SMART ACCESSIBILITY 2023

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

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SMART ACCESSIBILITY 2023 Editors

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SMART ACCESSIBILITY 2023

Forward

The Eighth International Conference on Universal Accessibility in the Internet of Things and Smart Environments (SMART ACCESIBILITY 2023) was held in Venice, Italy, April 24 - 28, 2023.

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 2023 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 ACCESIBILITY 2023 technical program committee as well as the numerous reviewers. The creation of such a broad and high quality conference program would not have been possible without their involvement. We also kindly thank all the authors that dedicated much of their time and efforts to contribute to the SMART ACCESIBILITY 2023. We truly believe that thanks to all these efforts, the final conference program consists of top quality contributions.

This event could also not have been a reality without the support of many individuals, organizations and sponsors. In addition, we also gratefully thank the members of the SMART ACCESIBILITY 2023 organizing committee for their help in handling the logistics and for their work that is making this professional meeting a success.

We hope the SMART ACCESIBILITY 2023 was a successful international forum for the exchange of ideas and results between academia and industry and to promote further progress in the universal accessibility field. We also hope that Venice provided a pleasant environment during the conference and everyone saved some time for exploring this beautiful city

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Digital Accessibility in Multinational Enterprises: a Meta Study

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***Abstract*—Ever since the ratification of Directive 2016/2102 (Web Accessibility Directive) and EU Directive 2019/882 (European Accessibility Act), digital accessibility has been gaining in importance for public administration and business within the European Union. Furthermore, the role of companies has changed during the last decades and the concept of corporate social responsibility has become increasingly relevant for multinational enterprises. As one aspect of Corporate Social Responsibility, digital accessibility can bring a lot of advantages, for example by driving innovation or by enhancing a company's brand. Therefore, even companies that do not have to meet legal requirements should act with digital accessibility in mind as one part of their Corporate Social Responsibility Strategy. In the current literature and legal regulations, digital accessibility is mostly described as a technical issue, while organizational, structural aspects and managerial tasks within the implementation of digital accessibility are ignored. By reviewing current literature, this meta study shows the relevance of digital accessibility for multinational companies, explains why the implementation of digital accessibility cannot only be considered from a technical point of view and discusses initial approaches to examine the integration of digital accessibility into company-wide processes.**

Keywords-Strategic Management; Digital Accessibility by Design; Corporate Social Responsibility; Society 5.0.

I. INTRODUCTION

To examine the status quo of digital accessibility in multinational enterprises, 77 papers have been analysed, which are linked with the keywords "digital accessibility", "strategy" and "enterprises", mostly focusing on papers and books from the years 2018 to 2023. The analysis included the electronic databases such as Web of science, SCOPUS, JSTOR, SSRN and b On. After a first review, 19 papers were selected as relevant for this article. Digital accessibility refers to the extent to which digital products, resources, and services (hardware, software, websites) and digital content are available for people with disabilities [1] [2]. According to the World Wide Web Consortium (W3C), software, websites and mobile applications must be "POUR" (perceivable, operable, understandable, and robust) to be accessible [3] [4].

The rest of this paper is organized as follows. Section II describes why it is important for companies to implement digital accessibility into their company-wide processes. In Section III, it lays forth why digital accessibility is not only a technical issue. In Section IV, this research also discusses possible approaches to examine how digital accessibility can be integrated into company-wide processes of multinational enterprises.

The research process required the following research hypotheses:

H1: Companies need to integrate digital accessibility into their processes to meet their social, economic and legal responsibilities.

H2: The integration of digital accessibility into administrative and management processes in companies has not yet been sufficiently researched.

II. DIGITAL ACCESSIBILITY AS A POLITICAL, LEGAL, SOCIAL AND ECONOMIC REQUIREMENT FOR MULTINATIONAL ENTERPRISES

Ever since the ratification of the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) [5], digital accessibility has been gaining in importance for public administration, businesses and society. The equal access to information and communications and electronic services is required in article 9 of the Convention [5]. After ratifying, the European Union performs a lot of activities regarding digital accessibility [6]. Directive (EU) 2016/2102 of the European Parliament and of the Council obliges all member states of the European Union, to incorporate the accessibility of the websites and mobile applications of their public sector bodies within their national legal systems. These new legislative changes have created a growing market for accessible digital products and services for public bodies, which may be an opportunity or a risk for market participants, depending on their ability to design their products and services accessible [7]. Due to the entry into force of EU Directive 2019/882 (European Accessibility Act) and the resulting national legislative changes, digital products that are seen as important by the European Union, have to be designed in a way that they are usable by all people [8].

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Therefore, companies that manufacture such products, will also have to face increasing accessibility requirements within the next years. The European Disability Forum also regards companies and market surveillance authorities as important key players for enforcement of the European Accessibility Act [9]. However not only companies that are obliged by law should act with accessibility in mind: the role of business enterprises has changed during the last decades and the concept of Corporate Social Responsibility has become increasingly important [10]. While in the past, the goal of corporations has been solely profit maximization, nowadays companies are expected to have a positive impact on society and to consider social and environmental impacts in their business decisions [11]. Furthermore, by acting with Corporate Social Responsibility in mind, companies can benefit on many different areas [12]. Recognizing this value, a Corporate Social Responsibility strategy is implemented in many large and medium-sized companies [13]. As one aspect of Corporate Social Responsibility, digital accessibility can bring a lot of advantages, for example by driving innovation or by enhancing company's brand [14].

III. Digital accessibility as a company-wide process

Many sources discuss the political, social, and economic importance of digital accessibility and the problems in achieving the accessibility goals [2] [15]. A number of guidelines for developers and disability advocates is set out [1] [4] [16]. While the technical requirements for digital accessibility of products have been extensively researched [4] [17], only few guidelines for companies exist on how digital accessibility can be integrated into a company's processes at the organizational level [10]. As the integration of digital accessibility into a company affects almost all parts of the organization, managers play an important role in adapting the processes and building an accessibility culture [18] [19] [20] [21].

These literature-based findings demonstrate a research gap on how companies may draw on political, organisational, and technical framework conditions in designing accessible digital products and services.

IV. How can the integration of digital accessibility into multinational enterprises' processes be examined?

The following paragraph provides some possible solutions to approach the topic. First, it describes some existing models, which may be adapted to investigate the maturity of digital accessibility in multinational enterprises. Next, it introduces useful concepts that may be helpful within this research project.

A. Existing approaches

The conducted literature review found two maturity models, which can help organisations to assess their digital accessibility programs [22] [23]. Both models assess the digital accessibility along different dimensions (e.g., communication, employees training), where accessibility can improve conformance with accessibility regulations. The models suggest measures, which can increase the accessibility performance. Maturity models are helpful in determining the status quo of a problem situation, but leave unanswered the question of how the capabilities needed to be solved can be identified and successfully applied [24]. In the case of digital accessibility, the existing models could be added with guidelines about how to identify the relevant knowledge, assimilate it, and apply it within the organization [25] [26].

Thus, depending on the branch and organization, the adoption of digital accessibility is influenced by different political, legal, social, and economic factors that may prevent or facilitate the implementation [1] [2]. For the successful integration of digital accessibility into a company's processes, these factors need to be identified and appropriately addressed.

B. Possibilities for further research

To close the gap shown above, the authors suggest the following research direction as one possible approach:

1) Soft Systems Methodology as methodological umbrella

Further research might be conducted under the umbrella of Soft Systems Methodology (SSM). The SSM provides structured guidelines to address social interventions to bring in change to the real-world affairs in a holistic, focused, systematic, and controlled approach. It also offers ways of examining a problem-situation, as both a 'social system' and a 'political system' [27] that might be useful to accommodate technological action. It emphasises explanation through learning rather than predictive testing by positioning the problem-situation within both the structural and cultural organizational contexts pursuing hermeneutical and phenomenological views i.e., a subjectivist perspective.

As a learning methodology, SSM aims at finding relevant views and choices to the situation. In this investigation, the conceptual model will be used as a source of debate about potential change providing the questions to ask concerning the existing situation [27].

2) Identifying capabilities by using Absorptive Capacity

To examine, which capabilities companies need to integrate digital accessibility, Absorptive Capacity might be helpful. Cohen and Levinthal [25] define absorptive capacity as the ability of the organization to recognize the value of external information, assimilate it, and apply it [25]. Moreover, Eisenhardt and Martin [28] consider that new competencies and abilities might originate on knowledge created, extended [28], and modified by absorptive capacity (ACAP) as a dynamic capability [26].

These researchers also suggest the division of ACAP into Potential Absorptive Capacity (PACAP) and Realised Absorptive Capacity (RACAP). Furthermore, social integration mechanisms overcome the barriers between PACAP and RACAP [26].

3) Using Corporate Social Responsibility for grouping social aspects

To examine the social dimensions of the integration of digital accessibility into the administrative processes, it may be helpful to examine, how digital accessibility could be integrated into company's Corporate Social Responsibility Strategy. Even there is no generally accepted definition of CSR [29] [30] [31] [32], many scholars deal with the CSR pyramid, shown in Figure 1, first published by Archie Carroll. Carroll's four-part definition of CSR was originally given as follows: "Corporate social responsibility encompasses the economic, legal, ethical, and discretionary (philanthropic) expectations that society has of organizations at a given point in time" [30].

Regarding digital accessibility, the four components of the pyramid may be relevant as follows:

- The economic responsibility of a firm is about producing goods and services that society needs and making profit on them, taking into account all other layers of the pyramid. In the case of digital accessibility, companies might adapt their production processes to meet accessibility requirements, being profitable at the same time.
- Legal responsibility refers to the company's obligation to meet legal requirements and regulations. Regarding digital accessibility, companies are obliged to meet EU regulations and the resulting national regulations to not risk fines, sanctions, or business restrictions.
- Ethical responsibility: Nowadays society expects companies to act in an ethical manner. For example, building a digital accessibility and inclusive culture may enhance a company's branch and improve the company's image.
- Philanthropic responsibility concerns social activities beyond the expectation of society. Firms may support superior digital accessibility that goes further than legal requirements and the expectations of society.

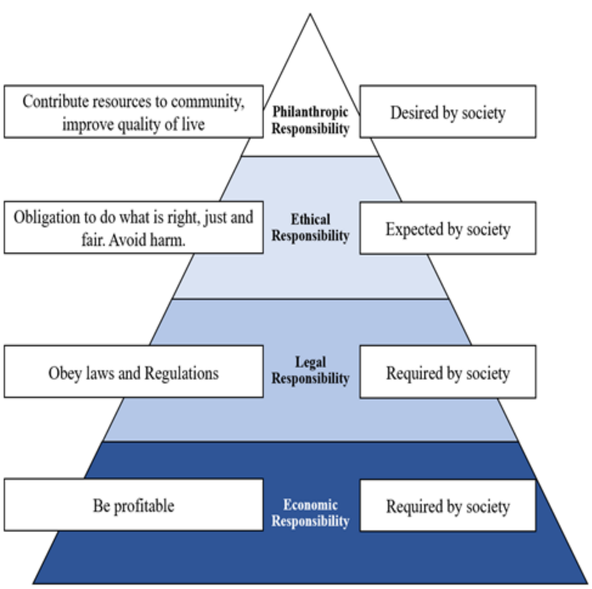

Figure 1. Carroll's pyramid of CSR - four-part definitional framework for CSR. Adapted from [30].

4) Society 5.0 as a model for an inclusive future

In addition, the United Nations (UN) adopted the 2030 Agenda for Sustainable Development which consider 17 Sustainable Development Goals (SDGs) [33]. These should guide the effort of all nations working together towards a sustainable world targeting both economic development and solutions to societal issues by responding to the challenges with inclusiveness, i.e., "leaving no one behind" [34] [35]. As shown by Maliszewska-Nienartowicz [15], accessibility is also strongly linked with the goals formulated in the UN 2030 Agenda for Sustainable Development.

Society 5.0 is aligned with the principles of SDGs of the UN by offering a new growth model with a view of "solving social issues" as well as "creating a better future" [36]. The "Investment for the Future Strategy 2017" represents a commitment of the Japanese government aiming at building a society in which all citizens, including people with disabilities can lead a fulfilling life and demonstrate their abilities to the full by the introduction of digital technologies through Society 5.0 [36]. These moves both merge with the United Nations Convention on the Rights of Persons with Disabilities (UNCRPD) [5], which marks the kick from digital accessibility. Since then, it has been gaining importance for public administration.

5) Stakeholders as fundamental players for any successful digital accessibility program

Since the company-wide implementation of digital accessibility is an overarching process, it is influenced by several stakeholders with many different roles and objectives [2] [37]. Therefore, stakeholder analysis is essential for further research. In a wide sense, stakeholders might be defined as "groups who can affect the achievement of the firm's objectives" [37]. As one important group of stakeholders, the shareholders perspective is seen as particularly relevant for examining the topic. Shareholders theory assumes that managers are expected to use financial and human resources only in a way that is authorized by shareholders [38].

For developing a digital accessibility culture, it is therefore important to convince the shareholders to offer enough budget for the digital accessibility program and to support digital accessibility activities [39], to fulfill the company's economic responsibility (see Carroll's pyramid of CSR [30]).

V. DISCUSSION AND CONCLUSIONS

As shown in this article, the ratification of the United Nations Convention on the Rights of Persons with Disabilities has led to activities worldwide to increase (digital) accessibility. Within the European Union, digital accessibility has become an important element within the sustainability development strategy and has led to legislative changes that oblige public bodies and many companies to comply with digital accessibility criteria. Furthermore, there is a change of mind in society about topics, such as inclusion and accessibility; and the roles of companies has changed in recent years accordingly. Concepts such as Society 5.0 and Corporate Social Responsibility have thus become increasingly important. While technical criteria for creating accessibility are well researched and partly regulated by law, this article shows a research gap regarding the integration of digital accessibility into the management practices and processes of companies. To close this gap, the authors propose an approach under the guidance of Soft Systems Methodology. Absorptive Capacity could be used to identify and apply the knowledge required, to implement digital accessibility within the companies' processes. Existing accessibility models could be adapted and supplemented with perspectives from different target groups and concepts, such as Corporate Social Responsibility and Society 5.0.

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Booth: Digital Audio- and Voice-Based Tools for Inclusion in Education and Everyday Life

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***Abstract*—Visually impaired persons encounter considerable hurdles in reading text and operating computer programmes. Whereas able-sighted people rely on screen output and mouse or touchpad navigation, blind and heavily ill-sighted users can not. Particularly those who lose eyesight later in life, in many countries constituting the majority of visually impaired people, find it impossible to learn Braille. These persons therefore have to resort to low-threshold, high performance digital aides. The Centre for Blind and Disabled Students at Technical University Mittelhessen, BliZ, have almost 25 years of experience in advising blind students and staff and interested organizations in using or providing such aids. This counseling is manufacturer-independent and based on best-of-breed experience of BliZ staff. In a booth at IARIA conference, camera systems, visual screen readers, smartphones with a variety of additional software and voice output, among others, will be on display for demonstration, the participants‘ personal experience, and subject-oriented discussion.**

Keywords—Inclusion in Education; Inclusion in Everyday Life; Overhead Camera System; Assistive Technologies; blind and visually impaired students.

I. Introduction

Assistive technologies of students, such as screen magnification devices and (mobile) workstations with speech output and Braille display, shown in Figure 1 and digital accessibility in higher education build an important fundament for equal opportunity and inclusive education at Universities and University of Applied Sciences [1] [2].

Visual impairments are categorized in the following three stages:

- mild visual impairment: < 30% vision,
- severe visual impairment < 5% vision and
- blindness < 2% vision.

The eye with the stronger vision is decisive [3]. The showcased auxiliary tools for magnification are utilized by severely visually impaired people. No optic corrective actions, such as glasses or magnifiers, suffice.

The electronic magnification aids are also utilized by blind people, who still possess a small remaining percentage of sight, e.g., Macular Degeneration. However, blind people primarily work with refreshable braille display or use audio output.

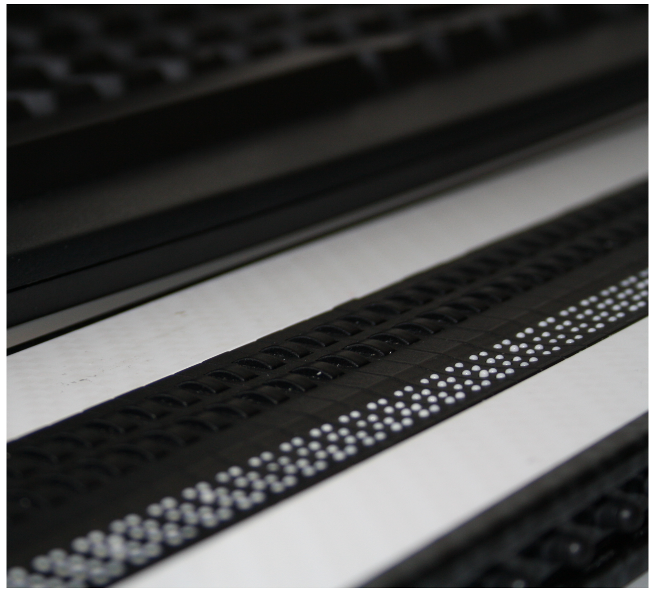

Figure 1. Braille display shows, the content of the source device in Braille.

The following article describes how Assistive Technologies for blind and visually impaired students may be used in higher education.

II. Digital Audio- and Voice-Based Tools

Among others, the following technologies and devices will be shown. In Figure 2, a device for reading text from print material and regarding printed pictures and objects can be seen. Steering of the camera is achieved by functional buttons. Via Bluetooth, the captured picture is displayed on the computer screen. Magnification can be up to a hundred times using a special software.

For users with a rest vision, this technology enables to read text and see pictures that would otherwise be inaccessible in portions and put them together in their imagination. With the same technology, also presentations and speeches can be recorded and magnified on a spectator's screen. As the technology is intuitive, newly-affected visually disabled persons can easily access print and IT contents. An advantage over the screen reader is that also print materials are made accessible on the one hand and the user remains approachable for discussion on the other.

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Figure 2. Overhead Camera System in Combination with Multitudinal Magnification.

A mobile solution for all everyday situation is provided by smartphone apps as seen in Figure 3. Inversion of colours does not only allow better conception of shapes and letters, but enables also users with color blindness, which with 10% of the population is one of the most frequent, albeit slight, visual impairments.

Reading signs, identifying signals of traffic signs, and navigation by map augmentation are among the most important capabilities for independent life. But also sightseeing is possible by considering snapshots on-site and deciding which detail will be worth to explore further.

Figure 3. Smartphone with Magnification and Color Inversion Technology.

As pictures can be shared by virtual drives and bluetooth, this method is highly inclusive and fosters communication with sighted people.

Moreover, it is more affordable than many other options. The devices shown in Figures 2 and 3 are also capable of reading text aload with integrated screen readers and voice-guided commands as already known e.g., from Google Assistant or Apple Siri.

In self-study and non-interactive situations, voice-based „reading and writing“ may be one of the most accessible and quickest options. It is left to training and personal preferences, to which extent the audio channels are used. All options have in common, that they are particularly valuable to persons for whom magnifying glasses or eyeglasses constitute too weak aids.

III. CONCLUSIONS

This paper shows that devices, together with a number of special software, will be on display on the booth. A visually disabled counsellor of the BliZ - Centre for Blind and Disabled Students at Technische Hochschule Mittelhessen will navigate through various possibilities for addressing ill-sightedness. Moreover, a specialist for digital accessibility will narrate about the implications of training and job integration of visually impaired students and personnel. Though the pictures in this exposé may at first sight look trivial, exploring low-threshold offerings in-depth will enable participants of the Special Track to further understand the needs and possibilities of digital accessibility for near-blind users. On-site counselling for special projects is available on request.

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An Audible Handheld Ultra-Sonic-Sonar (AHRUS) to Support Human Echo Location

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Abstract—A portable device to support human echolocation is presented in the form of a handheld audible ultrasonic sonar called AHRUS. The device generates a bundled ultrasonic beam with which the environment can be scanned. A special modulation process uses the non-linear properties of the air as a transmission medium. After reflection at an obstacle, the beam changes to audible sound, which can be perceived with normal human hearing. In this way, blind people can perceive illuminated objects as if they were emitting noise themselves. This gives the impression of a kind of simple bat hearing supporting orientation in unfamiliar surroundings.

Keywords—Human Echo Localization; Audible Ultrasound Sonar; Blind People; Spatial Hearing; Obstacle Detection

I. INTRODUCTION

The human echolocation is used by people who are visual impaired or blind to help build a mental spatial map of their environment. Echolocation is often enabled by creating a clicking sound with their tongue. Objects in the environment reflect discernible sounds to the human ear. The human brain can construct a structured image of the environment to build a mental spatial map. With this method, also known as flash sonar, trained users reach enormous perception performances. The position, size, or density of objects could be determined. [1]

Unlike bats, which perceive structures in submillimeter range by ultrasonic echolocation, the human perception is restricted by the large wavelength of acoustic waves. This article shows how these disadvantages can be overcome by using parametric ultrasound to get a little closer to bat hearing.

II. BENEFITS OF ULTRASOUND

Fig: 1 shows the difference between the sound propagation of a sharp tongue click and the featured Audible-High-Resolution-Ultrasonic-Sonar (AHRUS), which works as a kind of acoustic scanning beam.

Ultrasonic waves are reflected back by little, finely structured or soft objects where acoustic waves pass through objects like fences, bushes or thin piles without any considerable reflection.

