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SURVEY

Recommendations for Developing Immersive Virtual Reality Serious Game for Autism: Insights From a Systematic Literature Review

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ABSTRACT The use of serious games for the treatment of people with autism is currently considered a promising approach due to its positive effects on promoting learning through playful and motivating experiences. In recent years, increased research has focused on serious games utilizing Immersive Virtual Reality (IVR) technologies, such as large-scale projection-based systems and head-mounted displays. The high level of immersion provided by IVR has been found to benefit learning outcomes, as it reduces environmental distractions and helps individuals focus on learning tasks while also addressing social anxiety. Researchers have conducted significant work in this field over the past decade, yielding promising results. However, the development of these learning interventions comes with methodological challenges and issues, especially in how to conduct the development process and design IVR-based serious games for the learning of people with autism. Based on these premises, this systematic review thoroughly analyzes the literature on developing IVR-based serious games for individuals with autism, discussing inherent shortcomings and reflecting on them. Then, twenty IVR-based serious games for people with autism developed between 2009 and mid-2021 are selected and analyzed, focusing on the people engaged in the development process, the design methodology adopted, and the serious game design framework employed. From this analysis, a set of recommendations are proposed to support anyone interested in developing IVR-based serious games for people with autism. In addition, the gaps left unsolved in the autism literature are highlighted, upon which a research agenda is grounded.

INDEX TERMS Autism spectrum disorder, design guidelines, immersive virtual reality, serious games, systematic review.

I. INTRODUCTION

We live in a time of exciting technological innovations: the adoption of Information and Communication Technology systems (ICTs) is driving transformative change. The ICTs' latest advances are expanding the frontiers of the digital revolution reshaping products, as well as profoundly influencing and altering society. The future is arriving faster than expected since ICTs are increasingly embedded in many aspects of our daily lives: Wearable Technology, Sensor Networks, Big Data, Artificial Intelligence, Robotics, Internet-of-Things, and Virtual Reality (VR) play an essential role in this game [1]. Beyond all doubt, according to different market studies (e.g., [2], [3]), VR is projected to grow at an even faster rate due to its cutting-edge technologies applied to even more usable, affordable, and accessible commercial solutions [4].

VR, which refers to several technologies based on computer graphics, is mainly able to create virtual scenes and objects that the user can manipulate through input devices. These objects can be seen, heard, touched, or even smelt through output devices [5], [6], [7]. Thus, the users can feel immersed within the virtual environment as if they are really there. According to the level of user immersion, it is possible

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to distinguish between non-Immersive (nIVR) technologies, such as desktop-based VR systems, and Immersive VR (IVR) technologies, including large-scale projection-based systems (e.g., Cave Automatic Virtual Environments (CAVEs)) and Head-Mounted Displays (HMDs) [8]. Especially from 2013, the year of the launch of the first commercial HMD (the first Oculus Rift dk1) [4], [9], the IVR gained prominence as the core feature of modern ''high-tech'' in Industry with wide-ranging applications: entertainment, media, retail, manufacturing, aerospace, defense, education, and healthcare [10].

In particular, this upward trend of growing IVR systems popularity, related to the quality of HMDs and their significant cost reduction, encouraged not only the Industry to generically exploit these innovative technologies but, obviously, also the Academia to experiment with them [9], especially to discover how people can really benefits of them.

For example, in healthcare in general, and fields of rehabilitation, in particular, the interests of Academia have buoy by the promise that IVR can lead to tangible improvement in learning rates for both the typical and the clinical population [5], [7], [8], [9], [11], [12].

For neurodevelopmental disorders such as Autism Spectrum Disorder (ASD), Academia interest is more than evident from 2015 – obviously, two years later than the HMD launch (see e.g., [13]), as highlighted by the increasing number of systematic reviews published in the last years (e.g., [4], [7], [14]). Academia studies have deep roots: the IVR benefits are mainly due to the typical characteristics of such disorders. ASD is a neurodevelopmental disorder characterized by deficits in two specific domains: (i) social communication and interactions; (ii) repetitive behavior and a restriction of interests [15]. Usually, ASD people have a high affinity with technology, as these are more predictable and lack social demands [16]. ASD people also have a good visual memory and demonstrate high learning capabilities when the learning material is presented with visual-spatial information [7], [17]. Moreover, IVR can provide safe access to highly realistic and customizable virtual environments; in such environments, ASD people can learn in a controlled and repeatable context, as well as with good ecological validity, consequently improving performance and control of social anxiety [4], [7], [14], [18], [19], [20], [21]. Furthermore, there is a great deal of research that the level of immersion delivered by technological means plays a key role since it can influence the learning of people with ASD and their engagement, improving the learning outcomes by eliminating environmental distractions and supporting people with ASD in better maintaining the focus on the learning task to perform [4], [7], [8], [12], [22]. These deep roots motivate researchers to experiment with IVR as training and learning interventions for individuals with ASD, as specific affordances of this technology. In particular, all lend themselves to a meaningful environment that potentially can enable greater opportunities for acquisition, maintenance, and generalization of skills [8], [12], [17], [22], [23], [24], [25]. However, alone, IVR is not enough to ensure the efficacy and effectiveness of the implemented intervention. In fact, to be efficient and effective for individuals with ASD, IVR should be combined with an appropriate learning strategy design targeting the core symptoms of ASD [4], [7], [19]. According to several authors (e.g., [4], [26], [27], [28], [29], [30], one possible solution to this issue is to add entertaining and playful value to the IVR interventions by borrowing design elements from Serious Games (SGs).

As defined by Clark Abt [31], SGs are games that ''have an explicit and carefully thought-out educational purpose and are not intended to be played primarily for amusement''. The analysis of the available literature suggests that Serious Games (SGs) are the most promising learning approach for rehabilitation interventions for ASD, notably if they target social skills [29], [30]. Several studies reported positive outcomes in terms of acquired knowledge and demonstrate that SGs could promote (1) a motivating and engaging acquisition of learning and (2) the generalization and transfer of skills learned by playing to real-life [26], [28], [29], [30], [32], [33]. Given their very nature, designing SGs entails the merging of learning theory and empirical findings together with the principles of game design to create a unique intervention tool that can target any set of skills (e.g., cognitive, behavioral, and social skills) to improve knowledge and competencies beyond the context of the game. Thus, only a multidisciplinary team composed of different expertise is able to realize such games well balanced between learning and entertainment aspects [34]; this is particularly crucial when the SG target audience presents specific characteristics, needs, and attitudes such as people with ASD [29]. Consequently, different stakeholders should be involved, collaborating with each with their own skills and expertise. There should be not only pedagogical experts (e.g., educators, teachers, therapists) to guarantee the effectiveness of the learning approach proposed but also ICT experts (e.g., Human-Computer Interaction (HCI) experts, game designers/developers) to ensure the playfulness and usability of the SG proposed.

