SMART ACCESSIBILITY 2024

The Ninth International Conference on Universal Accessibility in the Internet of Things and Smart Environments

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SMART ACCESSIBILITY 2024

Forward

The Ninth International Conference on Universal Accessibility in the Internet of Things and Smart Environments (SMART ACCESSIBILITY 2024) was held between May 26th and May 30th, 2024, in Barcelona, Spain.

There are several similar definitions for universal accessibility, such as design for all, universal design, inclusive design, accessible design, and barrier free design. These and similar approaches are relevant to this conference. The focus will be on methods, tools, techniques and applications for human diversity, social inclusion, and equality, enabling all people to have equal opportunities and to participate in the information society.

The accepted papers covered topics such as accessibility by design, digital inclusion, accessibility devices, and applications. We believe that the SMART ACCESIBILITY 2024 contributions offered a large panel of solutions to key problems in areas of accessibility.

We take here the opportunity to warmly thank all the members of the SMART ACCESSIBILITY 2024 technical program committee, as well as all the reviewers. The creation of such a high-quality conference program would not have been possible without their involvement. We also kindly thank all the authors who dedicated much of their time and effort to contribute to SMART ACCESSIBILITY 2024. We truly believe that, thanks to all these efforts, the final conference program consisted of top-quality contributions. We also thank the members of the SMART ACCESSIBILITY 2024 organizing committee for their help in handling the logistics of this event.

We hope that SMART ACCESSIBILITY 2024 was a successful international forum for the exchange of ideas and results between academia and industry and for the promotion of progress in the field of universal accessibility.

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Analysis of Accessibility in Medical Devices in Health Technology Management

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***Abstract*— The availability of an affordable medical device is critical in the provision of healthcare to ensure that technology is not a barrier for users. It is essential to understand the accessibility issues present in medical devices to serve the diverse population of patients with varying limitations, abilities and disabilities. With the aim of promoting and discussing the impacts of accessibility in medical devices, this project aims to analyze accessibility problems in medical devices. A rapid review of the literature was prepared and a model for applying usability methods throughout the life cycle of health technologies was proposed to establish strategies to improve accessibility and mitigate risks. This work found a large number of accessibility problems involving different types of medical devices, as well as the lack of accessible technologies in healthcare environments. Different actions to provide a more inclusive and accessible health technology management throughout the life cycle were proposed, such as incorporating user-oriented development, training and development of standard operating procedures.**

Keywords-Accessibility; Medical Devices; Health Technology Management.

I. INTRODUCTION

The availability of an affordable medical device is critical in the provision of healthcare to ensure that technology is not a barrier to users [1]. To achieve the benefits for which the medical device was developed, it requires a safe and reliable technology-user interaction, so that errors in use by users do not cause harm, compromising the health of the population [2]. Therefore, a combination of human-centered project development, ergonomics, and accessibility tools, is necessary to ensure a high quality use of technological resources [3].

Considering accessibility aspects in the development of health technologies is essential to ensure inclusion and improve usability. Accessibility is defined in ABNT NBR 17060:2022 as follows: accessibility on mobile devices consists of the scope in which products, systems, services, environments and facilities can be used by people from a population with the widest variety of characteristics and capabilities, to achieve a specific objective in a specific context of use [4]. Incorporating usability into the projects aims to expand the target population, making technologies accessible to more people in different contexts of use [5]. In Brazil, the population with disabilities was estimated at 18.6 million (considering people aged 2 and over). The number corresponds to 8.9% of the population in this age group [6]. In the world, this number is estimated at 1.3 billion, representing 16% of the world's population [7]. According to law Nº. 13.146, of July 6, 2015, which establishes the Brazilian law on the inclusion of people with disabilities, every person with a disability has the right to equal opportunities with other people and will not suffer any type of discrimination. In addition, people with disabilities are being guaranteed comprehensive health care at all levels of complexity, with universal and equal access [8].

However, people with disabilities often do not have the opportunity to receive quality healthcare and sometimes have access to insufficient healthcare [9]. As technologies are increasingly present in healthcare, and are incorporated to assist users in their safer and more reliable use, consideration of accessibility aspects in technological development becomes a fundamental requirement to achieve the usability of a product [2]. Incorporating principles and methodologies considering usability and accessibility must be strategic business objectives, being essential to optimize performance, minimize undesirable consequences for human beings, maximize the well-being of the entire organization and improve relationships with customers [5].

The tool used to evaluate human interaction with a product is usability, and its consideration in health is fundamental and useful for evaluating the user experience [10]. Usability is a metric used to measure how much a product can be used by certain users and achieve specific objectives, when considering parameters such as effectiveness, efficiency and satisfaction in a context of use [11]. For a product or process to have good usability, it is necessary to consider different parameters and measure them with the intended users, such as effectiveness, efficiency, satisfaction, use, learning and accessibility. Accessibility is determined by the ease of access to the products necessary to complete the objective by people with the widest variety of capabilities [5][12]. When considering accessibility, it allows clarity and simplicity in design for people who may temporarily have some limitations or those who have them permanently [12].

The development of a product or service centered on the user's needs and perspective, integrated with their context and tasks, is called User-Centered Development [13]. It consists of an approach to developing usable and useful systems in an interactive way, with an emphasis on users when considering their needs, through the incorporation of ergonomic knowledge and techniques. There is a diversity of usability methods that aim to support human-centered design, used to increase the usability of a product or system, which can be used in both design and evaluation. Some methods consist of: user observations; questionnaires; critical incident analysis; interviews; think out loud; document-based methods, among others [14]. Accessibility must be included as part of the human-centered project, so that it can expand the population that can use technologies effectively, efficiently and satisfactorily, and consequently, increase usability for all users [5].

Healthcare accessibility is essential in providing medical care to people with disabilities. Due to barriers, individuals with disabilities are less likely to receive routine preventative medical care than people without disabilities. Accessibility is not only required by law, but is also crucial for the inclusion of all people in the use of health technologies [1]. Work involving accessibility in medical equipment reinforces the problems surrounding technologies, as presented in the research conducted by Story et al., which showed harm to people with disabilities when using scales, examination tables and diagnostic imaging equipment [9]. Other equipment and description of accessibility problems will be presented in this article in section III.

