Article

The Needs and Requirements of People with Disabilities for Frequent Movement in Cities: Insights from Qualitative and Quantitative Data of the TRIPS Project

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Abstract: Moving is an indispensable component of travelling. This paper discusses the experiences of persons with disabilities when moving around cities on foot or wheels, based on research conducted during the EU-funded project TRIPS. Findings comprise participants' vignettes from 49 interviews in seven European cities, views on smart assistive technologies (e.g., Augmented Reality) from a pan-European quantitative survey, and design concepts related to walking based on a co-creation workshop that actively engaged persons with various types of disabilities in ideation. Findings suggest that people need reliable and clear wayfaring information on accessible travel routes featuring the coordinated design of streets, pavement, stops, stations, and vehicles to ensure seamless, step-free, and obstacle-free access, as well as disability-sensitive management of disruptions such as maintenance works, for example. Findings also suggest that users are open to using any assistive technology that can enable them to live more independently, assuming it is accessible, and are keen to co-innovate. Finally, we make recommendations for policy changes that can facilitate the redesign of urban infrastructure to make cities more accessible for people with disabilities and drive structural changes in urban planning.

Keywords: accessibility; urban infrastructure; policy recommendations

1. Introduction and Literature Review

Improving urban sustainability is integral to the European smart city paradigm promoted by the European Commission (EC), but the implementation is yet to be materialised due to transport planning and designing processes aimed at improving urban sustainability [1]. The EU encourages the development and implementation of Sustainable Urban Mobility Plans (SUMPs) in cities and regions across Europe to achieve carbon neutrality in Europe by 2050 (see European Green Deal objectives). SUMPs are strategic planning tools that prioritise sustainable and active modes of transportation, including walking, cycling, and public transport, to reduce greenhouse gas emissions and improve air quality in urban areas. This requires a shift in urban environments from private car use to uses more conducive to walking. The Urban Agenda for the EU includes a thematic partnership on urban mobility, which addresses walkability and active transportation in urban areas. It promotes best practices and knowledge exchange among cities to enhance walkability. In this context, the EU Accessibility Act (Directive 2019/882/EU) includes provisions related to accessible pedestrian infrastructure and the removal of barriers in public spaces to improve walkability for individuals with disabilities, while EU policies and directives related to transport safety also consider pedestrian safety and pedestrian-friendly road design. On the other hand, the Mobility as a Service paradigm takes a service orientation

towards urban and transport planning. It suggests that the travel needs of people and business should be accounted for, as well as the desired travel choices' interactions with travel infrastructure, to design satisfying travel systems [2]. However, what constitutes a pedestrian-friendly environment from the perspective of persons with disabilities is not fully appreciated. In the literature, the term 'walkability' is often used to describe the extent to which walking and other non-motorised means of mobility are enabled by the surrounding built environment [3].

The TRIPS project (no. 875588) focused on the accessibility of public transport from the perspective of persons with disabilities more generally. It focused on developing a new approach to designing transport systems free of mobility barriers for persons with disabilities based on a participatory approach that involved people with disabilities in the research and innovation process. To fulfil the aims of this project, we formed working groups in seven EU cities—Bologna, Brussels, Cagliari, Lisbon, Sofia, Stockholm, and Zagreb—which took part in user research and ideation and helped to promote an online survey to the broader European community of persons with disabilities. Although the project focused on public transport, general insights regarding moving around cities surfaced. Moving is an indispensable part of travelling, whether short distances as a leisure activity, or to catch a bus or train, for example. This paper synthesises our insights from the overall project regarding moving in cities on foot or in a wheelchair.

Urban and transport planners should make provisions for accessible pedestrian infrastructure, such as sidewalks, crosswalks, and pedestrian crossings, in line with the European Accessibility Act (EAA) and non-discrimination laws, as well as the mandates of the EU-ratified United Nations Convention on the Rights of Persons with Disabilities (UNCRPD). The UNCRPD sets out the rights of people with disabilities, including their rights to accessibility, mobility, and participation in public life, which entails the removal of barriers to mobility and accessibility.

To guide the implementation of these rights, European accessibility standards and guidelines for the accessibility of the built environment specify the requirements for sidewalks, kerb cuts, pedestrian crossings, and other infrastructural elements to ensure public spaces are accessible to people with disabilities. In addition, many European cities and countries have urban planning and building codes that mandate the construction and maintenance of accessible sidewalks, ramps, and pedestrian crossings aligning with EU directives. Nevertheless, fully accessible cities are not yet a reality, and universal design principles and practices have yet to be widely adopted. Provisions for accessibility in SUMPS plans and implementation vary from country to country and from city to city, as is seen with the actual commitment to and implementation of SUMPS to date. Cirianni et al. [4] suggest that European cities set goals to improve safety for pedestrians and cyclists by adapting cycling paths and modernising pedestrian walkways, yet their emphasis on accessibility and their state of implementation from city to city differs. For example, Trpković et al. [5] mention that in Belgrade, SUMPS contains a special set of measures to adapt the city to the requirements of users with limited mobility (elderly, children, visually impaired, etc.), indicating that even in SUMPS, the requirements of this set of people are not part of the initial design but an afterthought, leading to adaptations to the original design that ignored them. According to Islam [6], Barcelona has "implemented a Universal Accessibility plan 2018–2026 which also includes accessibility to all disabled people". Their very process of developing the plan is inclusive based on citizen and stakeholder dialogue and cooperation, a focus on safety and a reduction in fatalities and accidents, and access to and enjoyment of the city's amenities for everyone. Since 2001, Berlin has built almost 500 new pedestrian crossings, over 120 additional central islands, around 75 new pavement extensions, and it has removed structural obstacles at around 1100 intersections or junctions throughout the city, which has been completed as part of the on-board lowering program. Since 2021, Berlin has focused on the accessibility of public spaces for enjoyment, rather than commuting. In Pellicelli et al. [7], requirements for walkability in Emilia Romagna cities can be summed up as the percentage of accesses without architectural barriers, signage, and charts; maps for

blind people to improve accessibility; and the provision of equipment for disabled people to improve the quality of public spaces. Yet, such priority is set only in Bologna but not in other cities. It should be noted that disabled-friendly infrastructure services are needed for all pedestrians, not just those who are disabled. For example, kerb ramps are essential for wheelchair users but also convenient for persons with luggage or baby carriages.