Given these premises, the merge of the SG-based learning experience with IVR technologies enables a new generation of more effective ICT-based rehabilitation tools in the ASD field: IVR-based SG for the learning of people with ASD [35], [36]. However, the design of these interventions is not without challenges and issues, given the lack of methodological approaches to follow [28], [35], [37]. In particular, as shown in a previous study [35], there is a lack of design methodologies that could be adopted ''*as-is*'' in the design of IVR-based SG targeted to individuals with ASD. From an investigation of the literature, it emerged that there are only general guidelines on game elements proving to have a positive impact on the learning of people with ASD [30] or frameworks providing a set of game elements that could improve the learning of some specific skills by children with ASD [37], [38]. Including even SG design frameworks for typical users, the available literature lacks some essential aspects that, rather than others, play a key role in designing effective, engaging, and accessible IVR-based SGs for people with ASD. For example, the characterization of target users [26], [29], the technology to be adopted as output devices [29], the methodology to follow within the design process [34], the composition of the multidisciplinary design team [34], and the active involvement of representatives of the target users [28].

Therefore, to take a step toward solving this lack, it would be valuable to investigate existing IVR-based SGs targeting people with ASD to identify recent trends and common methodological approaches meaningful to propose a practical set of guidelines for developing such systems that encompasses all the above-mentioned challenges. Thus, the aim of this systematic review is to answer the following research questions (RQ):

- **RQ1** What is the composition of the team involved in developing immersive virtual reality-based serious games for autism?
- **RQ2** Which design methodologies are adopted for developing immersive virtual reality-based serious games for autism?
- **RQ3** What design frameworks are used to design immersive virtual reality-based serious games for autism?

To address these research questions, an inspired Kitchenham review process for systematic reviews [39] was conducted. This process consists of three main phases: planning, conducting, and reporting the review. According to these phases, the rest of the paper is organized as follows: In Section II (*Background*), the justification of the need for the present systematic review and the summary of the research questions-related reviews are clarified and analyzed; In Section III (*Research Method*), data sources and search strategies, study selection and quality assessment, data extraction, and data synthesis are reported; in the Section IV (*Analysis of Results*), principal findings and their meaning for each research question are deeply are analyzed and then discussed in Section V (*Discussion*), proposing a practical set of design guidelines and recommendations for developing IVR-based SGs for the learning of people with ASD. Finally, In Section VI (*Conclusion and Future Works*), the conclusions drawn after the analysis of the studies are presented and future research activities in this field are shown.

II. BACKGROUND

In this section, the *planning phase* of the Kitchenham review process [39] has been reported. In particular, as suggested by this phase, before performing the present systematic review, it was necessary to be sure of the absolute need to answer the proposed research questions. To this end, several digital resources (e.g., ACM digital library, Scopus) have been investigated. Then, 23 reviews (e.g., surveys, scoping reviews, and systematic reviews) were identified and deeply analyzed. This analysis revealed no literature that perfectly matched the three identified research questions. Instead, these 23 reviews were related to two more general topics: (1) SGs for individuals with ASD and (2) IVR/VR-based systems for individuals with ASD (respectively referred to as cluster A and cluster B in the third column of Table 1). In addition, these 23 reviews presented some characteristics limiting the generalization of findings provided by them into IVR-based SGs: they narrowed their discussions on SGs or IVR/VR systems for ASD individuals, not specifically on IVR-based SGs. Thus, the reported outcomes must be evaluated cautiously and not assumed, with absolute certainty, to be valid for IVR-based SGs for people with ASD.

Below, a detailed analysis is provided of the main findings of these reviews, grouped according to the RQ to which they pertain.

Concerning **RQ1**, 43% of analyzed reviews (exactly 10) highlighted the importance of engaging a heterogeneous development team, with a strong attitude toward *multidisciplinarity* and *inclusivity*, for developing IVR/VR-based systems or SGs for the learning of people with ASD. However, none of them actually addressed this research question. In particular, authors of these reviews [7], [8], [40], [41], [43], [44] just advised to involve some specific people within the development process without giving enough information on their own characteristics, background, expertise, and roles and responsibilities they should have. Only the review presented in [26] partially addressed this RQ by analyzing the nature of multidisciplinary teams (i.e., whether participative or cross-functional) of thirty studies on SGs targeting people with ASD. However, this finding was partially transferable to IVR-based SGs and was weakly argued by the authors. In fact, only 10% of the studies included in this review (exactly 3) were delivered as IVR-based systems. In addition, the information regarding the nature of the team involved in the design of included SGs was only qualitatively reported, without presenting a quantitative analysis of this aspect or indicating for each study the nature of the team involved.
To sum up, by aggregating the findings across all analyzed reviews, it emerged that there should be *neurodevelopment researchers*, such as autism researchers [8], psychology researchers [44], and clinical researchers [40] to ensure the proper care of the characteristics, needs, and attitude of ASD population and, in turn, the effectiveness of the learning approach proposed. Similarly, *ICT researchers* (i.e., technology/computer science researchers and software developers) should be involved to guarantee the playfulness and the usability of the tool proposed [40]. Finally, a crucial role was also attributed to the active inclusion of *people with ASD* and *practitioners* working with them (e.g., teachers, educators, therapists) in the development process. In fact, they could contribute to ensuring the accessibility and usability of the final product [7], [19], [28], [41].

Concerning **RQ2**, 17% of analyzed reviews (exactly 4) highlighted the need to embrace a design methodology to guide the development team when designing IVR/VR-based systems (e.g., [7], [24], [40], [43] or SGs targeting people with ASD (e.g., [26], [28], [41]). However, none of them

TABLE 1. Existing reviews in the field of ASD focusing on SGs (cluster A) or IVR/VR-based systems (cluster B). The reviews were ordered according to the number of NeuroDevelopment and ICT researchers authoring the work (i.e., firstly, those in which the number of NeuroDevelopment researchers was higher than the number of ICT researchers (ND > ICT), then those in which the number of NeuroDevelopment researchers was equal to the number of ICT researchers (ND = ICT), finally those in which the number of NeuroDevelopment researchers was less than the number of ICT researchers (ND < ICT).

References	Authorships' profile	Cluster	RQ1 - Composition of Development Team		RQ2 - Design Methodology		RQ3 - ASD-specific IVR-based SGs design framework	
			Acknowledge the relevance of this issue	Address this issue (yes/partially) *(any limitations that may affect the generalizability of the reported findings)*	Acknowledge the relevance of this issue	Address this issue (yes/partially) *(any limitations that may affect the generalizability of the reported findings)*	Acknowledge the relevance of this issue	Address this issue (yes/partially) *(any limitations that may affect the generalizability of the reported findings)*
[4]	ND >>ICT 4 : 0	B	-	-	-	-	**Yes**	-
[14]	ND >>ICT 4 : 1	B	-	-	-	-	-	-
[40]	ND >>ICT 6 : 1	B	**Yes**	-	**Yes**	-	-	-
[27]	ND >>ICT 4 : 0	A	**Yes**	-	-	-	**Yes**	-
[20]	ND >>ICT 2 : 0	B	-	-	-	-	**Yes**	-
[13]	ND >>ICT 7 : 0	B	-	-	-	-	-	-
[22]	ND >>ICT 4 : 1	B	-	-	-	-	-	-
[41]	ND >>ICT 5 : 0	A	**Yes**	-	-	-	**Yes**	-
[12]	ND >>ICT 2 : 0	B	-	-	-	-	**Yes**	-
[42]	ND >>ICT 3 : 1	B	-	-	-	-	-	-
[7]	2 experts in ICT for ASD	B	**Yes**	-	-	-	**Yes**	-
[24]	ND = ICT 1 : 1	B	**Yes**	-	-	-	**Yes**	-
[32]	ND = ICT 3 : 3	A	-	-	-	-	**Yes**	-
[43]	ND = ICT 1 : 1	B	**Yes**	-	-	-	**Yes**	-
[44]	ND <<ICT 0 : 3	A	**Yes**	-	-	-	**Yes**	-
[26]	ND <<ICT 0 : 5	A	**Yes**	**Partially** Authors analysed if the team organization was cross-functional and/or participatory; however, this information was not always clear and shared as well as it was not reported for each included SGs *(only the 10% of analysed SGs was implemented as a IVR-based system)*	**Yes**	**Yes** *(only the 10% of analysed SGs was implemented as a IVR-based system)*	**Yes**	-
[29]	ND<<ICT 0 : 4	A	-	-	-	-	**Yes**	-
[45]	ND <<ICT 1 : 4	B	-	-	-	-	-	-
[8]	ND <<ICT 0 : 4	B	**Yes**	-	**Yes**	-	**Yes**	-
[46]	ND<<ICT 0 : 2	B	-	-	-	-	**Yes**	-
[28]	ND<<ICT 0 : 2	A	**Yes**	-	**Yes**	**Yes** *(none of analyzed SGs was implemented as a IVR-based system)*	-	-
[33]	ND <<ICT 1 : 2	A	-	-	-	-	**Yes**	-
[47]	ND <<ICT 0 : 3	A	-	-	-	-	-	-