Due to the importance of considering accessibility to ensure the inclusion of all people in the use of medical equipment, this work aims to carry out a rapid review of the literature in search of evidence as well as provide a model for incorporating in Health Technology Management.

The rest of the article is structured as follows. In Section II, we discuss the methodology used in the research. In Section III, the results are elucidated. In Section IV, we discuss the results found. Section V concludes the work with a summary and future research directions.

II. MATERIALS AND METHODS

This work was conducted in two stages. The first phase consists of the rapid literature review and the second phase consists of the proposal for a model that incorporates accessibility tools into the life cycle of a medical device in order to contribute to the safe management of health technologies. To explore accessibility in medical devices and discuss the contribution of Clinical Engineering to making healthcare environments more inclusive, a rapid review was carried out in the literature, which consists of a reliable and systematized methodology to synthesize knowledge. This approach is used when steps in the process of a systematic review are simplified to produce information from the selection of research that is available in the literature, and that is relevant to a study topic [15]. The constant increase in the amount of research carried out in the literature requires the implementation of an approach to evaluate published studies and contribute to decision-making, and thus provide an updated summary of the state of knowledge [16].

The conduct of this rapid review was based on the Methodological Guideline of the Ministry of Health for the preparation of systematic reviews [17], as well as on the PRISMA methodology of the University of Oxford, which consists of a set of evidence-based items that aim to assist in the presentation of research results [18]. The guiding question of the rapid review research proposed for this case study was: **"What is the evidence of accessibility issues in medical devices?"**

To answer this question, the search strategy used was through the definition of keywords to identify publications that respond to this theme. The use of the logical operators "AND" and "OR" helped in the literature search. The search in the databases was executed using the union of keywords: (*"medical device"* OR *"medical equipment"*) AND (*"accessibility"* OR *"disabled people"* OR *"disabled person"* OR *"disability"*) during the time period from January until February, 2024. The search was implemented in the following electronic databases: IEEE *Xplore* and Pubmed, which were used systematically. To determine the choice of articles, inclusion and exclusion criteria were established, which included population parameters of the intended technology, the type of intervention used, the availability of the work, the date of publication and the type of evaluation of the results. After the initial search, the date of publication, the titles and abstracts were read, selecting a total of 12 publications. Table 1 explains the number of articles found per database using keywords.

TABLE I. NUMBER OF ARTICLES FOUND PER DATABASE.

Database	***"medical device" OR "medical equipment")***	***("accessibility" OR "disabled people" OR "disabled person" OR "disability")***	***("medical device*" OR "medical equipment*") AN ("accessibility" OR "disable people" OR "disabled person" OR "disability")***
Pubmed	38.722	488.575	722
IEEE Xplore	11.512	20.788	139

The second stage of this work was to propose a model that incorporates accessibility during all activities of the life cycle, hence contributing to the Health Technology Management in pre-market and post-market.

III. RESULTS

The results obtained through a quick literature review highlighted accessibility problems in different types of medical devices, such as examination tables [19]-[21], weight scales [22][23], nebulizers [24], glucometers [25], positive airway pressure device [26], neuromodulation devices [27], mammography [28]. The usability techniques applied to explore and investigate the problems were mainly: questionnaires, interviews, focus groups and usability testing.

In the studies analyzed, it was found that medical devices are often not accessible to the entire population. Story *et al* highlighted problems faced by patients with disabilities who have difficulties using different types of medical equipment. The four main equipment with the biggest reported problems were: tables; radiology equipment; rehabilitation and exercise equipment and weight scales. Possible physical damage and incorrect reading of display values were the most recurrent problems, followed by physical positioning and transfer of patients on medical equipment [9].

The absence of accessible medical equipment was presented in some studies, such as the research conducted by Morris et al in outpatient clinics [19], which converges with Mudrick et al research that found the absence of adjustable exam tables and accessible weight scales in a large part of offices analyzed [20]. Iezzoni et al showed that doctors do not use accessible exam tables/chairs for patients, and that many doctors simply ask the weight of patients with mobility limitations [21]. Agaronnik et al presented in her study that medical diagnostic equipment, such as examination tables, scales and diagnostic imaging equipment are often inaccessible. Even if doctors have accessible equipment (e.g., examination tables), they do not always use them [23].

The mammography machine was also the target equipment for research. Yankaskas et al investigated women with visual, hearing, physical or multiple disabilities on reasons for not returning for regular mammograms. She found that women with multiple limitations were much more likely to report problems with transportation, parking, and accessibility to health services, as well as a lack of medical recommendation for screening [28].

Neuromodulation devices also had their accessibility assessed through the application of usability techniques. Glenn has found that most devices incorporate auditory cues, buttons with raised cutouts, speech commands, or other useful features to help people with visual impairments. However, no device has been found that is completely accessible to all users, regardless of visual, auditory and physical limitations [27]. In addition to medical devices present in hospitals, technologies present in the home environment also present accessibility problems, as presented by Blubaugh et al. In his study, the researcher showed that the vast majority of glucometers and blood pressure monitors available on the market have limitations for people with disabilities, especially people with reduced vision [25]. These studies discuss accessibility problems faced with medical devices that compromise the safety of using the technology. Ardehali et al also studied medical devices used at home, and found in his research that 71% of people with disabilities describe using medical devices as extremely difficult or somewhat difficult [29].

Another study that investigated problems with medical devices in the home was Constance, which explored in detail the types of difficulties experienced by patients with physical/sensory disabilities who use positive airway pressure devices. Problems were reported when performing manual tasks that were difficult for users, such as connecting accessories, changing filters, among others. These demands have contributed to patient frustration and reduced home medical device use [26].