Many researchers have written about approaches to rethinking the complexities of universal design, which must satisfy the needs of persons with disabilities travelling around cities to counteract their spatial and social marginalisation [8–15]. Every design challenge should gain deep knowledge of the perspective of its users.

Walkability is made achievable by urban planning measures that include mixed land uses, a high built density, high street connectivity, and suitable pedestrian and bicycle infrastructure [16]. For people with disabilities, walkability is based on additional built environment design instruments, such as signage and signal accessibility [17]. A study by Kwon and Aka [18] that was based on the 2017 National Household Travel Survey from California showed that higher levels of walkability (e.g., by connected streets and high residential density) are positively associated with the transit use of disabled individuals compared to others. The study concluded that enhancing neighbourhood walkability has a much larger effect on people with disabilities than the general population.

Prior research suggests that the ease of moving affects the overall motivation of persons with disabilities to travel and use public transport. According to Marcheschi et al. [19], the motivation to walk is driven by one's assessment of one's well-being (i.e., physical and psychological health), which involves a co-assessment of one's health, the physical and social environment, and emotional responses, particularly around self-efficacy and/or the ability to cope. When considering walking, the physical urban infrastructure elements deemed problematic are surface quality, crossing design, outdoor lighting, signs, environmental maintenance, resting possibilities, landscape characteristics, environmental variation, sounds, and odours [19]. The social dimensions affecting one's motivation to walk are related to social stressors (e.g., perceived safety, degree of difficulty, availability of social support, etc.), familiarity, and the stability of a social situation [19].

Findings by Kociuba and Maj [20] suggest a long list of common physical barriers that may be troublesome for persons with disabilities. These include narrow walking paths, parked cars, unpaved surfaces, significant height differences, bad road conditions, inadequate surfaces, narrow doors, poorly demarcated pedestrian and bicycle routes, protruding shop windows, gutters, tree holes, movable advertisements, multiple stage pedestrian crossings, insufficient crossing time, lack of shade, and stairs without ramps, railings, or lifts. Rosenberg at al. [21] found kerb ramps availability and condition, sidewalks availability and condition, missing lighting, the presence and features of crosswalks, availability of resting places and shelter on streets, among others, as key built environment barriers for the active mobility of older adults with disabilities. In addition, the walkability of a journey's first and last mile is paramount for the overall accessibility, connectivity, and safety of one's journey [22]. Hence, linking pathways to transportation modes such as buses and subways is paramount for safety. To this end, residential density, mixed land use, and neighbourhood connectivity are critical to people's motivation to travel and go out [18].

Walkability means different things to persons with various disabilities. For example, for blind people, walkability relates to sidewalk width, the condition of tactile pavement and its connection to crosswalks, obstructions, and the proximity of sidewalks to homes or commercial premises, which provide resting places and a sense of security [23]. While some physical features (e.g., ramps at intersections) cater to the needs of different user categories (in this case, blind people, wheelchair users, and people using walking sticks), others may conflict. For example, tactile pavements for blind people, much like the bevelled edges of interlocking concrete pavement blocks, can cause trepidation for wheelchair users [24]. Therefore, it is most efficient to co-design and test accessibility with users with different disabilities to reconcile conflicts early.

Regarding methods to measure walkability in the context of accessible cities, most practice is based on walkability surveys [25], in-depth interviews [21], and individual-level data travel surveys [18]. Furthermore, walkability is also assessed by methods based on geospatial data like space syntax analysis [26]. The global walkability index by Krambeck [27] comprises different aspects of walkability, among them being security from crime, crossing safety, and disability infrastructure.

In our previous work, we argued that smart technologies could potentially mitigate some of the issues faced by persons with disabilities by increasing their capability to navigate existing infrastructure. We argued, for example, that augmented reality (AR) could be used to identify the locations of bus stops or platforms, even when they had been relocated due to road maintenance and display accessible routes to reach them. AR and location-based services offer real-time navigation with live updated directions based on the movements of others to help users navigate obstacles and crowds. We also argued that AI can support disabled users by tailoring real-time planning to their specific abilities. It could act as a virtual assistant to alert providers that a passenger with additional needs is en route and request a delay or other accommodation to facilitate their transfer. Further, robotic technology could ease the movement of passengers with mobility impairments, improving the capabilities of assistive technologies, such as electrical wheelchairs and exoskeletons for locomotion, and helping users climb steps or ramps to reach facilities such as washrooms or restaurants. We also pondered the potential contributions of next-generation smart canes, exoskeletons, and autonomous personal mobility systems that use advanced digital technologies to assist users. We should, however, account for the digital divide. Previous research has revealed that persons with disabilities use digital technologies and the Internet less frequently than the general population. In most countries of the world, people with disabilities face a significant digital divide [28,29]. This paper adds to the existing literature in the following three ways:

(a)   It corroborates and complements previous research findings on user requirements regarding walkability;
(b)   It discusses users' openness to utilise assistive technologies that can facilitate walkability without changes to physical infrastructure;
(c)   It presents disabled users' design concepts to improve walkability.

Finally, we make recommendations for policy changes that can facilitate the redesign of urban infrastructure to make cities more accessible for people with disabilities and drive structural changes in urban planning.

2. Methods and Materials

This paper presents qualitative and quantitative user data from different studies conducted within the scope of the TRIPS project. It is worth reiterating that the scope of the project was to collect user insights about the accessibility of public transport more generally from the perspective of persons with disabilities and to engage persons with disabilities in research and innovation regarding accessible mobility. As such, the scope of the research was much wider than the cities' walkability, yet the topic was an inextricable part of the investigation. The studies presented below are connected under this wider agenda and partly inform each other.

First, we conducted an interview study on mobility barriers using a peer-to-peer approach conducted between June and September 2020. The members of seven working groups comprising persons with disabilities interviewed their peers in their local communities in Bulgaria (Sophia), Croatia (Zagreb), Belgium (Brussels), Italy (Bologna) and Sardinia (Cagliari), Sweden (Stockholm), and Portugal (Lisbon) in their local language. The interview guidelines were composed of open semi-structured questions regarding choice behaviour, barriers, assistance, and participation [30]. The interviews were recorded and translated into English from the native languages by professional translators. These transcripts were then analysed based on the content analysis approach of Mayring [31] with

the software MAXQDA 20.4.2. Since the scope of the survey was much wider, we present here only interview extracts related to walkability in line with the scope of this paper.

