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Review

The Use of Sense of Presence in Studies on Human Behavior in Virtual Environments: A Systematic Review

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Abstract: Sense of presence is a key element of the user experience in the study of virtual environments. Understanding it is essential for disciplines, such as architecture and environmental psychology, that study human responses using simulated environments. More evidence is needed on how to optimize spatial presence in simulations of built environments. A systematic review was conducted to define the use of sense of presence in research on human behavior in virtual spaces. Conceptualized dimensions, measurement methodologies, simulation technologies and associated factors were identified. The study identified a diversity of approaches and the predominance of subjective measures over sense of presence indicators. Several studies noted that environmental variables and spatial typologies had significant effects on presence. The results showed that different user profiles responded to stimuli in different ways. The results emphasized the importance of conceiving the construct in interrelation with the built context. A more comprehensive and multidisciplinary orientation is required to identify principles that optimize the spatial experience in virtual environments. This will be important for disciplines that research the human experience using virtual environments.

Keywords: sense of presence; spatial presence; virtual environments; virtual reality; extended reality; human behavior; sensory modalities; multimodal; architecture; emotion

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1. Introduction

Sense of presence, a central element in the human experience in virtual environments (VE) [1,2] has been widely studied. It has been defined as a psychological state or a subjective perception where technology mediates the experience of the individual, but the environment is perceived as if that technology were not involved [3]. Lombard and Ditton [4] described it as the "perceptual illusion of non-mediation," in which the technology and the external physical environment fade from the user's phenomenological consciousness. This "illusion" implies continuous (real-time) responses of the human sensory, cognitive and affective processing systems to objects and entities in a person's environment.

Sense of presence is a multidimensional concept [3,5]; that is, different types exist. Comparatively little is known about what types do exist, but scholars have proposed several dimensions (in many cases non-orthogonal or overlapping) [3]. Researchers are beginning to empirically evaluate the validity of some of these dimensions. Very often there has been confusion about how to study presence and its determinants and consequences. Among the most recognized dimensions of presence are spatial presence, co-presence, social presence and self-presence [3,6]. Of these, spatial presence has been defined as "a sense of being there" [3]. However, this conceptualization has sometimes been crossed with the general notion of presence, also sometimes described as the subjective experience of being in a place or environment, even when one is physically elsewhere [7,8].

Understanding the factors that modulate the subjective experience of presence is essential for disciplines that study human responses using virtual environments [9]. One field where this is particularly important is research into human behavior in architectural and urban spaces. The human experience in built environments has been defined as a mental state affected by environmental variables, reflecting in psychological, physiological and emotional responses [10]. A key challenge is the creation of controlled contexts that will allow researchers to quantify the impact of architectural design on that experience [10,11]. Virtual environments allow researchers to create controlled simulations of everyday situations, thus accessing contexts where physical presence is not possible [12]. They also make it possible to test proposals more quickly and economically than do physical models [10,13]. The versatility of virtual modeling tools facilitates the simple manipulation of variables, either individually or together, which improves experimental controls and the understanding of cause–effect relationships [10].

The effectiveness of virtual environments is commonly evaluated through the sense of presence they evoke in the user [7,14]. Loomis [15] theorized that "complete presence" is achieved when there is equivalence in sensory and cognitive experiences between the simulated and physical worlds. The human experience in the physical world is inherently multisensory [16]; therefore, it is natural that the number and consistency of sensory outputs in a simulated environment are determinants of sense of presence [4,17,18].

However, several authors have argued that presence is determined by two general categories of variables, that is, media characteristics and user characteristics [1,4,19]. Media characteristics are display properties (e.g., screen resolution), content (e.g., objects, actors and events that make up the environmental context) and the ability to interact with and modify the medium [17]. User profile characteristics range over sociodemographic variables, perceptual, cognitive and motor skills, previous experiences and personality differences [1].