Another problem is smooth surfaces whose normal does not point in the direction of the user. As light will be spread back at finely structured surfaces, even roughly structured surfaces act like a mirror for acoustic waves. As a result, transversal sound waves from the user to the objects are reflected away from the user (stealth effect). This way, it is not possible for the user to detect such objects. Ultrasonic waves with high frequencies or short wavelengths, conversely, are reflected to the sound source at smaller structures as soon as the wavelength reaches the order of magnitude of the structure size.

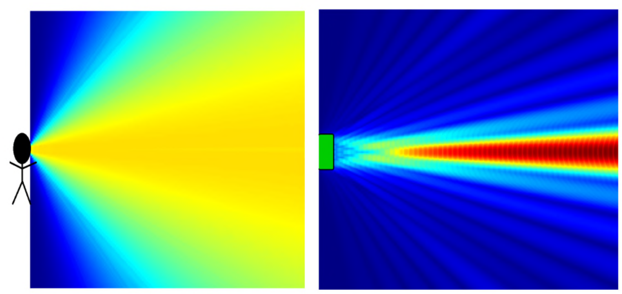

Figure 1. Comparison of sound intensity and directivity of a tongue click (left) and the AHRUS system (right). [3]

III. HOW IT WORKS

Nevertheless, a way to use ultrasonic waves in combination with the human ear is enabled by nonlinear acoustics. This principle is also called a parametric ultrasonic loudspeaker. They are usually used for highly directed audio spotlights, e.g. for a playback of sharply demarcated audio information in a museum. [2]

In the presence of high sound pressure levels, the air behaves in a nonlinear manner. This enables the transformation of ultrasonic to acoustic waves in the air itself by amplitude modulation of the ultrasonic signal.

During the process of transformation, the physical features of the ultrasonic signal retain in the acoustic signal. This auto conversion from ultrasonic to acoustic waves, enables the user at perceive ultrasonic signals with their own ears.

IV. REALIZATION OF A HANDHELD DEVICE

AHRUS is a new tool that brings human echolocation a step closer to bat hearing and makes it easier for inexperienced people to get started. The small device emits

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a sharply bundled ultrasound beam, which gradually turns into audible sound using the concept of parametric ultrasound.It can be compared to a kind of acoustic flashlight, with the sound cone of which the environment is scanned. In the imagination of the experienced user, an acoustic image is created that is far more finely structured than with classic echolocation with tongue clicks. [3]

Fig: 2 shows the prototype of the AHRUS system. It is operated via a menu with voice output to adjust system-parameters.

Figure 2. 3D-Printed AHRUS-Prototype.

The transducer is composed of 19 piezo ultrasound emitters, producing an ultrasound pressure level up to 135 dB at a frequency of 40 kHz. The beam is very focused with an aperture angle of about 5 degrees.

The short wavelength of the ultrasonic waves of 8mm (0.3 in) results in well audible echoes, also from rarely structured or small obstacles like wire fences or twigs.

A configurable synthesizer for signal generation has been implemented on an ARM Cortex-M4 signal processor. It allows the generation of click, noise or sound signals, as a continuous signal or pulses with selectable pulse frequency and width. A frequency modulation for generation of signals in which the frequency increases or decreases, so called chirp-signals, is also included. Chirps are also used by bats or dolphins for echo localization.

V. Conclusion

AHRUS was developed at the Institute for Technology & Computer Science in Gießen with the support of people that are blind themselves. It is intended to demonstrate the possibilities of spatial auditory perception and form a basis for future research activities.

AHRUS tries to eliminate the significant disadvantages of classic active echolocation techniques. By using self-demodulating ultrasonic waves, it enables the perception of much smaller object structures.

In contrast to electronic aids that use headphones as audio interface to the user, AHRUS uses the individual and efficient ears of the user himself. With the great advantage, the ears stay free to hear the normal information from the environment. By using soft but striking signals, e.g., noisy clicks, the signals are easy to hear but not disturbing during travel. Because of the advantages of ultrasonic waves and configurable signals, AHRUS is an excellent extension to classical flash sonar.

Nonetheless, the full potential of AHRUS will be discovered after more people who are blind use this technology to discover its pros and cons. We hope to find a strong partner for the production of the device soon to be able to offer the technology to a large group of blind users.

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A Framework for Developing Modular Mobility Aids for People with Visual Impairment: An Indoor Navigation Use Case

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***Abstract*—Electronic Travel Aids (ETAs) are devices that help people with visual impairments navigate and orient themselves. The development of such devices is often associated with a loss of time in repetitive work, resulting in slow progress in this field. A collaborative community that shares its expertise could accelerate this progress and lead to truly useful and market-ready products for visually impaired people. To make such an exchange efficient, a standardized, component-based ecosystem is required. So far, such an approach for ETAs has not been pursued in the literature and is therefore addressed in this paper. To this end, a model for identifying component boundaries is presented and illustrated by a project in the form of an ultra-wideband indoor navigation system. The advantages of such a component-based development in general are described. In particular, the use of the Robot Operating System 2 (ROS 2) for the implementation is highlighted and its suitability for such an ecosystem is discussed based on practical experience with it.**

***Index Terms*—ETA, electronic travel aid, mobility aid, ROS 2, ROS, robot operating system, component-based development**

I. INTRODUCTION

In the field of Electronic Travel Aids (ETAs) an active research takes place. ETAs are devices that help people who are visual impaired or blind in travelling tasks like orientation, navigation, and obstacle avoidance. Several overview papers summarize relevant and representative research [1]–[4]. It is important to continually expand the possibilities of these aids and thus increase the mobility of those people.

However, when looking at the systematic literature review of Khan et al., one can find tables containing groups of papers classified by the technology or hardware components used [1]. If the projects behind those papers rely on the same technology or hardware, the efficiency of their development could be increased by sharing common source code or libraries. This would increase the time that can be spent, e.g., on designing user interfaces. For example, if one researches a novel approach to the acoustic representation of obstacles, he can focus on his research, knowing there is a pool of hardware components, simulation methods and algorithms for locating obstacles in the environment. In this way, all human resources can be concentrated on the novel representation to achieve faster and better results.

This example is only possible, if the development of ETAs is based on common principles. For this purpose, we divide ETAs into interchangeable components and propose a framework to develop ETA components that can be shared. Such a development is presented with an indoor navigation system as an example.

The experiences made during the development of this system, as well as the development itself, are finally discussed to openly present the positive and negative sides and to justify a recommendation for such a development.

This paper is structured as follows. First, it presents several literature reviews that summarize and classify numerous concrete projects from ETA research in section 2. Section 3 discusses the problems identified in the research. As a solution proposal, section 4 describes a specialized Human Machine Interface (HMI) for ETAs to divide ETAs into their components, as well as the Robot Operating System 2 (ROS 2) as a software development kit. To discuss this solution, section 5 applies it to an indoor navigation system as an example. Section 6 discusses the practical experience of the development, with its advantages and disadvantages. Section 7 concludes the results and gives an outlook to further work needed to be done.

II. RELATED WORK

With a focus on ETAs, there are several development projects in the field of navigation systems for blind and partially sighted people. These projects use different approaches to help these individuals navigate safely in both indoor and outdoor environments. With the digital transformation of healthcare, Internet of Things devices can enhance the capabilities that can be achieved in this area. Khan et al. [1] conducted a systematic literature review to analyse the challenges and opportunities of such 'smart navigation devices' that have been researched and developed over the last decade. Using structured selection criteria, the review identified 191 relevant articles published between 2011 and 2020 in six different peer-reviewed digital libraries.

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Khan et al. [1] categorized various approaches to navigation systems for blind and visually impaired individuals into three parts. The study provides a comprehensive list of commonly used systems, tools, and hardware components as examples.

1) Approaches reported for navigation system development, e.g.:
   - Indoor navigation system
   - Mobile application
   - Wearable navigation system and consists of wearable application strategies.
2) Technologies/tools proposed for navigation assistant development, e.g.:
   - Raspberry Pi microcomputer
   - Android-based applications
   - Microcontroller
3) Hardware components proposed for obstacle avoidance, e.g.:
   - Bluetooth beacons
   - Haptic devices
   - Ultrasonic sensors
   - Global Positioning System (GPS)

It is evident that various projects developed in these fields share similarities in terms of system level, technology, and hardware components used, indicating that multiple development efforts can result in similar or identical solutions. This indication is present in most of the recent survey papers in the field of ETAs [1]–[4]. A similar situation in the field of robotics was part of the driver for the Robot Operating System [7].

III. Problem Statement

In 2007, then PhD students Eric Berger and Keenan Wyrobek discovered a fundamental problem in robotics research. A pattern was emerging in which researchers wanted to build on a proof-of-concept presented in a paper to implement their own idea. Either they lack details of the software used, or it is unusable for whatever reason, so they are often forced to spend 90 percent of their time rewriting other people's code and developing their own prototype test-bed. This leaves only the remaining 10 percent to develop their own innovation, which then lacks quality but enables the intended publication. This creates a cycle of reinventing the wheel and wasting a huge amount of time. This led to the idea of creating a kind of Linux for robotics with the Robot Operating System (ROS), containing a common set of software and developer tools that would allow roboticists to build innovative ideas on the successes of others [8].

Looking at the numerous projects that have already emerged in the field of ETAs [1], one discovers this problem pattern again in many respects. In particular, the description of the selection process of the literature to be evaluated shows that many projects are similar and only a few add value to the state of the art. However, these findings are rarely translated into products that benefit the end user. Both may be since the projects are usually developed from scratch and thus valuable resources are lost to be put into the actual core of the work. For example, the categorization in [1] of some of the ETA prototypes known from research according to their hardware components makes it easy to see that many projects use similar, if not the same, subsystems and devices. The same concepts and technologies are being used for similar, if not identical, tasks. This leaves little time for iterative improvements and testing with visually impaired people. To counteract this, this paper presents a component-based development that contributes to the exchange between working groups and thus to a faster and more efficient prototype cycle. To this end, we built up on ROS 2, the successor of the above-mentioned ROS, which also serves as a motivator. In the field of mobile robotics, ROS 2 has helped components to be exchanged and to communicate with each other in a uniform manner, so that individual working groups can work much more efficiently on their research problems. In this paper, the development of an indoor navigation system using a vibration vest as an output device is presented. This project is not put in focus because there are other projects with similar results. The focus of this paper is on how the development can be made more efficient, and this will be shown and evaluated using the indoor navigation example.

IV. Solution Approach

If we look at the model of a human-machine interface in a very abstract way, it can be broken down according to Kantowitz and Sorkin [9] into the subcomponents shown in Fig. 1. A person (left) has the ability to acquire information through the senses available to him or her. This information is processed in the brain to make decisions based on it, such as operating the machine (right). The control components provided by the machine for this purpose have an influence on the internal state of the machine, from which outputs are generated to present information to the person. The two transitions between the human side and the machine side are called *human-machine interfaces*.

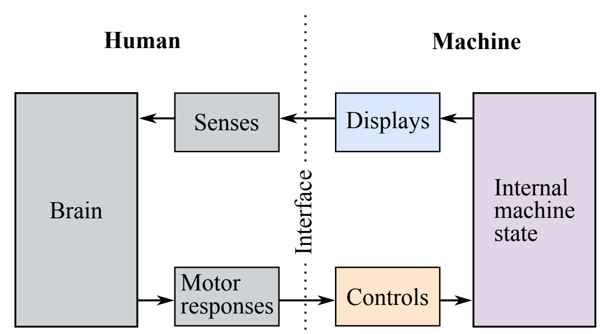

Fig. 1. Human-machine-interface model according to Kantowitz and Sorkin [9]

This model can also be used in an extended form to describe a visually impaired person and his mobility aid, where the physical environment is added as a crucial component (see

Fig. 2). The ETA itself takes on the role of the machine by sensing relevant information about the environment (e.g., obstacles) and making it available to the person through an accessible information channel. The person's sensory system (the senses and perceptions available to him or her) takes in both this information and the information perceived directly from the environment (e.g., a car horn) and uses it to build up a *mental environment model* in the brain. The person can then influence the environment through their motor skills and, by interacting with the mobility aid, control its machine state and the *digital environment model* based on it. Other external information channels (e.g., online weather services) can also be used to enrich this digital model.

Looking into ETAs, the following system components, which are directly linked to the internal machine state, can be identified:

1) *Sensors*: Used to gather information from the immediate environment to build up an internal system state.
2) *Controls*: Used to directly control the assistive device without having to go through the environment.
3) *Additional Information Sources*: Sources of information not associated with the system itself, but which contribute to the construction of the internal state of the system.
4) *Displays*: Used to present information to the user, for visually impaired people to substitute the sense of sight, usually in acoustic or haptic form.

An overall system thus represents a composition of concrete instances of these components and a kind of business logic that receives information from *Sensors*, *Controls* and *Additional Information Sources*, converts it into a digital environment model thanks to certain algorithms, and provides a representation of it via *Displays*.

By defining good and consistent interfaces for individual component types, there are two advantages to such a component-based view. On the one hand, you can achieve easy *interchangeability* of individual components without having to adapt much to the overall system. Consider, for example, a navigation system that uses GPS to determine the current position of the user. Developing the same navigation system, but using RFID technology, would now require very little overall effort with a common interface, since only the sensors component would need to be changed. On the other hand, *reusability* increases with different overall systems that use the same subcomponents. As an example, consider an obstacle detection system and a navigation system, both of which use a vibration belt as a display component. The former uses it to signal obstacles in a particular direction, and the latter to indicate the direction of travel. If developed within a component-based framework, it would only be necessary to determine the obstacle or walking direction from the digital environment model, but not to redevelop the vibration belt as a component.

When developing mobility aids, avoiding collisions with obstacles, following certain navigation routes or, more generally, minimizing dangerous situations play a crucial role. However, the testing of such dangerous situations is essential for the evaluation of the developed prototypes, which is why a *simulation environment* has great advantages in the development of ETAs. On the one hand, it increases reproducibility by allowing test persons to be led through the same scenarios and their behaviour to be recorded and statistically evaluated. It also increases variability, as a simulation environment can be freely parameterized and configured to meet a wide range of system requirements. For example, weather conditions, which often strongly influence the behaviour of a sensor- or camera-based ETA, can be changed with little effort. It is also possible to generate custom obstacles, roads, traffic situations, etc. Such variability is difficult to achieve in the real world. In addition, the dangerous situations mentioned above can be mitigated, as real collisions are impossible or can be provoked for testing purposes in a controlled environment.

Considering that individual components are to be used in a simulation environment with little effort, it makes sense to embed this environment in the model shown in Fig. 2. In principle, any of the components on the ETA side can be simulated, the most obvious being the physical environment and the sensors. The former is a *virtual reality* in the simulation, which requires it to be sensed by *virtual sensors*. Since such sensors can provide perfect, noise-free environmental data, it is possible to test displays, controls and the algorithm used to build the internal state of the machine individually and in a controlled manner. In the indoor navigation system presented in the next chapters, this is demonstrated in more detail using an example.

Looking at past research projects on ETAs, one can see the presented component-based structure in many of these overall systems, mentioned by Khan et al. in their literature review [1]. Often the boundaries between the individual components become blurred because they are very closely related, but the basic structure remains the same. This suggests that, again, components could be easily exchanged and reused in similar systems if they were developed within a standardized, common ecosystem.

One such component-based ecosystem is ROS 2, which is a set of software libraries and tools for developing applications that originated in robotics (especially mobile robotics). It is open source and aims to support developers from different industries from research to prototyping, deployment and production using a standard software platform. The modular and flexible architecture allows easy integration of different hardware and software components, enabling the development of complex overall systems. A standardized real-time capable communication protocol enables efficient and reliable communication between different subcomponents of a system. It is not tied to a specific platform, nor is it domain or vendor specific. Because of its origins in mobile robotics, it provides many algorithms and sensor drivers to address problems of environmental perception, navigation and orientation, problems that are also common in the field of mobility aids. ROS 2 simplifies the development and testing of complex systems by providing debugging, visualization and, above all, simulation

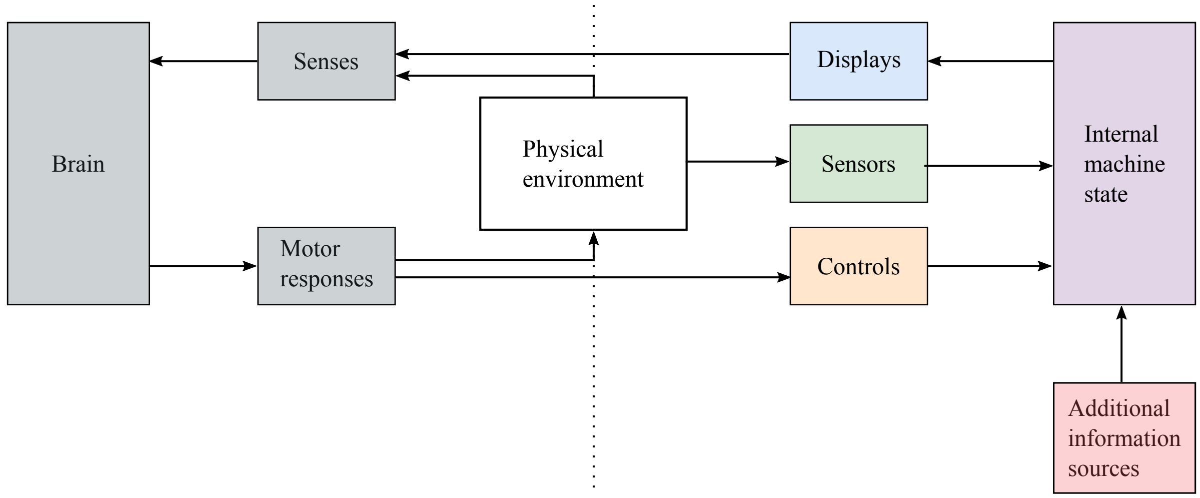

Fig. 2. Extended HMI model for ETAs

tools.

In ROS 2, development is strictly based on the "divide and conquer" principle by providing the following architectural components [5]:

1) *Nodes*: Independent processes that communicate with each other through different mechanisms.
2) *Topics*: Named event channels that allow nodes to communicate with each other. Nodes can publish messages to a topic, and other nodes can subscribe to that topic to receive those messages. Topics can have multiple publishers and subscribers, making it possible to build complex communication patterns between nodes.
3) *Services*: Remote procedure calls that allow nodes to request a specific task or information from another node in a synchronous way. Nodes that provide services and respond to requests are called servers, while nodes that request services are called clients.
4) *Parameters*: Parameters are used to store configuration data for nodes. Parameters can be set and retrieved by nodes, and they can be changed dynamically during runtime.
5) *Launch files*: Used to simplify the process of starting and configuring a ROS 2 system by specifying a collection of ROS 2 nodes, their parameters and other configuration details without having to start each node individually and configure it manually.
6) *Packages*: Collection of nodes, configuration and launch files and documentation, representing a subcomponent of a ROS 2 system. They provide a modular and extensible way to organize and distribute code, making it easier for developers to share and reuse code across different projects.

This architecture divides a system into a set of intercommunicating nodes, which are in turn organized into packages, providing a modular and extensible way to organize and distribute code, making it easier for developers to share and reuse code across projects. Beneath others, defining standard interfaces and the component-based development made it possible to build up a large and active community that constantly extends ROS's vast array of code libraries, hardware drivers, documentation and support. The community supports a continuous exchange between scientists and new products.

V. Proof of concept

Our proof of concept represents an indoor navigation system developed specifically for blind and visually impaired individuals.

A. Indoor navigation system

The following components were used in this particular use case.

- *bHapticsX40 vibration vest from bhaptics®* to provide haptic feedback for navigation instructions.
- *An ultra-wideband (UWB) real time location system (RTLS) from Pozyx®* to determine the indoor position and orientation of a person using anchors placed in the room and a tag attached to the person.
- *Smartphone App* for configuring the system and for recording and navigating along routes. Its compass feature can also be used as an alternative to the Pozyx tag for providing orientation information.
- A *Raspberry Pi 4* is used for computing operations such as handling services for route recording, providing heading correction for navigation instructions and feedback generation through vibration modes.

To operate the system, all components must be connected to the same network. The Raspberry Pi serves as the primary hub for most of the nodes required in the ROS 2 ecosystem. The vibration vest, with a Pozyx tag attached, can transmit its current position and orientation data to the Raspberry Pi.

