Virtual Reality for People with Visual Impairments in the development of Left-Right Discrimination Skills: A Systematic Mapping Study

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ABSTRACT

Integrating digital technologies, particularly Virtual Reality (VR) games, into Orientation and Mobility (OM) training has shown significant potential for enhancing the rehabilitation process for People with Visual Impairments (PVI). These technologies provide immersive and interactive experiences that foster greater autonomy and independence. In OM training, left-right discrimination helps individuals establish spatial relationships and shapes the foundation for learning more complex orientation skills. This systematic mapping study examines how VR games can be used to train left-right discrimination abilities in PVI, offering them new experiences. We reviewed 758 articles and selected 19 studies that highlight the importance of considering all types of visual impairments, involving PVI in the development process, and accounting for their existing skills when designing game interactions.

KEYWORDS

Orientation and Mobility, Virtual Reality, VR, Left-Right Discrimination, Games.

1 INTRODUCTION

According to "World Report on Vision", a publication from the World Health Organization (WHO), there are 2.2 billion people worldwide with some kind of visual impairment [50]. People with Visual Impairments (PVI) have one or more vision functions affected that could limit their interaction with the world and day-to-day activities. PVI may have difficulties determining their location in their environment, as well as the spatial relationships between themselves and people, objects, and other reference points [36]. Orientation and Mobility (OM) is a training field that focuses on enabling PVI to navigate their environment safely and independently, supporting cognitive, motor, and emotional development [33, 50], being usually recommended for people who are blind or have low vision.

Developing OM concepts with PVI enables them to use other senses and residual vision to train their spatial perception skills [40], analyzing tactile and audio cues for tasks such as navigation, route planning, and localization [58]. By training OM skills, we allow individuals to understand and interact with the world with more accuracy and confidence, as well as build a mental representation of the spaces they're in or will navigate on it [1].

One such concept is Left-Right Discrimination (LRD), which is the propensity that humans have to define a preference to use one side of the body more than the other through the development of neural, psychological, and motor skills [41]. Some activities involve the identification of body parts, learning to use the limbs as reference points, understanding how to use their smaller body parts such as fingers, and executing crossed commands (e.g. "Put your right hand on your left shoulder."). Other example is discerning left and right using their body as a reference point (egocentric) or projecting their orientation system into external references (allocentric) [16, 24, 41, 61].

Assistive technologies make it possible to improve spatial cognition through artifacts designed for activities that develop more than one spatial skill at once. Combined with technologies such as Virtual Reality (VR), it's possible to create engaging experiences that encourage the practice of OM exercises in an immersive and playful environment that is fully controllable. VR gaming can effectively substitute real-world games for cognitive tasks within a limited spatial environment, yielding comparable performance and user experience metrics in both settings [7]. It allows the player to explore new situations without the dangers present in the real world. Researchers have shown OM skills acquired can be transferred between virtual and real environments [11, 37, 58].

As such, integrating VR games for PVI in an OM practice model allows for more immersive experiences in virtual environments, provided the necessary audio and haptic cues are in place and the design combines the interactions that are exclusive to VR with existing PVI skills [53].

This work presents the results of a systematic mapping study to understand how VR games for PVI can be leveraged to develop LRD skills. The topic is relevant to WebMedia based on earlier submitted works about assistive technologies focused on PVI [12, 13, 15, 46], Virtual Reality solutions [46, 56], game development [14], and OM and LRD for People with Visual Impairments [46]. The concepts presented in this work are applicable for developing general VR multimedia solutions for PVI, which also extends to web-based VR technologies, that enhance the interaction with virtual environments.

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It's important to test things directly with the target audience, taking into account all types of visual impairments when developing solutions as they have different needs and can even require special attention to certain aspects (e.g. visuals for people with low vision). Most of the solutions focused on Text-to-Speech (TTS), multi-modal feedback, sonification and audio techniques in order to meet these needs to create more complete experiences, consulting with experts and PVI directly during the development process. While there are challenges to recruit PVI to participate in the process, evaluating people without visual impairments can become a pretty big threat to the validity of the process, so it is important to have an expressive sample size with PVI and take into account the entire spectrum. By performing tasks in VR, players can improve their skills over time, taking advantage of previous skills and experiences to improve their performance. As they gain interest in this emerging type of entertainment, we can tune efficiency, immersion, information, multissensory feedback and autonomy in our experiences in order to improve their quality and based on the user's needs based on their context. We also need to take into account the challenges of finding a balance of information at any given moment, supplying representable and customizable information, reducing the friction of interaction between PVI and the virtual world and providing a realistic enough representation for the player. With this systematic mapping, we noticed an opportunity space for creating a framework to aid in the development of VR games for PVI with a focus on physical interaction, multissensorial feedback and analytics that can also be useful in ludic OM contexts.

2 RELATED WORK

2.1 Orientation and Mobility (OM)

OM is defined by Simões and Cavaco [55] as the "ability to move independently, safely and efficiently from one place to another", developing necessary concepts to live a more active life. Orientation is the process of using remaining senses to understand their own position and their relationship with other significant elements present on the environment. Mobility, on the other hand, can be defined as being capable of locomotion through an environment safely, efficiently and comfortably by using their remaining senses [11]. Therefore, it's important that PVI go beyond just reading and following routes, but also are able to move from one place to another, being alerted and guided about it's destination, with the goal of building, even involuntarily, a mental map of this change [44].

Thus, OM is a special education area focused on rehabilitating PVI, whether due to congenital or acquired problems, with the aim of providing techniques for understanding, self-protection and navigation in space that are necessary to resume a life with more confidence and independence [11]. Rehabilitation is not a mere process with a set time and schedule, but rather a change of attitude towards a life without vision [54].

As described by Kreimeier and Götzelmann [34], OM practices focus on the development of PVI in many areas:

- **Cognitive**: acquiring and assimilating concepts, the nature and function of objects, problem solving, abstraction, retention and transfer of skills
- **Psychomotor**: offer experiences to develop perception for basic and fundamental movements, physical capabilities, motor skills and non-verbal communication
- **Emotional**: help PVI improve their self-confidence, self-esteem, motivation, values and self-image
- **Remaining Senses**: Stimulate the efficient use of residual vision in People with Low Vision (PLV), clue recognition, define reference points identified previously, connect the action space with the objects in their surroundings.