Some researchers have begun to examine the relationships between these media and user characteristics in terms of presence and the attributes of virtual environments. This approach takes into account landscape typologies [12,20], affective environments [1,10,12] and environmental variables such as smells, temperature, textures and other multimodal sensory qualities inherent in the built environment [21–24], and perceived morphological spatial attributes [19]. In environments "without physical boundaries" (i.e., the body), participants must engage in a variety of proxemics or cognitive functions in spatial domains (e.g., spatial positioning, spatial performance, spatial development, appropriation, socio-spatial interactivity) to solve problems and achieve goals [25]. Understanding human responses to different spatial configurations is key in architectural practice. Several studies have examined behavioral, psychological, physiological and emotional reactions to variables of the virtual built environment [5,21,26,27]. This approach integrates architecture, neuroscience and environmental psychology. Architectural research provides design characteristics that elicit different experiences in users (e.g., relaxing, restorative, motivating). Environmental psychology defines experiences in specific settings, and neuroscience provides means and methods to objectively measure these experiences [10].

However, there is no consensus on a comprehensive methodology to explain the impact of spatial variables on the human experience and presence [10]. The literature provides subjective and objective measurement approaches [28]. Subjective approaches use post-experience questionnaires to obtain conscious judgments of the psychological states evoked by environments [7,29]. However, answering questionnaires can cause a break in presence (BIP), potentially affecting evaluations [30]. Objective measures record automatic responses, such as heart rate, galvanic skin response and neurological signals, without conscious deliberation [26,31]. They are less frequently employed because they require specialized equipment and complex data analysis [32]. Both approaches have limitations, so the triangulation of subjective and objective measures would provide an enhanced understanding of presence.

To fully harness the potential of virtual environments in architecture and related disciplines, a better understanding of the experience of presence and its relationship with environmental contexts is required. In the present systematic review, the aim is to examine the state of the art on the use of sense of presence in research into human behavior in virtual built environments. Specifically, the following objectives were set: to identify (1) the dimensions of presence used in the field; (2) the measurement methodologies used; (3) the formats and technology media used to simulate virtual environments; (4) the relationships between environmental variables and presence; (5) the relationships between spatial attributes and presence; (6) the links between technology conditions and presence; and (7) the links between user characteristics and presence. It is expected that the results will advance the comprehensive conceptualization of sense of presence, taking account of measurement techniques, simulation technologies and associated factors. This will lay the groundwork for progress in the optimal design of virtual environments capable of evoking a sense of presence, a result useful in fields such as architecture, neuroscience and environmental psychology that address the human experience in response to environmental conditions.

2. Materials and Methods

This study adopts a transparent and systematic methodology. Denyer and Tranfield's [33] methodology was followed: (1) formulation of objectives, (2) identification of studies, (3) selection of studies, (4) analysis and synthesis and (5) presentation of results. The data collection method used was the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA), taking the PRISMA 2020's four-stage flow diagram for data screening [34].

Systematic reviews are essential for summarizing evidence accurately and reliably [35]. This type of review attempts to collate all empirical evidence that fits pre-specified eligibility criteria to answer specific research questions. It uses explicit, systematic methods, thus providing reliable findings from which conclusions can be drawn and decisions made [36]. The PRISMA methodology provides authors with ways to ensure the transparent and complete reporting of systematic reviews and meta-analyses [35]. The PRISMA methodology has been previously employed in similar studies, for example, in reviews on neuroarchitecture [37,38], architectural context stimuli and human behavior [39–41], virtual reality, augmented reality and Building Information Modeling (BIM) applied to architecture, engineering and construction [42–46] and reviews on sense of presence in virtual environments [47,48] and affective responses [49].