In all studies analyzed in the rapid review, accessibility problems were found in medical devices. But there was no evidence of a proposal for a methodology to incorporate accessibility throughout the entire life cycle of technologies, from the development stages to use. Therefore, considering accessibility must be considered at all stages of the life cycle of health technologies, from pre-market to post-market phases, for that, a model was proposed as elucidated in Figure 1. When applying universal design as a strategy and including people from all ages and abilities throughout the technology lifecycle, from the ideation phase of digital health solutions to development, developers can design solutions with better accessibility. Universal design aims to design products in a safe and autonomous way, in a simple, intuitive way and with equal possibilities of use [4].

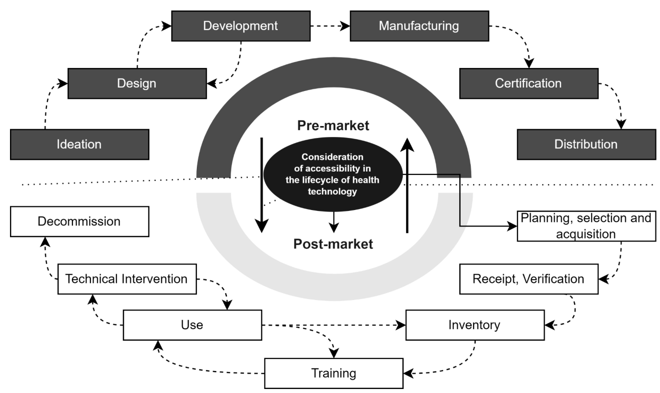

Figure 1. Consideration of accessibility in the lifecycle of technology.

The lack of accessible medical devices is among one of the factors that lead to the disparity in health services available to people with disabilities. It is essential to understand the accessibility and safety barriers present in medical devices used for all types of exams and procedures to meet the diverse population of patients with varying limitations, abilities and disabilities. The model shown in Figure 1 was developed with the application of usability techniques to investigate accessibility problems and improve the usability of medical devices.

The application of usability techniques with users at each stage of the life cycle considering population diversity is essential to develop more accessible technologies. The main steps consist of planning the project and defining the objective, studying the technology, choosing the usability techniques to be used, defining the population considering the diversity of users, developing a protocol for applying the technique, applying the protocol with users, analyzing the data, carry out an action plan with preventive strategies and continuously monitor to evaluate effectiveness and seek improvements. Considering current standards and regulations involving accessibility is a crucial part of the process. Some regulations and documents with accessibility standards for medical devices are listed in Table 2.

TABLE II. CURRENT REGULATIONS AND GUIDES WITH ACCESSIBILITY STANDARDS FOR MEDICAL DEVICES.

Name	Description
WCAG [31]	Web Content Accessibility Guidelines (WCAG)
ABNT NBR 17060:2022 [4]	Accessibility in mobile device applications - Requirements
ABNT NBR ISO 9241-171:2018 [32]	Ergonomics of Human-System Interaction Part 171: Software Accessibility Guidance
ABNT NBR IEC 60601-1-11:2012 [30]	Electrical medical equipment Part 1-11: General requirements for basic safety and essential performance — Collateral Standard: Requirements for electrical medical equipment and electrical medical systems used in domestic healthcare environments.
ABNT NBR 9050:2021 [37]	Accessibility to buildings, furniture, spaces and urban equipment
Law Nº 13.146/ 2015 [8]	Establishes the Brazilian law on the inclusion of people with disabilities.
Law Nº 10.098/2000 [33]	It establishes general standards and basic criteria for promoting accessibility for people with disabilities or reduced mobility, and provides other measures.
Regulatory Standard NR 17. Ministry of Labour [34]	Brazilian Ergonomics Regulatory Standard.
Guidance & Resources ADA [1]	Americans with Disabilities Act (ADA) regulations. Access to Medical Care for Individuals with Mobility Disabilities
Standards for Accessible Medical Diagnostic Equipment [35]	The Architectural and Transportation Barriers Compliance Board (Access Board or Board) is issuing accessibility standards for medical diagnostic equipment
Enforceable Accessible Medical Equipment Standards [36]	Developed by the National Council on Disability. Enforceable Accessible Medical Equipment Standards: A Necessary Means to Address the Health Care Needs of People with Mobility Disabilities

IV. DISCUSSION

Architectural elements within healthcare facilities represent the most recognized accessibility barriers, but the problems go far beyond stairs and bathrooms. Lack of accessibility in medical equipment is a major concern. More accessible healthcare solutions are critical in promoting equity and achieving health promotion, prevention and security. Consequently, it can help reduce disparity, increase inclusion and make healthcare spaces more equitable.

According to the report of one of the users of the research conducted by Story et al.: *"it takes more than ramps to solve the health care crisis for people with disabilities"* [9]. It is necessary to develop technologies focused on population diversity through the involvement of users from the initial design process of medical equipment. Continuously carrying out training with the entire team and developing standard operating procedures are other strategies to be implemented by Clinical Engineering together with other actors in order to establish a more accessible healthcare environment.

With each innovation, new accessibility problems may arise. As such, it is critical to engage universal design principles from the earliest stages of the manufacturing process to ensure that inclusive devices are designed and accessible to all users, which can ultimately improve device usability, adherence and effectiveness [27]. Several emerging technologies are being increasingly used in healthcare, such as artificial intelligence, augmented and virtual reality, Internet of Things, blockchain, among others. Inserting accessibility aspects from the beginning of development is crucial to developing accessible solutions. The diffusion of medical devices into Homecare is another challenge. It is necessary to establish and implement measures that aim to assist in the safety and ergonomics of these technologies for the most varied types and profiles of patients, from those with greater technological skills to those with no aptitude at all [30]. It is necessary to establish strategies to guide patients in the use of these technologies and consider the diversity of users and context of use.

The limitations of this work consist of limited use of databases to search for evidence on accessibility in medical equipment, which may lead to the non-consideration of other work that addresses the topic; low number of works analyzing the accessibility of medical equipment considering the users' perspectives.

