisu

Source: The authors

3.1 WHAT TECHNOLOGIES HAVE BEEN EMPLOYED IN MOBILE APPLICATIONS TO ASSIST INDIVIDUALS WITH DISABILITIES OR REDUCED MOBILITY?

In this study, 12 studies were identified regarding orientation and navigation systems for drivers. Although the Global Positioning System (GPS), a satellite navigation system launched in the 1990s, is widely used for smartphone navigation, it remains inaccurate in rural areas and indoor locations. However, other systems are available and were identified in the SLR as technologies for the location and orientation of people with disabilities.

The PERCEPT app [7] allows independent access for visually impaired individuals to public health facilities. The system includes a glove with a microcontroller, RFID reader and tags, antenna, Bluetooth chip, buttons, speakers, rechargeable batteries, and a power regulator. Tags are strategically placed, and the glove allows the user to scan them, sending the data to the microcontroller via Bluetooth. Navigation instructions are provided in audio through a text-to-speech converter system. In a smart city, smart mobility is essential for daily life, providing information about transportation, urban barriers, facilities, pedestrian pathways, and travel planning. The Smart Mobility for All (SMAll) system [24] is an urban mobility service management platform that tracks the real-time position and availability of trains, buses, subways, bicycles, and shared cars. It also allows user collaboration through crowdsourcing.

Internet of Things (IoT) technologies provide tools to include citizens in smart cities, such as the AR Application interactive system [22]. This system allows wheelchair users to shop and navigate independently, privately, and autonomously by digitally interacting with physical items on store shelves. Interaction methodologies include product selection, information retrieval, location, indoor navigation, and shopping. The system interface is designed in HTML5 using the Jquery and Javascript libraries, with access to a database through web services periodically updated by the RFID system. Web interfaces provide real-time information on the presence and location of products on store shelves, thanks to real-time inventory updates.

Accessibility and mobility are fundamental issues in both indoor and outdoor environments, especially for people with disabilities. The GAWA app was developed to facilitate access for people with disabilities to information in indoor and outdoor environments via smartphones [27]. The app includes content management services, mobile information and navigation, wayfinding, search, and the evaluation of various orientation systems for defining routes for a given trip. Wayfinding is crucial to improve the orientation of visually impaired individuals in unfamiliar locations and complex environments, such as urban centers, health units, education facilities, and transportation installations.

As architectural environments become more complex, people need visual cues, such as maps, directional signs, and symbols, to help them reach their destinations. Currently, smartphone cameras allow the use of visual techniques, such as Simultaneous Localization and Mapping (SLAM), to create apps that assist people with disabilities in locating and navigating in public places. Visual SLAM (vSLAM) uses the smartphone camera as an input source and calculates the 3D geometry of the explored environment. This method provides a much higher positioning accuracy than that achieved by GPS sensors. The IMAGO app uses vSLAM and has an average location error of 0.51 meters when compared to the average GPS error of 34 meters.

The SIMON app [24] contributes to improving access for people with disabilities to public parking spaces. The system uses mobile technologies that integrate solutions to support user identification on existing city parking meters, preserving citizen privacy. Two tags have been physically incorporated into the system, one Near Field Communication (NFC) tag with electronically written user identification, and an adhesive tag with a QR code (QR-Code) containing user identification. The NFC tags contain a magnetic induction reading chip that can be read through mobile phone cameras. The smartphone camera reads user identification through these tags, which must be affixed to the windshield of the parked car. This system should be used both by the user and by parking controllers to check the validity of the card or any other relevant system information on the tags affixed to the car windshield.

Brock et al. [13] compared the usability of a classic tactile line map with an interactive multitouch screen map with tactile lines and audio output. The test involved 24 visually impaired participants and showed that replacing the Braille system with a simple audio-tactile app significantly improved user efficiency and satisfaction. Although tactile maps are a traditional tool used by visually impaired individuals to navigate urban environments, they are not automatically updated. An alternative approach is the use of Voluntary Geographic Information (VGI), an open-source system that provides updates on local infrastructure and can be used in conjunction with an audio, text, and email system. These evolving technologies and apps aim to improve the accessibility and mobility of people with disabilities in urban environments, offering innovative solutions to assist them in achieving independence and autonomy.