In the first stage, relevant records were identified in the databases, in this case, 29,149 records, of which 19,417 were retained for analysis (see Section 2.1). Of these, 8201 duplicate records were removed, leaving 11,216 records for review. Next, following the PRISMA 2020 workflow, an evaluation was conducted based on: (1) selection of relevant titles for final inclusion; (2) abstract screening; and (3) full-text screening (see Section 2.2). In stage 1, title screening, 10,316 records were excluded, leaving 900 records for abstract and full-text screening. During abstract screening, 720 records were excluded, leaving 180 records for full-text evaluation. Finally, after full-text screening, 160 records were excluded, resulting in 20 final studies for data extraction and analysis.

2.1. PRISMA Record Identification

Three main search factors were used in the data collection: (a) links with sense of presence; (b) links with the built environment; and (c) links with human behaviors and related disciplines. The sense of presence search factor includes studies that explore the phenomenon globally or through specific dimensions. The built environment factor was used to locate research analyzing environmental variables of the built space, both physical and virtual. The search factor C "Human Response" is composed, on the one hand, of keywords related to behavioral, cognitive and affective responses (cognitive, perception, experience) and, on the other hand, of keywords linked to related disciplines (neuroarchitecture, environmental psychology).

A preliminary review was carried out to identify determining keywords within each search factor. A search was conducted in different databases using the following formulation: "Search Factor A" AND "Search Factor B" AND "Search Factor C", where "Search Factor A" corresponded to ("Keyword A1" OR "Keyword A2" OR "Keyword A3"), and similarly for B and C. The keywords examined are shown in Table 1. The search keywords were used twice (January and March 2023) in a total of 12 databases in the areas of architecture, social sciences and neuroscience. The search returned 29,149 results. These are shown in Table 2. Exclusion criteria were applied, that is, the material had to be: (a) in the English or Spanish language, (b) published in scientific journals (excluding conference papers, doctoral theses, etc.). It should be noted that the search did not take account of the publication date of the articles. After applying these criteria, 19,417 articles remained. Of this total, 8201 duplicate records were eliminated, so 11,216 records remained.

Table 1. Classification of keywords and search factors.

	Search Factor (A)	Search Factor (B)	Search Factor (C)
	Sense of Presence	**Built Environment**	**Human Responses**
1	sense of presence	environment	human behavior
2	experience of presence	architecture	cognitive
3	telepresence	urban	perception
4	co-presence	place	experience
5	copresence	virtual	sensory
6	virtual presence	space	sense
7	self-presence	building	emotional
8	social presence	landscape	affective
9	mediated presence		
10	presence-inducing		neuroarchitecture
11	inner presence		environmental psychology
12	physical presence		evidence-based design
13	object-presence		phenomenology

Table 2. Database search results.

	Database	Final Results
1	Science Direct	5762
2	Scopus	4750
3	Social Science Premium Collection	4572
4	Web of Science	4026
5	ProQuest Publicly Available Content Database	3021
6	ProQuest One Business	2697
7	ProQuest Education Collection	2500
8	APA PsycInfo	1215
9	PubMed	575
10	APA PsycNet	17
11	Avery Index	12
12	UrbanDoc	2
	Total Results	29,149

2.2. PRISMA Records Screening

The selection process had three stages: (1) selection of relevant titles for final inclusion; (2) evaluation of abstracts; and (3) evaluation of full texts. For 1, 2 and 3, criteria based on relevance to the set objectives were applied. Regarding the inclusion criteria, it should be noted that, with respect to "sense of presence", some articles referred only to "presence", a word with multiple meanings unrelated to the study's objectives, for example, "presence of/on/in/at...” (e.g., presence of vegetation). Studies examining “sense of presence” sometimes used the term differently, specifically in works on schizophrenia, religion, rituals, spectral presence and human presence (e.g., Paleolithic). The same applied to “Co-presence” or “Copresence” (e.g., co-presence of animals, nanoparticles). Legislative/politics-focused studies (e.g., on immigration, international relations) discussing social presence, unaligned with the present study’s objectives, also appeared. This led us to set the following exclusion criteria: (1) Studies using the term “presence” (or similar) with objectives unaligned with those of the present study. In addition, in examining the built environment, many studies referred to “environment” but did not analyze environmental contexts. It is common for presence-focused research to use virtual environments. In this case, this yielded multiple instances of the use of the word “environment” which were unrelated to the study’s objectives. (2) Studies where the built environment was an incidental variable were not included. After eliminating duplicates, selecting relevant titles, evaluating abstracts and full texts, the final list for analysis contained 20 documents. For more details, see Figure 1, which shows a flowchart of the development of the PRISMA methodology.