V. CONCLUSION AND FUTURE WORK

This work highlighted accessibility problems involving medical devices. Through a rapid review of the literature, it was found that most technologies are inaccessible and/or absent within healthcare environments. The fundamentals of accessibility must be incorporated from the beginning of technological development, throughout the other stages of the life cycle of health technologies. This research reinforced the low number of publications involving accessibility assessment in medical devices, and highlights the need to conduct more research incorporating the diversity of user profiles in the development process to make technology management more inclusive and accessible for the entire population.

Due to the reality of the low amount of evidence and research conducted considering accessibility, for future work the Institute of Biomedical Engineering (IEB-UFSC) intends to carry out research carried out with users to highlight accessibility problems in medical equipment inserted in the Living Lab ecosystem, will feature integration with both patients and healthcare professionals, technology manufacturers, clinical engineering, architecture, and other areas and professionals involved. For that, usability techniques will be applied to explore more problems and establish strategies to improve the design of the medical equipment in health. To implement the Living Lab is essential to create an interdisciplinarity and collaborative Health Ecosystem, for the development of accessible and inclusive technologies for all people.

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Challenge of Producing Accessibility Data for Public Transport and Travel Chains

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***Abstract*—Transport accessibility for all is considered essential. Passengers with temporary or permanent disability of movement or function face difficulties using public transport services. Taking these aspects into account to build a physically accessible environment and to produce digitally accessible information from the former have proven to be demanding. The demand is even greater when the goal is to make the entire travel chain physically barrier-free and to combine different forms of movement into customized, seamless travel chains, with a digital delivery system via a single connecting service—Mobility as Service (MaaS). The paper presents how the essential accessibility information on public transport travel chains is offered, and how the information meets the accessibility information needs of people with various mobility and functional disabilities. The provision of accessibility information is considered as part of official travel databases, e.g., National Access Points (NAP). The essential accessibility information needs included in travel chains for persons with mobility and functional disabilities were mapped for participants in the city of Riihimäki and the surrounding region in Southern Finland. The essential information was compared with accessibility information provided by official travel databases. The results showed that the databases contained relevant accessibility information, however, the information was not readily available. As a result, the information was also not available in the route guides. The reasons for the lack of data accessibility turned out to be multiple. According to the comparison carried out in this study between the accessibility information needs and the current legal framework on the provision of accessibility information to the public, there are clear areas for improvement in the current system in the city of Riihimäki. This analysis provides valuable insights into the development of public transport and seamless travel chains and improving the travel experience for all.**

Keywords-accessibility; barrier-free transportation; public transportation; travel chain.

I. INTRODUCTION

Transport accessibility for all is considered an essential element for a more equitable and fair society [1]. Accessibility refers to the physical environment, e.g., buildings, roads, stops, intersections, parks and other places, services, means of transport, etc. An accessible environment is a space that entitles everyone to free and safe movement, activity, and access, regardless of age, gender, or ability to function. It is about the extent to which the diversity of people is considered in the planning, implementation, and maintenance of the built environment. An environment, building, bus or train stop, or means of transport is barrier-free when it is functional, safe, and pleasant for users, and when all facilities are easy to access. In a barrier-free environment, the spaces and their functionality should be as easy to use and logical as possible. Barrier-free environments together with accessible services, usable tools, and comprehensible information realize equal inclusion. A universal design perspective intends to ensure the design and composition of an environment are achieved in such a way that it can be accessed, understood, and used to the greatest extent regardless of age, size, or ability. When spaces are designed to accommodate diverse needs from the outset, it benefits everyone—whether they have a disability or not.

According to the United Nations [2], sustainable transport aims to promote general accessibility, better safety, reduced environmental impact, flexibility, and greater efficiency. Sustainable transport is also expected to have effects on eradicating poverty, increasing equality, and combating climate change. In cases when the infrastructure, systems, and services are missing or are inadequate, the benefits of transport cannot be accessed. For example, remote rural areas are especially disadvantaged, as they often have poor links to regional and national transport networks. In some cases, the transport infrastructure and systems do exist, but they still fail to provide safe and convenient access for older persons and Persons with Disabilities (PwDs).

The European Union's Sustainable and Smart Mobility Strategy [3] aims to create a sustainable, inclusive, and resilient transport system that benefits everyone while addressing environmental challenges and embracing technological advancements. It emphasizes a smart, competitive, safe, accessible, and affordable transport network. According to the strategy, the principle of "No-one is left behind" underscores the commitment to create a transport system that serves everyone, promotes equity, and enhances the quality of life for all individuals across the European Union.

The Intelligent Transport Systems (ITS) Directive 2010/40/EU [4] and its Delegated Regulations require that each European Member State must establish a National Access Point (NAP) for mobility data. It aims to encourage the development of innovative transport technologies to create the ITS. It is part of a broader initiative to enhance connected mobility experiences in Europe. It serves as an open national gateway where mobility service providers must submit information about their digitally accessible essential data interfaces. NAP is not a service for end-users or passengers; rather, it is intended for mobility service providers and developers.

In Finland, the Act on Transport Services (643/2017) [5] obliges all transport operators to share information about their own services for the use of other operators in the sector. Data is shared through interfaces. Such interfaces are used to transmit information between two systems. Information on open interfaces is exported and compiled in the Finnish Transport Agency's NAP service catalog [6]. The provider of mobility services for passenger transport must ensure that essential and up-to-date information regarding the mobility service is also available in a machine-readable format. Opened data is used for making route guides and traffic services, for example. The relevant information varies by service type. For example, there are two obligations to share interfaces concerning the municipal sector. The obligation to provide essential information applies to all providers of passenger transport mobility services, regardless of the mode of transport. This information concerns aspects such as, the route, stops, schedule and price information, as well as information about the availability and accessibility of the service. Another only those entities that have a ticket and payment system.

