SMARTIE: Smart Museum for All using a Range of Technologies for Inclusive Experience

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Abstract
Visiting museums is challenging for people with disabilities for various obvious reasons. This explains why only 7% of museum visitors have disabilities. Encouraging inclusivity within museums and galleries can lead to a more diverse audience, allowing a broader range of visitors to fully engage with and gain value from the cultural offerings. Assistive technologies can create a better experience, potentially bringing the user closer to previously inaccessible artifacts and sites and enabling them to function independently and with dignity. Well-adapted technology may contribute to the visitors' varied needs, thereby encouraging participation, self-esteem, and quality of experience. However, it is still a gap and a hard-to-solve one, especially concerning the need for a holistic understanding of the process. We propose a model intended to address this long-standing issue suggesting a holistic framework and tailoring guidelines (for specific disabilities), for adapting and integrating innovative technologies into existing museum infrastructures (which are diverse as well). The model adapts and integrates state-of-the-art approaches such as User-Centered design, the International Classification of Functioning, Disability and Health framework, and the Matching Person and Technology model into one coherent model aimed at improving the visit experience for people with disabilities.

Keywords
Cultural heritage, Museum visit experience, Inclusive design, Technology innovation, Inclusive Museum, Human-Centered Computing, Accessibility systems and tools, User-centered design.

1. Introduction

Museums serve as pivotal hubs of cultural life and learning. Therefore, they not only preserve and exhibit artifacts and artworks from various epochs and regions but also act as spaces where individuals can immerse themselves in a rich tapestry of human civilization, knowledge, enjoyment, reflection, and artistic expression [29]. Through museums, people can learn and explore the world through objects, collections, and social interaction. This drives the purpose and approach that the museum should be relevant to all the visitors' needs and emphasize visitor-centered choices, including their intellectual, social, and emotional access to museum collections and successful experiences. Museums are responsible for ensuring that their spaces and content are accessible, providing inclusive experiences. Additionally, they should operate and communicate with the participation of the community [27]. The term inclusive suggests that no one should be excluded from experiencing the benefits of the museum, i.e., that the whole world—and every citizen in it—should be involved in and able to experience its exhibitions [13] [28]. Despite these goals, only 7% of museum visitors have disabilities [3].

Accessibility in museums involves criteria that highlight a holistic and inclusive approach, considering not just the museum's physical environment but also the broader experience of all visitors [11]. Accessibility considerations listed in the Smithsonian Guidelines for Accessible

Workshop on Recommenders in Tourism (RecTour 2024), October 18th, 2024, co-located with the 18th ACM Conference on Recommender Systems, Bari, Italy.
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Design include but are not limited to, public spaces, furniture, color usage, language and label design, text choices, interactive elements, and circulation routes. In recent years, much attention has been paid to accessible tourism, especially for the following audiences: visually impaired individuals, individuals with motor limitations, hearing impairments, and individuals with cognitive and developmental disabilities [18] [5]. Adapting existing museums for accessibility standards often introduces aesthetic challenges and requires significant changes, particularly in entrance areas and within the building's interior. In addition, in recent years, accessibility has also focused on integrating innovative technologies to enhance experiences for visitors with disabilities. Therefore, it is very important to consider accessibility in the development and deployment of new technologies in museums [4]. This helps create a more authentic experience, potentially bringing the user closer to previously inaccessible artifacts and sites [11].

So far, despite a significant amount of research dedicated to developing and implementing guidelines for making museums more accessible, traditional accessibility guidelines do not fully address the unique intricacies of design and interaction inherent to museum visits. Furthermore, they do not account for the rapid advancement of technologies, including those related to accessibility, which renders existing guidelines outdated and rigid. Hence, the focus of our proposed study is not on specific technologies that have proven to be effective or ineffective in enhancing accessibility. Rather, our aim is to establish a comprehensive model that will recommend tailored guidelines for specific disabilities, with the goal of adapting, integrating, and innovating technologies into current museum infrastructures while minimizing the need for extensive modifications to existing facilities.