actually addressed this research question. In particular, authors of these reviews [7], [24], [40], [41], [43] just recommended adopting inclusive or participatory approaches in the development process. Thus, they suggested actively involving people with ASD - not only as testers or evaluators - and other stakeholders (e.g., teachers and therapists). Only two systematic reviews, both on SGs for people with ASD [26], [28], partially addressed this research. However, among the research articles analyzed by these reviews [26], [28] which explicated the design methodology adopted, none of them was delivered as IVR-based systems. Thus, the findings of these works cannot be easily generalizable to IVR-based SGs. To sum up, by aggregating the findings across all analyzed reviews, it emerged that the most popular design methodologies followed for developing IVR/VR-based systems or SGs for ASD individuals are those typical of HCI, characterized by (1) having the end-users and their needs at the basis of design decisions, and (2) providing the active participation of representatives of the clinical population or other stakeholders in the decision-making and development process [26], [28].

Finally, concerning **RQ3**, 65% of analyzed reviews (exactly 15) highlighted the relevance of paying attention to how to design effective SGs or IVR/VR-based systems for people with ASD. However, none of them actually addressed this research question.

Instead, the main findings of these reviews deal with proposing some guidelines or indications on how to design IVR/VR-based systems or SGs in the ASD field. In particular, the review presented in [44] proposed some guidelines on how to design specific game elements to have a positive impact on the learning and the treatment of ASD, including those already existing in the field [30]. Similarly, regarding VR-based systems, the reviews presented in [7] and [8] proposed some design considerations shared among existing VR systems, focusing on the visual appearance of and interaction with virtual environments, free of any indications regarding the learning approach. In addition, the provided guidelines mainly focus on high-functioning ASD [8]. However, none of these works provides an ASD-specific SG design framework. As already argued in Section I, there was a large agreement in the academic community on the need to have a framework for designing SGs for people with ASD supporting designers at every stage of the design process without leaving them without guidance (e.g., [32], [35], [41], [44], [48], [49]). Only the systematic review presented in [41] partially faced this issue by providing an assessment framework for SGs targeting people with ASD, not specifically proposed to support the design of such systems. However, the authors tested their proposal through the assessment of SGs only for the learning and training of social and emotional skills, intentionally excluding SGs implemented as IVR-based systems.

Furthermore, it is essential to consider the inherent bias in the findings of the reviewed literature on SGs or IVR/VR systems for individuals with ASD, which may have influenced their results. This bias is represented by the fact that, despite the inherently multidisciplinary nature of this kind of rehabilitation tools, more than the 80% of these 23 reviews (exactly 19) were conducted by mono-disciplinary teams, i.e., involving a single professional profile (e.g., only neurodevelopment or ICT researchers) or, at most strongly skewed toward a particular domain. As already argued in the Section I, the effort of a heterogeneous multidisciplinary team is always required when the purpose of the research involves different specialties, such as psychology, pedagogy, computer science, HCI, and game design.

Therefore, to extend the preliminary findings previously published in [36], the present systematic literature review sets the ambitious goal of exhaustively addressing the three identified research questions by putting in place a balanced multidisciplinary inquiry team (i.e., two ASD-experienced neurodevelopment researchers experts and two ICT experts) to analyze all the meaningful aspects of IVR-based SGs available in the ASD field. These findings will result in guidelines for shaping future development processes in this area, intended to overcome the existing methodological issues. In addition, this paper is itself an attempt to overcome one of the primary limitations underlying the analyzed works since it is the product of work shared by a multidisciplinary team. In this way, this systematic review will provide useful guidelines for forthcoming research projects in this area while giving a concrete example of a multidisciplinary work team.

III. RESEARCH METHOD

A systematic review of the literature was conducted as it is a comprehensive, objective, and reproducible review methodology, allowing a trustworthy assessment of the existing literature on the topic [39], [50].

According to the Kitchenham review process [39], the core aspects of the adopted research method are presented in this section. For the reader's convenience, these aspects are organized as subsections: *Data Sources and Search Strategies*, *Study Selection and Quality Assessment*, *Data Extraction*, and *Data Synthesis*. In addition, to guarantee the transparency and reliability of the entire review process, it is documented and available in a repository [51]. Four are the quality parameters adopted in the present review process. They are:

- The involvement of a balanced multidisciplinary team composed of two ICT researchers, experts in IVR-based SGs design and development, and two neurodevelopmental researchers, experts in ASD diagnosis and rehabilitation.
- The presence of possible publication bias was checked using all standard search strategies suggested by [39]: scanning conference proceedings, scanning grey literature, and contacting experts and researchers working in the area and asking them if they know of any unpublished results;
- The exclusion of the grey literature, such as dissertations, theses, posters, reports, and unpublished works; only peer-reviewed journals and conference proceedings were included since they guarantee the highest quality

TABLE 2. List of search terms of the present systematic review. The three main terms are in bold in the first row, and their alternative forms are in their respective columns.

Autism Spectrum Disorder	**Immersive Virtual Reality**	**Serious Game**
Autism ASD	Immersive Virtual Environment HMD CAVE Virtual Reality	Educational Game

results possible, in line with other reviews conducted in the same field (e.g., [28], [29], [45]);
- The rigor in following Kitchenham's review process [39], except for study selection and quality assessment, for which more stringent specifications have been applied; this choice has become necessary given the significant number of research articles dealing with topics related to the research questions (SG and IVR-based systems for ASD) that did not contain meaningful information to address it.

A. DATA SOURCES AND SEARCH STRATEGY

Generally, the goal of a systematic review is to find as many research articles meaningful in answering the defined research questions as possible, using an unbiased search strategy [39]. Therefore, in the present systematic review, the search strategy includes the **search strings** and the **resources to be searched** to identify as many as possible research articles dealing with IVR-based SGs.