An estimated 87 million Europeans currently have some kind of permanent disability or temporary obstacles to movement or functioning [7][8]. In Finland, the number of people with various disabilities is estimated to be slightly less than 19% [9]. Whether it is a question of permanent or temporary obstacles to movement and functioning, obstructed infrastructure, inadequately guided routes, and insufficient digital travel information make traveling difficult. Public transport use and barriers to this use may be experienced differently by people with various types of disability, e.g., physical, sensory, or cognitive. To understand the various functional needs, these can be roughly categorized as follows: (1) *physical or motor disabilities* cause muscle weakness, balance difficulties or mobility limitation in physical movements, which in turn result difficulties walk, climbing the stairs, opening heavy doors; (2) *visual impairment* can vary from color blindness, low vision to complete loss of sight in one eye or both, which causes difficulties navigating, visualizing spaces and seeing directional signs and other visual information; (3) *auditory disability* or hearing impairments can vary from low to complete hearing loss in one ear or both, resulting in difficulty hearing spoken language and auditory information; (4) *cognitive or learning difficulties*, affect understanding and memorization of instructions and texts; (5) a*ging*, can cause varying degrees of weakness in movement, sensory and cognitive functions; and (6) *temporary difficulties in movement, sensory or cognitive functions* caused by accidents, medicines or diseases, may limit movement in traffic [10][11]. Passengers with temporary or permanent disability of movement or function face difficulties using public transport services. Taking these aspects into account to build a physically accessible environment and to produce digitally accessible information from the former have proven to be demanding.

The demand is even greater when the goal is to make the entire travel chain physically barrier-free and to combine different forms of movement into customized, seamless travel chains, with a digital delivery system via a single connecting service—Mobility as Service (MaaS) [12]. The characteristics of MaaS include the integration of multiple transport modes, various payment options, and the use of various technologies enabling the use of a single interface and platform while catering for personalization and customization to offer user-centric mobility services [13]. The origins of the MaaS can be found in ITS. MaaS is intertwined with the development of a sustainable transport system as a whole [14].

Currently, the literature on the barriers found in the built environment, on public transport and travel chains can be found relatively well [12][15]. On the other hand, there is very little literature about the type of information available on the environment and the public transport and travel chain and how this information is made available or used to serve the needs of PwDs. In addition, no literature is available on how the accessibility perspective of travel chains has been implemented in practice as part of MaaS services, e.g., in route guides. The final report of the Ministry of Transport and Communications in Finland [16] finds that at the national level, accessibility has not been considered much in Finland’s first MaaS service pilots, and the measures to promote the accessibility of MaaS services have not been sufficient. To respond to this gap in the literature, this study aims to examine what kind of essential accessibility information is offered and how it corresponds to the critical essential accessibility information needs experienced by PwD in relation to the travel chain.

The content of the article is structured as follows. In Section II A, we examine what is meant by the travel chain and how the different stages appear to the passenger, as well as what is meant by the officially defined essential accessibility information of the travel chain. Section II B examines the accessibility of the travel chain in the light of previous literature. Section III describes the methodology used, the research area, the research object, the research participants, and the data collection process. In the results of Section IV, A, the critical accessibility information of the travel chain identified by PwDs during the planning phase of the trip and during a trip is discussed. Section IV B examines essential accessibility information identified from data sources and compares it with accessibility information defined as critical by PwD. Section V considers the development aspects of perceived and official essential accessibility information based on the results, and Section VI concludes the results regarding how the results can be used in the development of accessibility information for public transport travel chains.

II. Travel Chain and Barriers

A. *Accessible Travel Chain and Essential Accessibility Information*

When designing and planning public transport, travel chains, and built environments, it is critical to consider accessibility and the needs of all potential users. A travel chain refers to a journey from point A to point B, which may consist of one or more different means of transport [17]. Ideally, it should be possible to arrange and pay for entire travel chain from one service provider. The travel chain may also have hubs, e.g., travel centers and train stations, where passengers change from one means of transport to another. In the optimal case, the passenger gets the mobility services she/he needs from door-to-door based on the principle of one payment and one ticket. The transport services are meant to work together seamlessly for all passengers, and real-time information about the progress of the journey is also available during the trip.

An accessible travel chain can be defined as a continuum consisting of accessible services, physically accessible, and multi-sensory guided routes, stops, means of transport, and station spaces, which enable all passengers to travel as independently, smoothly, and barrier-free as possible.

What is meant by the essential accessibility information of travel chain? According to the EU's directive (2019/882) [18] and the Act on Transport Services (107/2023) [19], essential accessibility information refers to information in digital form provided on websites and mobile applications about available services and assistance, in addition to intelligent ticketing systems, accessibility of the infrastructure and built environment surrounding the transport services, accessibility of equipment, equipment that facilitates the passenger's access to vehicles, available interaction with the driver, and access to real-time travel information.

B. *Barriers to Passengers' Movement and Functioning in the Travel Chain*

Concerning accessibility in travel chains, Mwaka et al. (2024) [14] reviewed 34 articles on the subject to identify physical and social barriers, and facilitators in the travel chain, and to highlight issues related to lack of confidence or self-efficacy and reduced satisfaction when PwDs and older adults were using public transport. The results are organized in relation to the phases of the travel chain. The most common barriers found by the authors are described in the following. (1) *In relation to travelling to or from a public transport stop or station* were long walking distance, irregular walking surfaces, narrow pathways, branches hanging in pathways, small holes, poor design of curb cuts, difference in levels, steep side gradients on pathways, low contrasts in surface changes, combined pedestrian and cycling lanes, grey posts on pathways, crossings with traffic lights but no auditory signals, short walking times for crossings at traffic lights, traffic from two directions, turnstiles without sound modules to provide information about remaining balances on travel passes, crossing busy streets, lack of sidewalks, road works, lack of pavements, and a lack of low curbs. The most common barriers (2 In relation to waiting at the stop or station information was found to be unavailable in terminals or bus stops, drivers did not stop to let people board the bus, there was poor platform design and lack of signage, or signage too bright and glargine, there were levels of noise, lack of visual announcements on trains, narrow bus stops, no weather protection or shelters, no seats or inadequate seats, many buses stopping at the same bus stop, lack of timetables, small text on timetables, poor visibility on monitors, incorrect information, difficult to interpret information, no information about routes in service, no information provided in braille, the presence of stairs in railway stations, broken elevators or escalators. (3) *In respect to boarding and getting off the public transport*, the most common barriers were related to ramps, including lack of ramp, inoperable ramps, steep slope for ramp use, and ramp deployment angle (≥9.5°). (4) *In respect to the public transport vehicle*, the most common barriers related to the presence of steps at the vehicle entrance. (5) *Other common issues related to public transport use* included inability to navigate public system, lack of confidence in the use of public transport, lack of knowledge of public transport network, and fear of injury related to public transport.