2. A Case Study - Supporting Blind and Low-Vision Visitors in Museums

To enhance museum accessibility for visitors with visual impairments, specifically those who are blind or have low vision (BLV), a recent study developed and implemented four Interactive Tangible User Interfaces (ITUIs). This initiative was undertaken as part of a multidisciplinary graduate course, wherein students from the information systems department and the department of occupational therapy at the University of Haifa collaborated with museum staff at a local museum [1]. Through this collaborative process, the multidisciplinary team of students aimed to create more inclusive museum experiences for visitors with varying levels of visual ability inspired by the work of Umanski and Avni [25], Vaz et al. [26] and Cavazos et al. [8].

The development followed three stages: developing an initial conceptual prototype, refining the prototype, and final experimental system. The process followed User-Centered Design (UCD) that involves continuous engagement with users, utilizing investigative methods like surveys and interviews for direct insights and feedback, along with generative techniques like brainstorming to address identified needs. The process unfolds in four phases: *(1) Understand the context of use*, *(2) Specify user requirements, (3) Design solution, (4) Evaluate against requirements*, within each iteration (see Fig. 1). The team refines the design through further iterations based on feedback until it meets users' needs and expectations [16] [23].

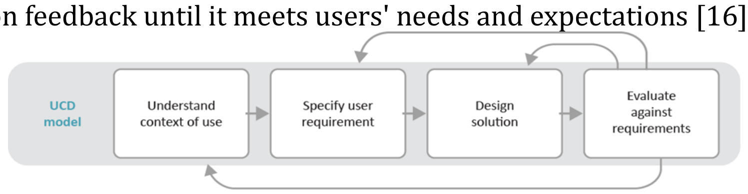

Fig. 1: Four distinct phases of the UCD.

To *understand* the context, students engaged in various activities: conversations with museum staff, blindfolded exploration methods, shadowing BLV visitors during museum visits, and literature reviews. User *requirements* were specified through rapid prototyping, including video prototypes with cardboard models. Concepts were refined based on feedback from museum staff, team members, and two BLV volunteers. Teams explored different interaction techniques, focusing on aspects like 3D print resolution, interface activation methods, and audio playback. In the *design solution* phase, teams created semi-working prototypes with 3D-printed replicas, recorded audio files, and core programming code. The evaluation stage included two preliminary rounds before final testing. The first evaluation, using the Wizard of Oz method [15] [19], assessed user comprehension with two BLV volunteers. Prototypes were then refined based on feedback. Following a demonstration and proof of concept, all four ITUIs were redesigned for *evaluation* in a realistic setting. Feedback from the two BLV users during the evaluation sessions informed the final iteration, which was further refined to facilitate user testing in a more extensive study.

The study addressed a critical gap in museum accessibility by developing affordable and effective ITUIs for artifact representation tailored to BLV visitors following User-Centered Design. The primary objective of the study was to compare usability, effectiveness, and user preferences among the different ITUI designs, ultimately aiming to improve accessibility in museum settings for BLV visitors. It involved 30 BLV participants testing three ITUI prototypes (one prototype was excluded following a pilot study): Autoplay, Pushbuttons, and RFID scanning. Employing a within-subjects design, each session lasted approximately 90 minutes and included a pre-interview, structured exploration of each ITUI, and post-exploration questionnaires. The researchers used various evaluation methods, including usability questionnaires (SUS) [6], satisfaction ratings, preference assessments, and video recordings of interactions.

3. Motivation – Limitation of Current Approaches

While UCD is a widely adopted approach in product and service development, aiming to create solutions that align closely with user needs and preferences, its application in addressing the needs of users with disabilities often reveals limitations. The traditional UCD model [2],[7] often falls short in providing a comprehensive framework for accessibility, particularly for populations with specific sensory or cognitive requirements. One of the primary limitations of UCD in this context is its heavy reliance on direct user input. While valuable, this approach may not fully capture the complex needs of users with disabilities. Users may struggle to articulate their needs comprehensively, especially when confronted with novel technologies or potential solutions they haven't yet encountered. This can lead to a focus on immediate, apparent needs at the expense of long-term functionality or innovative solutions that could significantly improve their experience. For example, one of the observations that emerged from the case study is the need to consult with a remedial teaching expert when editing the texts to create a better understanding between the artifact the users are holding and the explanation they are hearing. Most of the participants were so focused on giving feedback on the quality of the 3D-printed exhibits that they did not address the content and its comprehension.