Specifically, the search string was formulated using a list of relevant terms for this systematic review (i.e. Autism Spectrum Disorder, Immersive Virtual Reality, and Serious Game) and their alternative forms, as reported in Table 2. These alternative terms were obtained considering the most frequent ones appearing in the 23 reviews analyzed in Section II (e.g., [8], [22], [28], [29], [45]).

In detail, associated with "Autism Spectrum Disorder" term, the terms "autism" and "ASD" were considered. Similarly, associated with the "Immersive Virtual Reality" term, the "immersive virtual environment" term was included. In addition, the most popular IVR technologies have also been considered as search terms, i.e., "HMD" and "CAVE". Then, in agreement with other reviews in this field (e.g., [7], [22], the term "Virtual Reality" was included in the list of search terms. In fact, the term "Virtual Reality" was not so rarely used with a broad conceptualization without referring to the level of immersion provided by the adopted technology. Finally, concerning the "Serious Game" term, the "Educational Game" term has also been included since it refers to a subset of SGs that have an educational goal [28], [52].

Consequently, the search string has been formulated as follows, using Boolean operators AND and OR:

> *("autism spectrum disorder" OR "autism" OR "ASD") AND ("immersive virtual reality" OR "immersive virtual environment" OR "virtual reality" OR "HMD" OR "CAVE") AND ("serious game" OR "educational game")*

The resources to be searched through the formulated search string are the following 8:

1) Scopus[1]
2) ACM digital library[2]
3) IEEE Xplore Digital Library[3]
4) Science Direct[4]
5) Web of Science[5]
6) PubMed[6]
7) Semantic Scholar[7]
8) Google Scholar[8]

They have been selected since regularly used by other reviews in this field (e.g., [8], [22], [28], [29], [45], as well as by systematic reviews in general (see, e.g., [53], [54]). Specifically, Scopus is a large and multidisciplinary bibliographic database of peer-reviewed literature, including more than 70 million records. ACM digital library is one of the most comprehensive databases of full-text papers and bibliographic literature covering computing and information technology. IEEE Xplore is a digital library that provides access to over five million publications concerning engineering and technology. Science Direct is a large multidisciplinary bibliographic database of peer-reviewed literature on scientific, technical, and medical research. Web of Science is a subscription-based database of bibliographic citations of multidisciplinary areas, including medical, scientific, and social sciences. PubMed is a free search engine whose database contains more than 34 million citations and abstracts of biomedical literature. Semantic Scholar is an Artificial Intelligence-driven search engine for scientific literature with more than 200 million papers across many disciplines. Google Scholar, adopted as a supplementary tool to the previous (principal) systems, is a larger free crawler-based web search engine used to seek literature that may have been missed in the search of the other electronic databases [7], [54]. This list allowed access to an extensive collection of relevant resources covering computer science conferences and journals (e.g., International Journal of Human-Computer Interaction, Journal of Computer Assisted Learning, Interactive Learning Environments) as well as health conferences and journals (e.g., Autism Research, Journal of Autism and Developmental Disorders). All searches were conducted in August 2021 thanks to the free access to the selected digital resources allowed by the authors' institution.

B. STUDY SELECTION AND QUALITY ASSESSMENT

According to [39], once the potentially relevant research articles have been found, they must be assessed and then selected according to their relevance. Related to the identified

[1]https://www.scopus.com
[2]https://dl.acm.org/
[3]https://ieeexplore.ieee.org/
[4]https://www.sciencedirect.com/
[5]http://apps.webofknowledge.com/
[6]https://pubmed.ncbi.nlm.nih.gov/
[7]https://www.semanticscholar.org/
[8]https://scholar.google.com

TABLE 3. Inclusion criteria.

IN1	Research articles published between January 2009 and July 2021
IN2	Research Articles written in English
IN3	Research Articles published in peer-reviewed journals or conference proceedings
IN4	Research articles having the full text available (not only title and abstract)
IN5	Research articles focusing on the learning of individuals with ASD
IN6	Research articles dealing with IVR-based SGs
IN7	Research articles including the description of the design and development of IVR-based SGs

TABLE 4. Exclusion criteria.

EX1	Research articles published before 2009
EX2	Research articles that are not written in English (e.g., Chinese)
EX3	Research articles of the following types: surveys, reviews, systematic reviews, meta-analyses, editorials, dissertations, theses, technical reports, student reports, posters, and unpublished works
EX4	Research articles that have duplicates
EX5	Research articles whose full text is not available nor obtained after a precise request to authors
EX6	Research articles that do not deal with the topics of the systematic review (e.g., learning environment for nurses education)
EX7	Research articles focusing on other health conditions (e.g., motor disabilities) or mental disorders (e.g., dementia)
EX8	Research articles presenting interventions for ASD caregivers (e.g., parents and therapists), and not for individuals with ASD
EX9	Research articles with a different purpose than learning (e.g., diagnosis)
EX10	Research articles presenting interventions not implemented as SG
EX11	Research articles presenting interventions not realized with IVR technologies (e.g., robots)
EX11	Research articles that do not describe the design and development of IVR-based SGs

research questions, the relevance is shown by defining a set of selection criteria. As mentioned above, to improve the quality assessment, the present systematic review adopted a set of selection criteria more detailed than those provided by [39]. Table 3 and Table 4 list the selection criteria defined as inclusion and exclusion criteria: research articles to be included in the present systematic review must meet all the inclusion criteria, as well as those to be excluded meet at least one of the exclusion criteria.

Inclusion criteria from IN1 to IN4 and exclusion criteria from EX1 to EX5 are related to more general scientific argumentation. For example, including all the research articles published after 2009 (IN1) guarantees that results deal with the current generation of IVR technology, in agreement with other reviews in the same field (e.g., [45]. Including only the research articles written in English (IN2) guarantees that results are the highest quality possible since it is considered the universal language of science [55], [56], [57]. Likewise, excluding research articles that do not have full text available (EX5) (e.g., only abstract or title appear online) is necessary to guarantee that the research articles used for the present systematic review have sufficient and consistent data. On the other hand, the inclusion criteria from IN5 to IN7 and exclusion criteria from EX6 to EX12 have directly derived from the research questions the present systematic review deals with. For instance, including the criterion IN5 guarantees that research articles have to focus only on interventions for the learning of individuals with ASD. Including the criterion IN6 guarantees that the ASD rehabilitation interventions can only be realized as IVR-based SGs. Likewise, excluding all research articles that do not relate to the topics of the present systematic review (EX6) guarantees to focus only on research articles that are relevant to the defined research question (e.g., research articles that are clearly unrelated to the scope of the present systematic review based on the title and abstract). Excluding research articles presenting interventions do not realize with IVR (EX11) guarantees the exclusion of research articles presenting interventions based on other ICTs, such as non-immersive VR technology (i.e., desktop-based systems), robots, mobile technologies (e.g., smartphones, tablets), tangible user interface, and off-the-shelf commercial videogame console (e.g., Nintendo Wii). For more details, examine the ‘‘included and excluded research articles’’ electronic sheet in the repository [51].

Figure 1 summarizes and visualizes the five stages underpinning the study selection and quality assessment. As the output of each stage, the number of research articles is indicated to highlight that the numbers of this systematic review are in line with other reviews of the same field (see, e.g., [22], [26], [32]. Whenever possible, stage outputs are associated with the digital sources from which they were derived (see outputs of stages 1 and 2 in Figure 1). For each stage, the specific performed actions and visual icons representing these actions are reported in the high part of the boxes, as well as in the low part of them, the inclusion and exclusion criteria are specifically reported.