A smartphone app provides necessary communication interfaces to the ROS 2 ecosystem, allowing the user to change the

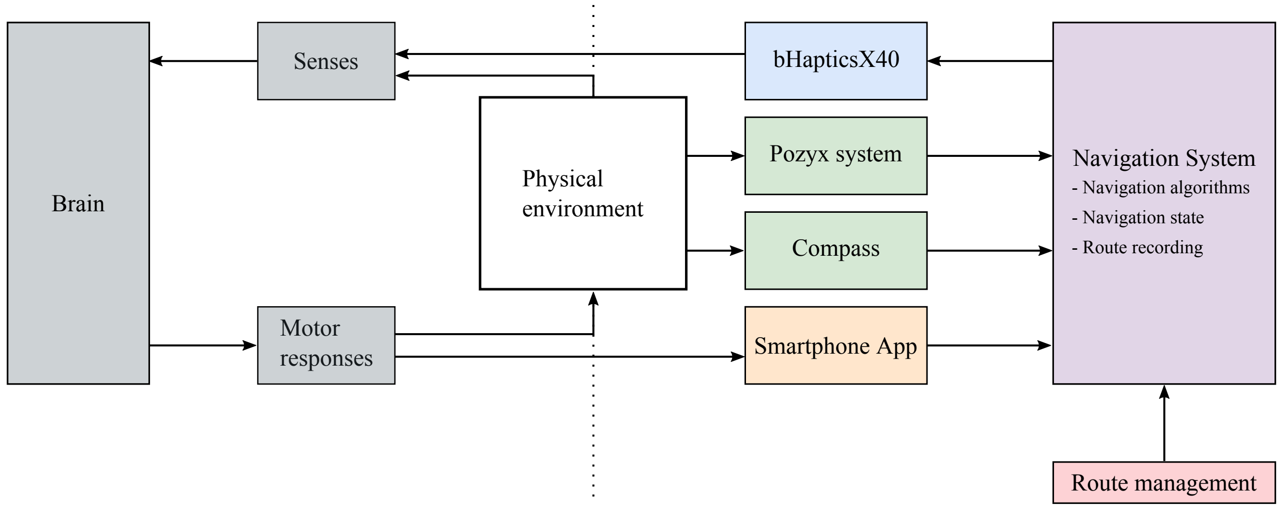

Fig. 3. Indoor navigation system according to Fig. 2

parameters of the system and so reconfigure it at runtime. In addition, he can record new routes and navigate along already recorded ones. When a route is selected, the navigation system running on the Raspberry Pi estimates the nearest navigation point available on the route and calculates a heading correction based on the real-time data from the Pozyx tag. This heading correction is translated into an appropriate vibration pattern on the vest to indicate the direction in which the user should move for safe navigation along the predefined path. As an alternative, audio feedback displayed over the headphones connected to the smartphone can be used for navigation instructions.

The system can be adapted to the model presented in section IV by breaking it down into its components. Here the vest takes on the role of the *display*, the Pozyx tag or the smartphone compass corresponds to the *sensors* and the remaining features of the smartphone application represent the *controls* part. The *internal machine state* is formed by the navigation algorithm and business logic running on the Raspberry Pi. The part of the business logic responsible for recording, persisting and retrieving routes can be seen as an *additional source of information* that enriches the internal machine state and the digital environment model it contains (see Fig. 3).

To demonstrate the practical use of a simulation environment in relation to the development of ETAs in general and specifically with ROS 2, the simulation tool *CARLA*, which is widely used in autonomous driving research, was used. It is also open source and, in addition to existing maps, actors and assets, allows the creation of custom scenarios and the free configuration of environmental factors such as weather and lighting conditions. It also offers a range of different virtual sensors such as LIDAR, cameras, GPS, etc. However, the biggest advantage for the concept proposed in this paper is CARLA's built-in integration with ROS 2 via a bridge. Using predefined ROS 2 topics, it is possible to both read simulated sensor data and control the movement of virtual actors such as pedestrians. In the use case presented here, CARLA replaces the indoor environment and the Pozyx system for determining position and orientation (see Fig. 4). This makes it possible, for example, to test the display components separately without having to reckon with sensor inaccuracies or the influence of a test person's behaviour.

Now we will look at the development process and architecture of this system and how ROS 2 supports it and enables to fulfil the properties of component-based reusability and interchangeability.

B. Development process

Starting with the core functionality, navigation, the necessary nodes, inputs and outputs were defined. The central node provides a single output, a heading correction value. To provide correct and up-to-date values, it requires the route to be followed and the current position and orientation of the user. Inputs and outputs lead to the definition of their respective interfaces and the nodes that provide the necessary inputs. This means that the navigation logic consists of three nodes and has five interfaces (see Fig. 5).

1) *Navigate route* (action), provided by the navigation and called by the user over the smartphone app
2) *Position* (topic), provided by the Pozyx RTLS or the CARLA simulation
3) *Orientation* (topic), provided by the Pozyx RTLS, the smartphone compass or the the CARLA simulation
4) *Load route* (service), provided by the Route Management and called by the navigation logic
5) *Heading correction* (topic), provided by the navigation system and consumed by the feedback device (bHapticsX40 or headphones)

The result is a fully functional navigation system with a freely configurable setup of sensing and user interface devices – even swapping devices on the fly is possible. Each device

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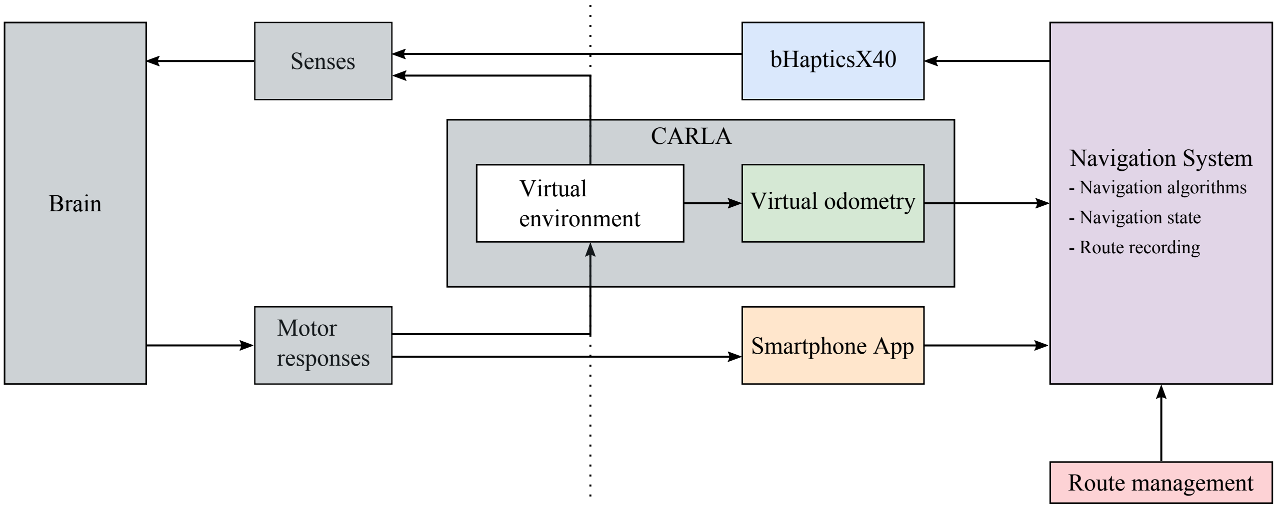

Fig. 4. Indoor navigation system with CARLA simulation as environment and sensors substitution

requires its own node or set of nodes to transfer data to and from the ROS 2 ecosystem and to satisfy the interfaces owned by the navigation service. For example, the software for the bHapticsX40 vest currently consists of two nodes: A driver node responsible for connecting to the vest via Bluetooth, and a feedback node that translates the heading correction feedback into different motor patterns (see Fig. 6).

To enhance usability beyond direct control via command line terminals, a user interface application must access a service client node. The interaction between the user interface and the service client node is the least clean implementation detail, as ROS 2 does not inherently support direct user interaction.

As the manual creation of routes as sets of coordinates was rather tedious and error-prone, the second service, for route recording, was conceived. It allows the user to record their current location and save it as a route for later retrieval by the navigation service. This route recording service was easily implemented using the existing nodes for the navigation service and proved to be a significant improvement over manually entering coordinates. At this stage, control of both services was limited to launching the required nodes with a set of parameters. To increase control and make it more dynamic, separate control nodes with additional user interfaces were next designed and implemented. As the number of nodes and possible configurations increased, it became necessary to organize the startup configurations using a modular system of ROS 2 launch files. A semi-automated deployment method allowed different distributions of nodes between hardware components to be tested. The actual (graphical) user interfaces in the form of the smartphone app were the last components to be implemented.

C. Architecture

The resulting architecture follows a microservices approach. For example, the existing system with two services, the navigation itself and a utility for recording the route, can be easily extended, both by adding new types of services and by redundancy of existing ones. This guarantees the degree of scalability and elasticity required by possible use cases, such as indoor navigation in public buildings.

The internal structure of the existing services has many similarities. Both consist of controller, business logic and helper components realized by ROS 2 nodes. The controller nodes provide the user-facing interfaces necessary to control the services and translate ROS external user input for the ROS 2 system. The business logic nodes produce the service functionality, possibly with the help of utility nodes. They interface with the controller nodes via ROS 2 interfaces, i.e., actions and services. By structuring services as a collection of nodes, a single service can be distributed across several separate hardware systems if a specific use case requires it. If this flexibility is not required, the nodes of a service can be run on a single system and configured to run in shared-memory mode to optimize performance. The trade-offs can be considered on a case-by-case basis without changing the node implementation.

The general trade-offs of the chosen architecture can be summarized as follows: Future requirements for new additional functionality, scalability and elasticity can be easily met. Components, especially sensing and user interface devices, can be added and replaced at low cost. Performance is limited by the degree of distribution chosen for a particular deployment. Even with only two services, the actual implementation is structurally and operationally complex.

VI. Results and Evaluation

Looking at the architecture of the indoor navigation system just presented, one can see the benefits of reusability and interchangeability of individual components presented in section IV for the HMI-ETA model. The bHapticsX40 vibration vest, which acts as a *displays* component and is represented by a

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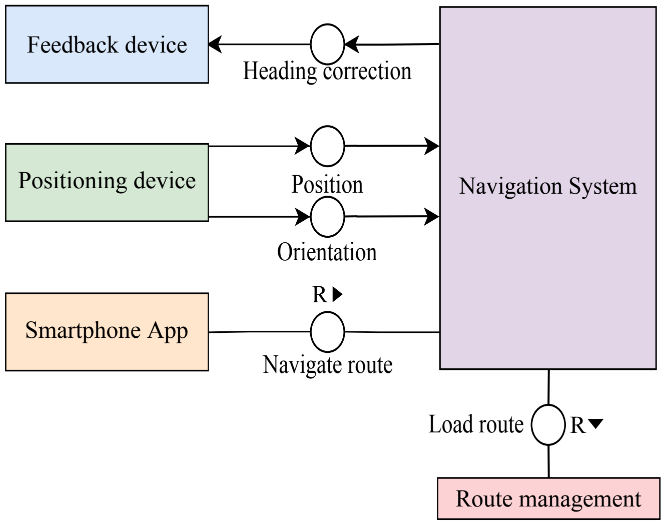

Fig. 5. Abstract FMC model [6] of a navigation system according to Fig. 2

package in ROS 2, will serve as an example. The navigation package provides an azimuth and elevation angle via the heading correction topic, which is consumed by the bHapticsX40 package. By defining this asynchronous data channel independent of the display component in the form of a ROS 2 topic, a high degree of loose coupling is achieved between the package providing the navigation feedback and the package consuming it. This loose coupling allows interchangeability on both sides of the data channel. On the one hand, the display component can be replaced by a headset package, for example, which communicates the feedback to the user acoustically using a text-to-speech algorithm. In this case, both the topic and its message format, as well as the navigation package, could be reused. On the other hand, the indoor navigation of pre-recorded routes could be replaced by any other navigation package (e.g., outdoor navigation using GPS and an external map service), as long as it respects the heading correction topic as an interface to the display component. Again, neither the data channel nor the display component (whether vest or headphones) needs to be touched.

However, ROS 2 supports modularized development of reusable components not only at the level of entire components of the HMI model, but also within the individual components. Fig. 6 illustrates this clearly. It shows the structure of the bHapticsX40 component as a composition of two ROS 2 nodes and the physical vibration vest. The separation into a ROS 2 driver node, which handles the actual Bluetooth communication with the vest, and a feedback generation node, which transforms the received heading correction into a concrete vibration pattern, again promotes loose coupling of the software components. While the former is independent of the concrete overall system and can therefore be reused at any time, the latter can be exchanged in the presented project depending on which of the two feedback representation modes is used. If, on the other hand, you were to use a similar vest made by a different manufacturer that uses a Wi-Fi connection instead of Bluetooth, replacing the driver node would allow you to quickly reuse the entire system.

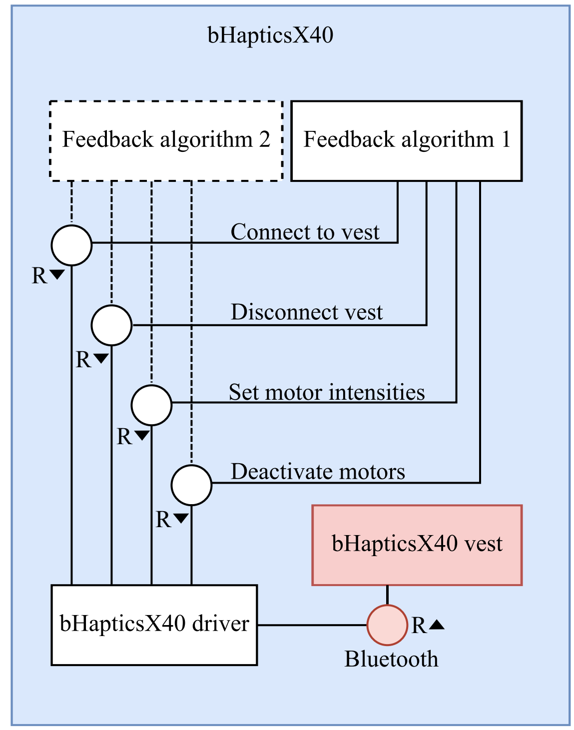

Fig. 6. FMC model of the vibration vest implementation regarding exchangeable algorithms. The red parts are visualized for a full overview and not part of the software system. The bHapticsX40 component is a display device according to Fig. 2

In addition to the simple definition of generic communication interfaces and the resulting loose coupling, the interchangeability of components in ROS 2 is also made possible by the definition of launch files. This is where the entire system is assembled and configured using so-called *launch arguments*. Components in the form of packages and nodes can be added to or removed from the system as needed and can be adjusted by specifying node parameters.

Generally speaking, ROS 2 proved to be very accessible. The first few tutorials provided enough knowledge to design and implement the whole navigation system with the ROS 2 Python API. Designing a distributed system did not require any additional work thanks to the node structure and the topic, service, and action interfaces. This pre-structuring also assisted with the definition of clean interfaces and division of labour within the team. Deployment, together with launch configurations, was less accessible and considerably less well documented. Only the myriad of existing ROS 2 projects and the associated launch files provided any orientation in this regard.

The lack of documentation in some cases may be due to the fact that ROS 2 is an open-source framework. Although the ROS 2 community is usually very active and helpful, there

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is no guarantee of support compared to proprietary systems, which can make the lack of documentation all the more problematic. However, the open-source status does have some advantages, including complete transparency in the provision of the source code. This means that issues or vulnerabilities can be discovered and addressed more quickly by the community. It also allows everyone to contribute to the development and to share knowledge and expertise, features that could drive forward ETA research. However, it must be recognized that building up a community can be a long and arduous process. Even ROS, which was developed at Stanford University in 2007 and evolved into its now well-known successor ROS 2 in 2015, did not immediately have the reputation it has today and took years to build such a large community.

The types of problems encountered in robotics have many similarities with those encountered in the indoor navigation project. This means that many of the robotics-oriented packages created for ROS 2 could be adapted accordingly. An example of this is the *tf2* package provided by the ROS 2 community, which makes it possible to track the temporal evolution of several interdependent coordinate systems and to perform transformations between these frames in a simple and efficient way. This is an essential component in robotics, as such calculations are the basis for calculating the individual joints of a robot arm, for example. In the indoor navigation project presented here, tf2 was able to help transform coordinates from the global coordinate system of the Pozyx system to that of the person being navigated, and thus determine a heading correction.

For the same reason, there are already some packages for hardware components for ROS 2 that allow the integration of different sensors from different manufacturers, although this is not visible in the proof of concept. Examples include camera, LIDAR or ultrasound drivers that can be used in robotics as well as ETA development without much expertise or training.

Simulation in ROS 2 is also well-supported. Nodes are configurable for a simulated environment without the need for any code changes. The debugging tools within the ROS 2 ecosystem proved to be extremely helpful and easy to use, as well. Not surprisingly, GUI functionality is an aspect not supported within the ROS 2 ecosystem, but various types of bridge tools provide the possibility to access ROS 2 interfaces.

In summary, ROS 2 provides the necessary building blocks for a high degree of loose coupling thanks to the provided architecture components such as topics, nodes, packages and launch files, thus supporting a modularized, component-based development of ETAs from the ground up. The challenges and work areas known from (mobile) robotics, which also need to be addressed in ETA development, such as navigation or environmental perception, are facilitated by the tools and drivers already available in ROS 2, allowing most of the time to be spent on the actual development of innovative ideas.

VII. CONCLUSION

While research into ETAs and mobility aids for the blind and visually impaired in general has produced numerous research papers and demonstrators over the past decades, reviews of these technologies show that the wheel is often reinvented. Both the individual hardware components and the algorithms used to generate feedback, among other things, are redeveloped instead of shared. A lack of exchange between research groups and the use of different development ecosystems means that these software and hardware components often have to be developed and integrated from scratch. This takes up valuable resources that are not available, e.g. for developing innovative concepts or testing them with visually impaired users.

This paper presented an approach to this problem by introducing a framework for a component-based development of ETAs that promotes the reusability and interchangeability of components across projects within a standardized ecosystem. To this end, a mode for identifying ETA component borders by using a human-machine interaction view was presented (see Fig. 2). The components were identified as displays, sensors, controls, a machine internal state and additional information services. It can be concluded that an ETA is generally suitable for decomposition into loosely coupled building blocks. This subdivision can also be seen in systems already known from the literature. Furthermore, individual components can be replaced by a simulation, allowing certain other components to be tested in a more flexible and risk-free manner.

ROS 2 was proposed as an existing open-source framework to support the component-based development of ETAs. The development with ROS 2 and the component-based development was shown in the form of an indoor navigation system. This example uses UWB technology for localization with a vibration vest taken from the virtual reality gaming domain, to present the advantages and disadvantages of such an ETA development.

Two features of ROS 2 proved to be particularly important advantages. One is the background of ROS 2, which is mainly in mobile robotics. The overlap between the problems addressed in robotics and ETAs, and the technologies used to address them, is remarkably large. Examples include real-time navigation and environmental perception, for which ROS 2 already provides appropriate sensor drivers, standardized interfaces and algorithms, and tools for testing and visualizing the systems. The need for a simulation is also a common use case in robotics.

On the other hand, ROS 2 is designed to support a component-based development. A loose coupling between ROS 2 nodes and packages is enabled by the definition of custom asynchronous data channels and launch files, in which components can be configured and integrated. This creates the reusability and interchangeability touted in this paper that could drive ETA development.

Although the fact that ROS 2 is an open-source framework has limitations, such as a lack of documentation or support, it enables rapid results and innovation, not least because of the large and active community, especially for research.

Considering the possible implications for the future development of ETAs using ROS 2, the framework we have started and presented would need to be extended with even more components and system compositions to further illustrate how generic and versatile it is. To facilitate exchange between different research groups, an open platform could be created where components, algorithms and complete systems could be published in the form of ROS 2 nodes, packages and launch files. However, to ensure compatibility between components from different developers and systems, a more concrete policy for their creation needs to be formulated by defining rules and specifications. Then new components could be easily integrated. Although, experience with other open-source frameworks has shown that building a community to collaboratively share knowledge and expertise can be challenging.

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Design of an Accessible VR-Escape Room for Accessibility Education

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***Abstract*—*Access to Escape* is a Virtual Reality (VR) Escape Room, aimed at sensitizing computer science students to the importance of digital accessibility. Since these students will develop digital content in the future, this target group is an important starting point to create awareness towards the topic. This article outlines the development of a VR game based on the viewpoints of Accessibility Education, Game Accessibility, and accessible VR to offer access to a wide range of people. The primary objective is to address the research question of what steps are necessary to create an accessible VR game and what the design process should entail to achieve this goal. The development process of *Access to Escape* showed that the Game Accessibility Guidelines (GAG) workflow offered a low threshold starting point, for example, by making the vast amount of accessibility guidelines more tangible. Here, it should be emphasized that the prioritization, as suggested by the workflow, must not lead to the exclusion of any applicable guidelines, since every guideline is needed to guarantee an accessible game experience. However, during the implementation process of our VR-Escape Room, it became apparent that many resources and a well-defined time schedule are needed to achieve a fully accessible game. To counteract this issue, more information material and open-source solutions are needed to meet all accessibility requirements.**

***Keywords*-Accessibility Education; Virtual Reality; Game Accessibility; Escape Room.**

I. INTRODUCTION

With the increasingly digital nature of everyday life, the importance of digital accessibility moves further into focus. “The fast-growing market for making digital products and services more accessible comprises a range of economic operators, such as those who develop websites [...].” [1], making it necessary to train these operators. In consideration of that, we developed the Virtual Reality (VR) Escape Room *Access to Escape* to educate computer science students about digital accessibility. As computer science students represent the future developers of digital products, it is necessary to educate these stakeholders on the importance of digital accessibility and teach them methods on implementing inclusive software. Using an immersive learning format such as a VR game, it was aimed to sensitize the players by making barriers more tangible and thus relatable. Although gamification and VR technology offer benefits such as the mentioned immersion, they also introduce new challenges, including the need for accessible VR gaming experiences. To design an accessible VR-Escape Room, we formulate the following research question:

“What does the design process for creating an accessible VR game entail, and what implementation steps are necessary to achieve this goal?”