Another limitation is the fact that Inclusive design may not be fully suitable in this case due to the diverse spectrum of visual impairments among BLV visitors, ranging from total blindness to various degrees of low vision. This diversity makes it challenging to create a single solution that works equally well for all users. Additionally, BLV individuals have varied skill sets and experiences, such as the ability to read Braille or the duration of their visual impairment, which significantly impacts how they interact with and perceive tactile interfaces. It's practically impossible to include representatives of every type of visual impairment in the design process, potentially leading to overlooking crucial needs or preferences of certain subgroups.

By relying only on UCD or guidelines such as the Smithsonian Guidelines for Accessible Exhibition Design, the design teams may also lack the in-depth knowledge needed to fully understand the nuances of different visual impairments and their effects on user interaction. This lack of expertise can result in well-intentioned but ineffective solutions. Attempts to create a one-size-fits-all solution may end up working well for some BLV users but failing others, potentially excluding certain groups from the museum experience. The complexity of balancing the needs of different types of visual impairments, which may require conflicting design approaches, further complicates the inclusive design process. In this context, a more targeted approach focusing on specific subgroups of BLV visitors or creating modular solutions that can be adapted to different needs might be more effective than a broad inclusive design strategy.

The UCD process also tends to emphasize accessibility compliance, which, while important, can sometimes overshadow the exploration of more innovative solutions that could enhance user experience beyond basic standards. This compliance-focused approach may not sufficiently consider the varied environments and contexts in which users with disabilities interact with products or services, nor does it typically incorporate comprehensive medical or functional assessments that could provide crucial insights. Within the context of the study, the students who worked on the development of the ITUIs focused solely on technologies in the museum setting. Familiarity with other environments and products where adaptation for the blind is required can greatly contribute to a more holistic solution and better understanding, such as: minimum size of 3D printed exhibits, preferred textured, textures positioning, tangible features that promote independent use, etc.

Furthermore, traditional UCD methods may struggle to effectively prototype and test designs for users with certain disabilities. Standard techniques might not be suitable or might provide incomplete or inaccurate feedback, leading to potential misunderstandings or missed opportunities for improvement. For example, Braille height and size, push-button positioning, unclear introduction explanation, etc. The interplay between designed products and the various assistive technologies used by people with disabilities is another area that may not receive adequate attention in typical UCD processes.

Lastly, UCD often focuses on current capabilities and limitations, potentially overlooking how a user's condition might change over time or how adaptive technologies might evolve. This short-term perspective can result in designs that quickly become outdated or ineffective as users' needs change or new technologies emerge. To address these limitations, incorporating more comprehensive frameworks, for example, from the fields of occupational therapy or adaptation of assistive technologies, can significantly enhance the UCD process. By integrating such frameworks, there is a need to develop a model that offers a recommended set of guidelines for designing visit experiences for people with disabilities, as well as tailoring guidelines for individual disabilities.

4. Smart Museum for All using a Range of Technology for Inclusive Experience

The SMARTIE model represents an innovative, multidisciplinary approach synthesizing cutting-edge design principles from human-computer interaction with accessibility guidelines. This integrated framework is specifically engineered to guide the development of novel assistive technologies aimed at enhancing museum experiences for visitors with disabilities. The core concept is the fact that the visitor is at the center of the process – this is common to both disciplines. The overarching framework is the idea of User-Centered Design. By positioning the visitor at the epicenter of the design process, SMARTIE ensures that the resulting assistive technologies are not only technologically advanced but also inherently responsive to the diverse needs and preferences of users with disabilities.