In what follows, the five stages are then detailed:

1) **Stage 1: Digital Resource Searching** - The search string has been applied to digital resources. The search string reported in the previous subsection has been adapted in ‘‘Autism’’ ‘‘Immersive Virtual Reality’’ ‘‘Serious Game’’ only for the Semantic Scholar, since it is an AI-powered digital resource that does not allow the usage of Boolean operators.
2) **Stage 2: Digital Resource Filtering** - Filters have been applied to the output of stage 1. Filters reflected the exclusion criteria of Table 4, for example, publication year (EX1) or the chosen language (EX2). According to the functionalities of digital resources, selection criteria have been adequately applied (for details, see specifications under the arrow between Stage 2 and Stage 3 in Figure 1).
3) **Stage 3: Additional Semi-Automatic Filtering** - The research articles obtained as output from Stage 2 were collected in a unique electronic sheet by reporting the related authors’ list, title, year of publication, and source (e.g., name of the journal or conference proceedings where it was published). If there were missing information (e.g., sources), they were retrieved manually and inserted in the electronic sheet. Since many digital libraries do not provide automatic filters related

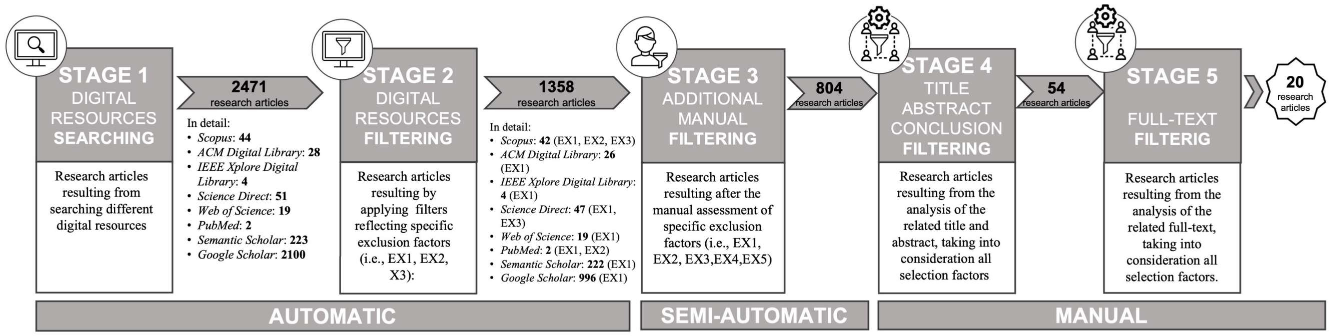

FIGURE 1. Study selection and quality assessment process conducted within this systematic review.

to all the listed exclusion criteria in Table 4, in this stage, they were applied semi-automatically. For example, many research articles that survived stage 2 were often archived twice or even three times; in stage 3, these duplicates were removed (according to EX4). Furthermore, research articles that were semi-automatically excluded were those not published in peer-reviewed journals or conference proceedings and presenting reviews or similar contributions (according to EX3). This activity was conducted by analyzing the titles and sources of the retrieved research articles. Additionally, in this stage, corresponding authors of those research articles not fully available were contacted (according to EX5).

4) **Stage 4: Title, Abstract, and Conclusion Filtering** - The 804 research articles filtered from stage 3 were, in stage 4, randomly divided into two sets of 402 and 402 research articles (denoted as StA and StB). A manual filter was applied to these two sets by analyzing titles, abstracts, and conclusions. To guarantee a high quality of this manual filter, two couples composed of experts (denoted as Cp1 and Cp2) dealt with the analysis of the two sets using a cross-referenced procedure. At the end of this stage, 54 research articles survived. Cohen Kappa Statistic was performed [58] to allow the reliability of the inclusion decision [39]. The results of Cohen K (0.90) showed 98% agreement among experts (Cp1 and Cp2) about the inclusion of the 54 surviving research articles.
5) **Stage 5: Full-text Filtering** - When the research articles filtered become 54, in stage 5, they were randomly divided into two new sets of 27 and 27 research articles (denoted as StC and StD). Cp1 and Cp2 apply an additional manual filter, analyzing full texts of research articles using a cross-referenced procedure. At the end of this filtering activity, 29 research articles survived. However, In this stage, it was determined that if multiple publications existed regarding the same IVR-based SG, only one research article would be included. Specifically, the article selected was the one that provided the most comprehensive and relevant information for the research questions at hand. This decision aligns with Kitchenham's review process indications [39] that including duplicate data in a systematic review synthesis would significantly bias the results. For more details, examine the "Multiple Publications" electronic sheet in the repository [51].

Therefore, at the end of the entire study selection process, the output consists of 20 research articles, each presenting the design and development of an IVR-based SG for the learning of individuals with ASD. Cohen K performed on the expert's agreement that led to the inclusion of these 20 research articles equals 1, i.e., 100% agreement. The list of included research articles is presented in the repository [51].

C. DATA EXTRACTION

Data extraction forms have been designed to accurately record the information needed to address the identified review question extracted from the selected research articles. The forms have been realized through electronic sheets. The contents of the data extraction forms used in the current systematic review, including also standard general data about the research articles, are listed below:

- Title
- List of Authors
- Year of publication
- Contribution type (i.e., journal/conference proceeding)
- Name of the project/application
- Team Composition (if available)
- People involved in the development process (e.g., ICT experts, neurodevelopment experts, ASD practitioners, people with ASD, families of people with ASD)
- Design methodology
- SG design framework adopted

The data extraction has been performed independently by all the experts conducting the present systematic review. The extracted data have then been compared, and disagreements have been resolved by consensus among researchers, obtaining a single electronic sheet for each selected research article.

D. DATA SYNTHESIS

All the data extracted from the selected 20 research articles have been analyzed by descriptive analysis (frequency analysis). The complete data analysis and synthesis are reported in Section IV.

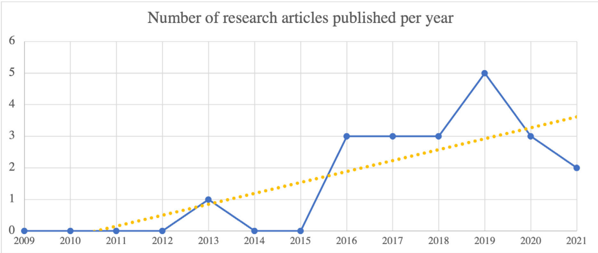

FIGURE 2. Number of research articles published from January 2009 to July 2021. The yellow dot line represents the trend of incremental interest in this field.

To guarantee the transparency, reliability, and repeatability of the present systematic review, the detailed description of the research methods adopted, as well as the documentation of the entire study selection and quality assessment process, was available in the repository [51].

IV. ANALYSIS OF RESULTS

In Fig. 2, the number of research articles published per year addressing IVR-based SGs for the learning of people with ASD is plotted. The yellow dot trend line drawn in this plot demonstrates the growing interest of the research community in IVR-based SGs for the learning of people with ASD, in agreement with the observation provided in Section I.