One example of how OM helps individuals to move better through an environment is by determining their positioning in relation to the space they're in, people, objects and other reference points, as well as identifying shapes and possible walking routes [25]. Any information about the environment can be relevant for PVI to define their locomotion and develop a mental representation that can be used to orient themselves spatially, projecting the navigated space and it's main features [36]. Such models can exist as mental maps based on Points of Interest (PoI), routes or by assimilating knowledge acquired through exploration [1].

At a concept level, OM tasks allow the development of orientation strategies in order to achieve efficient cognitive mapping of a space for navigation purposes [51]. By using a cognitive map, it's possible to nail down spatial relationship between the elements, changing how the ambient is explored and opening up navigation to be less focus on acquiring information and more on the previously identified connections [5, 55].

One approach that can be used when building cognitive maps happens either: during perimeter recognition, as PVI walk and scan the explored location; by creating routes based on the linear recognition of spatial features for navigating and exploring any location [63].

One of the main building blocks used by PVI when spatially mapping are nodes, which are relevant points found in the environment. While exploring, PVI can find moments where they must make a choice to reach a specific goal. Those are known as decision points, and can happen in nodes or in-between the connection of two nodes. PoI are fixed objects present in specific locations, typically integrated inside routes that help in orientation and localization [2]. Routes, meanwhile, are a step-by-step process to guide a person from point A to B [30]. PoI are usually easier to use in orientation, but going off route into unfamiliar surroundings can lead PVI into becoming lost [59].

To avoid this, it's possible to survey the location, creating spatial partitions of the ambient in order to make navigation easier and more manageable with a more complete cognitive map [1].

Assistive technologies can help with the development of OM skills, either through digital applications [55] or tools, such as tactile maps [4]. By combining OM with digital assistive technologies, we can create experiences that motivate users to practice spatial orientation tasks with a ludic approach created in a virtual or hybrid environment that can be interacted with.

When talking about navigation guidance, it's important to remember that PVI have different information needs than people without visual impairments.

There are two main ways to handle information providers in OM:

- Real Time: serves information to the user about their surroundings while the navigation is happening. Some examples include: a guide, cane or guiding dog as a navigation partner; the use of Electronic Travel Guide (ETG) that uses echolocation, GPS, sensors, cameras and other technologies to give audio and tactile information.
- Beforehand: supplies information to the user about a location before the user navigates it. Some examples include audio virtual environments, tactile maps, verbal descriptions, physical models or touch screens [51].

In this context, spatial orientation is an essential concept to be worked with PVI by using their residual vision and other senses to develop their space perception skills, analyzing audio and tactile cues to perform spatial tasks such as navigating and locating elements [58]. It's important to note that mental spatial representations built by PVI are not dependent on vision, being developed through other senses or even by using language [40]. Overall, spatial orientation is necessary for PVI to develop spatial competence in order to understand and interact with the world around with more accuracy and confidence.

Spatial Cognition is the ability to generate, retain, recover and convert well-structured spatial models [6], being a pervasive skill that's usable at any moment of the interaction between the person and their surroundings. Spatial and temporal representations are usually developed independently of the vision, with the combined usage of space and time allowing for a faster conscious perception [31, 58]. It's important to note that the use of spatial demonstratives between objects tends to be more effective than the use of temporal demonstratives [20].

Ideomotor theory says that action, perception and cognition are intrinsictly connected and all concepts are active contributors for the development of spatial orientation and not just passive receptors [6].

Therefore, encouraging OM is of vital importance for PVI due to psychological, physical, social and economic benefits and mainly because it provides their right to come and go as a common citizen [42].

2.2 Left-Right Discrimination

This work defines Left-Right Discrimination as "the propension that humans have of preferring one side of the body over another through neuropsychomotor skills" [41]. LRD is a basic concept that is developed through life, starting with understanding the most important parts of the body, learning how to use the limbs as reference points, assimilate the use of smaller parts of the body (e.g. fingers) and identifying if an object is to your left or right[61].

Once a child reaches the age of 12, they tend to have the same ability as an adult to distinguish between the left and right of their body and from someone in front of them [61]. They're also capable of carrying out crossed commands while being aware of the context (e.g. placing the right hand on their left shoulder) [61]. With this, they're capable of projecting their orientation system towards other references to establish spatial relationships [41].

As described by Ofte [49], LRD uses cognitive skills such as integrating sensorial information, receptive and expressive language, perspective taking, visual and spatial processing. Using the notions of their own body, a person locates objects based on the spatial relationships between them (body-object relation) and different points of view to tell apart if an object is to the left or to the right, eventually being capable of doing the same connection between objects. Even for people without visual impairments, discerning between left and right may require performing a conscious decision using body clues such as the limbs' movement or markers to define clearly one side of the body [19].

A spatial reference can be based on one of two types: egocentric, when it's based on the person (e.g. "raise your left hand"); allocentric, when it's based on an external reference point (e.g. "turn left on the bus stop") [16, 24].

Even though PVI have the same performance for tasks with egocentric references, they may encounter challenges when performing allocentric tasks. This happens since the transposition to other reference points through the visual channel is essential to developing LRD skills [61].

With a perspective based on the human body as described by Hegarty et al. [23], we can split spatial relationships in three scales:

- Figural: the region that is within limbs' range.
- Visual: everything within a person's field of view.
- Navigable: the environment to be explored.

Solving spatial tasks in the context of spatial relationships with the body may take two approaches: epistemic solving, where the actions are performed by the person in order to experiment and find the best solution; pragmatic solving, where the possibilities are explored mentally before taking an action [6].

Beyond spatial relationships, training LRD abilities also develops the motor coordination between hands and feet to perform simple tasks (e.g. walking, holding an object, point to a relevant object) or more complex ones (e.g. perform a crossed command). With practice over time, the person also develops dominance over one side of the body to perform a specific type of task: one example of this would be using the left hand to drink water from a cup.

It's important to note that factors such as emotional state and attention can affect the development of LRD skills (e.g. switching up which side is their left), making the previously unconscious task be performed consciously or by repeating their personal verification mechanisms to understand which side is which.

When working with LRD as a standalone topic that is part of the OM field, we can explore it's nuances and design controlled exercises to better develop competence to later advance into more complex tasks and concepts that require these notions. Mastery of LRD implies that the person reduces the time spent recognizing and/or using LRD, as well as a clear idea of what is left and right, not only by the spatial reference approach, but also through more complex scenarios.