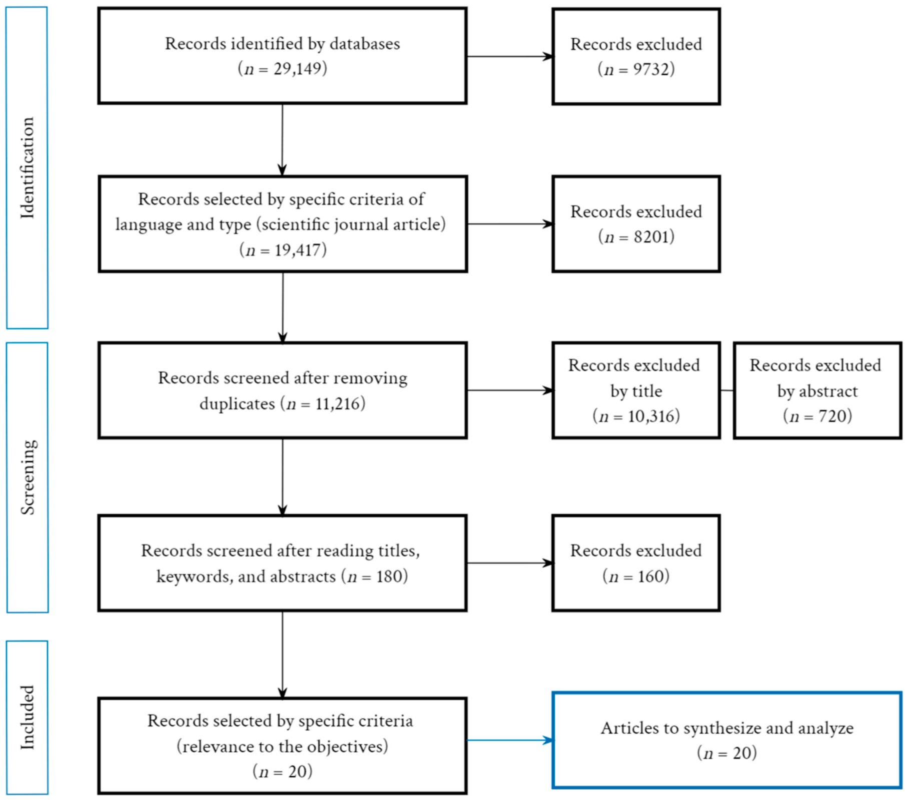

Figure 1. PRISMA data screening process.

2.3. Analysis Methodology

The methodology was based on an integrative synthesis applying content analysis. Integrative syntheses summarize data where the variables are secure and adequately specified [50]. This approach is mainly suitable for synthesizing quantitative studies [51]. Content analysis is a systematic technique that categorizes data into themes developed for primary research, and draws on a wide variety of information, mainly textual [52]. Stemler [53] defined content analysis as “a systematic and replicable technique for compressing many words of text into fewer content categories based on explicit coding rules”.

Data Coding and Tabulation System

For the data-coding process, several taxonomies were established based on sub-objectives 4, 5, 6 and 7, that is, those focused on identifying the internal relationships between variables and sense of presence. To address these variables and their coding, we developed a first taxonomy based on environmental variable type, a second based on built environment type (context) and a third based on condition (technology or user profile). The taxonomies were formally established after investigating and understanding how the studies were undertaken (see Figure 2 for a graphic taxonomy of environmental stimuli).