The model's multidisciplinary nature allows for a holistic approach to accessibility in museum settings, potentially addressing the limitations of traditional UCD methods discussed earlier. By integrating expertise from various fields, SMARTIE may offer a more comprehensive framework for developing assistive technologies that go beyond immediate user feedback, incorporating insights from specialists in areas such as occupational therapy frameworks and models.

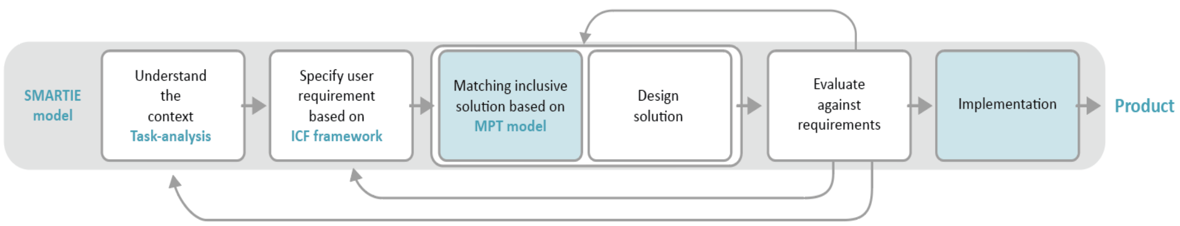

Fig. 2: The novel SMARTIE model.

4.1. Incorporating Users with Disabilities into the Design Process

The SMARTIE model presents a novel approach to mitigating the limitations inherent in traditional user-centered design methodologies, particularly in the context of accessibility for individuals with complex or diverse needs. It acknowledges a significant epistemological challenge: the potential inability of users, especially when confronted with innovative technologies, to fully articulate or comprehend their own needs and preferences. This cognitive limitation can substantially impact the accuracy and comprehensiveness of requirement definitions in the design process. To address this methodological constraint, SMARTIE incorporates the International Classification of Functioning, Disability, and Health (ICF) framework [17]. It serves as a robust, multidimensional tool for analyzing human functioning and disability within specific contextual environments. The ICF framework, as depicted in Figure 3 (left), delineates the complex interrelationships among five key dimensions: (1) Body functions and structures, (2) Activities, (3) Participation, (4) Environmental factors, and (5) Personal factors. The figure illustrates the bidirectional influences among these dimensions, demonstrating how specific body structures and functions impact museum visit activities, while environmental and personal factors modulate participation in the museum experience. By integrating this multifaceted approach, SMARTIE enhances its capacity to anticipate and address latent user needs that may not be immediately discernible through direct user feedback alone. This framework facilitates a more nuanced understanding of the "context of use" by analyzing user functioning and disability within the specific scenario of a museum visit.

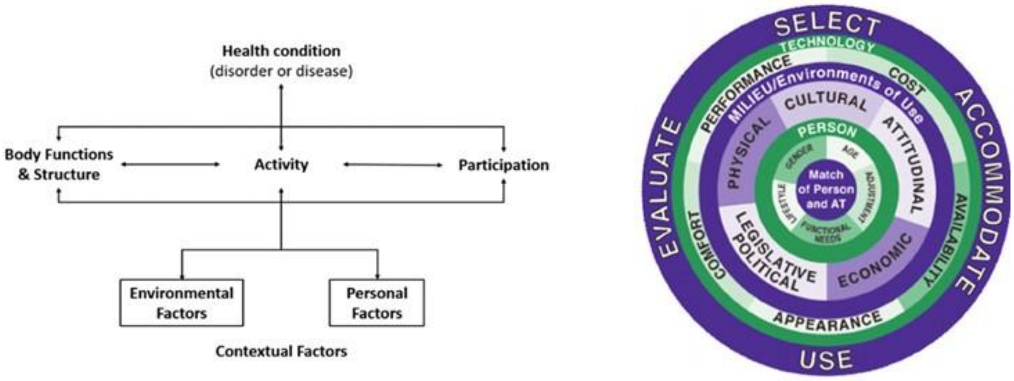

Fig. 3: The main concepts of ICF and their interrelations (left) and the main concepts of MPT (right).