Beyond just the dominance of one side over the other, LRD also helps with motor coordination in PVI.

2.3 Virtual Reality (VR)

The use of VR solutions in the scientific field allow the simulation of real world activities (e.g health [66], sports [9, 27]) in an interactive and immersive virtual environment.

Based on Elor et al. [10] and Speicher et al. [57], VR can have different models and formats to define the concept:

- Virtual environments are ambients that simulate complex situations capable of generating immersive experience through multisensorial feedback [10].
- Hybrid environments are physical spaces with a projector and sensors that allow interaction with the virtual world.
- Immersive Virtual Reality (IVR), commonly used as a synonym for Virtual Reality, defines a virtual environment with deeper physical interaction, usually through a Head-Mounted Display (HMD) device and motion controllers.
- Mixed Reality (XR) usually contains multiple definitions, but [57] defines it as "the mixing of virtual and real objects in a single display, on a spectrum that goes from completely virtual to completely real".

The focus on VR was chosen due to the possibility of working with HMD and motion controlles, as well as unique technologies (e.g. spatial audio, hand tracking) to focus on more active physical interaction [6]. The focus on immersion and presence in VR experiences with PVI also helps to better absorb learning and transfer skills to their day-to-day activities [6, 11, 47, 58].

The use of VR by PVI allows them to interact with environments extensively and with total control over the experience's parameters, without exposing them to the harms and dangers present in the real environment, avoiding accidents and unpredictable situations[58].

Beyond the transfer of skills, immersion and sense of presence helps PVI to have an experience similar to a real environment. For this, it's important to have a robust interaction language, either by having multiple feedback mechanisms or even a hierarchic model of information [24]. However, a low level of audiovisual fidelity is sufficient to fulfill the demands for immersion in a virtual environment [52, 58].

As an educational tool for OM, another advantage of creating VR solutions is that skills that PVI learn in the virtual world can be transferred to the real world and vice-versa [11, 38], with developers being able to take into account OM concepts to design better interaction mechanisms for PVI. This also applies when comparing VR gaming experiences and real-world gameplay using physical toys for cognitive tasks within a limited spatial environment, yielding comparable performance and user experience metrics in both settings [7].

It's also important that VR experiences do not reinforce a stigma in their visual presentation [4]. A good physical VR experience also takes into account the physical space available, locomotion constraints and the fidelity level of the virtual environment [58].

One of the obstacles in using IVR are the side effects brought by using the devices through long periods of time, even in PVI: although nausea is one of the most commonly reported effects, there are many factors behind cybersickness after a session within a virtual environment [39]. These side effects may be directly associated with the experience, whether due to the ergonomics of the devices used, navigation techniques in the virtual world, among other factors.

Solutions that simulate real world locations (e.g. buildings, museums) with tridimensional audio are used to improve OM skills on PVI [11]. Researches already shown that the use of auditive clues, sonar techniques and tridimensional audio combined with haptic feedback devices (e.g. joysticks and electronic canes) improve the user interaction and the acceptance rate of technology, with positive cognitive impact in OM [36]. Some improved skills with the use of the tech are self-location (e.g. identify the sound direction and contextualize it) and audio orientation (e.g. determine where a moving sound is coming to and move in it's direction).

Developers of VR games with PVI as the target audience must take advantage of common VR idioms to implement relevant features that improve their interaction experience, whether by allowing free exploration by mixing locomotion methods [24, 58], adapting visual techniques for use by PVI [52], maintaining realistic proportions of movement and stable representation of virtual objects [58], or through the choice of navigation mechanisms used. The use of previously learned concepts serves to enable an experience as close to reality as possible, where PVI can use unique skills they have access to, such as echolocation and the use of routes and points of interest [1].

Another advantage of simulating virtual environments is in using VR as a way to control the experience, making changes in the experience with the goal of improving learning: distinguishing sounds in front, behind, above and below the user; removing visuals to encourage people to use other senses; using proximity and telling sounds apart to balance the amount of active sound sources in the scene [24, 58].

For game developers, it's also important to offer relevant features for PVI that aid the interaction with VR devices, such as: screen readers, TTS, spatial audio and other similar technologies. The development happens using game engines such as Unity, Unreal or Godot Engine, which provide a base for deploying to VR platforms. Developers can also take advantage of proprietary Software Development Kit (SDK) frameworks supplied by HMD vendors to provide more tailored concepts for PVI.

In terms of commercially available VR games for PVI, Cosmonious High [35] is a narrative adventure where the player is enrolling in an alien high school and trying to save the school from it's many issues. While the accessibility features were added in an update after launch, the inclusion of features such as haptic feedback, audio descriptions, high-contrast modes and more makes it possible for people who are legally blind and have low vision can have a complete experience with the game [35].

Overall, the use of VR by PVI shows great potential as a tool for prototyping solutions, either to simulate tools and virtual environments or for creating ludic and/or emphatic experiences.

3 SYSTEMATIC MAPPING

This exploratory research aims to understand the current state of pervasive games utilizing procedural or semi-procedural methods for content generation and behavior change mechanisms. The research follows the methodological guidelines of Kitchenham et al. [29], Wohlin [64], and Façanha et al. [11].

The study comprises the following phases:

- Identifying primary resources
- Selecting the appropriate studies
- Qualitative evaluation of the selected studies
- Gathering and analysis of the obtained data

The main goal of this systematic mapping is to determine which existing VR solutions working with LRD concepts explicitly or implicitly by spatial orientation and OM concepts, as a means to find reference works for developing and evaluating such applications.

For this research, the selection of primary studies happened by creating a search string based on a quasi-gold standard composed by 4 articles selected by researchers in the research group and previously identified beforehand:

- Simões and Cavaco [55] presents an educational game for mobile devices that creates a virtual experience for training orientation skills, bringing a positive impact to the motor coordination of kids with visual impairments.
- Zhao et al. [68] presents an IVR experience by combining an HMD with a cane as a controller, using it to train cane skills with audio and haptic feedback in a virtual environment.
- Gonçalves et al. [16] shows the obstacles and strategies used by PVI to deal with inaccessible gameplay elements and navigate through complex virtual environments present in traditional digital gaming experiences.
- Wedoff et al. [62] presents a hybrid environment game for PVI, based on an accessible physical activity, detailing information to ground the development of future accessible VR experiences for PVI.

3.1 Main Research Question

This work contains one main guiding Research Question (RQ): How games and VR impact the development of LRD concepts for PVI?