Second, an online survey was conducted in 15 EU languages between November 2020 and February 2021. The online questionnaire was partly informed by the outcomes of study 1 above, the literature review, and the concerns of the members of the seven working groups of persons with disabilities collaborating on the project. We publicised the online survey via several international disability NGOs (such as the European Disability Forum and the European Network of Independent Living); via local disability NGOS in Italy, Croatia, Belgium, Portugal, Bulgaria, Sweden; and via social media in the aforementioned countries, as well as in Greece, Netherlands, Germany, and Lithuania.

Participants from different European cities responded to a call for participation in the survey on a voluntary basis. As a result, we collected the views of 553 persons with disabilities [32]. The number of study participants varies considerably between the countries, with Italy (n = 128) and Germany (n = 90) making up the largest share. The sample represented men (51.4%) and women (45.8%). Our sample included responses from 297 participants with physical disabilities, 85 participants with visual impairments, 45 people with hearing impairments, 16 people with mental health issues, 17 people with intellectual impairments, and 85 people with multiple disabilities. It is worth noting that throughout our studies, we refer to motor disability for neuromusculoskeletal and movement-related functions according to the International Classification of Functioning, Disability and Health (ICF). Wheelchair users are assigned to this group as well but specified in the description due to their regular use of a wheelchair. We have also adopted the ICF classification/definition regarding mental health issues.

The survey included a mix of open and closed questions regarding people's views on mobility and the use of public transport. Amongst others, we inquired about barriers with an open question "What are the main barriers you face while using public transport in your area?" (question 15) and participants' willingness to use smart assistive technologies using a Likert scale. For a detailed view of the online questionnaire, see appendix in [32]. We also inquired about participant views on assistive technologies. For the purposes of this paper, we only present participant views related to walkability, namely, smart canes, accessible navigation systems, 3D-printed prostheses, exoskeletons, wearables, location-based alerts, and augmented reality (for a precise description of the technologies, see [32]).

Finally, we presented four design concepts as part of a series of ideation and co-design workshops conducted in January and February 2021. In the workshops, workgroups including persons with disabilities, transport stakeholders, and technologists brainstormed future mobility concepts to overcome identified mobility barriers [33]. Table 1 indicates the composition of each workgroup.

Table 1. Workgroup composition.

City	Persons with Disabilities	Persons with Expertise in Transportation	Persons with Expertise in ICT/AT/Accessibility	Other
Croatia	7	3	6	1
Italy	8	6	5	3
Portugal	5	2	3	2
Sweden	6	5	4	2
Bulgaria	7	2	4	3
Belgium	6	3	3	4
Total	38	21	27	14
Dry run	3	2	12	5

In total, 100 participants were organised into 7 workgroups in Croatia, Italy, Portugal, Sweden, Bulgaria, and Belgium. An international workgroup was organised to test

the methodology and workshop protocols prior to these workshops. We conducted the workshops online due to the pandemic restrictions in 2021 and coordinated them in the participants' language with a local organiser.

3. Results

3.1. Study 1: Interviews on Identified Barriers

Participants of the peer-to-peer interview were asked: "What are the main barriers you encounter when using public transport? Consider the entire journey and all its different phases: Getting information, planning the trip, bookings, accessing the chosen service, reaching the station, vehicles, getting to the desired destination". As per best practice amongst qualitative researchers, we present participant quotes verbatim to insert the researcher's opinion and interpretations and give the opportunity to readers to determine the credibility, transferability, dependability, and confirmability of our research.

To enable, however, the organisation of material, answers to the questions were categorised into the following groups: (i) inaccessible physical infrastructure, (ii) inconsiderate handling of maintenance works, (iii) confusing signage and measures, and (iv) unpredictable public infrastructure design.

Unsurprisingly, when it comes to physical infrastructure, missing tactile floors remained an issue; as one participant explained, "the sound information and tactile floors with markings that would make it easier for the blind" (Lisbon_04, visual impairment). Participants indicated that sound information to highlight infrastructure elements would be helpful, as well as greater linking to public transport; "Definitely have a tactile path on the relevant sidewalk, possibly that takes you to the bus stop", one suggested (Cagliari_01, visual impairment). Our findings corroborate previous findings regarding differences in obstacles that people must negotiate from the beginning of their journey. As one wheelchair user explained, "The problems start the moment I leave my building. I need to sidestep 300–400 m to reach the cut kerb while moving on the road between cars and in the opposite direction. That is another unpleasant thing" (Sofia 04, wheelchair user). Another explained the difficulties in the last mile of the journey, identifying "the route afterward, between different stops, when I may come across high sidewalks and other such obstacles" as a challenging part of travel (Lisbon_02. Wheelchair user). Further problems arise inside destination buildings. As one visually impaired participant explained, missing handrails on stairs caused insecure walking (Brussels_07, visual impairment). Even when the route accessibility is considered, it does not negate the need for assistance. For example, consider the following excerpt:

> Participant: "It would have been better if more vehicles were low-floored. I'm talking about three steps!"
>
> Interviewer: "Is some assistance provided on public transport?"
>
> Participant: "No, it's a nightmare. Even if the vehicle is low-floored, and the driver stops near the kerb, I'll still need assistance". (Sofia 02, motor disability)

At other times, route accessibility has not been considered from a user perspective, creating new barriers, as the following participant explained:

> The problem with the adapted bus stops is that they are not on the same level as the pavements. They are much higher. Some structures need to be improved. If I want to take a bus, I have to cross the street because the stop is on the other side and the pavement is really high, and you cannot get on. So practically, you stay in the middle of the road. (Cagliari_05, wheelchair user)