The ZebraRecognizer mobile application [17] was developed to assist individuals with visual impairments in recognizing pedestrian crosswalks. The system is based on the ZebraX application and comprises three main modules: Navigator, Logic, and ZebraX. The Navigator module transmits audio instructions to guide the user along the crosswalk, while the Logic module calculates these guidance instructions. The ZebraX module receives the crosswalk's position, recognizes pedestrian crosswalks, calculates the safest path, and provides audio feedback to guide the user. ZebraRecognizer utilizes image processing capabilities to remove projection distortions and enhance recognition accuracy.

Sendra et al. [9] proposed an intelligent collaborative system based on sensors integrated into mobile devices to monitor the well-being of individuals with reduced mobility or elderly people. The application utilizes a smartphone equipped with various sensors and transducers, including proximity sensor, light sensor, acoustic sensor, microphone, compass, gyroscope, accelerometer, barometer, GPS locator, among others. The system collects information such as falls, changes in position, and levels of sunlight to monitor the individual's status.

The assistive technology device [27] was developed to assist pedestrians with visual impairments in navigating external environments independently, safely, and efficiently. This device utilizes the positioning and computing capabilities of a wearable touchscreen integrated with a smartphone to locate and guide users in urban settings. It employs a GPS sensor and a haptic device embedded in a shoe to ensure accurate positioning, tracking, and guidance. The device complements the use of white canes or guide dogs, providing a comprehensive mobility solution for blind pedestrians and individuals with visual impairments in urban environments. Navigation instructions are transmitted via Bluetooth. The electronic module is an embedded system equipped with an ATMEL-ATtiny2313 microcontroller that translates instructions into actuator commands and transmits them to the tactile display. A tactile feedback module located in the shoe provides tactile cues to the user's foot, delivering the necessary navigation instructions to reach the chosen destination. The device's interface is innovative, as it provides tactile feedback to the user, enhancing the intuitiveness and efficiency of navigation.

3.2 WHAT DIFFICULTIES HAVE BEEN ENCOUNTERED IN THE DEVELOPMENT OF THESE APPLICATIONS, AND WHAT SOLUTIONS HAVE BEEN IDENTIFIED?

People with disabilities represent a highly diverse group, making it challenging to develop specific solutions for individuals that can also be viable for others. Considering the wide variety of existing platforms, developing systems for mobile devices is a complex task. Mobile devices possess specific characteristics such as screen size, resolution, the presence or absence of a keyboard, format, and various technologies employed, which vary with the level of hardware and software. These differences raise an additional concern regarding the means of delivering and presenting content to mobile users in an accessible manner [28].

When it comes to data sharing in applications, several limitations were identified in terms of collaboration for individuals with disabilities in public road mobility. The rapid obsolescence of this data is a recurring issue due to factors like inadequate public road maintenance, emergency evacuations, and congestion resulting from irregular events such as parades or festivals [10]. Another limitation is the difficulty in obtaining sufficient participation from external sources and relevant data on mobility and orientation, as well as the qualification of data contributors to assess routes for different disabilities [23]. While it is common for groups to share information on barrier-free routes in applications for people with disabilities, it is essential to note that individuals with mobility impairments constitute a highly heterogeneous group with varying physical or functional characteristics, ages, and specific transportation needs that are often not met by available applications [23].

The issue of users' different age groups is also a complex problem since teenagers, adults, and elderly individuals with disabilities have grown up in different times with varying levels of acceptance of mobile device-based systems [26]. However, it is crucial that the response to overcoming accessibility barriers meets the specific needs of each end user after identifying the requirements for each user type.

To provide a service to a target group that usually lacks familiarity with technology, a continuous and autonomous mobile platform is essential for efficient operation, such as alert generation [6]. It is also vital for the system to use different sensory channels, such as visual, auditory, and tactile, to make information delivery accessible to all users, regardless of age, disability type, or user sensory preference [1].