To address the posed research question, we will first give an overview of the related topics in Section 2 which include Accessibility Education, Game Accessibility, and Accessible VR. Section 3 will offer an overview of the implementation of *Access to Escape*. We will explain the game story and the corresponding learning goals, how we implemented the GAG workflow, and demonstrate the outcome of the implementation of accessibility features. The lessons learned and limitations of the VR-Escape Room will then be discussed in Section 4. Finally, in Section 5, we summarize our findings and formulate tasks for future work.

II. DISCIPLINES OF ACCESSIBILITY

For a successful implementation of the introduced VR-Escape Room, it is necessary to consider different disciplines of digital accessibility. *Access to Escape*, for one, represents a tool for learners to grasp the content related to digital accessibility. For another, the VR game needs to be accessible so it can be played by every learner. In the following, the teaching of accessibility, the accessible design of a game, as well as of the VR application itself will be examined, which are needed to achieve the mentioned goals.

A. Accessibility Education

Accessibility Education is a broad field in which learners are supposed to acquire various competencies: Initially, they need to develop theoretical understanding and procedural knowledge regarding accessibility [2]. Only with the aid of this foundational knowledge, learners can build technical skills in this discipline.

To teach these skills, educators need resources that can teach accessibility while considering the current knowledge and skill set of students [3]. As digital accessibility is still not a widespread mandatory subject at every university, it is necessary to create such learning materials that provide a low-threshold introduction to the subject, so even students who do not have any prior educational knowledge about digital accessibility can have an easy access to the content.

In order to provide a simple introduction to the topic, it is beneficial to make barriers tangible and thus provide learners with a realistic experience [4]. For example, Kletenik and Adler [5] developed three games in which the players are confronted with simulated disabilities to generate awareness of the topic accessibility. It became apparent that students who played these games increased their empathy for people with impairments or disabilities and also their motivation to design more accessible content.

To simulate barriers even more immersive, VR technology has the potential to create such experiences and make them as tangible as possible [6].

B. Game Accessibility

Game Accessibility describes the subarea of game development that addresses the removal of barriers for people with impairments or disabilities [7]. It should be emphasized that removing the barriers, and by that, creating an accessible game, is limited by the game rules as games often include intended barriers which represent the challenges of the game story. If those challenges would be removed, the intention and / or the entertaining character of the game could be compromised.

For the development of accessible games in accordance with the corresponding game rules, the Game Accessibility Guidelines (GAG) [8] by the International Game Developers Association (IGDA) have been established in different elaborations [7], [9], [10], [11]. The GAG [8] are guidelines which are based on an online survey that gathered methods to make games more accessible to different user groups. The current version (May 2021) includes 122 guidelines that can be classified according to motor, cognitive, visual, auditory, linguistic, and general barriers. Each of these six groups is again classified into three subgroups (basic, intermediate, and advanced). The classification into these subgroups depends on the following three factors:

Reach: The number of people who benefit from meeting the corresponding requirements.

Impact: The qualitative difference this adjustment makes for players.

Value: The cost incurred for implementation.

The *basic guidelines* [8] describe accessibility features that make playing easier for a large number of players and are also easy to implement. The *intermediate guidelines* [8] include features that require additional planning and resources, but are still easy to implement and reach many players. Finally, the *advanced guidelines* [8] involve complex modifications and high costs. Although only a few specific players benefit quantitatively from these modifications, they have a very high qualitative value for those players.

The need for each guideline of the GAG is emphasized by a realistic use case, making the traceability of a barrier easier for developers [8]. Further support provided by the guidelines are the listed best-practice games that have particularly well implemented the respective guideline.

Regarding the implementation of accessible games, the following workflow is recommended by the IGDA [8]:

1) *Familiarize:* Before the implementation phase begins, the guidelines must be considered, since a variety of requirements can already be met through simple design decisions in the conception phase.
2) *Evaluate & plan:* In the second phase, it must be investigated which guidelines will be relevant and applicable in the context of the planned game to create a reduced subset of requirements to be implemented.
3) *Prioritize & schedule:* The chosen requirements from the second phase are prioritized with respect to the available resources and scheduled in the development plan.
4) *Implement:* To achieve the best results, experts and players with a disability or impairment should also test the game during the implementation phase.
5) *Inform:* Players should be made aware of the implemented guidelines in tutorials and loading screens, as there is a risk that they will go unnoticed in various menu settings.
6) *Review & learn:* Information on how often players have used accessibility features helps future projects when conducting the third phase, especially when prioritizing requirements.

C. Accessible VR

The use of VR is steadily increasing and is becoming a more prevalent tool in education. This makes the access to VR technology even more important. The developer manual of the company Oculus emphasizes that accessible VR applications can reach a wider range of users [12]. VR applications are considered accessible when people with different types of visual, auditory, mobility, perceptual, and cognitive impairments can interact with the given content. The manual presents procedures for seven application areas of a VR application, which partly overlap with the GAG and the Web Content Accessibility Guidelines (WCAG) [7]. The sections of the manual are presented in the following:

User Experience (UX) and User Interaction (UI) [12]: To achieve an inclusive UX, game developers must first become aware of exclusive UX design. As an example of such an exclusive design, the chosen size of the play area is mentioned: Players with a limited movement area could experience a below-average or even unplayable user experience. Only when the game can be completed without blockages or external help, an inclusive UX design is achieved. It must be constantly tested to see if this is the case. For example, it is useful to play the game with disabled sound or color filters. Also, the use of auditory, visual, and haptic interaction possibilities makes the UX more inclusive.

Controls and Interactions [12]: The predefined controls of a game can hinder players, for example those with motor impairments, in interacting with the game. To improve this situation, selection options and alternative types of interaction should be presented. Modifications help not only people with disabilities but also all players. For example, the ability to re-assign control keys not only helps players who cannot fulfill the default input requirements due to motor impairments but also benefits habitual players who prefer a personalized interaction.

Movement and Locomotion [12]: In order for the movement of players in the virtual world to be feasible for everyone, among other things, developers must consider how a person who cannot move in the real world could still move around in the virtual world. For example, navigation via joysticks eliminates the barrier for players who cannot move freely in the real world.

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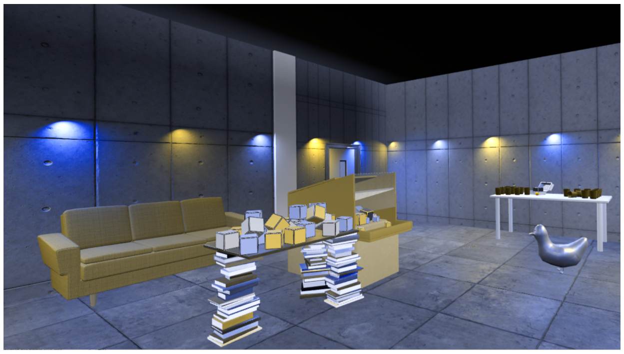

Fig. 1. Puzzle 3: Using a color filter, the player experiences the perception of a person with a color vision deficiency (deuteranopia)

Display [12]: Personalizing screen displays, such as variable brightness settings, is now standard on many devices. In VR applications, this personalization is even more important because the complete occupancy of the visual space and the proximity to the human eye pose a risk of sensory overload. A personalized display prevents this danger for all players, with and without impairments. For example, the ability to enlarge text elements or objects in the virtual world can support people with visual impairments.

App Design [12]: Elements of app design can support the accessibility of VR applications. For example, a clear and mandatory tutorial at the beginning of the game provides the opportunity to become familiar with the game mechanics. Clearly defined rules and objectives help players stay focused on the game. Through such methods, the basic understanding of the game can be simplified for all players. Additionally, the game can be made more accessible by adding a guiding character. For players who were unable to process auditory, visual, or haptic signals, these characters can, for example, provide additional hints.

Audio [12]: In addition to the possibilities of visual and haptic interaction, audio offers another form of communication. Short and simple audio tracks can signal actions and processes. However, despite the advantages of sound, the option should be kept open to deactivate it without loss: People who, for example, have difficulty concentrating and therefore choose to turn off the sound, must not experience any loss of information.

Captions and Subtitling [12]: Captions refer to the textual reproduction of spoken dialogues. Whereas, subtitling refers to the translated textual reproduction of spoken foreign-language dialogues. These forms of information transfer help a variety of people: players with hearing or cognitive impairments, players who do not understand the game language, and players who prefer to read dialogues instead of hearing them.

III. Implementation

The implementation is divided in different sections: First, we introduce the VR-Escape Room *Access to Escape* and its learning objectives. They specify what skills and knowledge the learners are supposed to gain. Next, the application of the GAG workflow is presented, which exemplifies how the workflow can be integrated in the development process. Finally, the implemented accessibility features are presented and categories for clustering them are proposed.

A. Access to Escape

At the beginning of the game, the player is in a university building and has to find a certain auditorium. Initially, the person playing is on the first floor were a training room is located. As soon as the player is ready, they can use an elevator to go to the desired location but because of a defect, the elevator crashes shortly after. Finally, the player lands on the basement floor where five puzzles, each representing a barrier, need to be solved to get the elevator running again.

- Puzzle 1: The player is faced with an incomprehensible speaker announcement that is caused by an incorrect language setting. The learning objective of the first puzzle is based on the *WCAG guideline 3.1.1 Language of Page (Level A)*. This requires the ability to programmatically determine the language of the content at hand. People who use a screen reader will encounter this barrier, for example, when a web page has no or an incorrect language tag. If the screen reader pronounces text in a different sound than the language in which the text is written, the read-out text is very difficult or even impossible to understand.
- Puzzle 2: An important code which is needed to move on within the game is displayed via an extremely blurry image. By that, the player is introduced to the difficulties caused by inaccessible graphics which are mentioned in the *WCAG guideline 1.1.1 Non-text Content (Level A)*. Here, it is described that non-text content needs an alternative textual access point.
- Puzzle 3: The player enters a room that contains a color-dependent puzzle but can only see a limited set of colors due to a color filter (see Fig. 1). The player is introduced to the content of *WCAG Guideline 1.4.1 Use of Color (Level A)*, which states that color should not be the only way to convey information. If content is conveyed through color alone, people with limited color perception may not be able to assimilate this information. Therefore, the player is introduced to other ways in which information can be conveyed, such as patterns.
- Puzzle 4: A cliff has to be crossed by choosing the correct order of labeled buttons which represent heading levels (see Fig. 2) and by that the player becomes familiar with the content of *WCAG Guideline 1.3.1 Info and Relationships (Level A)*. This guideline requires that the structure of (web) content must be programmatically determinable. If the correctness of the heading order is not given, the comprehensibility of the digital content is limited.
- Puzzle 5: To reactivate the elevator, the player is confronted with buttons of insufficient size (see Fig. 3). Based on the *WCAG guideline 2.5.5 Target Size (Level AAA)* it is necessary to maintain a minimum size for buttons (and other interactive elements) in order to guarantee their operability for all users.

Fig. 2. Puzzle 4: Three button options next to the magic carpet, each representing a different heading level

Fig. 3. Puzzle 5: Inaccessible target size of the ON-Button making it impossible to select the element

B. Implementation of GAG Workflow

The development process of the VR-Escape Room follows the phases of the IGDA workflow for an accessible implementation:

Phase 1 - Familiarization: The structure and content of the GAG and the presented Oculus manual were considered.

Phase 2 - Evaluate & Plan: The GAG are provided in form of an Excel spreadsheet in which each row represents a guideline whereas the Oculus manual contains various texts, which are spread over several pages. To allow a structured evaluation, we converted the content of the Oculus manual into an organized Excel spreadsheet. The further evaluation of the now prepared guidelines was approached together with the following phase.

Phase 3 - Prioritizing & Scheduling: The prioritization of the guidelines has been carried out in several steps. First, it was decided that, in addition to the Oculus manual, only the basic GAG guidelines would be considered. These do not require a complex implementation and yet help a large number of gamers, making them a suitable basis for the first prototypical implementation. In the next step, the Excel spreadsheet from phase 2 was extended by two additional columns, "Importance" and "Ease", which take a value between 1 (important resp. easy) and 3 (rather unimportant resp. difficult) for each guideline (see Fig. 4). "Importance" is used to indicate how necessary a guideline is for the concrete game experience of *Access to Escape*. Thus, the guideline to use a readable text size is associated with the importance of '1', whereas

Guideline	Importance	Ease
Hearing		
Basic		
Provide subtitles for all important speech	1	1,5
Provide separate volume controls or mutes for effects, speech and background / music	1	2
Ensure no essential information is conveyed by sounds alone	1	1

Fig. 4. Excel spreadsheet with rating of guidelines

the guideline to inform about accessibility features during the game is rated with an importance of '2'. The latter policy aims to improve the game experience by providing information; the former policy aims to provide a basic perceptible game experience, which is why it is considered more important. "Ease" describes how complex and time-consuming a potential implementation of the policy is estimated. After determining whether a policy is applicable to the game (see Phase 2), the values of "Importance" and "Ease" were discussed and recorded. By looking at the final scores, a prioritization of the guidelines or features could be performed.

Phase 4 - Implementation: Throughout the development process, the game was evaluated by usability and accessibility experts. Because of these evaluations, an implemented puzzle could be identified as a trigger for simulator sickness and thus as non-accessible. Therefore, an alternative path to the game was developed, which avoids the sickness indicating factors.

Phase 5 - Informing: Game-internal informing was not considered in the context of the prototypical VR-Escape Room. *Access to Escape* does not have any settings that can be accessed by the players but the implemented policies represent features that are inevitably encountered in the game anyways.

Phase 6 - Assessing & Learning: The testing phase of *Access to Escape* included 11 participants with connections to the study field of computer science [13]. We were present throughout the testing, which made it easy to observe how the participants reacted to the accessibility features. Here, it became apparent that the implemented features were also able to provide a better gaming experience for players without impairments or disabilities. They showed positive reactions to multiple access possibilities. Examples are the textual content conveyance through subtitles, the auditory signaling of events via sound effects, and the haptic feedback in form of different vibration patterns of the controllers.

C. Implementation of Accessibility Features

This section sketches the implemented and discarded guidelines and presents different categories in which these guidelines can be clustered. The respective categories are not to be considered disjunctively; thus, a guideline that is assigned to one category may also be part of another. In the following, the categories and exemplary associated guidelines are presented in ascending order of effort.

1. Implementation by the game engine: Besides guidelines which have to be implemented manually, there are also accessibility features which can be implemented by pre-developed templates of the chosen game engine (in our case

Unreal Engine), such as: "Representation of the controllers in the virtual environment" [12]. In order for the players to have a reference to the real controllers during the game and to simplify their use, a virtual copy of the controllers should be displayed (see Fig. 3). This not only shows the position of the buttons on the controllers, so that the players do not have to remember them, but also marks the position of the controllers in the real space, and thus simplifies their findability [12]. The game engine Unreal also provides this feature in the engine's own VR-template.

2. Implementation based on prior knowledge of accessibility: Further, there are such guidelines that can be implemented simply and with small expenditure, if there is knowledge of their necessity. One of these guidelines being: "Ensure no essential information is conveyed by a color alone" [8]. Since not everyone can perceive information through color, an alternative form of communication must be implemented [8]. This can be in the form of patterns, icons, or text.

In *Access to Escape*, a combination of these approaches is used. At one point, color signals the activation of a button which is additionally symbolized by sound and changing text. Another example are color-coded blocks that are equipped with patterns, so that they can be clearly differentiated without the visibility of color.

3. Implementation through elementary game design: A subset of the guidelines can be grouped under features that every common game design includes to make the application fundamentally playable, for example: "Placing UI elements in a user-friendly way" [12]. For an unrestricted gaming experience, the elements of the user interface must be easily accessible and visibly positioned, otherwise the game flow suffers [12]. The chosen position should indicate the relation of the element to the rest of the room.

In our VR-Escape Room, the guideline was planned into the visual conception of the games. The previous considerations about the positioning of individual UI elements have greatly simplified the fulfillment of this guideline.

4. Implementation through high effort: The guidelines sets also include policies that require costly implementation, such as "Provide subtitles for all important speech" [8]. Purely auditory instructions and narrations exclude persons with hearing impairments or persons who are more likely to take in written information from a full game experience [8]. To counteract this, the use of subtitles can be considered.

However, the implementation of these is not possible without further effort using Unreal Engine. The option to add subtitles to audio tracks is offered, but these are displayed in a font size that is too small and in an unsuitable position in the game. During our research, no option could be found to change font size and position, so another approach had to be taken: The subtitles are currently displayed as a separate text field based on predefined time frames (see Fig. 5). Due to the complexity of this approach, the subtitles in the prototype were only implemented as an exemplary feature in one scene of the game.

5. Implementation not possible: Lastly, there are policies that have not been implemented. In our case this had several reasons; for one, the guidelines may not be in accordance with the game rules or the game form: "Provide details of accessibility features on packaging and / or website" [8]. To benefit from the implemented accessibility features, players must first be made aware of them [8]. If these are implemented but not advertised, players may overlook them and, therefore, assume that the game is not playable for them. In addition, advertising the features can increase search engine traffic and distinguish the application from other games of the same kind.

Fig. 5. Visualization of captions of spoken dialogue of the guiding character

However, since *Access to Escape* is only a prototype and no public deployment is currently planned, this policy was not implemented for the current application.

For another, the reason for the lack of implementation may be resource constraints, as some implementations of policies may require additional expertise or time:

"Personalization of Controller-Based Movements" [12]. For example, players who have difficulty holding a game-required arm position for an extended period of time should have the opportunity to personalize controller-based movements [12]. If a position, such as an outstretched arm, cannot be achieved in the real world, it should nevertheless be possible to personalize the parameters of size, rotation or distance, so the virtual arm can be fully extended or moved to a different position. Due to different mobility abilities, these "hand profiles" should be individually implemented for the left and right hand. This guideline was not implemented within *Access to Escape* due to its extensive implementation work and project time restrictions.

IV. Discussion & Limitations

The discipline of Game Accessibility deals with eliminating avoidable barriers for people with disabilities or impairments within the framework of game rules [7]. This creates a dilemma between adhering to the game rules and making the game as accessible as possible. Game rules typically require overcoming intended barriers that are presented in the form of game challenges.

For example, a digital chess game where each move is timed cannot fulfill the guideline of variable game speed without violating the game rules [11]. Furthermore, not every guideline is relevant to every game. For example, the guideline that requires the use of subtitles cannot be applied to a game that does not have audio. Therefore, developers must be aware that a game may not be entirely accessible due to the game rules but also that a game can still be accessible even if not every

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single guideline is met. Thus, developers are faced with the challenge of recognizing which guidelines are feasible and relevant for the game.

Within the scope of this work, the GAG workflow has proven to be a suitable approach, especially for the needed structured exploration of the guidelines. Furthermore, the transfer of this workflow to other guidelines has also been successful and can be recommended. However, developers must consider that a resource-based prioritization, as suggested in phase 3 of the GAG workflow, cannot produce an accessible application. This goal can only be achieved by implementing all applicable guidelines. The EU Directive 2016/2102 (39) also emphasizes this fact: "Only legitimate reasons should be taken into account in any assessment of the extent to which the accessibility requirements cannot be met because they would impose a disproportionate burden. Lack of priority, time, or knowledge should not be considered as legitimate reasons." Therefore, while the GAG workflow provides a structured approach to develop an application with low barriers, it is only suitable for developing an accessible application if prioritization within the workflow does not lead to the exclusion of other applicable policies. This is crucial as each guideline ensures the access to the presented content for a specific target group and further, as confirmed by our results, they have the possibility to improve the game experience for everybody. To comply with all applicable guidelines, it is necessary to schedule enough time to implement the accessibility features that were not achieved to the desired extent in the discussed implementation. In retrospect, it could be recognized that a classification of guidelines into categories is possible, which could support better time management during the development process. Another aspect that must be addressed early on during the development process is the cooperation with people affected by impairments or disabilities. Since no test person stated that they are affected, the question of inclusion can only be answered theoretically, not practically.

In conclusion, the development of an accessible VR game requires enough resources and a well-defined time schedule. To plan these factors, the GAG workflow offers a supporting guide but is not sufficient on its own which is why thorough research and more tangible implementation templates are needed.

V. Conclusion

Summarizing, the research question "What does the design process for creating an accessible VR game entail and what implementation steps are necessary to achieve this goal?" can be answered supported by the GAG workflow. It offers a suitable starting point for developing accessible games and a structured approach on working with large sets of accessibility guidelines like the GAG and the Oculus manual. The workflow is especially useful for identifying and prioritizing policies that can be implemented in a first implementation cycle. But here, the examination of the guidelines alone is not sufficient for a sustainable assessment of which prioritization these features should take. A retrospective view of the implemented features shows that preceding steps are needed, like the consideration of the features that the chosen game engine already offers, as well as the documentation of existing implementations. Here, the classification into the categories presented in this paper could benefit the development process. They offer the possibility of assessing the workload that would be needed to meet each guideline. However, since many guidelines fall under the category of "Implementation through high effort" or "Implementation not possible", our VR-Escape Room *Access to Escape* cannot meet the requirements of an accessible VR game. Our research phase indicated that there is a need for low-level solutions for accessible games and VR applications so that accessibility features that were classified under the mentioned categories can ideally be classified into "Implementation by game engine". Since this is not the case yet, the guidelines were implemented in an exemplary manner at various points in our VR-Escape Room, but not consistently, which is unsatisfactory and needs to be addressed in future design iterations. Another aspect that needs to be included in future work is the evaluation of *Access to Escape* by people with impairments or disabilities to get reliable insights on the accessibility of the VR game.