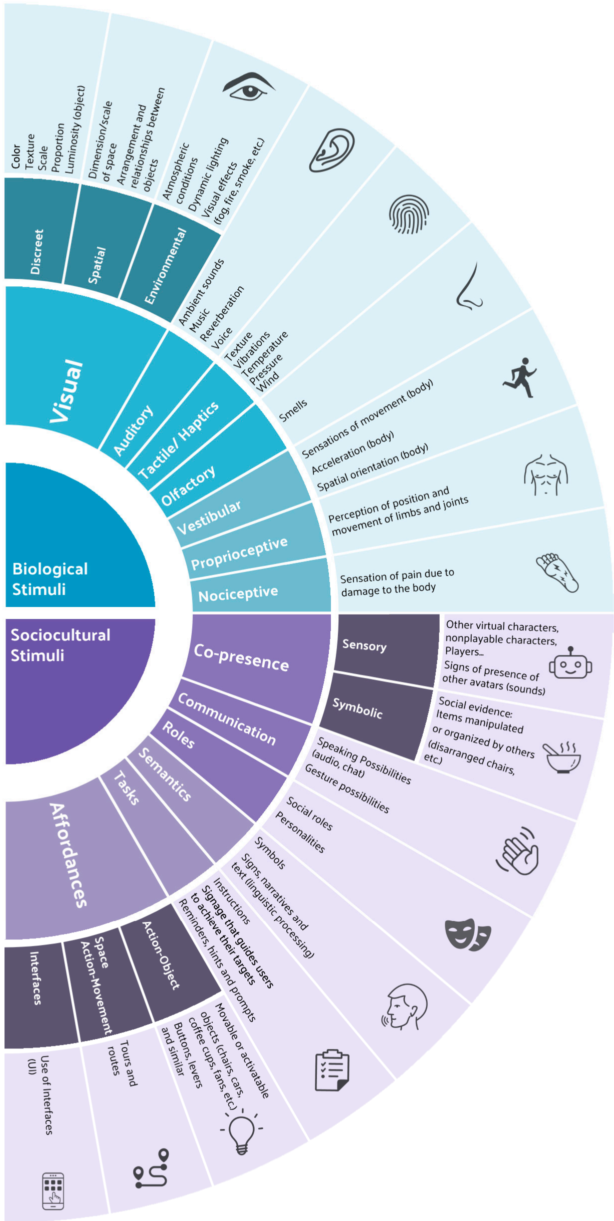

Figure 2. Graphical taxonomy for environmental stimuli.

Table 3 depicts the taxonomy developed for environmental stimuli related to the built environment. Archer et al. [26] defined these stimuli as attributes of the environment (environmental and architectural characteristics) that act through psychological processes, such as the results of sensory perceptions (e.g., spatial distribution, landscape, biophilic elements, furniture, smell, sounds, lighting). Sakaki et al. [54] argued that it is possible to differentiate between biological stimuli, i.e., those important for basic survival and which automatically affect cognitive processing (e.g., attention, memory), and stimuli important in social life, which require elaborate processing, for example, memory and attention. Biological stimuli include those related to both interoceptive and exteroceptive senses. In social stimuli, a distinction is made between: (a) co-presence stimuli, understood as those involving interactions with others, (b) communication possibility stimuli (e.g., audio, chat), (c) stimuli that prompt users to identify the roles of actors in the VE and to play roles themselves, (d) semantic stimuli, understood as those that require linguistic processing and interpretation, (e) task stimuli, understood as those that guide behaviors and goals, and (f) affordance stimuli, based on Gibson's theory [55], understood as users' perceptions of the environment that prompt them to interact directly within that environment, that is, they invite them to undertake specific behaviors.

Table 3. Taxonomy of environmental stimuli.