III. Methodology

A. *Identifying the Research Question*

The research question of the study is to examine what kind of essential accessibility information on public transport travel chains is offered and how it is offered, as well as how the information meets the accessibility information needs of people with various mobility and functional disabilities.

The research is conducted in three phases, and each has its own target. (1) The first phase focuses on mapping the accessibility of mobility services, service processes, travel chains and hubs from the point of view of persons with temporary or permanent impairments, with the target of acquiring knowledge about what kind of accessibility information about the public transport travel chain is offered and how. (2) Based on the mapped results, the second phase focuses on defining the critical accessibility information about mobility services, service processes, nodes and infrastructure included in the travel chain from the user perspective and in relation to official sources of essential accessibility data. (3) The third phase defines the actors of the MaaS architecture in charge of conducting services for barrier-free movement in the city and region of Riihimäki. The results of the first two phases are reported in this article in addition to aspects which came to light on the use of smartphones by PwDs when using public transport services.

B. *Description of Study Area and Participants*

The case study takes place in southern Finland, in the City of Riihimäki and the region. Riihimäki, has 30,000 inhabitants, and is a typical medium-sized city in Finland. As such it is an example of availability of accessibility information concerning the travel chain is realized in a smaller city, like most Finnish cities. Its distinctive features, however, are that it has a dense urban structure and a busy train station. The entire station-zoned urban area is within a three-kilometer radius of the railway station, where 97% of the population lives. Riihimäki has a Sustainable Mobility Program [20], with significant investments in the urban environment to increase sustainable modes of transportation. Sustainability refers to environmentally and socially favorable modes of transportation that are economical, smooth, safe and improve the health of the person moving. City dwellers are encouraged to use sustainable modes of transportation, such as walking, cycling, using public transport and travel chains, as well as carpooling.

The public transportation consists of regular local bus lines, small on-demand buses with door-to-door services, service lines on standard routes and taxi services for disabled. All local and on-demand buses have low floors. The most important hubs are the railway station, the bus station, and the expressway connection to regional buses. There is interconnectivity between the hubs and regions. Regional and local buses, including on-demand buses, feed regional, long-distance, and international trains.

Public transport uses a mobile application and an online version of the route application *Routes and Tickets* to reserve and pay for tickets and travel chains. The application can also be used to report transport needs for wheelchairs, strollers, and rollators. In addition, there is an option to reserve and purchase tickets by phone. Another route guide in use on the Internet and as a mobile application, especially for travel chains including train journeys, is provided by *VR Matkalla*.

The primary target group of the study are persons with temporary or permanent mobility and/or sensory challenges due to illness, aging, and/or disability (PwD). A sample of thirteen volunteer representatives of the target group from local and national disability organizations participated in the study.

TABLE I. TARGET GROUP

Target group deviation for different diseases and conditions			
Disease/Condition	***Count of PwDs***	***Assistive Devices/Services***	***Information and Communication Technology***
Physical or motor disability	6	Wheelchair (1x), Occasional Electric Wheelchair (1x), Electric wheelchair (4x)	Computer, Smartphone
Visual impairment, Blindness	3	White cane (3x), Guide dog (1x)	Computer, Smartphone
Visual impairment, Low Vision	1	None	Computer, Smartphone
Aging with Temporary physical difficulties	3	Assistant	Computer, Smartphone

The mobility challenges faced by PwDs are highlighted in Table 1, which summarizes the diseases and conditions affecting them. This table provides a comprehensive overview of the study's sample, showcasing the diversity of conditions and challenges encountered. In addition, the material shows the differences due to disability and functional capacity in relation to aids and services used by PwDs and information and communication technologies. The age range of participants was 40-82 years. Eleven of the participants currently use public transport independently and two with the accompaniment of another person.

All the participants had computer and Internet access at home, and owned a smartphone, but their skills in terms of searching for information on the Internet as well as using a smartphone varied. Another indirect target group are public transport authorities, operators, companies, and associations that provide mobility services in Riihimäki and the region.

C. Data collection

To define the necessary essential information, from the point of view of a PwD, information was needed on which accessibility information is perceived as usable and useful before and during the trip. Data collection took place between February 2023 to December 2023 (around eleven months). The data collection was carried out using the snowball sampling method. For participants to be eligible, they had to be current public transport users. Local and regional disability councils and organizations representing disability groups were contacted to invite their members who matched the criteria to participate. Organizations were given email addresses and phone numbers so that potential participants could contact the researcher directly, or the volunteers' contact information was provided to the researcher, who contacted then the volunteer. Once an individual participated, they were asked to invite other people they knew. This approach ensured potential participants of the research through personal endorsements. The goal was to recruit at least 12 participants so that the thematic saturation of the information and the validity of the data were realized [21].

The data collection was originally planned to be carried out through a self-administered online user preference survey, developed by using the online survey tool Forms by Microsoft. After the first workshop organized for visually impaired people, it was obvious that simply answering the survey independently online would not be a sufficient way to collect the data. Due to reported difficulties with the use of computers by the participating PwDs thematize interviews based on original questionnaire were implemented.