The application of the ICF within SMARTIE involves a systematic mapping of various dimensions of user functioning, encompassing motor, cognitive, and sensory domains. Concurrently, environmental factors that either impede or facilitate participation in museum-related activities are subjected to close examination. Through the definition and analysis of specific body functions that influence user engagement, designers can develop more accurate predictive models of how disabilities affect engagement and participation in museum environments. This integrated approach enables SMARTIE to bridge the gap between user-expressed needs and the broader contextual factors of disability and functionality. The in-depth analysis informed by the ICF framework guides the development of targeted technological interventions, resulting in more comprehensive and efficacious assistive technologies for enhancing museum accessibility. In essence, SMARTIE's incorporation of the ICF framework elevates the design process beyond the limitations of immediate user feedback, providing a structured methodology to anticipate and address the complex needs of users with disabilities in museum environments. This approach promises more inclusive and effective solutions that consider the multifaceted nature of disability and its impact on museum experiences, thereby advancing the field of accessible design in cultural institutions.

4.2. Matching Inclusive Solutions Based on MPT Model

To further enhance the efficacy of assistive technology selection in museum contexts, the SMARTIE model incorporates the Matching Person and Technology (MPT) model developed by Scherer [21]. MPT offers a complementary framework to the ICF, providing guidelines for selecting technologies that optimally align with individual users' needs, preferences, and the specific context of museum visits.

The MPT model is predicated on two fundamental principles, as illustrated in Figure 3 (right):

A focus on triadic interaction: The model emphasizes the dynamic interplay between environmental factors, user characteristics, and technological attributes. In the context of museum accessibility, this interaction manifests in the relationship between visitors with visual impairments (in the specific case study) or various disabilities (in the broader application of the model), the assistive technologies employed, and the museum environment itself.

A holistic and collaborative approach: It advocates for a comprehensive and participatory process in technology adaptation. This process is designed to facilitate collaboration between professionals (e.g., museum staff, accessibility experts, designers) and users (disabled visitors) to ascertain the user's needs within their respective environments. It involves a thorough assessment of technological features and their alignment with the intended user's requirements.

The implementation of MPT within the SMARTIE serves to refine the selection and adaptation of assistive technologies in museum settings. By applying a comprehensive assessment of technological features and their congruence with user needs, professionals can make more informed decisions regarding the most appropriate technologies, training strategies, and additional support necessary for optimal use within the museum environment. It is crucial to note the distinction between the specific case study, which focused on visitors with visual impairments, and the broader application of MPT, which encompasses all types of disabilities. This differentiation allows for both targeted interventions in specific contexts and the development of more universally accessible museum experiences. The integration of MPT into SMARTIE enhances its capacity to address individual variability in technology needs and preferences. By considering the unique characteristics of each visitor, their specific impairments, and the museum's environmental factors, the model facilitates a more personalized and effective approach to assistive technology implementation in cultural institutions. SMARTIE strength lies in its synergistic integration of UCD, ICF, and MPT. These frameworks interact and complement each other within SMARTIE. By combining them, SMARTIE addresses not just the technical aspects of accessibility, but also the personal, social, and environmental factors that affect a visitor's museum experience. This integrated approach allows for more nuanced, personalized, and effective accessibility solutions in museum settings.

4.3. Design Solutions

This holistic approach, combining the ICF's comprehensive understanding of disability with the MPT's focus on technology matching, positions SMARTIE as a robust and nuanced framework for advancing accessibility in museum environments. It acknowledges the complexity of human-technology interactions and the diversity of user needs, thereby promoting more inclusive and engaging museum experiences for visitors with a wide range of abilities. However, it is crucial to recognize that while existing models in the domain of technology-supported accessibility provide foundational frameworks, they often lack the granularity required for specific technological applications, particularly in the context of smart museums. The SMARTIE model (see Fig. 1) addresses this limitation by proposing a more detailed and comprehensive framework specifically tailored to designing accessible smart museum experiences.