Category	**Subcategory**	**Subclass**	**Study Variables (Stimuli)**
Biological Stimuli	Visuals	Discreet	Color Texture Scale Proportion Luminosity (of object)
		Spatial	Dimension/scale of space Arrangement and relationships between objects
		Environmental	Atmospheric conditions (rain, wind, etc.) Dynamic lighting Visual effects (fog, fire, smoke, etc.)
	Auditory		Ambient sounds Music Reverberation Voice
	Tactile/ Haptics		Texture Vibrations Temperature Pressure Wind
	Smell		Smells
	Vestibular		Sensations of movement (body) Acceleration (body) Spatial orientation (body)
	Proprioceptive		Perception of position and movement of limbs and joints
	Nociceptive		Sensation of pain due to damage to the body
Sociocultural Stimuli	Co-presence	Sensory	Other virtual characters, nonplayable characters (NPCs), Players... Signs of presence of other avatars (sounds, tactile, etc.)
		Symbolic	Social evidence: items manipulated or organized by others (disarranged chairs, etc.)
	Communication		Speaking possibilities (audio, chat) Gesture possibilities
	Roles		Social roles Personalities
	Semantics		Symbols Signs, narratives and text (linguistic processing).
	Tasks		Instructions Signage that guides users to achieve their targets. Reminders, hints and prompts
	Affordances	Action–Object	Movable or activatable objects (chairs, cars, coffee cups, fans, etc.) Buttons, levers and similar
		Space Action–Movement	Tours and routes
		Interfaces	Use of Interfaces (UI)

Regarding the taxonomy of study environments (Table 4), a distinction was made between mood-induction procedure (MIP) environments, which seek to induce previously defined affective and/or emotional states, and environment comparison studies, a category that includes studies examining two different environments with an exploratory approach toward examining their effects.

Table 4. Taxonomy of study environments.

Category	Subcategory	Study Variables (Stimuli)
Mood Induction Procedure (MIP)	Emotional	Induction of Sadness, Joy, Fear. . .
	Affective	Stress Induction, Relaxation, Concentration. . .
Exploratory Comparisons		Physical–Virtual Urban–Nature Interior–Exterior

Finally, the taxonomy of study conditions was established based on two categories (Table 5): technology conditions and user profile conditions. The first covers studies that explored the influence of software and hardware characteristics specific to the support used, as well as the differences between devices and the variations caused due to how the same devices were used. User constraints encompass those particularities examined in specific population groups to assess whether they provide different results.

Table 5. Taxonomy of Study conditions.

Category	Subcategory	Study Variables (Stimuli)
Technology Condition	Devices/Support	Displays (HMD, Videowall, Projector, PC) Wearables Audio channels, reverberation Types of rendering
	Hardware	Display (HMD, Videowall, Projector, PC) Wearables Audio channels, reverberation Types of rendering
	Software	System immersiveness (degrees of freedom) Types of spatial navigation (teleport, free roaming)
	Controls	Device (mouse, joysticks, etc.) Tactile screen Hand/gesture/eye tracking Voice
User profile condition	Psychological	Emotional/affective (prior state induction) Phobias and philias
	Physiological	Age group Physical limitations (mobility, vision...)
	Experiences	Experts–Beginners Order of experiences in the study (e.g., 1st with music, 2nd without music vs. 1st without music vs. 2nd with music)

3. Results: Publication Analysis

After careful classification, only 17 studies met the evaluation criteria. In this section, the results are analyzed based on the criteria specified in the sub-objectives, that is, an analysis is made of: (a) the dimensions of sense of presence, (b) the measurement methodology used to quantify sense of presence and (c) the set-ups (format and support) used to simulate the built space. Regarding the relationships between the study variables and sense of presence, links were identified with (d) environmental variables, (e) built context, (f) technology conditions and (g) user profile.