3.2 Secondary Research Questions

Here are the following secondary research questions as Mapping Research Question (MRQ):

- MRQ1: For which vision profiles the solutions are built for?
- MRQ2: What are the target platforms and common techniques used in building a solution for PVI?
- MRQ3: Which methodologies are commonly used for developing said solutions?
- MRQ4: How are the artifacts evaluated?
- MRQ5: What are the observed effects of VR use in developing LRD in PVI?
- MRQ6: What are the challenges encountered in the development of an application that serves the target audience?

3.3 Search String

The search string for this systematic mapping 1 was built based on the quasi-gold standard, being composed with words related to the four main research topics. We opted for selecting terms in both English and Portuguese, corresponding with the language criteria used for this mapping. The final string was created after multiple iterations of testing terms and expressions in search databases, taking into account the research context, population, intervention and results [65]:

("Game" OR "Jogo" OR "Gamification" OR
"Gamificação" OR "Game Design" OR "Design de Jogos")
AND
("Deficiência Visual" OR "PDV" OR "PVI" OR "BLV" OR
"Blind" OR "VI" OR "Visual Impairment" OR
"Visually Impaired" OR "Low Vision")
AND
("Realidade Virtual" OR "Head-Mounted Display" OR
"RV" OR "Realidade Virtual" OR "VR" OR
"Virtual Reality" OR "Ambiente Virtual" OR "Virtual Environment")
AND
("Direita-Esquerda" OR "Competência Espacial" OR
"Esquerda-Direita" OR "Left-Right" OR
"Percepção Espacial" OR "Right-Left" OR
"Spatial Competence" OR "Spatial Perception" OR
"Dominant Hand" OR "Mão Dominante")

Figure 1: Search String used in the Systematic Mapping.

- **Games** ("Game","Jogo","Gamification", "Gamificação", "Game Design", "Design de Jogos"): terms selected based on the expected contributions for this research, being the main research interest and motivation for creating LRD activities.
- **Visual Impairment** ("Deficiência Visual", "PDV", "PVI", "BLV", "Blind", "VI", "Visual Impairment", "Visually Impaired", "Low Vision"): terms selected based on the population/target audience, including acronyms and variations that refer to visual impairment.
- **Virtual Reality** ("Realidade Virtual", "Head-Mounted Display", "RV", "Realidade Virtual", "VR", "Virtual Reality", "Ambiente Virtual", "Virtual Environment"): terms selected based on the research intervention, with Head-Mounted Display being added as it is highly associated with VR.
- **Left-Right** ("Direita-Esquerda" OR "Competência Espacial" OR "Esquerda-Direita" OR "Left-Right" OR "Percepção Espacial" OR "Right-Left" OR "Spatial Competence" OR "Spatial Perception" OR "Dominant Hand" OR "Mão Dominante"): terms selected based on the main concept and it's nearest synonyms. It's important to note that the absence of terms such as "lateralidade" and "laterality" in the search string, as well as the lack of "discrimination" in the keywords selected are due to the term in Portuguese giving more unrelated results than relevant research articles as well as advice gathered in an earlier interview with an OM instructor.

3.4 Search Databases

The search string was applied in the following Search Databases: ACM, IEEE, Wiley, PubMed and Taylor & Francis. These places were selected due to the search feature's flexibility for using the search string in relation to the research topics.

3.5 Inclusion and Exclusion Criteria

For the selection, we will consider the following Inclusion Criteria (IC) and Exclusion Criteria (EC) for the selection process:

- IC 01: The work presents a VR game for PVI.
- IC 02: The work presents relevant information for ludic use of VR for PVI.
- IC 03: The work presents information for how VR can be used for developing LRD concepts.
- IC 04: The work presents relevant information about challenges and techniques presented in the development of a VR solution for PVI.

- EC 01: The work does not list a title, author and/or abstract.
- EC 02: The work is not one of the following: short paper, full paper or extended abstract.
- EC 03: The work was not published in a conference or journal.
- EC 04: The work was not published in the last 10 years
- EC 05: The work was not written in English or Portuguese.
- EC 06: The work presents a solution that is way beyond the possible scope for this research.
- EC 07: The work does not cover LRD or spatial orientation for PVI explicitly or implicitly.
- EC 08: The work does not offer ludic digital solutions or games to exercise this research concepts.
- EC 09: After a skim reading, the work was outside of this research's scope.
- EC 10: After an in-depth reading, the work was outside of this research's scope.
- EC 11: After an in-depth reading, the work did not fulfill any of the Inclusion Criteria.

The Exclusion Criteria was selected with the goal of filtering viable papers bringing solutions or techniques that work with the concepts since the beginning of the mapping process. With this, the goal is to make future stages focus on the research topics themselves and if the work does bring contributions that can be used by this research.

As for the Inclusion Criteria, they were established based on the following:

- IC 01 searches articles with game examples for PVI in the VR field that are directly related to this research, in order to both avoid following already traveled paths and determine common features between all solutions.
- IC 02 aims to find articles with ludic VR solutions for PVI that are not games, with the goal of obtaining information regarding important design references and considerations made in the development process.
- IC 03 focus on articles that work with LRD concepts with VR solutions. While the search string already applies this filter, the inclusion of this criteria aims to include works that do not explicitly involve PVI in the process, but do mention concepts that can be trained by the audience.
- IC 04 investigates challenges and techniques presented in the development process of the solutions created that are adaptable for this research. The criteria also looks for VR techniques designed with PVI in mind that can be adapted and/or reused in a LRD context.

For an article to be selected, it must fulfill at least one IC and not be removed by any EC by the end of the selection process.

3.6 Procedure

The selection process and qualitative evaluation of the studies found by the search string happened through the following stages:

- Identification: Initial query of general information, such as Title, Author and Abstract. Any work that fulfills EC01-08 will be removed at this stage.
- Selection: Skim reading of "Introduction", "Related Works" and "Discussion" sections. In order to cover as many works as possible, "Related Works" and "Discussion" can be replaced by equivalent sections or treated as optional, provided that the skim reading process is able to identify a connection between the work and this research. Any work that fulfills EC01-09 will be removed at this stage.
- Eligibility: In-depth reading and analysis of the work in order to deliver a final veredict. For the article to be selected, it must not fulfill EC01-11 and meet one of IC01-04

To aid in the procedure, we used Parsifal to label the works through the selection process, while also using it to analyze general information through the "Identification" stage. After the selection process, the selected works were used for collection and analysis of general information about the research process, with the data gathered being divided in four main categories:

- General Data: publication, authors, institution, number of references, number of citations, keywords.
- Research methodology
- Experiment: participants (detailing the participation of PVI and multiple vision profiles), procedures
- Results obtained and limitations of the research

The queries used in each Search Database and the spreadsheets with the selected articles are available as a spreadsheet[1].