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The Tension Field of Digital Teaching From the Perspective of Higher Education Teachers

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***Abstract*—The recent COVID Pandemic forced higher education teachers to come into contact with digital teaching and both positive and negative experiences have been made. Now, it is time to reflect on the advantages and disadvantages that have arisen as a result of digital teaching and what benefits the independence of location and time as well as the possibilities of digitization have yielded for teachers and students. An exploratory study was conducted to analyze perceptions of and opinions on digital teaching as well as statements about future teaching. For this purpose, 13 semi-structured interviews with higher education teachers and deans of studies at a large German university were conducted and analyzed using inductive categorization. As a result, four positions could be identified that describe the different perspectives of higher education teachers on the possibilities of digital teaching and the value of face-to-face teaching. When assuming a certain degree of heterogeneity among students, this results in a tension field of advantages and disadvantages for students, depending on the chosen teaching formats and preferences of the teachers. In this article, reasons behind these four different perspectives are given as well as recommendations for the future design of post-pandemic teaching.**

Keywords-digital learning and teaching; higher education; digital accessibility.

I. INTRODUCTION

A German proverb (1829) reads:

> "Allen Menschen recht getan, ist eine Kunst, die niemand kann." ("To do right by all people is an art that no one can do.")

What this means is that it is impossible to satisfy everybody involved or all affected parties equally. In the context of higher education, this dilemma is evident in the redesign of teaching following the pandemic-related university closures that were accompanied by a complete transition to online teaching. Both negative and positive experiences were made by teachers and students. So which path does one choose as a teacher after the pandemic?

The first reaction of many universities after the end of the full lockdown was to return entirely to on-site teaching. However, as experience reports show, this also has many disadvantages for students and teachers, and especially the aspect of (digital) accessibility [1] [2] [3]. The (forced) experiences with digital teaching, without the possibility to meet in presence, were perceived assessed very differently on several levels. With regard to study organization, flexibilization, study performance and learning success, communication and interaction, motivation and competencies, both positive and negative experiences were made by students and higher education teachers [1]. During the pandemic, it also became clear that what is a relief for some can be a complication for others [4]. It can be seen that educators must operate in an area of tension with respect to post-pandemic digital teaching. Considering their own needs and the needs of a heterogeneous student body is a particular challenge. Although higher education recognizes the diversity of students as a given in its mission statements, in reality heterogeneous learning situations are rarely taken into account in the conception of teaching scenarios, or are only taken into account by teachers when students articulate individual needs and request support [2].

This paper analyzes in more detail the patterns of argumentation regarding the choice and design of teaching formats and scenarios that can be found among teachers and how they justify their decisions for and against digital teaching. Section 2 describes the conducted qualitative study, we asked about experiences during the pandemic related online semesters, about changing attitudes and possible reservations about digital teaching, and the advantages teachers see in digital teaching, in order to illuminate a possible area of tension caused by different needs and teaching requirements. This results in the following two research questions for analysis. In Section 3, the findings from the interviews conducted are presented in detail:

- RQ 1: What reservations do higher education teachers express about digital teaching and how does this impact the future conception of their courses?
- RQ 2: What advantages do teachers see in digital teaching and what should be retained after the pandemic induced online semesters?

II. METHODOLOGICAL APPROACH

In order to answer the research questions, a total of 13 individual interviews were conducted with teachers from a large German university. Eight interview partners were from faculties of the natural sciences and medicine, three from social sciences, and two from the humanities. Among the 13 interview partners, 10 were simultaneously acting deans of studies of their respective faculties. The guiding questions were slightly modified for this group of persons. The individual interviews were conducted between 07/01/2022 and 08/02/2022 via videocall using Zoom videoconferencing software. To ensure the anonymity of the interviewees, no further personal data was collected.

The interview procedure chosen was the problem-centered interview according to [5]. This method tries to let interview partners speak as freely as possible to come as close as possible to an open conversation. At the same time, however, the interview is oriented toward a previously determined problem, the details of which are compiled in advance in an interview guide. For the conducted study, two guides for research questions were developed (deans of studies and higher education teachers). To avoid the interviewees formulating their assessments of reservations and advantages of digital teaching too broadly or too abstractly, they were asked to describe their experiences and impressions from different phases of the COVID-19 pandemic in each case. This is reflected in the wording of the questions in the interview guides, which respectively refer to the lockdown phase of the pandemic with Emergency Remote Teaching [6] and the post-pandemic phase, in which teaching returned to a "New Normal" [7]. The two interview guides included the following questions:

Interview guiding questions for deans of studies

- How did faculty members perceive virtual teaching during the past three online semesters? Are the teaching experiences from this time viewed more positively or negatively? To what extent? / What do you think are the reasons for this?
- In your estimation, inasmuch did the Corona pandemic change attitudes toward digital teaching among faculty members, if at all?
- What were the reactions of faculty members this semester when the "back to on-site teaching" tendency emerged?
- What reservations about digital teaching do you currently perceive on behalf of the faculty? (technical problems, social problems, didactic limitations, etc.). In your estimation, to what extent are these reservations related to the experiences from the Corona semesters?

Interview questions for teachers

- How do you assess your experiences with digital teaching during the past Corona semesters? What are the reasons for your assessment?
- What negative effects of digitalization processes in teaching do you see? What kinds of downsides emerge from them?
- Has your attitude towards digital teaching changed as a result of the pandemic? In what way?
- Have you used digital teaching practices, methods and tools from the Corona semesters in this semester? - If not, what are the reasons for this?

The recorded interviews were automatically transcribed with the software Amberscript and completely anonymized so that no more conclusions can be drawn about persons or subject discipline. Subsequently, the material was analyzed in a Qualitative Content Analysis (QCA) according to Mayring (2015) with the software QCAMap [8]. An inductive evaluation method was chosen, in which the category system is developed from the material concurrently with the analysis and evaluation process, guided by the research questions. The coding of the interviews was done in an inter-coder procedure with two coders each. The reliability of the overall result was ensured by checking all codes during an evaluation conference with all four coders. In this session, major categories were also formed from the individual categories, which are described in the following section.

III. Results of the qualitative content analysis

The qualitative content analysis of the transcripts was conducted along the two research questions RQ1 and RQ2 (see Section 1) and the results are presented separately below.

A. Reservations about digital teaching (RQ1)

The reservations about digital teaching expressed by the teachers in the interviews address social, didactic, organizational and technical aspects. The statements of the teachers were assigned to a total of 56 different subcategories, which in turn can be summarized in 10 main categories [9]. A selection of the most relevant categories will be discussed in more detail in the next section.

1) Social aspects: Lack of contact and absence: Frequent concerns expressed by teachers about digital teaching relate to social aspects of the teaching-learning process, such as a lack of social contact, insufficient contact with the subject and also (physical) absence from the learning location. The interviewees complain that there is no direct contact in online scenarios (RQ1-1) and thus no real discourse and dialogue as well as no sufficient interaction (RQ1-2). Interview partner 3 (IP03) describes it like this:

> “Even in the lectures we try to include as many practical elements as possible. And even if it’s just a matter of discussing problems and getting the students involved in the dialogue, so to speak, so that they have to think about it and follow the train of thought and not just sit there and let it wash over them. Of course, that doesn’t work in the digital world.” (IP03)

Digital teaching would also lack the spontaneous small talk before and after the lecture (RQ1-23). As online lectures end abruptly, student communication is assumed to suffer (RQ1-39) due to a lack of opportunities for exchange, discussion and reflection (RQ1-24, RQ1-25). This is regretted by interview partner 5:

> “On the way to the seminar, they talk about the content of the seminar, as well as about the lecturer. But they reflect in the process. This reflection is lost.” (IP05)

2) Pedagogical-didactical reservations and motivational aspects: Some of the reservations expressed in the interviews relate to the didactic design possibilities of digital teaching. In the eyes of some interview partners, these are less effective than those available in face-to-face teaching (RQ1-36). Likewise, the willingness and ability of students to perform presumably decreases in online teaching (RQ1-12). Several of the interviewees also point out that digital teaching-learning formats are didactically flawed and generally do not correspond to their ideas of "good" teaching (RQ1-11). Interview partner 6 says, for example, videos would tend to prevent engagement with texts (RQ1-38):

> “To understand the digitisation of teaching as a bit of an alternative to text-based teaching, so to speak, in the direction of, let’s say, video or audio content, that would also be a problem from our specialist point of view" (IP06)

Teachers are also dissatisfied with the didactic possibilities of the existing systems. In their opinion, the systems and tools are not very appealing in design and could be more playful (RQ1-31). Teachers also perceive the “digital divide” associated with online teaching as problematic, i.e. the effect that high-achieving students benefit more from digital teaching than lower-achieving students, who tend to be disadvantaged by the use of online teaching (RQ1-53). Interview partner 8 describes their experience as follows:

> “I think that to those who are good didn’t matter that much because they dealt with it well. But those who are not so good, you lost them to a certain extent because you couldn’t nudge them directly." (IP08)

The respondents attributed this effect to the fact that lower-performing students in particular were less motivated in online teaching (RQ1-10). Due to the lack of scheduled learning opportunities in presence as well as the lack of social exchange, students partly lose the structure for their daily study routine (RQ1-47) and learn less as well as less independently (RQ1-42).

3) Organizational and legal barriers: In addition to concerns about the didactic reservations of digital teaching, the interview partners also mention organizational and legal reservations about the increased use of virtual and hybrid teaching formats. Digital teaching is above all time-consuming (RQ1-5) and expensive (RQ1-32), as teachers sometimes have to familiarize themselves with new tools first (RQ1-45), must first create or prepare additional materials or provide additional online support. According to the interviewees, the additional workload then leads to work intensification and deadline pressure (RQ1-27). Teachers see it as particularly problematic that the amount of work they invest in producing and supporting additional digital courses is not remunerated (RQ1-37). Interview partner 6 said:

> “Well, I’m basically doing face-to-face teaching, but I’m also doing a lot of nice digital stuff on top of it, a bit of personal commitment that you do because it’s close to your heart. But the effort is somehow not compensated in a certain way." (IP06)

In addition to the extra effort, respondents also raise legal concerns about the use of digital teaching. For example, Interview partner 3 argues that online is rarely compatible with legal regulations such as the licensing regulations for medical professions (RQ1-18):

> “If we do not return to real practical content, we are not educating future doctors properly. That is a very clear fact. So we are in breach of the licensing regulations, so to speak, if we continue to keep them away from the hospital bed." (IP03)

Last but not least, respondents also fear that their digital course material will be distributed uncontrolled and illegally on the web (RQ1-13).

4) Technical barriers: The implementation of digital teaching is inextricably linked to the use of different digital tools, systems and technologies. Thus, various reservations are also mentioned in the interviews that are closely related to the use of technology as well as the specific characteristics of the respective technologies used. In addition to infrastructural problems such as an inadequate WLAN connection (RQ1-54), the usability of the available digital systems is criticized as being inadequate, especially for "beginners" and digitally less inclined teachers (RQ1-9). Interview partner 10:

> “Where the eLectures are recorded and where you can also upload things yourself as a user. [...] I also used that once, I have to say at the beginning, and then found it complicated after all." (IP10)

It is often the university’s own systems that do not work well (RQ1-46). Another reservation is the fact that some technological solutions (such as AR or VR applications) offer didactic advantages, but cannot be used properly on a broader scale at present (RQ1-19) as interview partner 3 argues:

> “VR is indeed quite nice, but as I said, it is still a long way from being usable for all students. There are not enough devices." (IP03)

In addition to these points, which relate more to the teachers themselves, the interviewees also bring up technical barriers on the part of the students that limit or even prevent their participation in digital teaching. First and foremost, an insufficient internet connection of the students is mentioned (RQ1-17) as well as a general uncertainty of the teachers due to the technical challenges on the part of the students (RQ1-41).

5) Personal reservations and lack of teaching skills: While the reservations about digital teaching described so far tended to be of an external nature, the respondents also mentioned internal reasons. These include, on the one hand, personal sensitivities and preferences of the teachers, but, on the other hand, also their own teaching competence levels, which are perceived as insufficient. The personal reservations mentioned include fear of the unknown (RQ1-49) or the uncomfortable feeling of communicating with students via camera and microphone (RQ1-40). For example, interview partner 12 reports that

> “the tiles were black, and speaking to a black screen, especially in the first semester, for example, was considered by many to be very unusual or difficult to get used to and not very advantageous." (IP12)

Furthermore, some teachers have the opinion that a majority of their colleagues would prefer face-to-face teaching to online teaching (RQ1-34) or they themselves could not imagine teaching online (RQ1-48). However, there were also complaints about the lack of support from the university, especially with technical problems (RQ1-51), which prevented them from incorporating more digital elements into teaching. Interview partner 11 is disillusioned, given that

> “the technical support was rather poor and we had to work out a lot on our own." (IP11)

Last but not least, the teachers also surveyed a lack of competences as a reason for not offering more digital teaching. The main reason cited here is the lack of digital skills among teachers (RQ1-4), which made it difficult to deal with the tools needed, as interview partner 5 explains:

> “Of course, there were enormous difficulties in dealing with a digital format, for example. So how do I actually do an online session or something?" (IP05)

Similar problems in the use of technologies for digital teaching are described by interview partner 2:

> “But I have no idea how to create these videos in a visually different way and maybe put them on another page. [...] Or what is a Scorm learning content. These are all things that you normally have no idea about" (IP02),

and interview partner 13

> “How does zooming work? What is the best way to do it? [...] There was a lot of uncertainty on all sides." (IP13)

A lack of didactic skills is also cited as a further obstacle to the more extensive use of digital teaching (RQ1-20). Interview partner 5 recognises the greater deficit here.

> “For me, it was relatively clear that the know-how was still lacking on the part of the teachers, both from a didactic and a technical point of view. Above all from a didactic point of view." (IP05)

In addition to the competence deficit, the interviewees also mention the problems caused by the introduction of new technologies (RQ1-6) and insufficient guidance and instruction on new digital systems as further barriers to the use of digital teaching (RQ1-52).

B. Advantages of digital teaching (RQ2)

In addition to the reservations, the teachers were also asked in the interviews about the advantages of digital teaching. In their experiences, teachers report on the pedagogical-didactical and technical-organizational advantages of digital teaching as well as positively perceived effects on students' motivation and learning success. In addition, they talk about advantages that compensate for individual disadvantages, as well as about increasing their own digital skills. The statements of the teachers were assigned to a total of 26 different categories, which in turn can be summarized in six main categories [10].

1) Pedagogical-didactical, motivational and performance-related advantages: The temporal and spatial flexibility of digital, asynchronous teaching (RQ2-7) in connection with the possibilities of uncomplicated repetition of the learning materials at one's own learning pace (RQ2-8), also for the preparation and follow-up of synchronous phases, are repeatedly mentioned in the interviews as advantages and a way to self-determined learning. The following two statements are representative of several statements about these advantages:

> “So some like it, appreciate it very much, that they can schedule things themselves, that they can work independently at home, when they want to." (IP11)

and

> “Asynchronous elements, especially now, when students are supposed to work on their own, alone or in stucy groups or so, you can design that well or even better with virtual tools." (IP12)

Teachers also perceive that digital teaching is popular with students (RQ2-4), motivates students (RQ2-22), and contributes to learning success (RQ2-3). Students' desire to have digital teaching as a choice is reported several times. Representative of this apparently frequently expressed wish are the following two statements:

> “Can't we also have the material virtually as well?" (IP01)

and

> “With students you also hear more often that they really want to have a choice, face-to-face or digital. For different reasons, personal reasons." (IP09)

In addition, the high motivational effect of digital teaching was also reported during the pandemic:

> “They all turned on their cameras and they had a very intense exchange that 30 minutes were usually not enough for because everyone was so engaged in it." (IP05)

And they also perceived an increase in performance among some students, as interview partner 4, among others, states:

> “We've made the observation that high-performing students actually show performance improvement from online teaching." (IP04)

For the future design of teaching, teachers take with them the insight from pandemic times that the mixture of digital and face-to-face offers is important, (RQ2-23) as the following quote of interview partner 9 illustrates:

> “We cannot replace face-to-face teaching with digital offers, but only expand and supplement it. That's something that was a clear takeaway." (IP09)

In this context, the development of one's own competencies (RQ2-14) and the further development of one's own teaching (RQ2-1) were also perceived as positive effects of the pandemic, as described by interview partner 10 and 2 as representative of several statements in this direction:

> “But I have now become acquainted with many more opportunities and possibilities. In this respect, the attitude has changed a little. I think so, because now I will also use blended learning formats more readily. And in this respect, it has changed somewhat, because I now take the opportunity more easily or more frequently, even in a seminar that does not take place virtually, but to incorporate real work phases that use virtual tools." (IP10)

and

> "So the bottom line after the three semesters, I would say, among the colleagues the vast majority or a great majority have found this to be an enrichment. And as yes [...] now looking back at the possibility to develop one's teaching further." (IP02)

With regard to the further development of their own teaching, teachers also emphasize that the analysis of data generated by digital teaching could be used for a more precise didactic evaluation (RQ2-16).

2) Organizational advantages: In the interviews, a whole series of arguments for digital teaching came up, which concern advantages for the organization of teaching. Emphasis is placed on the easier and increased provision of learning content (RQ2-18) and recordings (RQ2-6), temporal and spatial independence (RQ2-13), and the reusability of digital materials (RQ2-2). For some programs, such as teacher education, these organizational advantages are of particular importance, as interviewee 05 makes clear:

> "I have a lot of teacher trainees who have a lot of problems with overlap in their curriculum. For them, of course, it was a blessing that now in the lecture, that they can also participate asynchronously." (IP05)

In addition to making it easier for students to organize their studies, teachers also see advantages of digital asynchronous teaching for their own work (RQ2-24):

> "Yes, because of course it gives teachers the opportunity to create new freedom for themselves through the asynchronous offers." (IP09)

The initially high effort to produce digital materials is now, after the creation seen as an advantage for students and as a relief for themselves, as interviewee 08 states:

> "And I now have digital materials for all three semesters. If I teach this course again, then in principle I could profit from it or I would profit from it, then I could make all the digital things that I already have, I could then make them accessible again. And then, of course, that's very luxurious for the students." (IP08)

3) Advantages of digital teaching that compensate for individual disadvantages: Two interviewees also describe aspects of digital teaching that can reduce individual disadvantages for both students and teachers. With the help of digital teaching, teachers with health risks due to the pandemic were still able to offer and conduct courses (RQ2-25). In addition, one interviewee also perceives benefits for students whose personality traits allow them to overcome disadvantages of face-to-face formats through digital teaching (RQ2-26):

> "And yes, there are students who find it convenient when they can turn off their camera and then speak quasi-anonymously." (IP12)

IV. Discussion

The results show that, after the experience of the pandemic, some teachers emphasize the desire for on-site teaching and the associated direct contact with students and colleagues. This goes hand in hand with teachers' concerns and reservations about digital teaching. Besides the pedagogical and didactic difficulties of digital teaching, they also see motivational and performance-related problems. In addition, there are personal reservations in connection with their own lack of competence and perceived organizational, technical or legal hurdles. On the other hand, however, some advantages of digital teaching are also perceived, for example with regard to motivation, pedagogical-didactical possibilities and potentials, and organizational facilitation. These different perceptions are not necessarily contradictory, but rather reflect the individual situation and perspective of teachers and students. There is a tension between the advantages and disadvantages of face-to-face and digital teaching, which poses a dilemma for the design of teaching (which is shown in Figure 1). Advantages of a format for some may represent disadvantages for others.

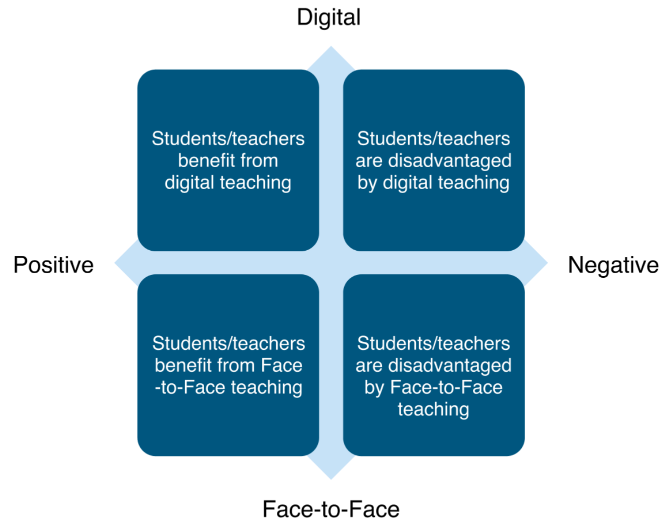

Fig. 1. The Tension field of digital and face-to-face teaching. The four positions of a teacher's view on the benefits and disadvantages regarding both settings.