The SMARTIE model's innovative approach lies in its synthesis of established methodologies and its application to the unique challenges presented by smart museum environments. By adopting a user-centered design methodology and drawing upon recognized models of human functioning and technology matching, SMARTIE ensures that solutions are empathetically aligned with visitor needs and preferences. Its distinguishing feature is its ability to bridge the gap between general accessibility principles and the specific requirements of smart museum technologies. It achieves this by:

1. Integrating the comprehensive disability understanding provided by the ICF with the technology-matching focus of the MPT model.
2. Applying the integrated concepts specifically to the museum context, addressing the unique challenges and opportunities presented by advanced technologies in cultural institutions.
3. Providing a more granular framework that allows for precise mapping of user needs to technological solutions within the museum environment.
4. Emphasizing the dynamic interaction between visitors, technologies, and the museum space, acknowledging the complex ecosystem of a smart museum.

By creating this detailed and comprehensive model, SMARTIE offers museum professionals, designers, and technologists a more nuanced tool for conceptualizing, and implementing accessible smart museum solutions. Not only it enhances the potential for creating more inclusive museum experiences but also advances the field of accessibility in cultural institutions by providing a framework that is both theoretically grounded and practically applicable.

4.4. SMARTIE Development

To develop the SMARITE model, the following steps will be undertaken:

Gather relevant data from multiple sources to define the model: a systematic review using a meta-analysis to map technology-supported accessible museums in the health and information systems domains. Searches will use a combination of keywords such as "smart museums", "museum accessibility", "information and communication technology in museum", "assistive technology in museums", and "inclusive museum experience". We will identify, evaluate, and summarize the findings of relevant individual studies, thereby making the available evidence more accessible for developing the SMARTIE model[14].

Develop the model architecture and components: To develop the model, we will use a multidisciplinary approach that involves technological and clinical expertise as well as input from primary users, aligning with the ethos of "Nothing about us without us," [9]. We will focus on multidisciplinary groups to recognize the necessity of incorporating diverse perspectives to ensure that the designed solutions are not only technically sound but also empathetically aligned with the needs and experiences of the end-users, particularly those with disabilities.

Implement the model: To implement the model by constructing and designing three technology solutions for real-life test cases of users with hearing, motor, and cognitive disabilities, using the focus on harnessing the capabilities of mobile devices, leveraging the interconnectedness offered by the Internet of Things (IoT), and utilizing the creative potential of 3D printing technologies. These technologies will be instrumental in transforming conventional museum spaces into 'smart museums' for the benefit of visitors with disabilities, with a minimal impact on the museum itself.

To implement each one of the models, for each one of the disabilities, user requirements need to be defined first. To define user requirements, we will employ the co-design methodology [20] with each type of impaired user. This approach will ensure that potential visitors are not merely sources of requirements, but active co-designers, allowing us to capture diverse motivations, behaviors, aptitudes, visiting styles, and technology preferences.

4.5. SMARTIE Evaluation and Refinement

Next, the upcoming steps will involve the iterative evaluation of the new model through two different aspects: (1) usability, satisfaction, and implementation testing to assess the inclusive experiences in smart museums, and (2) the use of the person-environment fit model to assess environment implementation.

As a result, prototypes developed following the SMARTIE model's recommendation will be evaluated iteratively against the requirements and with real stakeholders. In evaluating the product's suitability for the initial definition, we consider not only the fundamental need (such as the ability to physically interact with an exhibit for individuals with visual impairment) but also the user's ability to use the product independently, as well as whether they would need assistance from a companion. Our primary objective is to facilitate independent visits and enjoyment of the museum for individuals with disabilities. This may increase the percentage of visitors with diverse disability types who spend more time interacting with exhibits.

Evaluation results will allow us to refine the model to support the transformation of existing museum spaces into 'smart' settings that benefit visitors with disabilities while preserving their usage by conventional visitors. By bringing together the perspectives of exhibition designers, curators, experts in the field of development and accessibility, conservators, collections managers, designers, editors, developers, educators, and users, we will explore the optimal ways to create holistic and empathetic accessibility to museums model.