4 RESULTS

Figure 2 shows the outcome for this systematic mapping: In the end, 19 results were selected, all of them being obtained originally from ACM's Search Database.

In the final list, both articles by Zhao et al. [67, 68] refer to the same research and were published on Conference on Human Factors in Computing Systems (CHI) 2018. After further analysis, we concluded that the content on both articles was different enough to keep them both as separate entries in the tables and when calculating percent rates. However, discussion will treat them as a single research artifact (Canetroller).

Key publications frequently covering the theme include CHI (5-26%), "ACM Transaction on Accessible Computing" (21%) e ACM SIGACCESS Conference on Computers and Accessibility (ASSETS) (11%), all related to the Human-Computer Interaction (HCI) field, with the latter two focused on computing and accessibility.

An interesting pattern found during this mapping was that most authors identified in the results only featured in one document, with only a few authors featured in two distinct ones: Yuhang Zhao, André Rodrigues and João Guerreiro. The last two belong to the *Universidade of Lisboa* (11%), which appeared often on the research: other institutions with more than one project include Cornell University (16%), University of Washington (16%) and Microsoft Research (16%).

It is important to note that while some results addressed LRD concepts, the solutions were not explicitly or exclusively focused on LRD training.

The digital solutions presented are primarily games and applications for PVI, except for Kreimeier and Götzelmann Kreimeier and Götzelmann [32], which did not include PVI in the experiment. Other types of solutions found include standards for using gestures

[1] https://docs.google.com/spreadsheets/d/1jSLrQq9b-DkCXlzXfH$_L8yPVTSxWiABAvNNptsJ2noY/edit?usp = sharing$

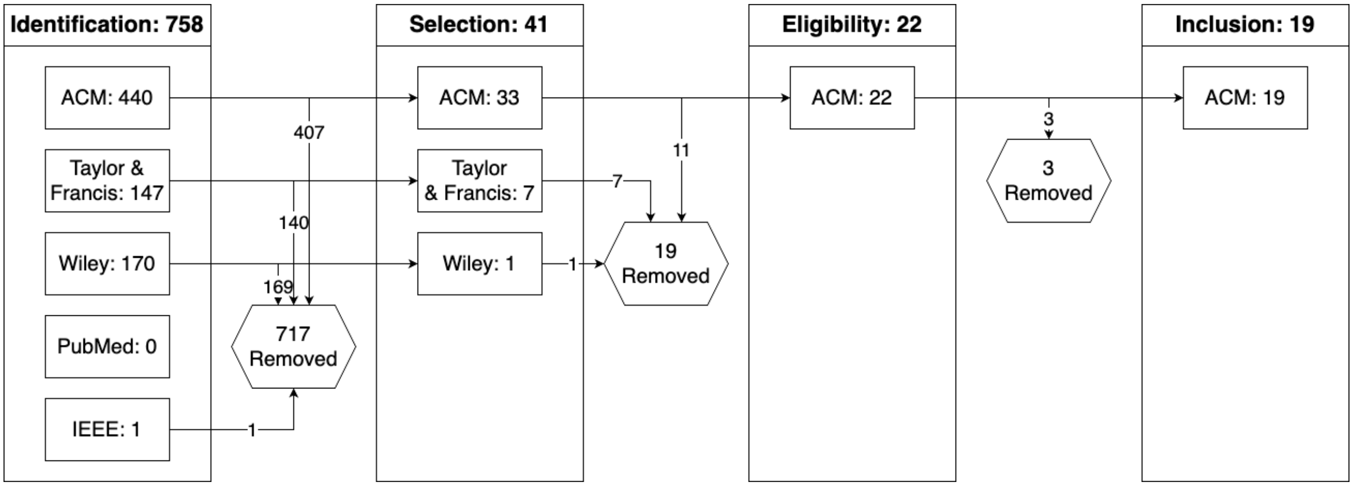

Figure 2: Systematic Mapping Results

to obtain information in a virtual environment [18] and the patterns used by PVI to explore virtual environments [16].

Overall, 63% of the selected works use Unity to build their experiences, showing acceptance from the developers for using it in VR development.

While were able to find results related to this research, examples are scarce: out of 19 selected works, only 5 were identified as games, with only Wedoff et al. [62], Simões and Cavaco [55] and Mohd Norowi et al. [45] explicitly working with LRD. However, the other works provide useful contributions for developing VR games for PVI focusing on LRD concepts, even though they were not initially designed with these topics in mind.

4.1 Games, Virtual Reality and PVI - IC 01

This section will present the solutions identified, highlighting important elements for building games for PVI. Initially, it's possible to notice that the games had a positive reception by PVI and had a positive impact in the skills trained.

Virtual Showdown [62], for instance, introduces a digital adaptation of Showdown, a sport similar to air hockey where players using blindfolds must hit the ball using rackets to score it into their opponent's goal. The game was implemented as a hybrid environment solution, combining Kinect v2, Nintendo Switch Joy-Con, cardboard, and a table to define the physical space. It uses the Unity game engine to simulate the virtual play space of a Showdown match and adjusts the physics emulation to make the game more playable while staying recognizable. The game employs Kinect to track the player's position in the table, with the bat rotation based on the player's body and wrist locked into set angles to keep it steady. To help with inferring depth, the game uses panning and spatial audio to indicate to players where the ball is coming from, as well as employing audio techniques such as a custom volume rolloff, Doppler effect and other audio filters. Also, the game adopts multi-modal feedback through Joy-Con, both for when a player hits the ball, but also to lead the hands back to the table in case they drift out of it, using different vibration intensities based on the type of feedback required. While the game is made to be played as a multiplayer game, the experiment was conducted with a computer opponent to be defeated in a set of levels with progressive difficulty to evaluate how verbal/vibration scaffolds affect the player's performance and movement, with earlier levels having hints to help the player understand the context of gameplay.