In what follows, the results of the current systematic literature review are reported, grouped by research question.

A. RESULTS FOR RQ1: WHAT IS THE COMPOSITION OF THE TEAM INVOLVED IN DEVELOPING IMMERSIVE VIRTUAL REALITY-BASED SERIOUS GAMES FOR AUTISM?

The analysis of the included research articles showed that authors rarely declared the entire composition of the team involved in the development p process (10% of the included research articles, exactly 2). More frequently, authors specified the involvement of specific individuals in the development process (60% of the included research articles, exactly 12).

Further analysis of the included research articles allowed for the evaluation of the profiles of the individuals included in these teams, yielding the following insights:

- 60% of included research articles (exactly 12) explicitly stated the involvement of practitioners working with people with ASD, such as teachers, educators, and therapists;
- 25% of included research articles (exactly 5) explicitly stated the involvement of people with ASD;
- 20% of included research articles (exactly 4) explicitly stated the involvement of families or carers of people with ASD;
- 10% of included research articles (exactly 2) explicitly stated the involvement of ICT researchers/experts;
- 5% of included research articles (exactly 1) explicitly stated the involvement of neurodevelopment researchers or clinical researchers.

The frequency analysis just described, based on the explicit statements provided by the authors of the 20 included research articles, is concerning. Indeed, it showed that the authors do not consider the essential focus on the composition of the multidisciplinary development team. Based on this surprising result and the small number of included research articles, it was possible to conduct further investigation. Specifically, additional details about the individuals engaged in the development process were deduced by analyzing the authors' affiliations, curricula, and acknowledgments in the included research articles. Notably, it was found that 100% of the included research articles (exactly 20) featured authors who were researchers/experts in the field of ICT. Similarly, it was found that 40% of the included research articles (exactly 8) featured authors who were neurodevelopment or clinical researchers/experts. For example, the study reported in [59] was carried out within a multidisciplinary research laboratory (i.e., the Behavioral and Robotic Neurorehabilitation Laboratory of IRCCS Centro Neurolesi "Bonino-Pulejo" - Messina, Italy). Instead, the affiliations of the authorship of [60] revealed the collaboration of authors belonging to three different institutions (i.e., the Socio-Cognitive Robotics Laboratory at the Sharif University of Technology, the Institute for Cognitive and Brain Sciences (ICBS) at the Shahid Beheshti University, and the Center for the Treatment of Autistic Disorders (CTAD) of Tehran, Iran).

Table 5 provides a detailed analysis of the included research articles concerning this research question. Empty cells in the table indicate that the corresponding research article did not include meaningful information addressing this research question.

B. RESULTS FOR RQ2: WHICH DESIGN METHODOLOGIES ARE ADOPTED FOR DEVELOPING IMMERSIVE VIRTUAL REALITY-BASED SERIOUS GAMES FOR AUTISM?

The analysis of the included research articles revealed that only 30% of the articles (exactly 6) explicitly reported the design methodology employed in the development process. However, it is important to acknowledge the possibility that other articles may have followed a specific design methodology without explicitly stating it due to limitations in publication length or limited awareness of the importance of including this information. Consequently, the accuracy and reliability of the entire development process could be questioned. In a few cases (10% of the included research articles, exactly 2), authors declared the active involvement of individuals with ASD [63] and other stakeholders, such as parents, educators, and therapists [68], in the development process of the proposed IVR-based SGs, without specifying the design methodology followed.

The analysis of the design methodologies explicitly reported by the authors provides the following insights:

- 10% of the included research articles (exactly 2) explicitly reported the adoption of Participatory Design [66], [79];
- 10% of the included research articles (exactly 2) explicitly reported the adoption of Co-Design [62], [65];

TABLE 5. RQ1 - analysis of included research articles.

Ref.	Declaration of Team Composition	People involved				
		ICT Researchers	ND Researchers	Practitioners	Final users	Family members of final users
[61]	x	x*	-	x	x	-
[62]	x	x	x	x	-	-
[63]	-	x*	x*	x	x	x
[64]	-	x*	-	x	x	x
[65]	-	x*	x*	x	x	-
[66]	-	x*	x*	x	x	-
[67]	-	x*	-	x	-	x
[59]	-	x*	x*	x	-	-
[60]	-	x*	x*	x*	-	-
[68]	-	x*	-	x	-	x
[69]	-	x*	-	x	-	-
[70]	-	x*	-	x	-	-
[71]	-	x*	x*	-	-	-
[72]	-	x*	x*	-	-	-
[73]	-	x*	-	x	-	-
[74]	-	x*	x*	-	-	-
[75]	-	x*	-	-	-	-
[76]	-	x*	-	-	-	-
[77]	-	x*	-	-	-	-
[78]	-	x*	-	-	-	-
		** information deduced from authorship/acknowledgement*				

- 5% of the included research articles (exactly 1) explicitly reported the adoption of Collaborative Design [64];
- 5% of the included research articles (exactly 1) explicitly reported the adoption of Empathic Design [79];
- 5% of the included research articles (exactly 1) explicitly reported the adoption of User-Centered Design [69].

It is noteworthy that in one case, there was an explicit mention of the joint adoption of two design methodologies: Empathic Design and Participatory Design, in the study described in [79].

In summary, the results indicate that although the design methodology was presented in a limited number of research articles, there was a clear preference for design methodologies commonly employed in the HCI field. These methodologies focused on addressing the needs and characteristics of the final users, with active involvement from individuals with ASD and other stakeholders such as families, teachers, educators, and therapists.

C. RESULTS FOR RQ3: WHAT DESIGN FRAMEWORKS ARE USED TO DESIGN IMMERSIVE VIRTUAL REALITY-BASED SERIOUS GAMES FOR AUTISM?

From the analysis of the included research articles, it was found that none of them explicitly stated the adoption of any SG design framework. However, it is important to note that the absence of explicit mention does not definitively exclude the possibility of a design framework being utilized but not disclosed by the authors. Given the wide range of existing SG design frameworks not specific to ASD, it is not possible to conclusively determine from the analysis of the respective research articles whether a framework has been employed.

On the other hand, when considering the available design-support resources specifically tailored for ASD, only one of the included research articles [67] explicitly indicated the incorporation of VR-systems design guidelines provided by [8] in the design process of the proposed IVR-based SG. In contrast, in one of the included research articles [75], the authors stated that the development process of the IVR-based SG took into consideration the "American College of Sports Medicine's guidelines for exercise", which are more general design guidelines for physical exercises, not specific to ASD.

V. DISCUSSION

This section brings forward a discussion on the challenges and methodological issues characterizing the development of IVR-based SGs for ASD individuals, primarily focusing on the findings derived from this systematic review. The focus is on analyzing these findings in relation to the RQs presented in Section I, with the aim of providing a comprehensive understanding of the issue and drawing some recommendations that may be helpful to designers, developers, and researchers approaching the field of IVR-based SG for the learning of people with ASD.