Obstacles are another issue category, and they come in different forms. One participant explained, "As soon as I leave my building, I come across high kerbs, holes, setts, and other physical barriers" (Sofia_04, wheelchair user), while another said "there are things on the footpath, like garbage bags or…Terrace? No, what's called in English? Places to sit for the bars?" (Brussels_04, wheelchair user). Competing demands from limited pedestrian

space and poor maintenance create systemic issues. The critical issue is how these areas are constructed; in many areas, the surfacing is of poor quality and street furnishings and terraces, which often grow, act as obstacles for persons with reduced mobility. For persons with visual impairments, all forms of street furnishings, such as billboards, outdoor terraces, plants, signs, or floating flags, present problems, as do scooters. A wheelchair user explained that they have to drive around scooters on the sidewalk (Brussels_06, wheelchair user). The condition of the pavement can be a barrier. Several interviewees complained about obstacles on the pavement (e.g., Brussels_07, visual impairment), the conditions of kerbsides (Sofia_07, visual impairment), and the missing maintenance of kerbsides (e.g., Zagreb_03, wheelchair user). This complaint was reinforced by another participant, who said "and then there is the pavement, which could be dangerous. I used to go out with the walking stick before, but now I use a walker because I have more balance then" (Cagliari_04, motor disability). Crowding creates another barrier for people with disabilities, often making them resort to unsafe options. As one participant explained:

> In Brussels sometimes a lot of people is on the footpath, which I don't have the... I want to drive faster with my wheelchair, so I go on the street. So... I think, for manual wheelchair users, it's a bigger problem, but for my wheelchair, it's not too bad. (Brussels_04, wheelchair user)

Sometimes obstacles can be created by the absence of something. For example, "there are no elevators on Vardar metro station. There is a ramp that you can use if you feel very experimental. It's very dark" (Sofia_02, motor disability). Maintenance works are not handled in a disability-friendly way. One participant explained the impact of construction on their travel:

> Many times, the traffic stops are moved because the municipalities or the Swedish Road Administration are in the process of building. And it makes it very hard to get to the traffic stop or get off the bus because of badly place diversion signs, and it is very hard for us to use the bus...a route that you travelled yesterday might be different tomorrow. The kerbsides are generally not ensured for people with visual impairments. (Stockholm_07, wheelchair user)

This sentiment was echoed by a Croatian respondent, who said "some places in the centre are problematic, where there are those kerbs on the road, so it's harder to drive" (Zagreb_04, wheelchair user).

> Signage can also be confusing. A Swedish interviewee described the issue:
> Proper signs showing where to go when you are... for example, in the central station. It is chaos. Like, not even people with wagons can take themselves straight upstairs or downstairs when you're coming from, let's say, the blue line. (Stockholm_05, mental health issues)

Participants from many countries echoed these sentiments. One interviewee from Belgium explained the impact of poor construction work:

> They re-did the pedestrian crossings. And with the pedestrian crossings, they didn't install the correct tactile paving slabs that are normally used; they used different ones. So now with the new system they have, it is no longer detectible with a white cane. (Brussels_07, visual impairment)

Poor design of special accessibility measures can be frustrating, as reported by interviewees. A lack of homogeneity of measures is a barrier for people with disabilities, such as crossings that are equipped with traffic lights with sound function and others without (Brussels_05, visual and auditory impairment). Such variation can easily lead to potentially dangerous misconceptions. Other examples highlight the need for the co-design and user testing of urban infrastructure. One Bulgarian respondent reported "the green light signal is too short. I can't run. I can see how some drivers are getting angry with me that I am so slow. But I'm slow" (Sofia_02, motor disability), while another noted that "the new

trams are very silent, and you can't know when the tram is coming" (Sofia_07, visual impairment).

The heterogeneity in accessibility regulations and guidelines is also an issue, as shown in the following statement from an interviewee in Belgium:

> There are indeed rather a lot of publications produced by Bruxelles Mobilité...
> You see, today, this morning, I received the charter for pedestrian surfacing, for example. But there are other charters; there are other publications that indicate specifically how to correctly carry out works, how to take 'homogeneity' into account—precisely what I'm in the process of requesting, to try and stop this anarchy with everything, as there is great anarchy where works are concerned! [...] it's UN-BE-LIEVABLE when you see the quantity of discrepancies. From one pavement to another, even between two pavements opposite one another, there are already differences. (Brussels_06, wheelchair user)

This lack of cohesion leads to inconsistencies in the design of urban infrastructure. The same Belgian interviewee used discrepancies in the height of bus stops as an example (Brussels_06, wheelchair user).

3.2. Study 2: Survey Results on the Use Intention of Future Assistive Technologies

The user survey collected data about users' assessments of future assistive technologies regarding use intention, which was compared by analysing the share of respondents who stated that they will use the technology "frequently or always". According to the results, wearables were the most popular solutions, preferred by 57.9% (n = 320) of the sample. Augmented reality was popular with 47.4% of the sample, location-based alerts were favoured by 46.8%, exoskeletons by 41.2%, accessible navigation systems by 40.5%, 3D-printed prosthetics by 29.8%, and smart canes by 19.7% (see Figure 1 below).
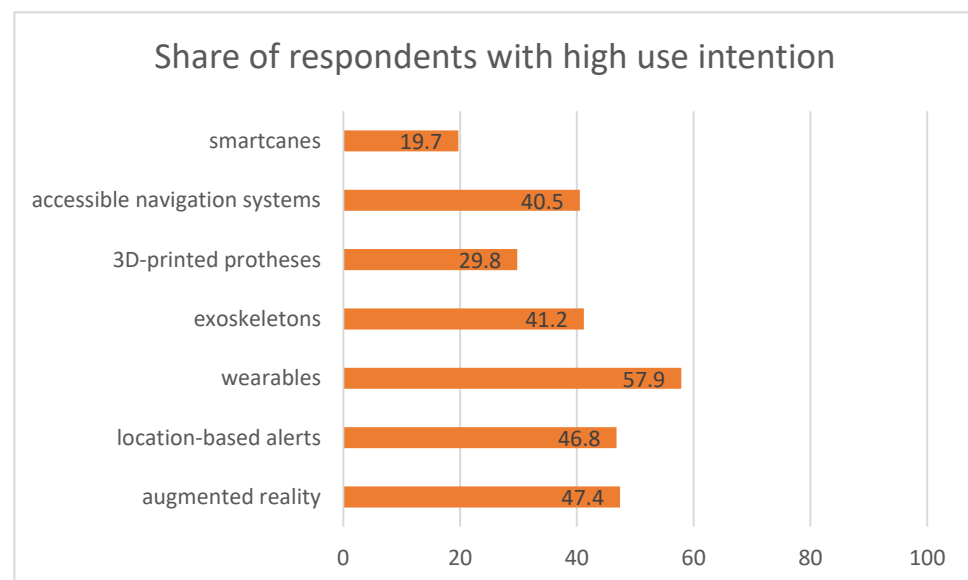

Figure 1. Share of respondents with high use intention ("frequently" and "always") for the seven future technologies.