Planning the travel chain (1): The first phase of the research began by examining how the participants typically planned a journey chain before traveling. The travel chain consisted of leaving from the origin of the journey to the destination with the required vehicle exchanges at hubs. The thematic interviews and travel chain planning were done in eight workshops. At each workshop, the participants explained their travel chain planning processes and justified their choices. During the discussions, the researchers asked

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the participants clarifying questions as needed. All conversations were recorded. The content of the recordings was analyzed using content analysis methods. Each volunteer participated in 2-6 workshops and interviews, depending on the number of trips they made. Planning was done on the Internet with a focus on access to passenger accessibility information, available information about barrier-free mobility services, service processes, and accessible vehicle exchanges at hubs. The purpose was to understand the methods PwDs used to search for accessible travel information and how they accessed the different information they required through various digital tools, websites, or by calling customer service.

On the journey implementation (2), data was collected by retrospectively recalling the step-by-step implementation of the trip, and by observing the implementation of the trip with jointly realized trip chains. These observations were collected during thematize interviews, by reading travel diaries, and by implementing a variety of monitoring methods, e.g., shadowing, and passive observation, during field journeys, and after the journey with theme interviews based on recalling the travel experiences retrospectively from the entire travel chain including the various transport nodes. In connection with the workshops, essential accessibility information was also defined from the perspective of PwDs. Observations and thematic interviews in connection with the workshops were used to find out how accessibility information was present when PwD passed through the different stages of the travel chain and where the problem areas in terms of accessibility were. PwDs, the authorities and other stakeholders were invited to a joint seminar at the end of this data collection phase, where the results were presented, and the views of all parties, and conclusions from the results were heard. The aim of the seminar was to deepen the common understanding of accessibility information needs and strengthen the reliability of the results.

The second phase of data collection compared the mapped critical essential accessibility needs with the officially defined accessibility information standards. To enable a comparison, the official data sources in use were assembled by interviewing stakeholders and authorities responsible for the data sources. Comparing these elements began in the workshops after the actual journey experiences of the PwDs. The most critical accessibility information of PwDs' travel experiences, the mobility services, service processes, stops, vehicles and vehicles exchange at nodes, and multisensory guidance were analyzed. The identified essential accessibility information needs were compared with the information available through route guides and with the official digital data sources behind them. A second seminar with the same purposes was organized at this point and thus all concerned contributed to the analysis process.

IV. RESULTS

A. Experienced challenges of the travel chain

During the analysis process, the results from the questionnaires, theme interviews, workshops, observations, and experiences from physical excursions were classified based on the content and theme (Table 2). This table provides a comprehensive overview of all the information gathered during the different phases of the travel chain.

TABLE II. CHALLENGES IN THE TRAVEL CHAIN

Challenges of travel chain phases	
Preliminary phase	***Implementation phase***
Travel booking challenges	The challenges of means of transport
Challenges of needed accessibility information of routes, junctions, and vehicles	The need for information while traveling
Lack of customer services and challenges of assistance services	The challenges of assisting
The challenges of reserving, buying, and getting hold of a ticket	The challenges of nodes

During the trip planning phase, the need to reduce various uncertainties regarding the trip was highlighted. Travel booking challenges of the preliminary phase were related to the selection of the most suitable route options, and vehicles' choices, as well as keeping the number of hub changes as few as possible. Optimal choices of the travel chain were made based on available accessibility information, e.g., train trips were preferred instead of long-distance buses, and the distance was important between the arriving and departing platforms at transport nodes. Other important aspects, included finding a suitable ticket for journeys and purchasing it easily, allowing enough time for vehicle changes at nodes, providing sufficient information about vehicle accessibility, and information about assistance services. These elements were considered crucial for ensuring a sense of safety while traveling. The most important aspect discussed by the interviewed PwDs was traveling safety provided by the preliminary information which was seen as lacking in many cases.

During the implementation phase, identified critical needs included the availability of assistance service points, certainty of assistance, and access throughout the entire travel chain. It is crucial to consider how to access information in case of unexpected changes in the travel chain. Tracking the progress of the trip, tactiles, multisensory guidance, and sound beacons were recognized as essential for individuals who were blind or visually impaired.

B. Narrow view of essential accessibility information in data sources

Accessibility data was examined through various data sources and was utilized to gather information to analyze different interfaces. The formats of these sources vary, impacting how the data is presented for diverse uses and its accessibility in machine-readable formats. This study concentrates on accessibility information which is, typically available on service provider websites, although locating this information can be challenging. In Finland, the General Transit Feed Specification (GTFS) is a prevalent method for presenting travel information and showcasing trip details, routes, and stop information in a machine-readable format [22]. However, GTFS-format data primarily represents singular aspects such as wheelchair-accessible locations, vehicles, paths, or stops and does not address the breadth of accessibility difficulties.

Information must be presented in multiple ways to cater to diverse needs. This necessitates employing various formats and methods to ensure information is accessible digitally and that physical environment accessibility information is conveyed throughout the entire travel chain. The varied data formats are depicted in Table 3. These data sources were analyzed to reveal potential accessibility information within the data sources. The collection of this data was guided by the requirements identified from the interviews, which focused on gathering preliminary information and specifics about the trip.

TABLE III. USED DATA SOURCES AND FORMATS

Data sources for accessibility information present		
Data source name	***File format***	***Accessibility***
GTFS	Data presented in CSV files which are collected in a ZIP file.	wheelchair accessible, wheelchair boarding
NAP	Data presented in GeoJSON. It utilizes the JSON file format for representing geographical data structures.	boarding-assistance assistance-dog-space, accessible vehicle, low-floor, step-free-access, suitable-for-wheelchairs, suitable-for-stretchers
NeTEx	Data is presented in XML file format which is a markup language for organizing and storing data in a structured format.	Wheelchair access, Step free access, Escalator free access, Lift free access, Audible signs available, Visual signs available
VR	Website	Written information
Matkahuolto	Website	Written information
Opas.matka.fi	Website	Written information

To ensure comprehensive accessibility, it is crucial to address the diverse needs of users by presenting information in varied formats and using multiple methods. This strategy ensures that accessibility information is available in digital formats and is effectively communicated throughout the entire travel process, thereby enhancing the overall user experience. The analysis of different data formats, as detailed in Table 3, facilitates a thorough examination of potential accessibility information within the data sources.