A study evaluating an application targeting visually impaired individuals found that 40% of participants encountered difficulties in understanding synthetic voice and following the application's instructions [7]. Therefore, it is essential to consider that in certain circumstances, an excessive use of audio messages can distract the user, harming the application's usability. It is crucial that the application provides alerts only for essential information, such as the proximity of vehicles, cyclists, and pedestrians, for instance [17]. Additionally, navigation information must be clear and intuitive [8]. It is essential to emphasize that regarding tactile maps, information overload can impair readability, becoming confusing and hindering the user's perception [13].

In a practical test with an application for visually impaired individuals, all participants preferred the combination of an auditory and tactile guidance system [1]. In response to the difficulties encountered by users of the PERCEPT application, modifications were made to the system to include proximity information in step-by-step guidance, provide instructions for users with guide dogs, allow adjustments to the application's voice rhythm, and offer short or abbreviated instructions, such as "turn left" or "turn right" [7]. To ensure the accessibility of interfaces for different users, it is essential to provide alternative media features that can cater to specific interaction needs. Digital resource description information models can help balance system features and individual user needs, enabling access for all users [29].

Mobile devices with location recognition technology have the potential to collect, store, and disclose an abundance of confidential data, raising security and privacy concerns [8]. [16] addresses two main challenges: reducing cyberfraud in system implementation and proposing a specific multimodal navigation solution for the elderly and individuals with disabilities. Both cases require extensive integration of multiple databases with personal information collected. Therefore, a viable solution for the project would be the implementation of a proven methodology to preserve data privacy and authenticate users.

A study by [22] on individuals with reduced hand mobility, the elderly, and individuals with brain damage concluded that wheelchair users felt more comfortable with smartphones than tablets because handling a tablet in a wheelchair is challenging, and a smartphone can be operated with one hand. User interfaces can be designed with large fonts, buttons, and images, facilitating application usability [22].

GPS systems are often used for pedestrian navigation, but they suffer from inaccuracies, especially in rural areas where navigation is typically needed more [14], and weak signals in enclosed spaces such as museums or facilities where access points are weak or obstructed [24]. Furthermore, GPS does not determine the user's location within a building [15]. Some location and orientation technologies are used to replace or complement GPS functions: infrared light, photographic camera, Bluetooth, Zigbee, Location Based System (LBS), and IoT [22]. The use of the accelerometer and compass for user tracking, as employed by the Ebsar mobile device, has proven to be superior and more available than GPS tracking, which requires a wireless connection to function. To enhance accuracy, the application uses location markers as checkpoints to ensure that even in cases of deviation from the path and accelerometer and compass failures, a scanned digital QR code allows the system to adjust the user's location and continue guiding them [15].

To enhance the functionalities of tools, several improvements should be planned for the short and medium term, combining various services and technologies available to enhance the quality of applications [29].

3.3 HOW HAVE COLLABORATION SYSTEMS BEEN UTILIZED IN THE DEVELOPMENT AND MAINTENANCE OF THESE APPLICATIONS?

The following systems have been identified: information exchange via applications among end users; collaboration of formal and informal caregivers; sharing experiences through social media; and collaboration of volunteers with and without disabilities [6, 10, 12, 20, 21, 25-26]. Smart cities represent a broad and integrated approach to improving the efficiency of a city's operations, the quality of life for the population, and the regional economy. One crucial dimension is enhancing the quality of life for people with disabilities who often face inequalities in accessing government-provided facilities. Collaboration among various stakeholders is essential for the city's design, processes, and improvements. Communication between the population and government institutions is fundamental to this. As [31] emphasizes, communication systems form the foundation of collaborative systems, enabling different people to act together towards a common goal.

In the field of travel and tourism for people with disabilities, applications can be used to provide personalized and suitable information for tourists, including the ability to know in advance if their needs can be met at their intended destination. Furthermore, the opinions of other tourists with similar needs can be used to improve the system and the accuracy of the information and recommendations provided. The study [23] highlights that these recommendations are a way to enhance the travel experience for people with disabilities. A collaborative approach that aims to capture feedback on sidewalk information in public roadways, such as slope, width, length, damages, among other parameters, can be adopted by wheelchair users. In this research, end users share and exchange experiences by following the route suggested by the application to reach their destination. During the walk, the user is queried about the sidewalk quality through the application, and the collected feedback is incorporated into a database. This database is periodically adjusted to provide other users with a more satisfactory route [20].