A. The Tension field of digital and face-to-face teaching

In addition to aspects of isolation and loneliness or difficulties for lower-performing students, the perceived disadvantages of digital teaching relate primarily to the lack of direct exchange and dialog with students. This perception leads to a strong desire on the part of some teachers to return to the former face-to-face teaching formats rather than to maintain digital ones. This reaction risks overlooking the fact that "back to face-to-face" may well be associated with disadvantages for some students and teachers. Assuming a broad understanding of heterogeneity, respectively diversity [11], in which heterogeneous (learning) starting points are acknowledged, with different prior knowledge, interests, cognitive abilities, motivations as well as social and cultural backgrounds of students, digital elements play an eminently important role with regard to diversity-sensitive, inclusive teaching. Disadvantages of a purely verbal and fluid face-to-face teaching offer arise, for example, for students who have difficulties following due to auditory perception disorders, physical hearing impairments, reading/spelling difficulties, grief or ADHD/ADS [2] or have problems actively participating in presence due to shyness or anxiety. Advantages of digital teaching can provide significant support. A continuous asynchronous learning offer or the possibility to make use of it in addition to face-to-face teaching would be very helpful for these students. For example, students with reading and spelling difficulties have enough time to read texts, use reading programs and apps for written assignments, and enter their own written submissions, e.g., via Readspeaker, and have them automatically checked for spelling and grammar. In the case of concentration difficulties or simply different discussion and learning speeds, an asynchronous learning offer can provide relief by allowing contributions and tasks or asynchronously conducted discussions to be worked on autonomously at one's own pace or in smaller units, so that the working memory is less burdened. In addition, for some students in special life situations, e.g. when they are prevented from attending due to illness, parenthood or other care work, a continuous asynchronous learning offer makes it possible to maintain their studies in the first place.

V. Conclusion and Future Work

The qualitative study identified four positions that can be used to describe the tension between the perspectives of which teachers view the specific opportunities and threats of digital teaching and face-to-face teaching (see Figure 1). In the future, these different perspectives must be considered on two levels when designing contemporary teaching. For one, on the institutional level, in strategic decisions about the goals and orientation of academic teaching at the university. For another, on the individual level of the single teachers, in the planning and realization of their own teaching, but also in the reflection of their own teaching activities. In this context, it will be crucial to always have different possible solutions in mind in a multiperspective sense and to choose solutions that take several of these positions into account and lead to a synthesis through dialogue [12]. Interview partner 9 also argues in favor of such an approach by speaking out against thinking in either/or categories:

> "So it's neither a demonization of digital possibilities, but also not a clear prioritization of face-to-face presence. Yes, perhaps not just prioritization, but really the mix, it's the mix that makes it. Both have their place, digital teaching, face-to-face teaching, and you can't replace one with the other."

In the future more research is needed to further explore this tension field of digital teaching. On the one hand, the perspective of the students is important, whose needs and wishes must be taken into account when designing digital teaching. On the other hand, the group of persons with special needs due to e.g. visual, hearing or motor impairments or with care work is interesting. Even if all students (and teachers) benefit from digital accessibility in principle, it is this group whose needs should be given special attention. Further work will focus on the question of how university teaching can become more inclusive by incorporating the possibilities of digitization [2] and in what form the multi-perspective approach described can support this process. One approach could be the creation, systematic preparation, and distribution of learning designs for inclusive, digital teaching. These patterns, which require both individual teachers (individual level) and institutes for academic development (institutional level) to create, would provide teachers with a valuable source of inspiration for designing contemporary teaching.

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UEmbed: An Authoring Tool to Make Game Development Accessible for Users Without Knowledge of Coding

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***Abstract*—There has been a rising interest for Serious Games in recent years, which lead to more and more Game Engines becoming available for everyone to use. Although this availability is very welcoming, the usage on the other hand is sadly not that accessible. There is a dearth of knowledge on the technical side needed to have an usable output. This problem excludes those who are brimming with ideas to move the needle in their departments with Serious Games but lack the insight on the useability of these Game Engines. This makes it a daunting task to design and develop a Serious Games as this problem can only be solved with time, knowledge, new hires and a moderate budget. Thus, an Open Source Authoring Tool named UEmbed is being developed. It would make the task of creating and developing a game with the latest technology of the Unreal Engine very accessible for everyone, including individuals with cognitive impairment or dyscalculia. Without any prior knowledge, it would be possible to design and set the environments, dialogues, characters for an immersive Serious Game with the help of a Browser-based Authoring Tool in conjunction with a pre prepped project. Also, a template scene with characters and story will be provided to showcase the individual functionalities. This tool can be used to showcase various scenarios with a high-end graphical fidelity. With this open source project concept, it will be accessible to anyone and it can also be modified and further extended by the community. This approach will ensure that any institute or individuals with a tight budget will have access to develop a product on par with the latest technological trends.**

Keywords- UEmbed; Serious Game; Authoring Tool; Accessibility.

I. INTRODUCTION

Digital accessibility has become a critical issue in recent years, with millions of people around the world facing barriers to accessing digital products and services. In 2019, the European Union took a bold step to address this issue by adopting the European Accessibility Act (EAA). This directive aims to improve the functioning of the internal market for accessible products and services by removing barriers created by divergent rules across member states. The EAA has brought digital accessibility to the forefront of national agendas across Europe, signaling a major shift in how we approach inclusivity in the digital age. Germany has made significant progress towards digital accessibility by implementing the Barrierefreiheitsstärkungsgesetz (BFSG), which is in line with the European Accessibility Act (EAA). This groundbreaking legislation demonstrates Germany's unwavering commitment to promoting inclusivity and ensuring that digital products and services are accessible to everyone, regardless of ability or disability. The EAA enshrines accessibility as a fundamental right and empowers individuals to fully participate in the digital economy.

Discussions regarding this topic have been held at universities for quite some time. Therefore, the idea occurred to approach this topic in the form of Serious Games.

Section 2 defines the problems of serious game development. Since comparable tools are often more complex to use and offer less impressive graphics, a comparison of the state of the art is made in Section 3. The design and technical aspects of the authoring tool are described in detail in Section 4. Section 5 presents the workflow from the user's perspective. The paper concludes with a short summary and an outlook on the future of this project in Section 6.

II. SERIOUS GAMES

According to R. Dörner, S. Göbel, W. Effelsberg, and J. Wiemeyer (2016), a serious game is a digital game created with the intention to entertain and to achieve at least one additional goal [1]. These games can have an additional goal to teach players about certain topics in a playful way. The game "Lola's First Semester" [2], developed by studiumdigitale, the central e-learning unit of the Goethe University Frankfurt, uses the university as a scenario and illustrates the everyday life of a visually impaired student named Lola. Players are put in a situation where they have to cope with various everyday challenges from Lola's point of view and learn to empathize with the situation of a visually impaired person. The goal was to make the players more aware of the different problems such a person might face. This was done through a series of mini-games, each dealing with a specific situation in the life of the protagonist "Lola" at university. For example, these mini-games highlighted the inaccessible design of PowerPoint slides or PDFs, or the criteria to consider for accessible videoconferencing. At the end of the game, the players were asked about their experiences during the game and the results were evaluated in a study [3].

During the design, programming, and publishing phases of this serious game about accessibility, several issues arose throughout the process. It became clear that creating a serious game from the ground up requires a significant amount of time, budget, and manpower. The question arose as to how best to allocate the available expertise. The game industry and the usual processes for creating a game quickly came to mind. Typically, game engines are used for programming. However, as programming is too complex for many university staff, the previously identified problem areas (time, budget and staff) would hardly be alleviated. There are game engines that can be used for free under certain conditions, but they still require a lot of time and manpower without specialized knowledge. This led to the idea of an authoring tool. This tool should allow people without programming knowledge to use the possibilities of complex game engines. Ideally, everyone would have the chance to create their own game, whether it's a serious game or just for entertainment. This tool should also be accessible and usable outside the university.

Part of an authoring tool was programmed where users can click on buttons on a web interface to summon buildings, trees, and characters on a top-down map and also change some basic properties such as name or size. This construction can then be exported as a JSON file that can be imported into the Unreal Engine and rebuilt in 3D.

III. State of the Art

The number of video game players is constantly growing [4], and there has also been significant growth in the serious games sector, particularly in academia [5]. This increased interest in the medium has led to some changes in the gaming industry. It has become much easier for gamers and other interested parties to develop their own games on their home computers. There are many reasons for this, one of which is easier access to game engines. The history of the availability of the Unreal Engine can be used as an example to illustrate this. In November 2009, the Unreal Engine 3 was made available for free for non-commercial use. You could download and use the Unreal Development Kit for free, but you could not sell the result. In early 2015, the Unreal Engine could also be used for free for commercial purposes, but only up to a certain revenue limit (3,000 USD / quarter). Another five years later, in May 2020, the licensing model was changed again, allowing the engine to be used completely free of charge if the gross revenue does not exceed one million US dollars. This development shows how easy it has become for small projects and studios to implement the use of professional game engines. Other large game engines, such as Unity, have also become more accessible over time. The use of such engines is no longer limited to large companies. Now anyone can download and use them as they see fit.

However, using game engines requires good programming skills. As a result, many people are prevented from implementing their own game ideas simply because they do not have the time to acquire or train the necessary skills. Other developers have recognized this problem and implemented tools to give people without programming skills access to professional game engines. In the following, we will discuss some of these tools and explain how they differ from the UEmbed vision.

A. RPG Maker

This tool has been available since the 1990s and has been continuously developed. The games created with this tool have pixelated graphics from a top-down perspective, like the games from the mid-80s to early 90s. However, it is somewhat limited in design as it is mainly designed to create role-playing games (RPGs). Although no programming skills are required, the interface has many menu items and submenus, making the tool very complex. As a result, it is more suitable for users who are familiar with computers and also requires a longer learning curve. However, to fully exploit its potential, programming skills are still required. Although not mandatory, they provide more options in the design of the game. Therefore, it is not suitable as a tool for people without programming skills. It is also not free, although the price is quite low. In addition, it limits the implementation of game ideas. Because of the perspective and the limited interaction possibilities, only certain types of games can be implemented. It would be desirable to have more freedom in implementation and less restrictions on creativity.

B. CoSpaces Edu

CoSpaces Edu is a tool that comes very close to the idea of UEmbed. With CoSpaces Edu, users can create a game with 3D graphics. These games are heavily focused on Virtual Reality (VR), although they can also be used without VR equipment. However, playing the games outside of VR requires knowledge of certain gaming conventions, such as controlling the character with WASD or arrow keys (the standard keyboard keys used to move characters in PC games) and using the mouse to look around. In addition, the character controls can be a bit clunky, so the games don't reach their full potential outside of VR. No programming skills are required to create the games. The implementation is done in the browser using their visual coding language called CoBlocks. This is structured like a building block and users can choose from a wide range of assets (characters, objects, flora and fauna). These are then dragged and dropped into the game world. Using a kind of frame, users can assign different movements and texts to characters and objects. Nested structures can be created within these frames, allowing for complex processes. Nevertheless, the entry level is kept low.

However, there are a few points that the UEmbed project wants to approach differently. CoSpaces Edu is not available for free, so it is only accessible to people and projects with sufficient budget. This excludes certain groups of people and is not accessible to everyone. Although there is a free version, many features are not available and users are generally more limited in their options than in the paid version. Projects are not stored locally, but only online on the CoSpaces Edu platform. If the operating company DelighteX GmbH decides to block projects or goes bankrupt, it is possible that users' work will no longer be available. As a result, users put their projects in a certain dependency and do not have full control over their games. In addition, although the graphics are 3D, they are low-poly, simple, and cartoonish. For example, characters often have disproportionately large eyes, which makes them look cute. Many textures and assets are quite rough. This style of art does not lend itself well to certain subjects. Serious topics such as depression, war or crime seem out of place in such a scenario. This is why CoSpaces Edu is aimed more at a younger audience, while UEmbed wants to serve an adult audience as well.

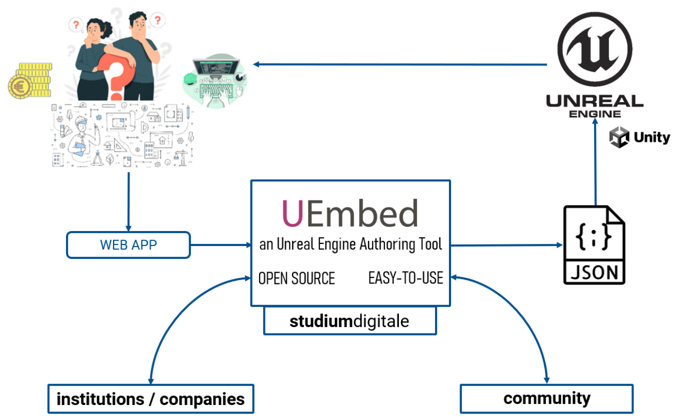

Figure 1. Overview of UEmbed: Quick, cost-effective Serious Game creation with community support.

C. Unreal Marketplace

UEmbed also allows the use of the Unreal Marketplace, an online store from Epic Games, where countless assets are offered. Many of them, such as 3D models, textures and sounds, are free and can be used by users in their games. There are also templates available, which provide a specific type of gameplay pre-programmed with all the necessary codes with placeholders. These placeholders can be replaced with any other asset of your choice. The template can also be modified at will. However, creating such assets is time consuming and requires a certain amount of creativity. It also requires programming skills, making it too cumbersome for the target audience to create such assets themselves. Therefore it is a great advantage that these assets are already created in the Unreal Engine and partly available for free. Of course, there is also the option to purchase additional assets if the budget allows. In addition to the official store, there are many other websites that provide templates or assets, often for free as well.

IV. The Approach

A. Design

The main drive behind this project is to allow everyone to participate in the game development process, regardless of their technical expertise. The workflow of creating an immersive game should be made more accessible not only to those with limited knowledge, but also to those with different accessibility.

The serious game "Lola's First Semester" was a visual novel-style game with 2D graphics mixed with mini-games. You might ask why we don't want to make a 2D game anymore. We are leaning towards 3D because we want to give our players more immersion. According to Slater et al. (2013) [6] immersion is the description of a technology and evolves to the extent to which an individual is provided with an inclusive, comprehensive, surrounding, and vivid representation. Therefore, systems with high levels of immersion increase the perception of presence [7]. Presence, in turn, represents the potential psychological and behavioral response to immersion. Moreira et al. (2016) conclude in their pilot experiment that the 3D experience promotes high levels of presence perception compared to the 2D experience [7].

From here on, we will refer to people who work with the authoring tool, design and plan games as "the user", and people who play those games as "the player".

There are two points of accessibility provided with this project. Since the UEmbed Authoring Tool is browser based, it allows the user to work with it on any operating system of their choice, be it Windows, MacOS or Linux. All these operating systems are also supported by the Unreal Engine. Someone with a disability can also technically work with the authoring tool. For example, a visually impaired person could use a screen reader to navigate and use the tool. From the player's point of view, they will be able to play an immersive and modern looking serious game in 3D or VR. The deployment of the non-VR serious game should be done in such a way that anyone with hardware and an internet connection can play it.

The user should be able to create both exterior and interior 3D environments. Buildings, nature and non-playable characters (NPC) can be placed in the exterior environment. The player would be able to explore the 3D environment. If the environment is indoor, the user can define rooms with doors on a floor and place objects in them with NPCs. The user could decide to either give the players the freedom to walk around the environments or the user could decide that the players should be on-rails. On-rails means that the players will only be able to experience the gameplay as the user has designed it to guide the players sequentially from start to finish. The user can also decide what kind of movement options are available. Since modern console games are played with a controller, Unreal Engine already has this functionality built in. But there is also the issue of accessibility. Users can select the controls to be used with a controller to manually choose the direction in which a character can move. They can also select the option where there is a list of points of interest and the player can select one by mouse click or touch (if on mobile) and the character will automatically move to the selected point of interest. The last option is very necessary not only to include players with disabilities, but also people in general who have never played a game before. Or those for whom controlling a character with a modern controller or WASD keys is too difficult.

When it comes to interaction, the player can walk up to an NPC and start talking to them. While talking to an NPC, the player will have choosable dialogues that will trigger different dialogues depending on the choice. NPCs can also give the player quests to complete in order to advance in the game. If necessary, the NPCs can also accompany the player to the place where they can start, continue, or finish their quest. The world can also contain interactive objects that can be pushed, pulled, triggered, or placed in the player's backpack. The user can interact with these elements to create an immersive experience for the player.

If not decided before, the user can convert his game into a Virtual Reality (VR) game for more immersion at any time during the production phase or even afterwards. The VR version will get rid of the controls for the game controller to navigate, as motion sickness is one of the big problems

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that could occur and a lot of tinkering with the settings is needed to solve it. UEmbed will include the jump navigation for the VR version. If the player has a VR controller in one hand, he can move it around and it will show a point on the ground in that direction where he can jump to in the game by clicking a button. This is not possible unless the controller is pointed at an object or NPC. The player can point and click on an object to interact with it, or the same action can trigger a conversation with the NPC. For some players with disabilities, jump navigation can be a problem. Therefore, we will take the same approach as the non-VR version and implement a clickable menu with all points of interest listed. This way the player can select the point of interest and jump directly to it.

For our part of the project, which is programming the authoring tool and preparing the Unreal project, the authoring tool will be done as a web application. This method of delivery also allows those with accessibility issues to use this tool with assistive technologies such as NVDA.

B. Technical

The result of this work should be something that is indistinguishable from the work of someone who would develop a game natively with a game engine, or even better in some cases. The products developed with this project should be able to be showcased and released to the intended audience. We also need to make sure that the exported games can be played by anyone, despite their hardware limitations.

When the decision came to choose the game engine, we looked at the most popular game engines Unity and Unreal Engine according to steamdb, a website that detects technologies used in games [8]. This site goes through each of the games available on the digital game store called Steam [9] and lists all the software used to develop them. Any search for the most popular game engines will always show these two at the top of the list. We made sure to include only those engines that were available for free, so that access to the engine could be guaranteed.

Godot was also on the list to look at. While it is lightweight and good for smaller projects, it is unfortunately not as feature rich as Unity or Unreal. A more feature-heavy approach was needed for this project, and Godot is still a new engine in development.

The basic functionalities required by Unity and Unreal are similar, but there was only one element that argued more strongly for the Unreal engine. It was the availability of usable 3D assets, which Unreal Engine provides with Quixel Megascans. These assets (3D models of building walls, trees, people, textures, etc.) can always be implemented in projects for free only when used with the Unreal Engine, which takes care of collecting quality assets with distributable licenses. This gave us more time to focus on the development side.

One question that came up was: Is the process we are following necessary? The mere existence of templates, which are pre-programmed settings, code and workflows, would seem to make the idea obsolete. Sure, there are plenty of templates available on the Unreal Marketplace (a store for developers to buy and sell assets or templates), but all the predetermined workflows for a specific game genre make them not very flexible to use. The big problem with these templates, as useful as they may be, is the necessity to have a decent understanding of the Unreal Engine workflow to make even the smallest changes to the template, let alone completely modify it according to the user's plans. This brings back all the problems of time, knowledge and budget.

The pain point that should be addressed with this approach: Having a system based on known elements that users can easily interact with. This would require splitting the project into two separate software entities: The Unreal Engine project, with all the functionality implemented in advance, and a browser-based application that the user interacts with to plan and design the game. These two systems will communicate with each other using Json and Ini files.

The core aspect of immersion is to infuse design and technology. Players are placed in a realistic 3D environment where they interact with NPCs. To increase immersion, the interaction between the non-playable characters and the player should be as close to real life as the game can simulate. Therefore, Unreal Engine's Metahuman technology was used for these characters. Metahumans are pre-configured lifelike digital avatars that are ready to use with the Unreal Engine. The user can go to their website and create their own avatars, import them into the Unreal Engine and implement them into the environment with animations. Since this process is very time consuming and difficult for users, we would provide some pre-configured metahumans for users to implement immediately. These characters also have the pre-configurations for lip-syncing. Their dialogues will be displayed as subtitles. If the dialog is recorded beforehand and the voice recordings are added in the authoring tool, they can be heard by these characters with basic lip-syncing. This will give the player the feeling of a natural conversation.

Unreal Engine also provides a set of 3D assets with its Quixel Megascans that can be used free of charge. Each asset on this platform is a 3D scan of a real object and is of very high quality. Using assets from this platform results in UEmbed having graphical fidelity on par with modern video games. In addition, Unreal Engine 5.1 has the Nanite functionality, which can render very high quality assets without much impact on performance compared to previous rendering methods.

However, the existing hardware must be taken into consideration. Not everyone will have the latest hardware to play the developed serious game. The assets used by Metahuman or Quixel can all be scaled down via in-game settings, so that the game can also run on low spec hardware. But since even the lowest spec hardware can bring a lot of problems, a solution has to be found so that everyone can enjoy the game without any problems. One solution is the pixel streaming of the Unreal Engine. When the game is ready, it can be placed on a Pixel Streaming server. Whenever someone wants to play a serious game, all they have to do is open their browser, enter the website, and the game can be played right there on their mobile or PC without any graphical downgrading. The game is running on the server, taking input from the device, sending it back, and calculating the new frames to display on the device. Since this happens in milliseconds, the player will

Figure 2. Top: Map created in browser-based authoring tool that exports Json. Bottom: Environment automatically recreated in Unreal Engine 5.1 after importing this Json file.

hardly notice anything. On the server side, an instance of the game is started for each player accessing the site. Therefore, it is recommended to limit the access to keep the budget low.

The collaborative development aspect is also something this project strives for. As resources for development in general is something everyone struggles with, it becomes a necessity that we try to incorporate any further development done with this project. Therefore, this project will be available as an open source GitHub project to the extent of our development work, as Unreal Engine is owned by Epic Games and needs to be kept separate. The goal is for everyone to pitch in to help this project move forward and reap the benefits.

It is imaginable that in addition to developing serious games with the authoring tool in this project, other professionals from technical departments will use the underlying scripts and functionalities to develop their own work. This collaboration will benefit everyone involved, from the users to the players. An overview of this idea is shown in Figure 1.