Following this hybrid environment approach, Kim et al. [28] present Sonic Badminton: a prototype for adapting badminton to be playable between people with and without visual impairments. It uses sensors, electronic components, and a simulated environment. The prototype uses rackets augmented with a wireless sensor and substitutes the physical shuttlecock with a virtual one, which is represented through localized binaural audio output that players must interpret and swing accordingly. The controls are handled by a Wireless Sensor Module attached to a Badminton racket The movements are captured and sent via Wi-Fi to the host server, which processes the data to recognize the location of the racket between three locations (left, center, and right) and tell the matching motion for the swing (e.g. swinging from left to right).

Apple Swipe [45] offers a game for mobile devices based on the game Fruit Ninja, where the goal is to slice the fruits and avoid obstacles to get the highest score possible while also avoiding obstacles. The objects appear on the screen coming from different directions, with each object having a specific sound that is played at the position it came from, offering the possibility to train left-right discrimination. The work highlights the importance of using existing conventions to provide a better gameplay experience for PVI, including how the device is held, interaction mechanisms, interface navigation, and verbal feedback.

Simões and Cavaco [55] devise a mobile game experience with three scored challenges where the player take photos of alien insects and fulfill tasks inside his spaceship using LRD abilities, using the device to find the interactive elements. The game uses spatialized audio and vibrations to convey information about localization concepts such as left/right, and front/back. Touch screen and gyroscope were used for determining the user's facing direction and interacting with the game's elements. The game also applied adaptive difficulty concepts, increasing or decreasing based on the player's learning curve and overall performance. One of the challenges encountered by the children participating in the experiment was the learning curve for rotating the body, as participants usually only rotated the top half of the body, keeping the feet still on the floor.

While Apple Swipe [45] only highlights LRD, Aligned Commands and Clue Recognition, which are common to all games in the table, they are sufficient to define the main goal of the game of slicing fruit as they appear, with the player swipe needing to swipe from the same direction as the fruit when it enters the screen.

On the other hand, Virtual Showdown [62] and Sonic Badminton [28] offers great opportunities to work with LRD concepts, using: LRD with the projectile's origin, trajectory and possible destinations; Aligned and Crossed Commands through how the player receives and returns the ball/shuttlecock; spatial references to understand where the ball/shuttlecock is coming from in relation to the player's bat in earlier levels and where the player wants to launch the projectile towards in order to score; body image and motor coordination through the physical interaction the game requires, with a focus on the player's hand movements; clue recognition through a hint system and multi-modal feedback; dominant side based on which hand the player uses to hold the bat/racket and it's performance, with Wedoff et al. [62] noting how participants obtained better scores when the ball came from the same direction as their dominant hand or from a neutral location such as the center of the table.

Simões and Cavaco's untitled spaceship game [55] uses LRD concepts in all 3 challenges, training LRD, aligned commands, body image, clue recognition and motor coordination to move around and find the creature: while the first and second challenges task you with finding a creature and capturing it, the third challenge is to determine the direction and distance from the sound source, also working depth perception skills by allowing the player to walk through the virtual room, searching for objects and completing simple tasks while avoiding obstacles.

4.2 Other Applications - IC 02

Even though they're not games, the following solutions can be used for creating VR games for PVI.

X-Road [58] is a VR app for mobile devices for doing classic OM tasks during the classes, as well as an application to explain the audio-spatial concepts (AR Cube Hunter). While developing the application, the work highlights features about the use of VR devices by PVI, such as using similar feedback mechanisms to represent similar objects and allowing the user to locate elements in space. By using virtual environments to explore scenarios, the solutions allows users to explore them in a way that is impossible in the real world, positioning themselves in physically impossible spaces, adjusting the simulation speed or manipulating elements such as the number of cars.

As a tool to acquire information from a virtual environment, Andrade et al. [1] developed an implementation of echolocation, an ability that is actively used by 20-30% of PVI. The app contains five scenes for exploration using passive and active echolocation to find the goals in the map, being viewed by some participants as entertaining and a relaxing experience for acquiring OM skills. Despite the artificial echolocation being useful for spatial orientation, the research highlights that natural echoes can be more relevant for the success of a navigation task, as they provide a sense of presence even when having an initial learning curve.

VStroll [25] is an exercising app for mobile devices that allow PVI to explore a real-world location virtually, building a mental map of the explored environment. Using the device's sensors, the user puts the phone on it's pocket and walks in place in order to navigate through PoI in the map, having total autonomy via voice commands to select paths in intersections and receiving information while moving.

The preference for autonomous experiences is also reinforced by Gonçalves et al. [17], which expose a virtual social space for PVI to interact in different situations with other virtual agents. By exploring different navigation modes (Free Exploration, Teleport, Automatic Walking and Copilot), as well as approximation techniques with audio cues, the experiment highlights the users' preference in navigating with autonomy rather than the navigation method's efficiency. They also value having access to information in the space and how interactions with other users should be approached.

Another solution is to simulate existing tools: Zhao et al.[67, 68] propose the Canetroller, a physical cane that simulates interactions in VR. The device offers haptic, tactile and sound feedback, with the goal of training cane skills such as length adjustment, use strategies and more, all of this inside a virtual environment. The tool shows a faster and more efficient way to interact with virtual environments that is approved by OM instructors. During the evaluation process, participants highlighted the need for more sound elements and the authors highlight difficulties encountered to identify the altitude in a virtual world and when using the device physically. Overall, participants showed a great sense of spatial presence in indoor and outdoor virtual environments and showed interest in using Canetroller in more experiences that are currently not as accessible.

4.3 Left-Right Discrimination and PVI - IC 03

When training LRD concepts in Virtual Showdown [62], participants performed better when the ball that was hit back stayed on the same side as his dominant hand or when the ball returned to the center of the table, showing how hand dominance impacts on the experience.

Mohd Norowi et al. [45] highlights how it's mechanic of cutting fruits can be used to train LRD skills: as the player identifies which direction the fruit enters the screen from, it executes a corresponding gesture in the same direction to cut it and earn points.

The use of life experiences of PVI can also be used to successfully identify features of the virtual world players are immersed in. As mentioned by Andrade et al. [1], the use of echolocation in virtual environments develops the skill further over time, such as to distinguish the position of objects and obstacles. The same approach could also be applied to LRD in order to reduce the learning curve of controls and improve the user experience.