3.1. Analysis Methodology

The tabulation of data on dimensions is based on the terminology used by the authors of the articles. In addition, the definition of presence cited in each study was examined to assess the interpretive context of the phenomenon. The results are shown in Table 6.

Table 6. Contextualization of presence.

Ref.	Dimension (Using the Authors' Terminology)	Definition Cited by the Authors (Context of Study)
[21]	Presence	(The authors do not provide a definition of presence)
[22]	Presence	"Heeter's definition stating that the term refers to the impression of being in the VE." Heeter, 1992 [56].
[26]	Spatial Presence	"It is generally defined as a user's subjective sensation of "being there" in a scene depicted by a medium." Barfield & Zeltzer, 1995 [57].
[32]	Presence Spatial Presence	"Presence can be defined as a state of consciousness, i.e., the psychological sense of being in the VE and corresponding modes of behavior" Slater et al., 1996 [8]. "Presence is the sense of "being there," the subjective experience of being in a place or environment, even when one is physically situated in another". Witmer & Singer, 1998 [7].
[23]	Presence	"Presence is a feeling of being there" (no reference)
[31]	Presence	"Presence is used to assess the participants' sense of "being there" in the virtual environment". Slater, Usoh & Steed, 1994 [58]. "It can be defined explicitly as the subjective experience of being in one place or environment, even when physically situated in another". Witmer & Singer. 1998 [7].
[59]	Presence	"For the case of VEs, this translates into the user having the sensation of "being there," inside the rendered environment". (no reference)
[9]	Presence	"The concept of virtual presence, the feeling of being immersed in a virtual environment". (no reference)
[60]	Presence	"Presence can best be defined as "being there," a feeling of immersion and involvement". Ellis, 1996 & Sheridan, 1996. [61,62].
[5]	Presence Spatial Presence	"Presence is usually defined as the "sense of being there" Steuer, 1992 [2] and "The feeling of being in a world that exists outside the self". Riva & Waterworth, 2003; 7. Riva, Waterworth & Waterworth, 2004 [63,64]
[1]	Presence	"Slater defined sense of presence as a subjective experience and only quantifiable by the user experiencing it". Slater, Usoh & Steed, 1994 [58]. "Kalawsky states that presence is essentially a cognitive or perceptual parameter". Kalawsky, 2000 [65].
[12]	Presence Spatial Presence	"Presence refers to the users' response to immersion, that is, do they feel like they are in the environment?" Slater, 2003 [66]
[24]	Presence	"Experience a sense of presence -the illusion of being there". Baños, Botella, & Perpiná, 1999 [67].
[20]	Presence	"The user's 'sense of being there' in the virtual environment". Witmer & Singer, 1998 [7].
[19]	Presence	"Presence is defined as the sense of being in one place or environment, when one is physically situated in another" Witmer, Jerome & Singer, 2005 [68]
[69]	Spatial Presence	"The synthetic environments of virtual architectural worlds invoke the sense of being inside them a sense of presence". Skarbez, Brooks & Whitton, 2018 [6].
[70]	Spatial Presence	"The sense of presence, commonly defined as the sense of being in a virtual space that is presented by technological means". Slater & Wilbur, 1997 [71] and Witmer & Singer, 1998 [7].

The studies mainly referred to two dimensions, sense of presence (general) and spatial presence. Eleven studies referred to the concept as a general sense of presence, three as spatial presence, and three used both simultaneously. Regarding the contextual definitions of "presence", one study [21] did not provide specific definitions, while 16 of the remaining (all except [1]) defined it in terms of "sense of being in the virtual environment, place or space" or as "The sense, illusion, experience or feeling of being there". These definitions are linked to spatial presence [3]. The results indicate that, in most of the analyzed studies, the authors used "sense of presence" instead of "spatial presence", despite the fact that the definitions proffered relate more to the latter term. This has several implications:

1. There is a lack of conceptual precision, since a generic term ("sense of presence") is used instead of a more specific term ("spatial presence") that corresponds more closely to the phenomenon.
2. Confusion is caused to readers and researchers by the failure to clearly distinguish between the general dimension of presence and its spatial subdimension.
3. The failure to make clear whether the same construct is being measured makes it difficult to compare and replicate studies.