A. WHAT IS THE COMPOSITION OF THE TEAM INVOLVED IN DEVELOPING IMMERSIVE VIRTUAL REALITY-BASED SERIOUS GAMES FOR AUTISM?

As discussed in Sections I and II, the analysis of existing literature in the field of ASD indicates that teams involved in developing learning systems for individuals with ASD should possess a heterogeneous nature. In particular, it is crucial for these teams to demonstrate a strong commitment to multidisciplinarity and inclusivity [7], [32], [40], [43], [44], [80]. Furthermore, although the literature lacks a standardized framework for the composition of development teams, existing reviews on SGs and IVR/VR systems in the ASD field suggest the involvement of various stakeholders. These include ICT researchers, encompassing both computer science/technology researchers and software developers, as well as neurodevelopment researchers and clinical researchers, individuals with ASD, and practitioners working closely with them, such as teachers, educators, and therapists [7], [32], [40], [43], [44], [80].

The findings derived from the analysis of the included research articles partially align with these indications. Specifically, it was observed that multidisciplinarity and inclusivity were not always adequately emphasized within the development teams of the included research articles. On one hand, a comprehensive presentation of the characteristics of the development team, including its members, is not always provided by the authors. On the other hand, when authors do provide information, there is a tendency to involve ASD practitioners more frequently than neurodevelopment and clinician researchers/experts. Additionally, in some cases, deduced information suggests that only ASD practitioners were involved, without the inclusion of neurodevelopment and clinician researchers/experts. The lack of information regarding their expertise, background, and knowledge raises questions about their equivalence to neurodevelopment researchers in the ASD field and the effectiveness of the proposed learning approach. Then, from the inclusivity viewpoint, people with ASD were engaged only in a few cases. Finally, sometimes even the families of people with ASD were involved, aligning with current suggestions in the ASD field for designing ICT systems for individuals with ASD (e.g., [81], [82]).

The underestimation of multidisciplinarity and inclusivity of the involved development teams may have different motivations. The authors may not have reported all individuals involved in the development process due to publication length limitations or lack of attention to this information. This suggests a lack of awareness of the relevance of these aspects in this type of study. Additionally, since the Literature lacks a structured composition of the team to be engaged in the development process of IVR-based SGs for autism, researchers can only rely on what concerns their know-how when deciding the people to involve in the development process. Finally, from the methodological perspective, the collaboration between researchers with different backgrounds and the active involvement of ASD subjects and other stakeholders may be challenging due to the lack of specialized design methodologies and approaches [83], [84], [85].

Addressing these issues requires filling existing gaps in the literature. A structured composition of the multidisciplinary and inclusive team, specifying the actors to be involved and their profiles, expertise, skills, knowledge, and roles and responsibilities, should be proposed.

Concerning the multidisciplinary aspect, from the ICT viewpoint, there should be experts/researchers with a background in SG design, IVR Technology and related affordance (i.e., level of immersion, sense of presence), HCI, sound and graphic designers. On the other hand, from the psycho-pedagogical viewpoint, there should be experts/researchers with a background in rehabilitation and education of people with ASD. Regarding the inclusivity aspect, the active involvement as informants or co-designers of representatives of this clinical population is strongly required [82], [86], as well as the involvement of families of people with ASD (especially in the case of non-verbal subjects [82]) and of practitioners working with people with ASD (especially if the proposed systems are intended to be integrated into the therapeutic/educative path [24], [43]).

B. WHICH DESIGN METHODOLOGIES ARE ADOPTED FOR DEVELOPING IMMERSIVE VIRTUAL REALITY-BASED SERIOUS GAMES for AUTISM?

Over the past few decades, there has been an increasing awareness of the importance of following appropriate design methodologies in both Academia and Industry [87], [88]. The value of design methodology is widely recognized due to its numerous benefits, such as improving communication between diverse disciplines involved in the design process, facilitating knowledge transfer, and increasing efficiency in terms of quality, cost, and time [87], [88], [89]. In the development of IVR-based SGs for individuals with ASD, a design methodology plays a crucial role in supporting designers in dealing with the complex demands of varying contexts and environments [87], [88].

As mentioned earlier, the key to developing these systems lies in embracing perspectives from diverse disciplines and engaging a heterogeneous development team with a multidisciplinary and inclusive attitude. However, working together can be challenging for several reasons. On one hand, there is a gap between technology researchers and neurodevelopment researchers, stemming from their different views, working approaches, expectations, backgrounds, and specialist language [8], [84], [90]. Coordinating these different perspectives can be demanding [84], [85]. On the other hand, effectively involving individuals with ASD in the development process presents challenges related to their impairments, such as working in unfamiliar settings with researchers with whom they have no previous social relationships [83]. Therefore, adopting rigorous methodological approaches that provide a general structure for organizing team activities and specifying the roles and responsibilities of stakeholders is valuable [84], [85].

As discussed in Section II, existing reviews indicate that the most appropriate design methodologies for developing IVR/VR systems or SGs in the ASD field are those commonly used in the HCI field. These methodologies focus on incorporating end-users' needs into design decisions and actively involving representatives of the clinical population and other stakeholders in the development process [28].

The results of the analysis of the included research articles align with these indications. Although the design methodology was only presented in a limited number of research articles, there was a clear preference for HCI-based design methodologies that prioritize the needs and characteristics of the final users and embrace a participatory approach. In particular, Participatory Design and Co-Design emerged as the most popular design methodologies.

However, it is important to acknowledge the limitations and generalizability of this design methodology in addressing the challenges specific to this context. While Participatory Design is valuable in considering the characteristics, needs, and attitudes of the end-users and involving all beneficiaries in the development process, it may not adequately address the specific requirements of IVR-based SGs for individuals with ASD (e.g., balancing learning effectiveness and engagement, social acceptability, and usability of the proposed systems) or effectively coordinate the work of a multidisciplinary and inclusive team that includes individuals with ASD. Many researchers highlight the lack of specialized methodological approaches for developing ICT systems for individuals with ASD as a significant issue [8], [84], [85], [91]. For instance, [84] observed that previous efforts in Participatory Design primarily focused on engaging individuals with ASD through innovative participatory methods, with less emphasis on harmonizing the perspectives of the diverse team members involved in the multidisciplinary and inclusive design process. Additionally, as is the case in general [89], [92], the increasing understanding of the characteristics, needs, and preferences of the clinical population and advancements in IVR technology have expanded the problem space, requiring explicit consideration of issues such as the balance between learning effectiveness and playfulness and the increased functionality and complexity of IVR devices.

Therefore, effectively addressing these issues in this context necessitates the development of a new design methodology that adapts and tailors existing approaches, such as Participatory Design, Co-Design, and User-Centered Design, specifically for the development of IVR-based SGs for individuals with ASD. This specified design methodology should provide a structured "step-by-step" guidance for conducting the development process, supporting all participants in efficiently addressing the complex and challenging problems that may arise. Moreover, the proposed design methodology should ensure the coordination of development steps by providing: (1) specific activities and objectives for developing IVR-based SG systems to meet their unique requirements, (2) clearly defined roles and responsibilities for the diverse team members to enhance collaboration and harmonization of perspectives, and (3) appropriate methods and techniques for actively involving individuals with ASD and other stakeholders, such as family members, teachers, educators, and therapists.