Figure 2 below presents participants' intentions to use assistive technologies according to the type of disability. According to survey results, smart canes, i.e., GPS-enabled white canes, would be regularly (i.e., always or frequently) used by approximately 11.45% (34/297) of people with physical disabilities, 50.59% (43/85) of people with visual impairments, 8.89% (4/45) of people with hearing impairments, 31.25% (5/16) of those with intellectual impairments, and 27.06% (23/85) of those with multiple impairments.

Accessible navigation systems, i.e., GPS-enabled wayfaring systems with accessible user interfaces, would be regularly used by approximately 18.52% (55/297) of people with physical disabilities, 68.24% (58/85) of people with visual impairments, 22.22% (10/45) of people with hearing impairments, 25% (4/16) of those with mental health issues, 35.29% (6/17) of those with intellectual impairments, and 44.71% (38/85) of those with multiple impairments.

Automated captions, i.e., automatically generated transcriptions of auditory messages, would be regularly used by approximately 26.26% (78/297) of people with physical disabilities, 44.71% (38/85) of people with visual impairments, 77.78% (35/45) of people with hearing impairments, 18.75% (3/16) of those with mental health issues, 52.94% (9/17) of those with intellectual impairments, and 45.88% (39/85) of those with multiple impairments.

Artificial intelligence alerts, i.e., AI-generated nudges and notifications, would be regularly used by approximately 31.65% (94/297) of people with physical disabilities, 60% (51/85) of people with visual impairments, 55.56% (25/45) of people with hearing impairments, 43.75% (7/16) of those with mental health issues, 41.18% (7/17) of those with intellectual impairments, and 55.29% (47/85) of those with multiple impairments.
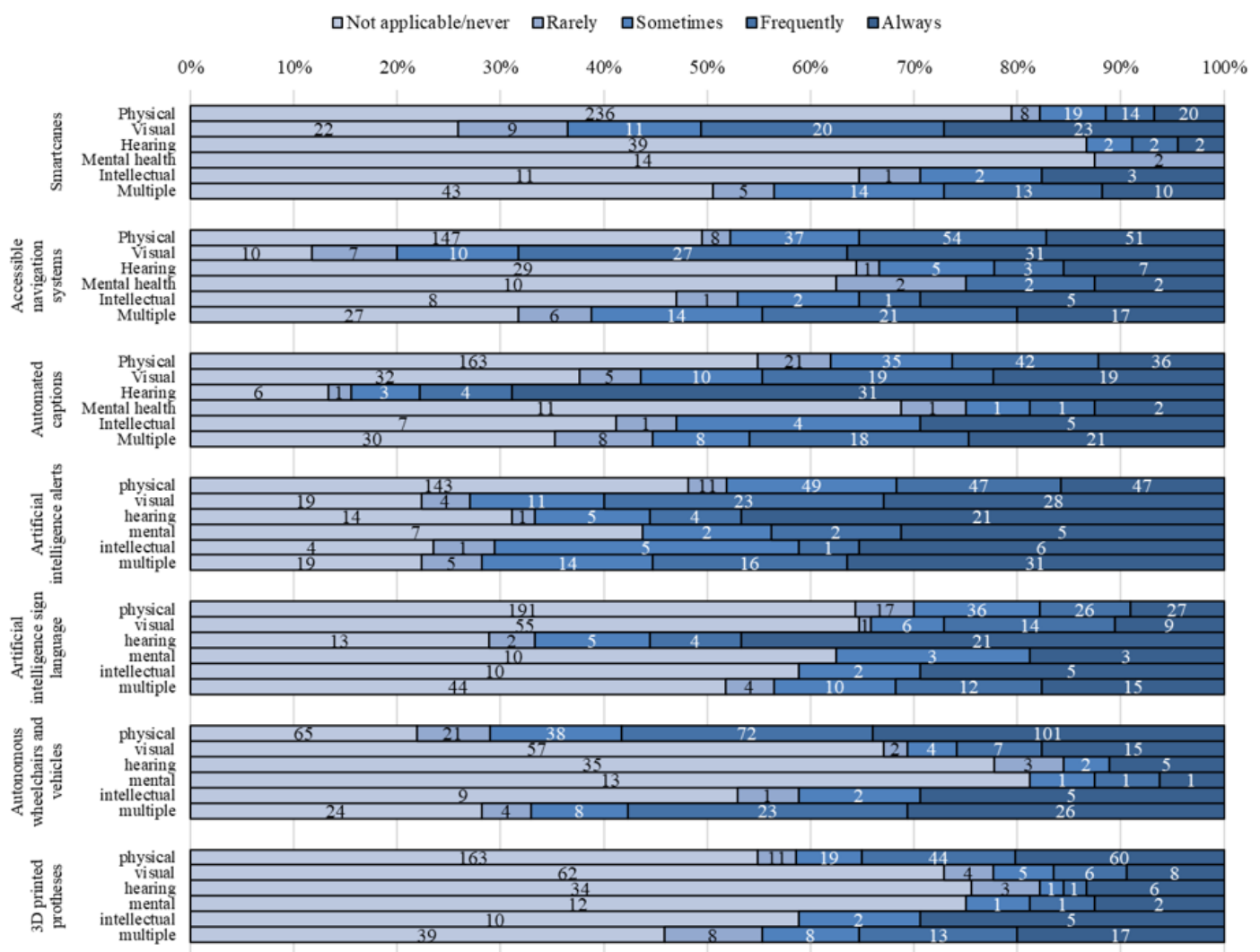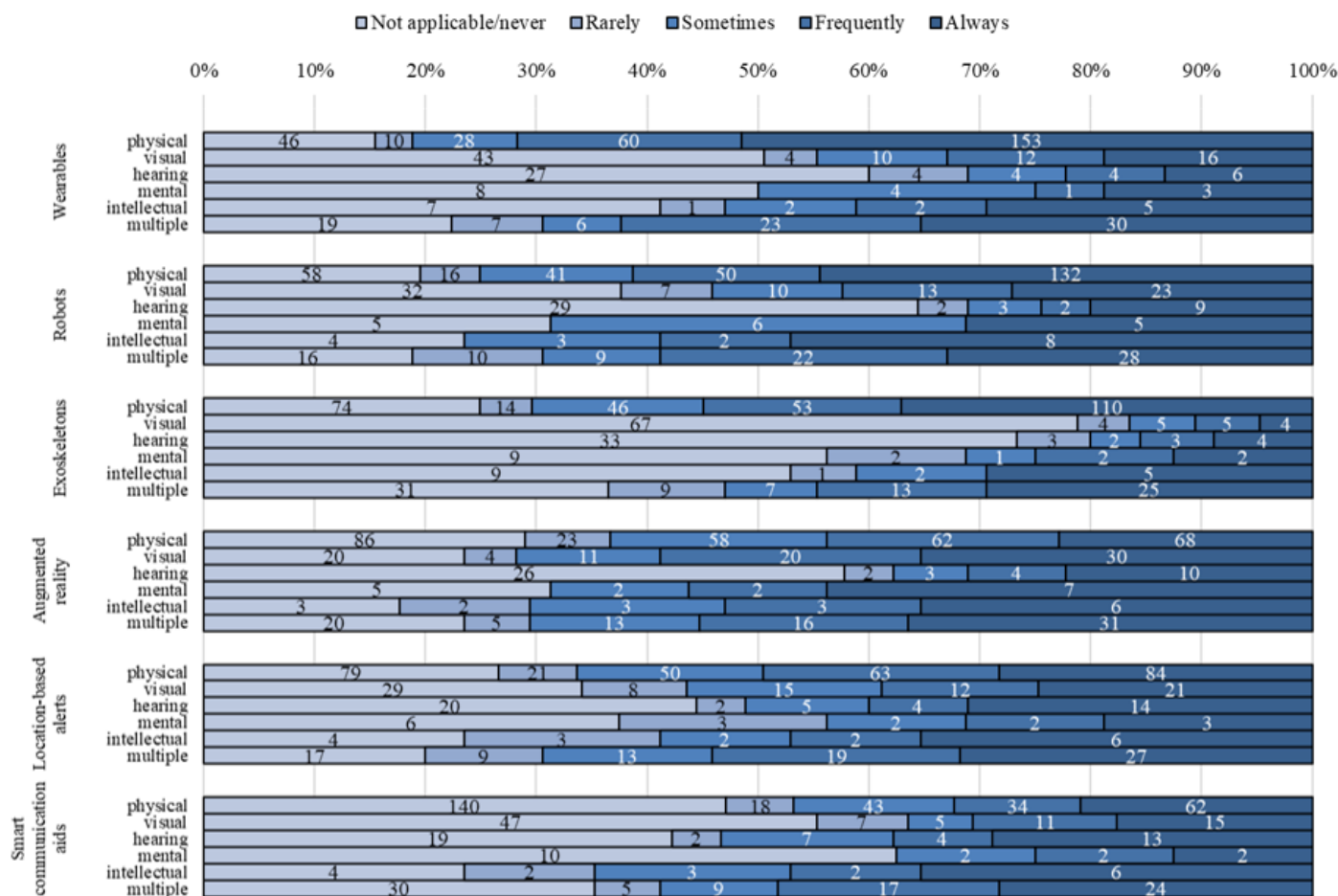