In terms of feedback, the use of audio as means to practice LRD is also very present in many of the solutions found. However, the results presented by Simões and Cavaco [55] show that just panning s insufficient for PVI to have a sense of presence in space. This requires more complex features to be used, such as spatial audio or distinct sound techniques [21].

In addition to sound, haptic feedback can also be used to help PVI to understand their surroundings and identify the presence of objects in their personal space [32, 68]. However, Wedoff et al. [62] highlights that Showdown players prefer avoiding simultaneous haptic and verbal feedback, having a clear preference for verbal cues.

4.4 Challenges and Techniques - IC 04

By analyzing the identified solutions, the most common feature was the many representations for feedback, be it by audio (spatial or binaural) or touch (haptic, tactile, vibrotactile or force feedback). The use of TTS, gestures, motion sensors, customization features, tips system and in-game analytics also contributed for more robust solutions, not only for the end-user, but also for conducting their respective researches.

May et al. [43] presents the optimization strategies for soundscapes in XR environments, seeking to avoid overloading the listener in high-density sound environments and improve the process of creating cognitive maps by PVI. Here, the participants preferred: the use of realistic Auditive Icons (AI), descriptions via TTS or a mix of both to provide a more complete description; limit the sound experience to only sounds present in the same location as user; adding redundancy and explicit representations for information; customization options based on the user's navigation needs and interests.

With a VR application for PLV, Oda et al. [48] augments the user's vision by correcting certain visual functions in the digital scene by applying transformations to the virtual world. The technique was then demonstrated with a shooter game, with results showing improved performance from PLV.

Through an experiment of exploration and scene reconstruction, Andrade et al. [1] show how sound cues can be used as a tool for PVI to acquire environment information such as relative room size, openings in walls, materials of indoor surfaces and obstacles. By designing virtual worlds that are compatible with the skills known by PVI, the work shows that the artificial echolocation mechanism wasn't as effective as the natural echolocation that is generated by the sounds users make when moving through a space. This shows how important it is to have virtual worlds designed with PVI in mind, in order to make better solutions.

As for developing methodologies, Mohd Norowi et al. [45] creates one for making games for mobile devices with PVI, both for the development process and conducting the project, as well as establishing good practices related to the player's learning curve, how audio is used and how to make a comparative analysis between people with and without visual impairments.

Using hand gestures, Gonzalez Penuela et al. [18] propose the use of a standard set of commands so PVI can obtain descriptions about an object or the space they're in, giving agency as to how and when the user wants information and which information should be given. The model described in this work can be adapted for use in HMD VR devices using gesture detection and the device's cameras.

Guarese et al. [21] brings a set of experiments for sonification patterns, where the participant used the mouse to point where the audio cue was guiding them. The article highlights the advantages and disadvantages for each method, while also highlighting the challenge for recruiting PVI to participate in the research, as it is just a small sample compared to the total number of participants.

With the goal of improving how PVI perceive their virtual surroundings, Ji et al. [26] suggest an audio model for social experiences in virtual environments. Participants were positive about how the information was adapted based on the context it was in, as well as how peripheral information was used as selection criteria for sounds.

X-Road notes that, when creating a visual simulation of the world, reaching a minimal ground for audiovisual fidelity is sufficient to make scenarios accessible for PVI, with OM instructors saying to avoid hyper-realistic experiences, as to not generate confusion between what is in the virtual environment and what is in the real world.

With accessible sound maps, Aziz et al. [2] make available a tool for PVI that allows prior exploration of routes in a passive way. The work highlights important design and usability criteria for developing and testing the solution, such as adding AI to give richer information when exploring a route.

Kreimeier and Götzelmann [32] uses commercial IVR controllers in an experiment where participants explore tactile sensations in a virtual environment in order to identify the shapes of virtual objects, while also being unable to see the shape for the object touched. This establishes a way of assimilating spatial information from virtual objects using haptic feedback.

In terms of game design, the models of progression found in the games presented could be described as: linear [45], where the stages get more difficult as the player advances, which can also be seen in the experiment made by Andrade et al. [1]; adaptive [55], where the difficulty changes based on the player's performance.

We also identified that participants in India et al. [25] were interested in games or gamified experiences, treating the experience as a game even though the app was not designed as such. The participants also wanted to keep using the application even after the experiment ended.

It's important to note that experiments such as Kim et al. [28], Mohd Norowi et al. [45], Wedoff et al. [62] showed comparable results between people with and without visual impairments, with PVI taking the edge when the experiment didn't depend on the participant's vision.

5 DISCUSSION

5.1 Vision Profiles - MRQ1

MRQ1 Summary: (i) Participants included individuals with and without visual impairments; (ii) PVI samples mostly made up of Totally Blind (TB) or PLV individuals; (iii) Some works do not differentiate participant numbers based on the type of visual impairment; (iv) Including people without visual impairments in research focused on PVI requires a meaningful role that involves comparison or collaboration between the two groups.

Based on the data provided by the authors, the classifications presented define various types of visual impairment, enhancing our understanding of the research to create more tailored interventions for PVI.

At the same time, including people without visual impairments in research for PVI can threaten the research's validity, as they are not the target audience. Therefore, it is important to have a well-defined reason for including them in the research.

When working with games for PVI, knowing the type of visual impairment of your audience also affects which techniques should be used to relay information and improve interaction, locomotion and navigation in the game, as some approaches are more effective when working with certain groups (e.g. high-contrast modes for PLV), ordering tasks based on the most effective features.

5.2 Technologies Used - MRQ2

MRQ2 Summary: (i) Predominance of solutions for computers, smartphones and HMD; (ii) Use of TTS, spatial and binaural audio, customization features and multimodal feedback; (iii) Unity as the engine of choice for development

The digital artifacts developed (games, virtual environments, IVR simulations and other apps) demonstrate the use of commercially available devices to create VR solutions for PVI. By using established technologies for PVI such as TTS and spatial audio, we can improve the learning curve for users, leading to a better experience. Choosing Unity as a development engine underscores it's versatility and widespread adoption, enabling seamless deployment across multiple devices and operational systems.

5.3 Development Methodology - MRQ3

MRQ3 Summary: (i) Incorporating expert consultations when building artifacts for PVI; (ii) End-user participation in the development process; (iii) Defining use cases for the solutions;

Through the analysis of the selected works, we can identify the following characteristics that are relevant for this research:

- Consulting experts to define requirements for the developed artifacts.
- Proposing techniques for building experiences and their respective development process.
- Including user feedback during the solution's development.
- Evaluating with test sessions, collecting relevant data before and after the session.
- Testing solutions with the latest version available
- Evaluating Virtual Environment techniques in stages created exclusively to demonstrate their use cases.