V. Workflow of UEmbed

For the first phase, the user must first download and install the latest version of the Unreal Engine (which is 5.1 at the time of this writing). Then download and extract the UEmbed zip file. This will contain a UEmbed Project folder and a UEmbed App folder.

The user should open the app and two options will be available: either create a new project or load an existing one. If the user chooses to create a new project, a guided process will begin to set up the project properties. During this process, the user will be asked definitive questions about the game mode (first person, third person or VR), navigation style (full 3D movement or select and click to automatically walk to the goal) and graphics (realistic or stylized). An ini file containing all the information is generated and implemented in the UEmbed project folder.

The user can now start planning the game. The planning page has five sections: Maps, Characters, Dialog, Scenes and Sequences. Each of these sections contains specific elements that can be added or deleted. First, the user should create the characters by choosing the name and selecting a predefined model. Then a map should be created, where you can specify how many buildings, trees and which of the already created characters should be added. Dialogs, which will be a conversation with choices between the user and the character, can be created separately without being assigned to a character. When everything is done, the user can create a scene that contains the map and the dialogues that will be assigned to the existing characters on that map. In this way, different scenes can be created with different combinations of maps, characters, and dialog.

All this can be brought together in the Sequence section. All created scenes can now be added in the desired order. Placeholder scenes can be placed between the added scenes so that any custom gameplay, such as mini-games, can be manually developed there.

When everything is ready, the user can click Export and each of the sections will save its elements as individual Json files in their respective folders. All the json files will have their associations to each other included via IDs. The next step would be to open the Unreal Engine project. The user can follow the documentation provided to locate each of the visual scripts for maps, characters, dialog, scenes, and sequences needed to build the world, and click on their Re-Import buttons to import the previously created Json files. Now the user can play the game and see his plans visualized. Once everything is in place, the game can be built and distributed. The example of map creation is shown in Figure 2.

Changes to the game will always be needed during the production phase. Therefore, the user can load the previously created project, make changes to it, and rebuild the game using the same process mentioned above.

VI. Conclusion and Future Work

The growing demand for Serious Games leads those working in education to look for ways to participate in this field. However, the lack of technical knowledge hinders them to communicate their approach in the context of serious games. Of course, they could start by learning game development, but in practice it is a daunting task to start even with coding skills, as each engine is filled with a large set of functionalities. Also, hiring employees or even external help is limited by limited financial resources. Therefore, with this proof of concept, we are on our way to democratize the whole process of serious game development. An authoring tool that will give access to everyone who wants to present their stories in a 3D space with modern graphical fidelity.

Further work is needed in this project on the user interface (UI) and user experience (UX). It needs to be ensured that users can work with an authoring tool that is easy to understand. The immersion can also be deepened if the NPCs used here could be imbued with character AI that has certain specific knowledge and associations with other NPCs. For a more natural conversation, the NPCs could be talked to via speech recognition, with the results of the speech-to-text being fed to their internal chatbot-like AI, which will then respond to you via text-to-speech. An automated lip-sync process will help sell the immersion more.

Targeting the right hardware should also be a focus, as there are so many configurations already out there. If needed, there could be different sets of preconfigured UEmbed projects for different hardware, for example a UEmbed project just for virtual reality. This wouldn't change the authoring tool, but it would give users a faster starting point instead of having to deal with configurations themselves.

A thought process from a game design perspective will be helpful to think of use cases that are commonly used. Implementing more of them will help the community as a whole, and it will also attract more interest. If the community pulls it all together and expands this project on its own merits, it will not only expand the feature set, it will also expand the boundaries of serious games much more.

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Making Smart Phones Accessible to Braille Users

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***Abstract* — Smartphones are an important tool in modern life, but they are primarily a visual medium. This poses an accessibility problem for the blind and vision-impaired in interacting with the internet-connected world. The ultimate goal of this research is to create a small, lower-cost braille-type screen reader and display for use with smartphones. The device would use a 6x6 grid of piezoelectrically actuated pins being controlled by an application on the phone. Not just text, but images from the phone can be represented on the device. By producing an affordable touch-based screen reader that can also display images from the screen, smartphone accessibility could be improved for those with vision impairments, which ties into the conference theme of smart accessibility.**

Keywords-braille; haptic; smartphone; accessibility.

I. Introduction

Smartphones have become ubiquitous tools in everyday life. These devices, however, are primarily a visual medium, presenting a challenge for those who are blind or sight-impaired. While electronic braille screen-reading devices exist on the market, they are designed to display text and can be cost-prohibitive at over $500 [1]. The goal of this research is to develop such a device for smartphone use that would be more affordable and display images as well. The device will consist of a smartphone app that connects to a microcontroller to actuate a 6x6 grid of piezoelectrically actuated pins.

Braille and haptic displays have shown themselves to provide great benefit to blind people. Many devices have been developed and tested to help visually impaired people navigate the world independently, such as in the case of Amemiya [4] where the research demonstrates its use within the deaf and blind communities of Japan as a portable wayfinding device. In this case the importance of portability is demonstrated as it pertains to the usability of braille devices in everyday life. Beyond portability it demonstrates the ability for those without sight to use touch as a viable way to interpret the world around them. It is with the understanding of other contributions within the haptics realm that we intend to focus on the user within our research.

Work on this research was started as part of an unpublished master's thesis by Jason Blood at Weber State University and continued by Professor Dhanya Nair [2]. This research was eventually passed on to our team. At the time we received the project, an Android app had been developed which connects to a USB development board (Microchip Technology dsPIC33E); this app would take a screenshot of a portion of the phone's screen, convert it to a bitmap, and send it to the dev board over a USB connection. This setup is shown in Figure 1.

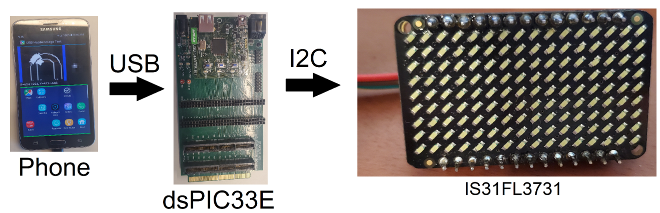

Figure 1. Initial electronics design

This dev board would display the image on a mono-color LED array (Adafruit IS31FL3731) controlled through an I2C (Inter-Integrated Circuit) connection to stand in for the pin array for initial testing. This setup had two problems. First, the dsPIC33E was an older design, and, for its feature set, was more costly and cumbersome than more recent microcontrollers. Second, the board's I2C connection was unreliable, leading to only portions of the LED array being updated at times.

In Section 2, we will describe our current progress on improving and updating the electronic hardware for the device and its accompanying application. In Section 3, we will describe the progress on designing the pin grid to eventually replace the LED array. In Section 4, we will conclude and describe our next future steps on this work.

II. Electronics and Android Application Progress

In order to solve the problems involving the microcontroller with the design we received, we have been working to replace the dsPIC33E with an ESP32. The ESP32 is a more recent microcontroller with extensive support available and a much lower cost (approximately 1/12 the cost to us). In addition, the ESP32 supports a Bluetooth connection. This would allow the device not to need to be physically tethered to the phone. Further,

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Bluetooth connections are easier to develop on the app side due to the API and smartphone support being geared more toward Bluetooth peripherals than USB peripherals. This new design is shown in Figure 2.

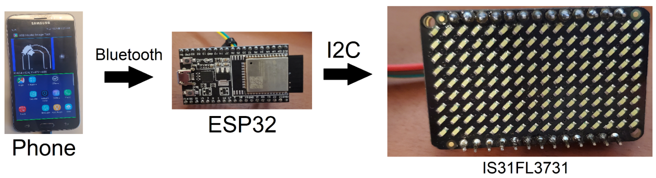

Figure 2. New electronics design

At this time, the app has not been updated to the new design, but using a basic Bluetooth terminal emulator, we are able to send images over Bluetooth to the device to display an image now reliably. Our immediate next step for this would be to update the application to communicate with the new microcontroller.

III. Pin Grid Design Progress and Methodology

To ensure this design's viability in the real world, we are looking to conduct tests using samples and interview schools for the blind to ensure that the implementation of our haptic system fulfills the needs of the blind. The first question we need to answer for this is whether the spacing of the pins is comfortable to read. To test this, we have 3D-printed example 6x6 matrices with different designs and different spacings using measurements from braille standards to stay within the usual parameters followed in everyday braille characters [3]. For these measurements specifically, we are investigating the maximum and minimum values presented in the given ranges, as the difference in millimeters is already small. By 3D printing the models, we can accurately present braille, as seen in Figure 3, and present a final outline of a design without having the design completely present.

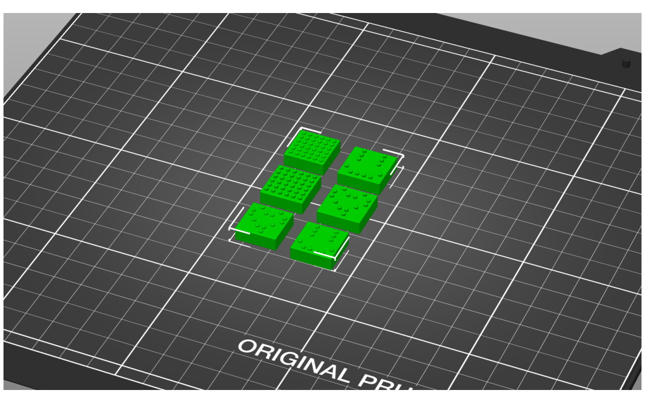

Figure 3. Models of braille matrix designs for testing in the PrusaSlicer software.

This allows a proof of concept and an opportunity for revision before the design is created to ensure minimal problems. Second, it is important to take into account the user in such a design, as without understanding its flaws, we can not offer the best solution. To solve this problem, we plan to gather suggestions on how to make this haptic system work most to their benefit. This will make sure that our design fits the best with the lives of those it is looking to help.

IV. Conclusion and Future Work

Given the progress outlined above, our next steps are developing the haptic board that will have actuated pins and be 3D printed to the specifications determined through the discussion with the blind. This will replace the LED matrix itself but utilize its driver board, which should provide the control signals for actuating the pins in the new matrix. Further testing would also be necessary to ensure its functionality and reliability. Testing with this finished device by blind or visually impaired people will be necessary to test if the device provides greater accessibility to smartphones through displaying images on a portable pin grid.

Acknowledgment

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Developing a Sustainable and Transferable Visitor Information System 2.0 with the Internet of Things - A Prototype

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***Abstract*— In response to the COVID-19 pandemic, there is a growing need for accurate information about the real-time flow of visitors in public buildings, such as schools or university campuses. Conventional monitoring methods, including entrance checks and wide-area cameras, face challenges in terms of technical complexity, public acceptance, and privacy concerns. This paper proposes an alternative solution based on Internet of Things (IoT) sensors to establish a visitor information system. The system leverages the concepts of smart city and smart campus design to create a more intelligent, connected environment. The system uses smartphones, wearable devices, and low-cost sensors to collect and transmit data packets via Wi-Fi or Bluetooth. The received Signal Strength Indicator (RSSI) is used to draw conclusions about the distance between the transmitter and receiver, enabling the system to locate visitors. Thus, this paper reflects the growing use of assistive applications in IoT scenarios in terms of spatial orientation systems, as well as for smart management systems.**

Keywords-IoT-based solution; smart campus; visitor information system; low-cost sensors; real-time information

I. Introduction

Information about real-time visitors and circulation in public buildings, such as administrative or school buildings, has become increasingly important since the COVID19 pandemic. However, especially for those premises that are larger, monitoring by controlling visitors at building entrances is insufficient to obtain reliable information on how visitors are allocated. Implementation by area-wide cameras is not considered to be effective, not only because of the high technical effort involved, but also due to acceptance problems and possible infringements of personal rights.

The presented approach for a visitor information system is different, as it is based on the use of connected IoT (Internet of Things) sensors. It incorporates concepts of smart city and smart campus design.

Urbanization has resulted in large populations gathering in metropolitan areas, requiring a smart management solution for issues, such as traffic, pollution, energy, waste, and security. In this sense, a campus can be considered a miniature version of a smart city. In terms of integrating technology and communication, this brings both new opportunities, as well as challenges [1].

In order to provide fine-grained, but privacy-compliant position data for a visitor information system, not only established devices, such as smartphones or tablets are used, but also the growing number of so-called "wearables" (e.g., smartwatches, fitness bracelets, bluetooth headphones). These devices are capable of communicating with one-another and exchanging information through standardized information technologies, often generating an enormous but unused amount of data.

Before the components of the prototype are outlined in Section III, the following Section II introduces into sensors used. Section IV explains the web-dashboard in which the collected data is brought together. The paper ends in Section V with a conclusion and an outlook regarding future potentials.

II. Using Sensors to Capture Individuals

Various methods exist for measuring the number of individuals at a specific point in a building (e.g., entrance), room, or area (e.g., hallway). Wahl, Milenkovic, Amft [2], and Tsou et al. [3] used Passive Infrared Light (PIR) sensors and motion detectors, respectively, to count people and detect visitor flows in buildings. However, if there is not a sufficient number of motion sensors, this method will not provide reliable results for estimating on how many visitors are present.

The smartphones and wearables mentioned above, by contrast, communicate via Bluetooth or Wi-Fi to each other or to available Wi-Fi access points, transmitting data packets to the area around them. Conversely, these data packets can also be used to capture people in close proximity. The received Signal Strength Indicator (RSSI) is an essential factor in detecting communication with devices nearby. Narvaez and Guerra [4], for example, have already shown that this can be used in order to maintain safety distances. The RSSI enables conclusions to be drawn about the distance between the transmitter and receiver. In combination, Bluetooth and Wi-Fi can also be used to locate people [5][6][7].

Single-Board Computers (SBCs) equipped with low-cost sensors can be utilized to collect these data packets. In this case, a Raspberry Pi 4 Model B with 8 GB RAM is used as the SBC. The sensors include Wireless Local Area Network (Wi-Fi) and Bluetooth (BLE) modules, and a PIR motion detector and a second Wi-Fi adapter. One Wi-Fi adapter is required for communication with the data link layer, while the second adapter is set into monitor mode. The sensor

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setup also takes into account information from the indoor Wi-Fi or its controller interface.

III. PROTOTYPE OF THE VISITOR INFORMATION SYSTEM

The prototype was developed at Mainz University of Applied Science and consists of three components in its basic design: Client, Web Service(s) and Sensors. The detailed structure – see Figure 1 - with its individual components is shown below. The sensors used are either the SBCs outlined above or the controller interface of the indoor Wi-Fi network, which provides information about connected and logged-in devices per access point. A total of just over 180 indoor and outdoor access points are available at Mainz University of Applied Sciences with its two campuses and one external building.

Data management and storage of the values collected is handled via the Open Geospatial Consortium SensorThings API *(*OGC SensorThings API) [8]. The implementation of this standard is based on the Fraunhofer Open Source SensorThings API Server (FROST), which is freely available from the Fraunhofer IOSB. The background maps of the buildings, floors or rooms required in the web dashboard are integrated according to the OGC Web Map Service [9] and OGC Web Feature Service specifications [10]. The publicly available GeoServer of the non-profit Open Source Geospatial Foundation organization (OSGeo) is used for implementation. The geodata originates from the OpenStreetMap project (OSM) and was extended by the university's own floor plans.

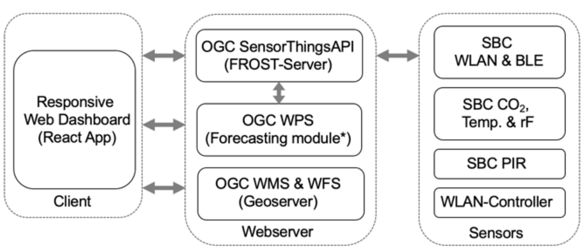

Figure 1. Architecture of the visitor information system.

Furthermore, the information system is designed in order to generate the necessary knowledge on the basis of the differently collected measured values in an effort to be able to determine future projections on visitor numbers and allocation, as well as movement flows. This will be realized in a forecasting module - see Figure 1 - which has not yet been finalized. It is planned to implement a process via the OGC Web Processing specification [11], which recognizes patterns from the input data by applying machine learning methods in order to draw conclusions from the actual to its future utilization of a building's capacity. This allows a smart building and visitor monitoring to be carried out.

IV. WEB-DASHBOARD

The data collected from the sensors and analysis results are combined in a web dashboard – see Figure 2 - for users (e.g., university management or students orienting themselves in the building).

Figure 2. Web-Dashboard of the visitor information system.

Unlike existing systems, not only static but also real-time information for one or more buildings can be displayed. In addition to the number of people present in the buildings (or floors or rooms), the visualization of flows or hot spots is an alternative. Visitors can thus call up information about building or room occupancy in advance or, if necessary, be automatically notified if the maximum number of people is exceeded, as long as there is an integration into the existing systems.

V. CONCLUSION

To ensure the sustainability of the presented prototype in terms of technology, the implementation was carried out using open source software, open data and open standards and data formats. This has resulted in a modular and open-source spatial orientation system for the use case of a visitor information system that can be widely shared and customized by other universities, small and medium-sized enterprises, and public institutions. Thus, a technological transferability is made rather easy to achieve. By adding low-cost sensors, the system could be supplemented with further metrics, such as air quality or temperature. For example, this allows the monitoring of hygiene concepts, but also provides relevant information for other issues.

Additionally, the implementation outlined here is intended to contribute to the discussion of subcomponents of a smart campus in terms of the expected multiplication of sensors, devices, and terminals. Considering future developments, it is possible to argue that the ability to combine smart technologies with physical infrastructures to improve services, decision-making, and efficiency of public buildings is an emerging trend [12].

A concrete extension would be, for example, the use of modern machine learning techniques based on the various sensor inputs as part of the aforementioned forecasting module. This can be used to predict future room occupancy in order to support the management of visitor flows and reservations. Roussel et al. shows that especially the use of multiple sensor sources - as also proposed in this publication - is promising for these use cases [13].

In this context, the transition to an a more integrated digital building or a smart campus will rely significantly on Information and Communication Technology (ICT) and IoT infrastructures.

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Inclusive and Accessible Homes for Older People: The Preparation of Guidelines for Home Design

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***Abstract*— The target of this research is to create an inclusive living environment in urban houses for Indian older people through guidelines for home design. Along with the study of associated problems of older people and international concepts, an extensive literature review has been performed to understand the theoretical and methodological foundations. Preliminary diagnostic surveys are performed to study and establish the need for the creation of inclusive living environments for Indian older people for the built environment design. Field surveys were conducted to identify the challenges/ issues that older people face in the 'Activities of Daily Living' (ADLs). The surveys are performed for the upcoming urban housing typologies in India. The upcoming typologies were identified through the scientific layering of the data with a market survey. Older people in the existing urban housing typologies and in the age group of 60 to 85 years, independent elderly, frail elderly, and dependent elderly were studied using environment-behavior study tools. The data collected from interview questionnaires, audio, trace-study, and photographs, were analyzed to identify environmental issues. Analysis and synthesis are done based on these issues to identify the possibilities of interventions for the built environment in housing. It has been established through validation and testing that the gap to create inclusive living environments for Indian older people can be filled by guidelines for home design. Thus, a methodology to develop the guidelines to create 'Inclusive and Accessible Homes for the Indian Older People' is prepared. With help of these guidelines 'Inclusive and Accessible Homes' in urban residences can be designed for Indian older people.**

Keywords- Older people; Inclusive and Accessible Homes; Environment-behavior Research Tools; Guidelines

I. INTRODUCTION

In India, the increased life expectancy, decreased mortality rate, and increased birth rate, are resulting in an increasing older people population. Longevity by itself is to be celebrated, but increasing vulnerabilities of older people arising out of income insecurity, poverty, rural living, illiteracy, dependency, age-related morbidity, and decreasing support base require attention [1]-[4].

The physical environment, as it relates to the dependencies of older people, remains one of the most overlooked areas in the built-environment design. The people who are responsible for planning that environment must develop a new understanding of ways in which their influence can improve older people's physical and mental functioning [3][4].

The paper has been structured to give the background of the study in section A. The aim of the study and the objectives has been stated in section B and C. In section II, the complete methodology followed for the conduct of the field survey, identifying the issues from the transcriptions of the interviews, and the coding of statements to identify the issues has been detailed. It further explains the methods adopted to achieve the guidelines for home design, for older people. The paper concludes by stating that 'Inclusive and Accessible Homes' for Indian older people can be created following these developed guidelines.

II. BACKGROUND

As people age, certain sensory changes cause them to perceive and respond to the physical environment in different ways: a person may move more deliberately, hold reading material farther from their eyes, walk more slowly, or strain to distinguish a voice in the crowd. The person becomes more dependent on the environment for support as limitations in functioning are experienced, [3] [4]. As the sensory organs incur deprivation, strength fails, and the individual experiencing these losses reaches out to both the physical environment and the general social environment in order to continue functioning [5]. Sensory changes are usually compounded by the simultaneous occurrence of changes in several sensory systems, and it increases as people grow older. However, the rate of decline for these functions differs markedly within the various sensory systems [4][6].

The Indian situations, with the huge size of the country, diversity of political, economic, social, and cultural background, and wide variety of people with different religions, cast, etc. are very complex. [4][7]. The Indian situations are very different from the Western world because of the characteristically interdependent social scenarios, severely different demographics, religious and traditional systems, a culturally different society, a wide range of economic disparity, and beliefs [8].