Figure 2. *Cont.*

Figure 2. Use intentions for assistive technologies according to type of disability. For an explanation of the colours please refer to the on the top of the figure ranging from light blue representing non-applicable to dark blue representing Always. The numbers on the graph represent absolute number of incidents in our sample.

Artificial intelligence sign language, i.e., AI-generated translation of voice messages into sign language, would be regularly used by approximately 17.84% (53/297) of people with physical disabilities, 27.06% (23/85) of people with visual impairments, 55.56% (25/45) of people with hearing impairments, 37.5% (6/16) of those with mental health issues, 29.41% (5/17) of those with intellectual impairments, and 31.76% (27/85) of those with multiple impairments.

Autonomous wheelchairs and vehicles, i.e., self-propelled wheelchairs and vehicles based on the user's instructions, would be regularly used by approximately 58.25% (173/297) of people with physical disabilities, 28.24% (24/85) of people with visual impairments, 15.56% (7/45) of people with hearing impairments, 12.5% (2/16) of those with mental health issues, 41.18% (7/17) of those with intellectual impairments, and 57.65% (49/85) of those with multiple impairments.

Prosthetics that are 3D-printed, i.e., smart prosthetics that connect to user physiology, would be regularly (i.e., always or frequently) used by approximately 35.04% (104/297) of people with physical disabilities, 16.47% (14/85) of people with visual impairments, 15.56% (7/45) of people with hearing impairments, 12.5% (2/16) of those with mental health issues, 41.18% (7/17) of those with intellectual impairments, and 34.12% (29/85) of those with multiple impairments.

Wearables, i.e., hands-free smart gadgets that can work and provide travel and contextual information, would be regularly used by approximately 71.72% (213/297) of people with physical disabilities, 34.12% (29/85) of people with visual impairments, 22.22%

(10/45) of people with hearing impairments, 25% (4/16) of those with mental health issues, 41.18% (7/17) of those with intellectual impairments, and 62.35% (53/85) of those with multiple impairments.

Robots that can provide assistance, information, protection, and/or companionship would be regularly used by approximately 61.28% (182/297) of people with physical disabilities, 45.88% (39/85) of people with visual impairments, 24.44% (11/45) of people with hearing impairments, 68.75% (11/16) of those with mental health issues, 58.82% (10/17) of those with intellectual impairments, and 60% (51/85) of those with multiple impairments.

Exoskeletons, i.e., a mechanical frame that supports the body and assists movement, would be regularly used by approximately 61.95% (183/297) of people with physical disabilities, 10.59% (9/85) of people with visual impairments, 15.56% (7/45) of people with hearing impairments, 25% (4/16) of those with mental health issues, 41.18% (7/17) of those with intellectual impairments, and 44.71% (38/85) of those with multiple impairments.

Augmented reality, i.e., the enhancement of real-world perception by superimposing computer-generated information, would be regularly used by approximately 44.11% (131/297) of people with physical disabilities, 58.82% (50/85) of people with visual impairments, 31.11% (14/45) of people with hearing impairments, 56.25% (9/16) of those with mental health issues, 52.94% (9/17) of those with intellectual impairments, and 55.29% (47/85) of those with multiple impairments.