Furthermore, the data collected from these data sources was specifically tailored to meet the requirements identified during the interviews, which focused on preliminary information and trip specifics. Incorporating insights from these interviews, the study seeks to improve the understanding of accessibility challenges and opportunities within the context of various interfaces and data structures. This comprehensive approach is vital for developing inclusive and user-friendly solutions that meet a wide range of accessibility needs in transportation and travel services.

The data formats present accessibility information at a basic level. For example, the common GTFS format categorizes accessibility in three stages with values ranging from 0 to 2, indicating the level of accessibility for different stages in the travel nodes. These values represent the stage of accessibility as follows for stops:

- 0 = No accessibility information
- 1 = Some vehicles at this stop can be boarded by a rider in a wheelchair.
- 2 = Wheelchair boarding is not possible at this stop.

For trips, the information is as follows:

- 0 = No accessibility information for the trip.
- 1 = Vehicle being used on this trip can accommodate at least one rider in a wheelchair.
- 2 = No riders in wheelchairs can be accommodated on this trip.

In Riihimäki's public transportation system, GTFS files indicate an accessibility level of 0, which means there is no accessibility information available for any trips or stops in the city of Riihimäki, which is a clear deficiency according to the information mentioned earlier about the obligation to provide essential accessibility information by the ministry [5]. The lack of accessibility information results in the inability to search for wheelchair-friendly or accessible options for trips in Riihimäki, posing challenges for finding suitable public transportation options for PwD.

Travel chain accessibility information is distributed through various sources, and operators collect this data for the NAP. The instructional materials provided by the NAP are intricate, and the guidelines for submitting information suggest that accessibility details are to be filled in multiple fields. However, the instructions lack clarity on how and where the information should be entered.

During the interviews with travel service providers, it became evident that they possessed a wealth of information. Nevertheless, there is a lack of a standardized method for presenting this information on their websites and for submitting accessibility data to the NAP. Improved guidelines are needed to ensure that the information is effectively filled in, benefiting both authorities and passengers.

During the data collection process in this study, there was a need to map various data sources and explore methods for presenting accessibility information and data formats. Among the materials investigated, the Network Timetable Exchange (NeTEx) format emerged as particularly noteworthy for its ability to offer a more comprehensive range of accessibility information compared to GTFS. NeTEx can organize collected data in a manner that allows for more detailed accessibility information, including the presentation of information at different stages within the travel chain. This format provides an opportunity to conduct an accessibility assessment, highlighting the accessibility characteristics of various entities utilized by passengers and outlining limitations in six distinct accessibility needs [23]:

- Wheelchair Access: indicates whether the service or location is accessible for individuals using wheelchairs.

- Step Free Access: indicates whether some steps or obstacles could hinder access for passengers.
- Escalator Free Access: indicates if escalators are available for passenger use.
- Lift Free Access: indicates the presence of lifts for vertical transportation.
- Audible Signs Available: indicates whether audible signs or announcements are provided for passengers.
- Visual Signs Available: indicates whether visual signs or information are provided for passengers.

V. DISCUSSION

The obtained results highlight aspects that still require clarification and definitions regarding essential accessibility information into data sources. In conclusion, the challenges faced by PwDs can be formulated in six major themes for improvement, which serve as focal points for lack of information in the preliminary phase, during trips, throughout the travel chain, and in MaaS possibilities. These include:

- Improving accessibility information: providing clear and comprehensive details about the accessibility of different modes of transportation, such as stair heights, ramp availability, and the location of assistance points, is essential for helping passengers with disabilities plan their journeys effectively.
- Enhancing assistance services: it is crucial to ensure that assistance services are easily accessible and that the ordering process is clear and seamless. Additionally, having assistants available at critical locations like stations and trains is important.
- Utilizing technological solutions: offering practical mobile applications to passengers that provide real-time information on transportation accessibility, schedules, and ticket reservations can significantly enhance independent travel for passengers.
- Collaboration among stakeholders: close collaboration among public transportation operators, tourism services, and associations for persons with disabilities is necessary to promote accessible travel. Through collaboration, better solutions and services can be developed for passengers with disabilities.
- Improving guidance accessibility: ensuring that accessibility information is available in various formats, such as tactile pathways, easy-to-read maps, and providing Braille, and audio guidance. It is crucial to ensure all passengers can access the information they need.
- Customer services and location accessibility: ensuring the availability of customer service locations, providing location-based information about the traveling center building, and determining the availability and specifications of accessible routes and services, e.g., toilet spaces are important considerations for enhancing accessibility for all individuals.

The accessible travel chain is a matter of social equality and justice. Barrier-free travel chains ensure that all people, including people with reduced mobility, such as people in wheelchairs, visually impaired, or hearing-impaired, can travel on public transport as independently as possible and without barriers. A barrier-free travel chain is smooth, safe, and effortless for everyone. For example, physically barrier-free stops, stations, elevators, and multi-sensory signs, make traveling from one place to another easier and smoother. Raised platforms and low-floor train carriages reduce the risk of tipping over and enable easy access to and from the train. The ease and comfort of traveling improve everyone's travel experience.

VI. CONCLUSION AND FUTURE WORK

The comparison of accessibility information needs with the accessibility information definition and production processes presented in the databases and various data sources reveal areas for improvement. This analysis provides insights into the development of public transport and seamless travel chains and improving the travel experience for all.

Legal frameworks and ethical guidelines promoting equal treatment for all passengers emphasize the importance of accommodating the diverse needs of individuals during the development and execution of public transportation systems and services. Both information about mobility services and their purchase are increasingly dependent on online services. Personal service is being reduced at stations and service points. The challenge is to ensure that using mobility services is possible for everyone including individuals with limited digital skills, those who need assistive technologies to access online and mobile services, and people for whom obtaining travel information digitally poses challenges for a variety of reasons. It is important to note that although we put effort into improving digital information flows, we must not forget the aspect of customer service development.

DECLARATION OF CONFLICTING INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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