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The paradigm change in the model of disability from the linear model to a model which emphasizes the role of the environment to reduce or enhance the individuals' ability to perform, specifies the role of designers, architects, and planners because it is their creation of built-environment, which makes them struggle or let them use it comfortably [4].

The aim of the research is to understand the situations of Indian older people and to generate design guidelines, that when followed will create, 'Inclusive and Accessible Homes' for the Indian older people.

The objectives of the study are:

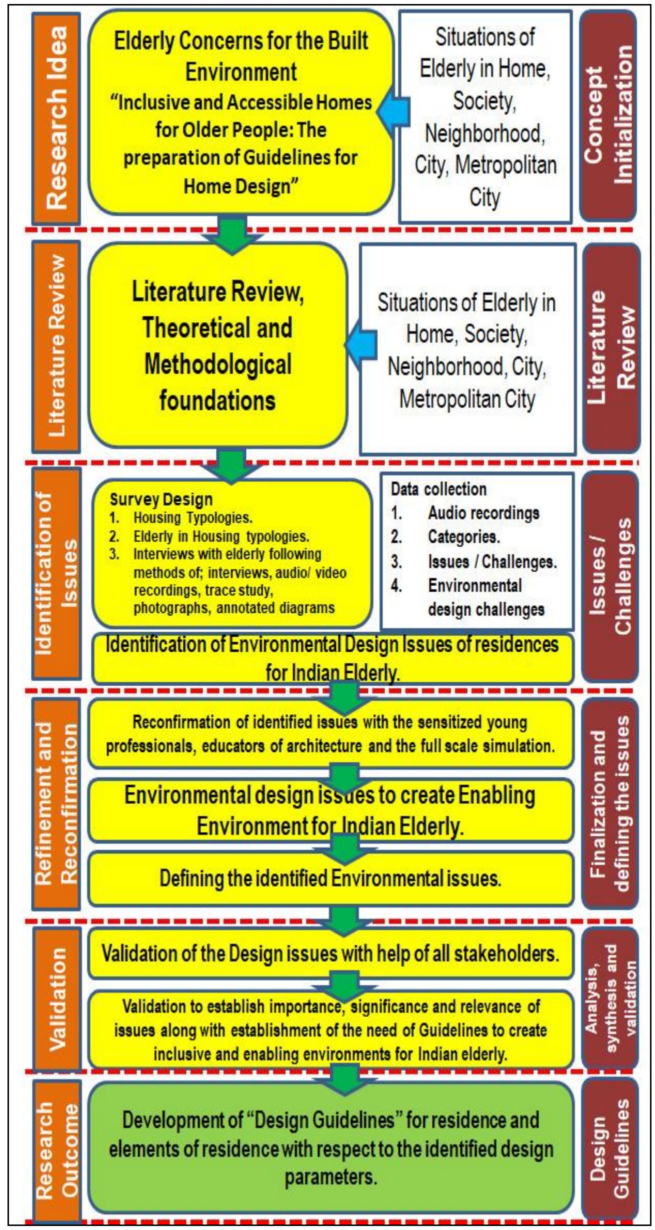
- To study and understand Indian older people, their residences, and residential neighborhood environment.
- To study the 'Activities of Daily Living' of Indian older people in their residential environment.
- To conduct a field survey to identify the issues, based on the 'Activities of Daily Living', which the Indian older people face while interacting with their residential environment.
- Based on the identified issues, and the elements of residence, develop guidelines for the creation of an 'Inclusive and Accessible Homes' with the help of identified and validated list of enabling environmental issues for Indian older people.

III. Methodology

The study investigates the problems and issues, Indian older people face with their built environment and attempts to identify the issues to enumerate, analyze and synthesize them, to develop a set of guidelines, to create inclusive, and accessible homes for Indian older people [4]. Refer the methodology diagram as shown in Figure 1.

Initially, preliminary diagnostic surveys are done to study and establish the need for the creation of inclusive and accessible homes for Indian older people. Then a field survey is performed to identify the challenges that older people face in their 'Activities of Daily Living' (ADLs) in the Indian context. The survey is done for the upcoming urban housing typologies in India. These upcoming typologies are identified with market surveys and scientific layering of the data. Then older people in the age group of 60 to 85 years representing independent older people, frail older people, and dependent older people are studied using environment-behavior research tools, living in joint and nuclear families, in identified urban housing typologies [4]. The collected data from interview questionnaires, audio recordings of interviews, trace-study, and study of photographs, is analyzed in layers to identify twenty environmental issues. Based on these identified issues, analysis and synthesis are done to identify the possibilities of interventions at the architecture design level for the built environment in housing. It has been established through testing and validation that the gap can be filled by guidelines to create, Inclusive and Accessible Homes for Indian older people [4].

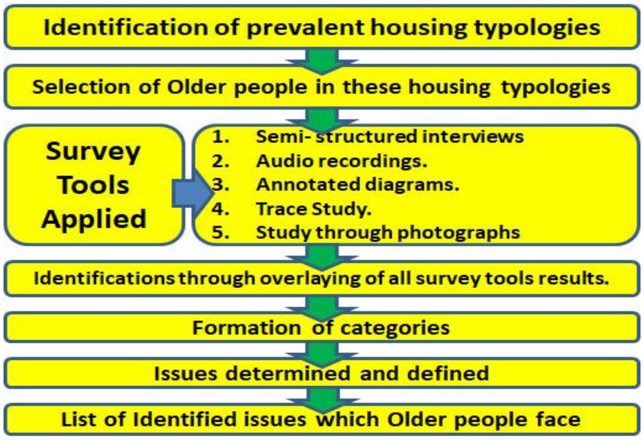
Thus, a methodology to develop the guidelines has been prepared. Following the developed guidelines, inclusive and accessible homes in urban residences can be designed for Indian older people [4].



"Figure 1. The Methodology"

A. *The Field Survey*

The field survey was conducted to identify the challenges/ issues Indian older people face in the residential environment, using multiple environmental-behavior tools as shown in Figure 2 [10][13]. The focus of this survey was to understand the situations of Indian older people in their residential environment. And it aimed to identify the issues that older people face in their 'Activities of Daily Living'. Based on these identifications a comprehensive list of issues for the challenges that older people face was identified [4].



"Figure 2. The Field Survey"

B. Housing Typologies and Selection of Older People

The prevalent upcoming typologies are identified with a market survey of the new housings in the city of Bhopal, India. A system of scientific layering of the data was adopted to identify the prevalent newer housing typologies. The overlapping of various floor plans of apartments, row houses, single houses, detached and semi-detached houses was done to select the sample of housing typologies [4].

Older people residing in these housing typologies were identified based on age and type of family settings. Total 48 elderly were selected as sample. Table I shows the sample of older people as per the age groups and distribution in the housing typologies. The sample of these 48 older people was then interviewed for the identification of issues based on their 'Activities of Daily Living'. Out of these 48 samples, in 7 cases the answers and the interview talk seemed to be biased because of the influence and presence of the other family members or due to non-interest or being in hurry due to some other work, etc. These cases of biased opinion were not considered for the analysis and removed from the list of samples. This resulted in the sample size of 41 older people of which 34 were from the newer housing typologies and 7 were from the existing old age homes. The interview started appearing repetitive after almost 30 interviews. Therefore, the overall number of older people interviewed has not increased beyond a total number of 48 samples.

TABLE I THE OLDER PEOPLE IN HOUSING TYPOLOGY

S.no	Age Group	Elderly (nos)	Elderly Living in Row House (nos)	Elderly Living in Apartment (nos)	Elderly Living in Individual houses (Detached or semi detached) (nos)	Elderly Living in Old Age Home (nos)
1	60-65	13	5	6	2	-
2	65-70	8	3	2	2	1
3	70-75	10	2	4	3	1
4	75-80	9	2	2	2	3
5	80-85	6	2	2	-	2
6	85-above	2	-	2	-	-
	Total	48	14	18	9	7

C. Research Tools

The field survey was an attempt to collect qualitative data by understanding the 'Activities of Daily Living' of Indian older people. Multiple layering of the below-mentioned tools was applied for the collection of data [4].

- Interviews with a semi-structured questionnaires.
- Audio recordings of the interviews.
- Annotated diagrams.
- Trace study.
- Photographs and observations.

D. Semi-structured Interviews

The interviews aimed to identify 'Activities of Daily Living' to understand the complete daily routine of older people. It is focused to identify the activities in terms of early morning activities, using the toilet, bowel/ bladder control, oral hygiene, grooming, pooja (prayer), dressing, cooking, meal planning, eating, mobility inside the residence, using stairs, mobility outside the residence, daily job/ work, driving, household chores, doing laundry, using phone, money management, managing own medications, etc. in detail [4].

E. Audio Recordings

The audio of each interview is transcribed to identify the statements. From these statements of the samples, the categories were derived and then from these categories, the built environment design issues have been identified and ascertained as shown in Table II.

TABLE II. IDENTIFICATION OF ISSUES OLDER PEOPLE FACE

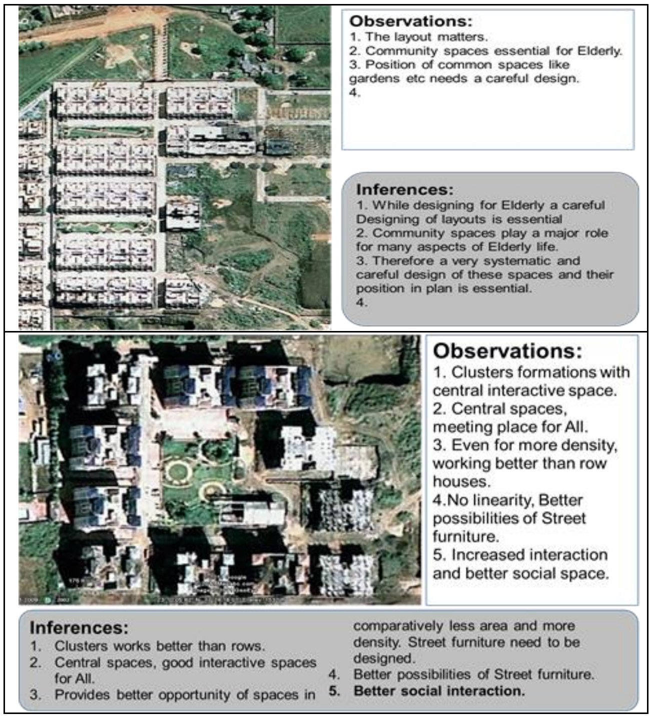
S. No.	Category	Environ mental issue	Definition of Environmental issue
1.	Indoor areas: • Safety from falls. • Non-slippery floors. • Uneven, unstable Surfaces. • Safety from projections and protruding objects. • Wet areas in the toilet. • Holding toilet accessories for support. • Safety while climbing stairs. • Safety while working in the kitchen. • Safety from burns. • Safety within home. Out doors: • Safety from uneven, unstable surfaces. • No walking space on roads. • Safety from vehicles while waking. • Fear of fall.	**Safety**	"Need for providing safety in the residential indoor and outdoor areas while using all elements of residence, specially kitchen, toilet, stairs, ramps, etc. along with outdoor areas in terms of their use to improve the physical environment with design and appropriate use of material."

F. Annotated Diagrams

After each interview, rough annotated diagrams were prepared to understand the pattern of spatial usage. Findings from these documented diagrams are then analyzed to understand the issues faced by older people [4].

G. Environmental Observations and Trace- Study

The environment of older people is also analyzed through environmental observation and trace study to further identify the challenges as shown in Figure 3.



"Figure 3. Environmental Observations"

H. Method of Identification of Issues

The identified issues through all tools are then overlaid to formulate a common list of issues faced by older people. Every issue is rated for its level of importance and the Table III below lists these issues in random order.

TABLE III. IDENTIFIED ENVIRONMENTAL ISSUES

Identified environmental issues			
1	Safety	11	Socio-cultural disconnect
2	Environmental Support for mobility, balance, and slow movement	12	Affordability
3	Environmental support for better vision	13	Leisure and recreation
4	Environmental support for better hearing	14	Security
5	Light Ventilation	15	Live with nature
6	Health	16	Spiritual connect
7	Memory	17	Technology Disconnect
8	Privacy and Personalization	18	Usable
9	Degree of Independence	19	Emotional comfort
10	Interdependence	20	Loneliness

IV. DEVELOPMENT OF GUIDELINES

The methodology followed to develop the guidelines investigates each element of residence for its design to be inclusive for older people with respect to the identified enabling environmental design issues.

A systematic sequential process has been followed to achieve the enabling environmental design guidelines for the residences. All the identified enabling environmental issues were considered to generate guidelines for each element of residence design. Combining all the guidelines generated with respect to each element gave the final guidelines for the whole residence. Figure 4 below defines the pattern of development of guidelines.

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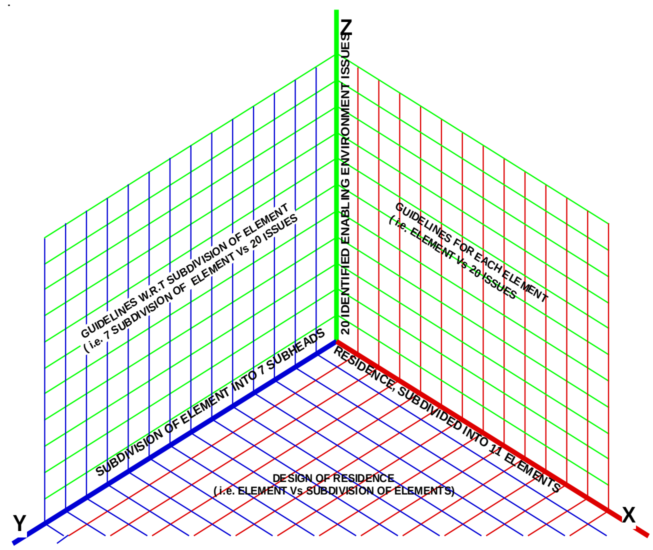

"Figure 4. Pattern of the Development of Guidelines"

The pattern of development of guidelines is a simultaneous considerations of three major components namely;

- The Residence, subdivided into 11 elements.
- The subdivision of the element into 7 subheads.
- The twenty identified enabling environmental issues.

A. The Residence, subdivided into 11 elements

The Residence is subdivided into 11 elements (the elements of residence) taken along the X axis as shown in Figure 4 and listed in Table IV. The elements of the residence are the various spaces of a residence. The residences under consideration are the urban residences having typologies of;

- Detached and semi-detached houses
- Row Houses
- Apartments
- Bungalows.

These typologies are the upcoming, prevalent housing typologies identified for the urban areas. The common elements of all the above-mentioned typologies are listed below in Table IV.

TABLE IV. LIST OF ELEMENTS OF RESIDENCE

Elements of Residence			
1	Entrance and Porch	7	Bath rooms
2	Garden	8	Balconies and Terraces
3	Verandah/ Lobby	9	Stairs
4	Drawing room Living room and Dining room	10	Ramps
5	Kitchen	11	Lifts
6	Bedroom		

B. The subdivision of seven elements into 7 subheads

The subdivision of the element into 7 subheads is seen with respect to the design of the element as the major component and under design the subheads are;

- Furniture,
- Circulation,
- Openings
- Surfaces
- Light and ventilation
- Miscellaneous
- Material characteristics,

These 7 subheads are shown along the Y-axis in Figure 4. For this the major components of an element of residence are considered with respect to ***Design****:* The design of the elements of the residence. The design is the main head and its 7 subdivisions considered are:

- ***Furniture:*** The furniture of the elements of the residence and all accessories of the spaces such as; furniture, street furniture, lamp posts, post boxes, etc. in case of outdoor spaces, and carpets, scatter rugs, sculpture painting, and products, etc. in case of indoor spaces.
- ***Circulation****:* The circulation space of the residence and its element with clearances.
- ***Openings:*** All the openings in the form of doors, windows, and ventilators in the indoor areas, and entries, gates, etc. in the outdoor areas.
- ***Surfaces:*** All surfaces of the elements of residence, the ground, vertical, and ceiling surfaces.
- ***Light and ventilation****:* The provision of light and ventilation in the whole residence and its elements, whether it is natural or artificial.
- ***Miscellaneous:*** Anything not covered in the above-stated components of the residence design or need to be highlighted as an important guideline.
- ***Material characteristics:*** The characteristic features of the material required for residence and its element.

C. The Twenty Identified Enabling Environmental Issues

The twenty identified enabling environmental issues taken along the Z axis are listed in Figure 4. Below mentioned is the list of identified enabling environmental issues. The guidelines were developed considering each of these issues.

TABLE V. LIST OF IDENTIFIED ENABLING ENVIRONMENTAL ISSUES

List of Identified Enabling Environmental Issues			
1	Safety in environment	11	Environmental support for sociocultural connect
2	Environmental Support for mobility, balance, and slow movement	12	Affordable environments
3	Environmental support for better vision	13	Environment to support leisure and recreation
4	Environmental support for better hearing	14	Environment to support security
5	Light and ventilation in the environment	15	Environment to live with nature
6	Environment to support better health	16	Environment to support spiritual connect
7	Environment to support memory loss	17	Technology connect in the environment
8	Privacy and personalization in the environment	18	Usable environment
9	Degree of independence in the environment	19	Environment to provide emotional comfort
10	Environmental support for interdependence	20	Environment to address loneliness

Thus, the hierarchy followed to subdivide the residence into its components for in-depth and detailed development of guidelines is mentioned below;

TABLE VI. RESIDENCE AND ITS ELEMENTS

Residenc e	11 Elements of residence (as mentioned in table III)	7 subdivisions (as mentioned in above)

Thus, the formula for the preparation of the guideline for each element of residence is mentioned below;

Guidelines for Z = X1Y1, X1Z1, Y1Z1

Where Z = Guidelines for the elements of the residence. For example Z1 = Guideline for the element of residence, "Entrance and Porch".

The combinations along all three axes generated the guidelines as mention-below;

X1 Y1 = Residence (subdivided into 11 elements) and subdivisions of elements (i.e. 7 subdivisions)

This explains the hierarchy as, residence → 11 Elements of residence → 7 Subdivisions (i.e. Subdivision of element of residence into 7 subheads, under the main heading design).

X1 Z1 = Elements of residence and 20 identified enabling environmental issues

This will generate guidelines for each element with respect to the 20 issues.

Y1 Z1 = Subdivision of elements (i.e., 7 subdivisions under design) and 20 identified enabling environment issues

This will generate guidelines for each element (when the element is seen as a spatial subdivision into seven subheads) with respect to twenty enabling environmental issues under the main heading design.

Similarly, for all the remaining 20 enabling environmental issues, the guidelines were developed.

Following the pattern of development of guideline as explained in the methodology above the guidelines for each element of residence is developed.

Explanation of development of guidelines for elements of residence:

A systematic stepwise process is adopted for the preparation of guidelines for each element of residence design based on the above-mentioned pattern of development of guidelines.

Step 1: Sequentially, an element is selected for the preparation of guidelines from the list of the elements of the residence.

Step 2: The element is subdivided into 7 subdivisions under the main heading design.

Step 3: Guidelines with respect to each subdivision and the main heading design were developed for twenty enabling environmental issues.

This process gave the guidelines for each element of the residence design (listed in Table III) these are the separate detailed guideline for all 11 elements of the residence. (The detailed guidelines for all 11 elements of the residence with respect to twenty enabling environmental issues is not part of this paper due to a large number of pages).

D. Final Guidelines to Create Inclusive and Accessible Environment in Urban Residences for the Indian Older People

The guidelines for each element of the residence were prepared separately with respect to the twenty enabling environmental issues. Due to the reoccurrence of the spatial and material characteristics for the issues, there was a lot of repetition and overlap. To remove this overlap and repetition, the guidelines for urban residences are prepared by combining the guidelines of all elements of the residence. The development of these guidelines was based on the concept that, "with the solution of the twenty identified enabling environmental issues, inclusive living environments can be created for the older people in urban residences. Thus, following the methodology and pattern of development of guidelines, first the guidelines for each element of residence, (as listed in Table IV) is prepared. Then the separately developed guidelines for each element of residence are combined with respect to each enabling environmental issue to finalize the guidelines for the urban residences.

V. CONCLUSION

The situations of demography, a characteristically interdependent social scenario, a culturally different society, a wide range of economic disparity, religious and traditional systems, and beliefs, the Indian situations are entirely different from the other countries [14]. This research study focused on the ‘Activities of Daily Living’ of older people and investigates and identifies the issues faced by older people while using their built environment. Improvements in the built environment with respect to the needs of older people can improve the situation of Indian older people. Thus, the construction of urban residences following the developed guidelines will result in the inclusion of older people and ultimately result in ‘Inclusive and Accessible Homes for Older People in India’.

The outcome in the form of guidelines is the reference and guide for the creation of an inclusive built environment for Indian older people but, the same has opened newer avenues as mentioned below;

- The developed guidelines are qualitative, but the area has the potential to develop quantitative guidelines and developing standards specific to older people.
- The guidelines developed can be applied to the upcoming typologies of residences and followed for home modification for Indian older people.
- The identified issues and the guidelines can be collectively pursued to create smart homes for the ease and comfort of older people. The same has the potential to be the background and initiation for the design of assistive devices required in the homes of older people.
- Developing designs focused on vernacular and indigenous solutions based on these findings can be another area for future design research.

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