4.6. SMARTIE Application in Museum Accessibility

The SMARTIE model facilitates the development and implementation of tailored technological solutions to accommodate a diverse range of disabilities in museum environments. This approach enables a more nuanced and effective adaptation of museum experiences to meet the specific needs of various visitor groups. The model's application can be illustrated through examples across different disability contexts: (1) Visual Impairments: we will examine how the SMARTIE model allows us to improve the interactive tangible user interfaces (ITUIs) we developed to enhance museum experiences for visually impaired visitors [1]. (2) Mobility Impairments: the SMARTIE model proposes comprehensive adjustments that extend beyond basic accessibility measures. For instance, it recommends more extensive adaptations than simply aligning the height of paintings with visitors' eye level [22]. By using the ICF perspective, the SMARTIE model will identify physical barriers in museum layouts and exhibit designs and select appropriate mobility aids or virtual reality solutions for inaccessible areas by MPT application. It also collaborates with mobility-impaired visitors to design accessible paths and interactive exhibits based on the UCD approach. (3) Cognitive Impairments: the SMARTIE model informs the development of multi-faceted accessibility solutions for visitors with cognitive impairments. SMARTIE uses the ICF perspective to understand how cognitive functions affect learning and engagement with museum content. These lead to the development of simplified guides, interactive games, or augmented reality experiences tailored to cognitive abilities based on application of MPT and UCD approach to create clear, simplified language, engaging, and adaptable exhibit information, and provide tailored audio descriptions.

The implementation of SMARTIE across these diverse disability contexts demonstrates its versatility and effectiveness in addressing a wide range of accessibility challenges in museum settings. However, it is important to note that the model's development is an iterative process. Following the real-life test cases involving various types of disabilities, the next phase of research will focus on refining the model based on lessons learned during different implementation cycles. This iterative approach ensures that SMARTIE continues to evolve, incorporating practical insights and emerging best practices in museum accessibility. Then, SMATIE will be used for different additional disabilities, such as Autism Spectrum Disorders (ASD), hearing impairments, and others, to provide a comprehensive impact on museum accessibility, visitor experience, and overall inclusivity.

5. Conclusions and Future Work

Considerable research efforts have been invested in developing and implementing guidelines for designing accessible museums. At the heart of this study is a fundamental assumption that traditional accessibility guidelines do not fully address the unique design and interaction intricacies that are intrinsic to museum visits. Nor do they consider the rapid evolution of technologies (including accessibility technologies) that make prevailing guidelines outdated and inflexible. For example, the rapid rise of analytic tools based on artificial intelligence and machine language provides access to previously too costly or insufficiently robust ways. Accessible mobile devices also play an important role in accessibility to settings that were previously difficult to customize. The novelty of the proposed model lies in its integration of analytical methods from the fields of Information and Communication Technology, the Internet of Things, and 3D printing technologies with the key principles of inclusive disability participatory design. The goal is not to focus on specific technologies that have been effective (or ineffective) in technology-supported accessibility; rather, it is to identify a comprehensive model in which successive technical developments can be evaluated prior to their adoption.

Future work will focus on applying the model in various real-life cases of different disabilities, for further improvement of the model. Furthermore, a future step may be to consider how these results can help individuals with disabilities interact with other visitors in order to understand how all types of visitors (disabled and not) can co-exist and interact in the museum space (e.g. [10][12]. In addition, SMARTIE could be applied across various museum contexts. Its principles can be adapted to enhance accessibility in various tourist attractions, such as Historical sites and monuments, Natural parks and wildlife reserves, and more. By adapting SMARTIE's integrated approach of UCD, ICF, and MPT to these diverse contexts, a wide range of tourist attractions can become more inclusive and accessible to visitors with disabilities. While SMARTIE offers a comprehensive approach to museum accessibility, its implementation across various museum contexts presents several practical challenges, such as (1) Diverse Museum Types (Art Museums, Science Museums, Historical Sites); (2) Resource Constraints; (3) Technological Integration; and (4) Legal and Ethical Considerations and more. Finally, further empirical research is needed to rigorously validate the SMARTIE model, providing comprehensive evidence of its effectiveness and guiding future refinements.

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