Location-based services, i.e., the provision and information about available user services in the vicinity, would be regularly used by approximately 49.49% (147/297) of people with physical disabilities, 38.82% (33/85) of people with visual impairments, 40% (18/45) of people with hearing impairments, 31.25% (5/16) of those with mental health issues, 47.06% (8/17) of those with intellectual impairments, and 54.12% (46/85) of those with multiple impairments.

Smart communication aids, i.e., computer-assisted translation of other forms of communication (non-verbal and symbolic) to speech or written messages, would be regularly used by approximately 32.32% (96/297) of people with physical disabilities, 30.59% (26/85) of people with visual impairments, 37.78% (17/45) of people with hearing impairments, 25% (4/16) of those with mental health issues, 47.06% (8/17) of those with intellectual impairments, and 48.24% (41/85) of those with multiple impairments.

3.3. Study 3: Brainstormed Design Concepts

This section presents four design concepts brainstormed by persons with disabilities during the TRIPS ideation workshops. Users were instructed to imagine mobility concept solutions that would serve their desired lifestyle without thinking about practical feasibility constrains. While other technologies were considered, these four design concepts relate directly to walkability, i.e., moving within urban environments (see Figure 3).

Mobile walkways city network: A city-wide network of rapid mobile walkways where people can automatically get on and off safely was envisioned, particularly for moving in city centres and interchanges. This idea extends existing technologies often used in large public spaces and metro stations. Users suggested special considerations for carrying luggage and introducing safety and security measures. Few would know, however, that mobile walks are a thing of the past. They were originally invented in the 1800s. The Rue de ll'Avenir (Paris) and the Great Wharf Moving Sidewalk (Chicago) were designed and implemented by American architect Joseph Lyman Silsbee and American engineer Max E. Schmidt and even had fast and slow lanes. At that time, however, such systems were unreliable and prone to breakdowns, and their health and safety were poorly considered [34]. Current advances in mechanical engineering and control systems have made reliability issues easily rectified, and moving walkways are often in operation in airports nowadays. Even in modern walkways, safety concerns during onboarding and offboarding still exist, particularly for persons with disabilities who have been excluded from riding many of them [35]. Hence, our scope is engaging disabled users on redesigning such systems to make them useful to and usable by everyone.
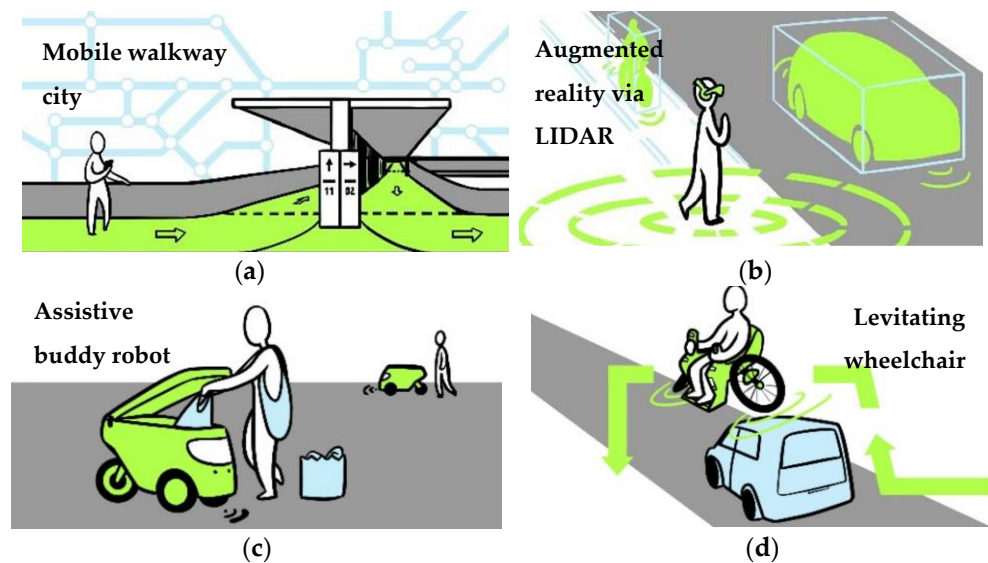
Figure 3. Co-created design concepts: (**a**) mobile walkway city network, (**b**) augmented detection device via a LIDAR 3D reconstruction of the environment, (**c**) assistive buddy robot, and (**d**) levitating wheelchair.

The LIDAR (Light Detection And Ranging) 3D reconstruction of the environment: This technology would enable the early identification and avoidance of obstacles. Participants envisioned wearable glasses, which allow the visually impaired wearer to precisely reconstruct the external environment. The glasses would be equipped with a LIDAR sensor and headphones for sending alerts and would enable users to navigate through the built environment to safely access transport, change vehicles, and disembark. Obstacles and other elements detected by the LIDAR would be transmitted to users' mobile phones, which would process the information and transmit alerts to the user via headphones. This approach would benefit third parties who could develop various apps to communicate with the glasses and enable different approaches to information processing which could be customised by the user. A similar approach using a harness rather than glasses is currently being developed by the company biped.ai. (Lausanne, Switzerland).

Assistive buddy robots: These travel buddy robots would follow users and could carry luggage, provide information, and support users as they transfer from one position or vehicle to another. The buddy would increase the willingness of persons with disabilities to walk home, especially after shopping or starting/ending a long journey, as it could carry a person's load. Users envisioned that buddies would also have the additional social capabilities of companionship, addressing users' social needs of not travelling alone. Similar to systems such as pay as you go rental systems, special considerations include the booking features, affordability of such technologies, and ability to return to their charging stations after escorting users. So far, assistive robots that can perform supportive tasks and social robots with social capabilities have been developed independently. As a result, one can rarely find a single robot with both capabilities. However, multi-functional robots are expected to lead robotics innovation to maximise their social utility in the future [36].

The "Levitating" wheelchair: The envisioned wheelchair is robotised and could fly at a low altitude using drone technology. It enables persons with physical disabilities to move more freely in urban settings and avoid traffic jams, crowds, and obstacles. Additionally, the wheelchair could allow users to go anywhere, reducing the need for other means of transportation and enabling them to reclaim their autonomy. Use of the wheelchairs would mean that no changes would need to be made to the physical transport infrastructure, as the wheelchair would allow users to overcome any physical barriers. Safety measures should be considered, as should protection from weather conditions and practical considerations about the systemic introduction of such an innovation in society. Passenger drones

have been invented and tested in Europe [37]. Even dual-purpose machines like drone motorcycles are currently being prototyped [38]. Hence, drone-powered wheelchairs may be developed in the near future, although several adoption barriers should be considered, such as safety and security, weight, and flying regulations.