The methodologies presented illustrate how research projects benefit from incorporating end-user input into the development process. Including expert consultations and end-user feedback into the development process is crucial for creating solutions that genuinely address the needs and preferences of the PVI community. This helps effectively identify and prioritize features and requirements in order to develop better artifacts.

5.4 Testing with Users - MRQ4

MRQ4 Summary: (i) Expressive sample size of PVI; (ii) Challenges in recruiting PVI; (iii) Hybrid samples (mixing people with and without visual impairments) are not recommended unless there's a clear goal behind it; (iv) Research with PVI must take the entire spectrum into account;

Since it is crucial to evaluate directly with the target user, most research projects include only PVI participants. However, challenges in recruiting can make for unrepresentative samples enough of the population, both for visual impairment and for representing the entire spectrum.

The most common experiment structure is a direct evaluation session with the end-user. However, the procedure can vary from a simple test session with the artifact gathering user feedback to a standardized procedure, with some common practices being:

- Controlled environments for testing.
- Semi-structured interviews at the start and/or end of the experiment.
- Questionnaires after finishing parts of the experiment.
- Use of assessment scales such as NASA-TLX [22], SUS [3], BUZZ [60] and Likert [8] in the questionnaires.
- Discussions about the experience with participants during and at the end of the experiment, either formally through a questionnaire or interview, or informally through conversation.
- Completing goals in the experiment environment, with prior instructions about how the task and the artifact(s) work, as well as tips during the process when requested.
- Instructions can be relayed through an initial presentation, a tips system embedded in the solution, or a sandbox where the player can test things out before beginning.

With the exception of Kreimeier and Götzelmann [32], all experiments featured PVI as participants, either through hybrid samples for comparative studies between the two audiences or only PVI participants in order to evaluate specific criteria related to the audience.

However, recruiting PVI to participate require existing contacts to gather a good sample size. In cases where this is not possible, Guarese et al. [21] invite participants without visual impairments. While this solution can improve the sample size, it also adds a threat that must be mitigated. However, having a hybrid sample can be beneficial for comparative studies or creating shared experiences between people with and without visual impairments [17, 28, 62].

5.5 Observed Effects - MRQ5

MRQ5 Summary: (i) Skills improve after an initial learning curve; (ii) Previous experiences impact performance and results; (iii) Artificial mechanisms and interactions are more efficient when using established PVI skills; (iv) Efficiency, Immersion, Information Models and Autonomy are important parameters for the experience; (v) PVI are interested in VR entertainment experiences; (vi) Use of multi-sensory feedback;

The experiments carried out demonstrate initial friction when PVI play VR experiences, which can vary based on previous experiences with the devices, physical space, proposed experience, feedback and interaction mechanisms available in the virtual world. However, using already known concepts to balance efficiency and autonomy while also motivating practice through entertainment, we can create immersive and engaging experiences utilize and evolve spatial abilities like LRD.

5.6 Challenges and Limitations - MRQ6

MRQ6 Summary: (i) Audio panning is not enough to represent a three-dimensional space; (ii) Avoid overloading PVI mentally with the information presented; (iii) Ensure representativeness in the spectrum of visual impairment for the sample of participants; (iv) Importance of supplying information that is both representable and customizable; (v) Balancing a realist representation of the virtual world while keeping it distinct from the real world to avoid confusion; (vi) Reduce the friction of interaction between PVI and the virtual world;

To ensure a good experience, it's important to consider several criteria for developing VR for PVI, such as using audio solutions for three-dimensional spaces, building the information architecture to offer representative information that can be customized by the user without causing a mental overload, and balancing the fidelity levels of the experience. Another challenge is fulfilling the needs of various types of visual impairment, making use of their unique skills and adjusting the experience accordingly based on the system's interactions.

6 FINAL CONSIDERATIONS

6.1 Summary

This systematic mapping presented how VR training can be used by PVI, highlighting the training of LRD skills. By studying OM and LRD concepts, we seek to establish the importance of practicing these abilities to better develop each skills.

The studies of VR listed in this paper also create engaging VR experiences, where PVI interact physically with the virtual world, using their unique skills and obtain a immersive feeling while playing.

The results of the systematic mapping also presented games and techniques for VR development, as well as how the experience is like for PVI. Even though there was only a select number of examples, the games show approaches that can be used to train skills over time, evolving the player's aptitude with advantages such as more engagement, motivation, physical activity and social inclusion.

6.2 Threats to Validity

The procedure had prior discussions with the research group before being executed, but was performed by only one of it's authors due to time constraints. Some measures were taken to mitigate problems with this process. Articles from the quasi-gold standard were picked to direct the mapping process in order to fulfill the objectives. However, it's possible that the works selected influenced in the lack of explicit mentions to LRD. To alleviate this issue, the search string was built to add neighboring concepts, combined with an extra careful readings during the process to check for implicit mentions of LRD.

Another possible threat to validity lies in the search string itself, as works that trained LRD skills implicitly can use different terms from the selected or the article can use different definitions or acronyms to define PVI. To relieve these concerns, we looked for relevant terms based on the articles previously read by the authors. One example of this is the terms chosen for LRD (e.g., "Spatial Competence", "Dominant Hand"), which were selected based on works that focused on LRD explicitly. Also, the string was presented to the other author before starting the systematic mapping process. However, selecting the terms based on the quasi-gold standard may be the cause for the lack of important terms (e.g. "handedness"), which we discovered during the mapping process.

The Inclusion Criteria and Exclusion Criteria developed may also be possible threats to this systematic mapping, as relevant articles for this research may have been removed in initial stages due to lack of information about the theme in the title, abstract and/or the Sections read in the skim reading process. To reduce those risks, we aimed to choose criteria capable of selecting relevant articles since the first stages of the process and focusing on the Introduction, Related works and Discussion sections. These choices were made with the goal of quickly identifying the purpose of the research, it's bases and contributions.

Another threat identified was in avoiding including articles that do not fit the mapping. To soothe this risk, the procedure was built to retroactively apply Exclusion Criteria, with an extra item for when the work does not fit any of the inclusion or exclusion criteria. The Inclusion Criteria chosen were also structured so that the articles found have contributions that are useful and applicable in the research.

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