The SoNavNet application is a collaborative and user-experience-based approach through communication on social media platforms. This platform enables people with disabilities to find suitable routes that meet their needs in outdoor and indoor environments [10]. Additionally, customers have instant access to information about barrier-free vehicles, driver ratings, driving routes, estimated arrival times, discount information, cost estimates, and travel records, and they can share their experiences and information through social media platforms [26].

The orchestration of microservices results in a workflow in which crowdsourcing and crowdsensing assist in user planning, travel, and reporting phases, considering their needs and preferences. Crowdsourcing is a production and process structuring model that uses collective wisdom and insights to solve problems or develop solutions. Crowdsensing occurs when a large group of individuals with mobile devices collectively detect, compute, and share data and extract information to measure, map, analyze, estimate, or infer any common processes of interest. Through these microservices, users can fill datasets related to their points of interest, such as monuments, public service stops, parks, historical sites, among others. They can also collaborate by providing information about accessibility points of interest, such as barriers, stairs, urban facilities, gaps, obstructions, etc. Crowdsensing functions automatically with the acquisition of various types of information and sources, including real-time GPS and access point information. This information is gathered to generate notifications about route availability, streets, and public service schedules [30].

The Wayfinding application has functionality for sending messages to users about physical barriers, such as trash bins or crosswalks. To provide information to visually impaired users, the best combination found was auditory and tactile feedback. When tactile feedback is provided, the application vibrates at a specific rhythm, alerting the user when they are walking in the correct direction. If the user is close to their destination, the smartphone vibrates at a faster pace to signal their location [1].

A study aimed to increase interaction between end users and formal and informal caregivers through collaboration and tutorials for caregivers [12]. The discussion and interaction helped both the elderly and people with disabilities as well as caregivers to learn from each other, share experiences, and communicate. In this regard, collaboration can go beyond the exchange of information among people with disabilities, including doctors and other healthcare professionals [6].

The Tiramisu application was developed to improve urban mobility through crowdsourcing, allowing passengers with or without disabilities to share location and transit data on their smartphones

[25]. It offers users the ability to indicate bus boarding, whether the bus has passed, or whether it was crowded to board, through a pop-up dialog box. When indicating that they are boarding a bus, users choose a destination stop and evaluate the bus's crowding upon boarding, selecting "record" to share a location tracking. The application automatically stops sharing location information when the vehicle reaches the desired stop. To enhance the system's efficiency, it is expected that other experienced users will provide route recommendations to users in a specific manner. However, it is possible that the system may not find the optimal route when only inexperienced users or users with disabilities are considered. To mitigate potential feedback errors, a combined approach was proposed, where the path suggested by the application is not based solely on the feedback of inexperienced users or users with disabilities. A mitigation coefficient based on the user type was included in the system [19].

A case study with five applications investigated how users, including the elderly, wheelchair users, visually impaired individuals, and volunteers without disabilities, collaborate in providing environmental accessibility information [21]. Individuals from different user groups exhibited distinct behaviors when collaborating on accessibility information. On the other hand, volunteers without disabilities had some limitations in identifying environmental accessibility issues.

4 CONCLUSIONS

The present Systematic Literature Review (SLR) aimed to analyze studies on the development of assistive technology based on mobile devices. The results emphasize the complexity involved in the development of these applications and underscore the significance of mobile applications in promoting the independence of users with disabilities, as well as understanding the importance of the collaborative aspect of these tools. This kind of development is a complex task due to the heterogeneity of end users.

The challenges of accessibility that society currently faces are more pronounced in urban areas. It is of utmost importance to differentiate between the resources needed for each group since each individual has specific needs and preferences. The application of technological mechanisms can yield positive outcomes in social inclusion and the daily lives of individuals with disabilities. The results of this SLR can guide professionals in projects aimed at developing applications for people with disabilities, not only by identifying challenges but also by describing solutions found by researchers. This can serve as guidance for defining the functional requirements of applications based on end-user needs.

Demonstrating a commitment to innovation in urban environment transformation allows all individuals, including those with disabilities, to fully enjoy city life. The inclusion of these individuals is a complex task that necessitates collaborative action from professionals across various fields, the population, family members, and governmental authorities.

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