These innovations indicate not only the willingness of persons with disabilities to engage in technological innovation but also their ability to relate technological advances to practical everyday problems. Except for mobile walkways, the innovations focus on personal assistive technologies rather than infrastructure changes. This raises a fundamental question about whether assistive technology companies and social services should be included in strategic decisions regarding the accessibility of urban planning. Advancing assistive technologies and making them available to disabled users may increase their ability to navigate different terrains and decrease the costs associated with urban infrastructure changes.

4. Discussion and Recommendations

The goal of this study was to present users' perspectives on the barriers that persons with disabilities face when moving around in cities, whether on foot or on wheels. Our motivation is to raise awareness of the user requirements of persons with disabilities so they can be accounted for in the development of SUMPS plans, especially by those adopting a MaaS paradigm for the improvement of urban transport [1,2,4–7].

The findings contribute to the short list of literature aiming to decipher the specific user requirements of persons with disabilities with respect to walkability [18–22]. We suggest that people need reliable and well-communicated wayfaring information on accessible routes, street design, pavements, stops, stations, and vehicles to ensure seamless, step-free, and obstacle-free access, as well as disability-sensitive management of disruptions, such as those caused by maintenance works. Decluttering urban walkways is fundamental for the accessibility of cities. However, this is difficult to achieve, particularly for traditional European cities that have evolved over several eras and include historical centres with narrow streets, cobbled roads, and uneven pavements, which are often considered an integral part of the character and heritage of these cities. Further, cities are made for cars, and much urban space is still dedicated to car traffic and parking. At the same time, new modes of mobility compete for the leftover pedestrian space, along with an increasing number of pedestrians, buses, resting places, greenery, traffic lights, and signage. Rethinking the land use of urban space should be considered amongst competing priorities, with disabled users present during strategic decision-making and in public consultations.

Maintenance is common in European cities, whether as a pre-planned activity or in response to an incident (e.g., a broken water pipe). This often affects the accessibility of routes. We suggest that a disability-friendly protocol should be established for informing the public, perhaps via wayfaring apps (such as Google Maps), disability NGOs, or travel apps, and that standardised provisions should be made to ensure diversion routes are designed and standardised to be disability-friendly. Information is only useful when one can trust its accuracy and integrity. Hence, initiatives should focus on harmonising signage within individual cities, between cities in the same country, and across broader regions, such as the EU. Signage should be accurate, credible, and timely, and communicate in a clear and accessible way. To ensure that signage complies with rules and regulations and serves the actual needs of persons with disabilities, we recommend testing new or changed signs with persons with disabilities. By extension, we propose a greater collaboration between disability NGOs and urban and transport planning sectors to design accessible routes and increase the accessibility of cities and transport infrastructure. The participation of disability representatives should be mandatory in urban and transport planning, development and procurement standards, and mobility innovation overall.

These findings suggest that transport and urban accessibility regulations should not only ensure the accessibility of infrastructure but mandate the availability of information about these accessibility initiatives, integrate this information across public agencies, and

provide accurate real-time information about conditions. Regulations and standards, governance policies and practices, and service-level agreements must ensure the policing of such standards, their maintenance over time, and appropriate day-to-day management. Findings also suggest that users are open to using any assistive technology that can facilitate their independent living, assuming it is accessible, and are keen to co-innovate. Our user survey suggests that persons with disabilities are open to using personal technologies to gain greater autonomy. We suggest that innovation investments in urban accessibility technologies such as wayfaring, augmented reality, wearables, and robots could be considered new market opportunities and that social security systems should consider the inclusion of such technologies as standard offerings for persons with disabilities.

However, challenges remain relating to the accessibility of these digital technologies, people's confidence in using them, and their affordability. Therefore, it is imperative to provide adequate digital education to persons with disabilities to raise their confidence and skills in using digital technologies. Besides digital education, financial support for users with disabilities should be provided by social security systems, so they can own such technologies to navigate urban infrastructures better. Not only are persons with disabilities open to using smart assistive technologies, but there is an implicit societal-wide assumption that, in the future, passengers will use smartphones to interact with digital transport, for example, to book services or instruct vehicles. However, smart technology subsidies are not currently offered in many EU countries. Therefore, governments and healthcare systems should consider funding or subsidising smart technologies to make them more affordable and accessible to all persons with disabilities. In addition, social policy should consider initiatives that can bridge the current divide in digital skills for persons with disabilities. Embracing a commitment to inclusive education and digital learning can provide disabled individuals with the knowledge and skills needed to live in a digital world.

Moving is an indispensable component of travelling. The findings of the EU-funded project TRIPS have led to several insights and recommendations for policy initiatives that can drive structural changes in urban planning and the redesign of urban infrastructure to make cities more accessible for people with disabilities. We have argued for a more holistic, human-centric approach to the problem of accessibility and highlighted the need to explore the nexus between transport, urban, social, and educational policy to devise the necessary changes that can facilitate systemic change towards accessibility.

Institutional Review Board Statement: The study was conducted under EU rules concerning research ethics, described in the project handbook and reviewed throughout the project. These also included information regarding Informed Consent procedures and reported on adherence monitoring, deviations, and countermeasures. All processes have been documented in relevant deliverables and approved by the EU, as the funder organization. In addition, an Ethics Advisory Board was consulted annually and on an ad hoc basis for critical project decisions to prevent the misuse of research findings. Advisors played a crucial role in defining the briefs for the demonstrators and advising on the ethics principles that should guide their operationalization. To engage research participants, the European Network of Independent Living (ENIL) held the primary responsibility across Work Packages to ensure that users' requirements, concerns, and aspirations were voiced openly and on an equal footing.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. See details above.

Data Availability Statement: All supporting material can be found on the TRIPS webpage https: //trips-project.eu/deliverables/, accessed on 10 November 2023 Raw data from the survey can be made available upon demand.

Conflicts of Interest: Author Tally Hatzakis was employed by the company Trilateral Research Ltd. Author Laura Alčiauskaitė was employed by the company European Network of Independent Living. Author Alexandra König was employed by the company Deutsches Zentrum für Luft- und Raumfahrt. The European Commission had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

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