C. WHAT DESIGN FRAMEWORKS ARE USED TO DESIGN IMMERSIVE VIRTUAL REALITY-BASED SERIOUS GAMES FOR AUTISM?

As extensively discussed in the Literature (e.g., [29], [32], [35], [36], [37], [44], [49]), the design of SGs for individuals with ASD presents several challenges and complex issues that necessitate the support of a design framework. Broadly speaking, a design framework provides valuable and reusable "building blocks" that can be utilized to design various types of SGs [34], [37], [93], [94]. Additionally, such a framework encourages both ICT and neurodevelopment and clinician researchers/experts to concentrate on the design of all essential elements of an SG, thereby fostering effective communication and collaboration among them [34], [93]. This approach guarantees the achievement of a harmonious balance between learning and engagement, resulting in enhanced effectiveness of the proposed educational tool [12], [34], [35], [36], [37], [49].

Over time, several design frameworks have been proposed to serve anyone interested in designing well-balanced and successful SGs (e.g., [34], [94], [95], [96]). However, being not intended to be used for a specific purpose or in a specific context, they generally appeared irrespective of final users and their needs as well as the technological aspects [35], [48], [49]. In addition, this wealth of design frameworks for SG is not found in the field of ASD, although it is well established that such solutions cannot be readily adopted "as-is" [35], [48], [49]. In fact, existing SG design frameworks need to be carefully analyzed and revised if adopted in the ASD field for designing SGs targeting a clinical population with such specific characteristics and special needs [32], [48], [49]. Moreover, they are not supportive enough if the SGs under design should be implemented with technologies whose inherent features and affordances (e.g., immersion, sense of presence) entail different issues and challenges [9], [35], [49]. Therefore, it is widely recognized that the existence of ASD-specific frameworks for designing SGs is still an open issue (e.g., [32], [35], [44], [48], [49]).

Focusing on the results of the analysis of the included research articles, it seems that none of the proposed IVR-based SGs was designed according to a SG design framework. In addition, the existing guidelines for designing VR-based systems for autism [8] were taken into consideration only in one case [67], while existing guidelines for designing SGs for ASD [30], [44] were never mentioned.

Consequently, given the increasing interest in such systems and the inherent challenges in designing them, it is time to propose an ASD-specific SG design framework able to effectively support a multidisciplinary and inclusive team in the development process of IVR-based SGs targeting people with ASD. It should provide a comprehensive building structure including all essential SG elements upon which develop different SGs for the learning of people with ASD, such as those implemented as IVR-based systems [35], [37], [49], [93]. For each SG element, there should be a set of design guidelines to consider. They should be delineated from the lessons learned from previous studies, corroborated by empirical evidence found in the ASD Literature, and validated by both ICT experts with a background in SG and IVR-system design and neurodevelopment experts with a background in the treatment of people with ASD. Wherever it is impossible to identify valid guidelines on the basis of available findings, it will be essential to plan and conduct studies to define them [7], [8]. In addition, through this comprehensive design framework, all the SG elements will be designed also bearing in mind the characteristics and related affordance of IVR technology.

By adopting a comprehensive design framework, the team will work more effectively as they will be guided in designing all essential aspects of IVR-based SG elements, not only some specific game or visual elements. Thus, the team will conduct the design process without neglecting any aspects of such complex systems, aware of features they should have to be considered learning effective, engaging for such a clinical population, and, in turn, practically relevant. The intended design framework will help designers work more efficiently thanks to the use of reusable design elements [37]. In addition, it will push all team members to focus on the design of all of them, ensuring the achieving of a proper balance between learning effectiveness and playability and of an optimal level of immersion, acceptability, and usability of the developed IVR-based SG for people with ASD. As a result, the final systems could be considered "true" SGs, with an appropriate balance between *serious* (e.g., learning effectiveness, generalizability, and maintenance of learned skills) and *game* (e.g., enjoyability, playability, engagement, motivation) aspects. Alternatively, given the lack of an ASD-specific IVR-based SG design framework, it should be valued to adopt and revise at least one of the most consolidated SG design frameworks (e.g., [34], [94], [95], [96], [97], [98], [99]), along with the available SG and VR system design guidelines (although the support they can provide is limited).

VI. CONCLUSION AND FUTURE WORKS

The present systematic review was born from the evidence that ICT-based interventions, particularly IVR-based SG, are promising for the learning of people with ASD. However, despite the greater attention toward this kind of system, it is widely recognized that developing IVR-based SGs for people with ASD is fraught with challenges, and Literature still lacks appropriate support for designers in effectively facing them [7], [32], [35], [100].

This systematic review goes in this direction, charged with the aim of delineating some primary indications for shaping the development of IVR-based SGs for the learning of people with ASD to face some of the open methodological issues arising in this field, such as the composition of the multidisciplinary and inclusive development team (RQ1), the design methodology to follow in the development process (RQ2), and the SG design framework to be adopted (RQ3). To this end, a balanced multidisciplinary inquiry team (i.e., two ASD-experienced neurodevelopment experts and two ICT experts) conducted an in-depth analysis of the Literature in the ASD field, including 23 reviews focusing on SGs or IVR/VR systems and 20 research articles dealing with IVR-based SGs for people with ASD retrieved through a systematic review process, with the ambitious aim of identifying guidelines for shaping future development processes of IVR-based SGs for autistic people.

Concerning the **composition of the development team** involved in the development process, it should be valuable to emphasize its multidisciplinary and inclusive aspects. From an ICT viewpoint, the team should consist of researchers specializing in SG design, IVR technology and related affordances (such as immersion and sense of presence), HCI, sound, and graphic design. Meanwhile, from a psycho-pedagogical standpoint, researchers with expertise in ASD rehabilitation and education should be included. To ensure inclusivity, the active involvement of individuals with ASD is crucial. Additionally, the engagement of families of individuals with ASD and practitioners working in this field is essential, particularly if the proposed systems are intended for integration into therapeutic or educational pathways.

Concerning the **design methodology** to be employed during the development process, it is advisable to adopt HCI methodologies that prioritize the end-users and their specific requirements. This involves actively involving individuals with ASD in the design process, along with other stakeholders such as families of autistic individuals and professionals working with this clinical population, including teachers, educators, and therapists. By incorporating the perspectives and insights of these diverse stakeholders, the design process can better address the unique needs and preferences of individuals with ASD.

Lastly, it should be necessary to delineate a **specialized design framework** for developing effective IVR-based SG for the learning and training of individuals with ASD. This framework should encompass a comprehensive "building structure" that addresses all essential elements of these systems, with a particular emphasis on enhancing motivation to play and the generalization of learning skills within this clinical population. By adopting such a framework, the resulting systems can be considered authentic SGs, striking a suitable balance between the serious aspects (such as learning effectiveness, generalizability, and maintenance of acquired skills) and game elements (such as enjoyment, playability, engagement, and motivation). However, since there is currently a lack of an ASD-specific IVR-based SG design framework, it is valuable to consider existing design guidelines for SGs and IVR-based systems, albeit with limitations in their applicability to this specific context. Nonetheless, leveraging these guidelines can provide some level of support in the absence of a dedicated framework.

In conclusion, it would be valuable to emphasize the added value of the findings of this extensive work, both in terms of identifying the key lacks in the research on this topic and outlining the future research agenda to fill these lacks. Subsequent research in this field should focus on developing methodological solutions based on the proposed guidelines. This will ensure the provision of tangible and practical support for designing these systems in a more effective, ethical, safe, and sustainable manner. It is important to emphasize that these advancements should not be limited to the academic realm but also extend to the industrial sphere, fostering collaboration and implementation of innovative approaches.

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