This may be because the term "sense of presence" is better known and has been historically more used in the literature. However, since the development of the concept of "spatial presence", it is important to distinguish between them to specify which dimension is being discussed. On the other hand, the results of the analysis showed only five articles share common definitions of presence [1,20,31,32,70], while the remaining twelve used definitions proposed by different authors. This diversity indicates there is no consensus on the conceptualization of presence, but rather that there are multiple theoretical perspectives and competing definitions. Clearly, the study of this phenomenon is still in a preliminary phase, and there is no consolidated, unified conceptual framework. The variety of definitions makes it difficult to build knowledge about presence, as this situation does not allow direct comparison between studies or systematic replication of results.

3.2. Methodologies Used to Quantify Sense of Presence

When categorizing the methodologies used in the studies, a complexity was observed in terms of the scales and questionnaires used to measure sense of presence. Some research employed scales specifically validated for presence, such as Witmer and Singer's Presence Questionnaire (PQ) [7] and Lessiter et al.'s ITC-SOPI [29]. However, other studies complemented these scales with additional questionnaires that assessed constructs described as determinants or subdimensions of presence. For example, the PQ features the Involvement/Attention subscale, while some studies, for example, [22], measured this factor independently using The Modified Tellegen Absorption Scale (MODTAS) [72]. In this way, the studies addressed presence more comprehensively by using measurements that, while not in the core presence scale, estimate relevant constructs based on their conceptual framework. This situation makes tabulation and categorization of the methodologies difficult, as some constructs (e.g., attention) are in some studies part of the presence scale, while in others they are determinants evaluated in a complementary way. Therefore, to perform a comprehensive analysis, it is necessary to tabulate both the core presence scales and any additional questionnaires used in studies to examine dimensions or factors considered relevant based on their theoretical perspectives. The results of this analysis are shown in Tables 7 and 8.

The results reveal that a great diversity of scales and questionnaires have been used to measure sense of presence in the examined studies, and that there has been little coincidence in the instruments used to make the measurements. The scale used most was the ITC-SOPI [29], employed in five of the analyzed works. This is followed in frequency of use by Witmer and Singer's PQ [7] and Slater, Usoh and Steed's Presence Questionnaire (SUS) [58], both used in three studies. The authors of five articles developed their own measures of sense of presence. The most examined presence subdimensions were spatial presence (12), participant involvement/attention (7) and subjective sense of realism (6). Regarding scales complementary to the core presence scales, emotion and affect measures were used five times, employing, for example, PANAS-X [73] and the Self-Assessment Manikin

(SAM) [74]. Cybersickness (4), spatial memory and attentional tendency evaluations, used twice each, followed in frequency of use. An analysis of when the measurements were taken showed that the instruments were applied post-experience in all cases, and only five during the experience, two of which coincided with physiological measurements, and the remaining were made by simply asking participants, while they were in the VE, what level of presence they were experiencing (on a scale of 1 to 100). Psychological self-report measures predominated, with few studies (two) incorporating complementary physiological indicators. The methods used are shown in Table 8.

In synthesis, the analysis highlighted the lack of methodological standardization that still characterizes research into sense of presence. This situation has several implications for the advancement of knowledge in the field. The diversity of scales and techniques makes direct comparison between studies, and determining to what extent they are examining the same phenomenon, difficult. It also reduces the possibilities for systematic replication of the findings, which is key to consolidating the theoretical and empirical aspects of presence. The lack of standardization also hinders the integration of results from different lines of work, since it is unclear to what extent they start from coinciding conceptions of the construct. In addition, the very limited incorporation of complementary physiological indicators into self-report measures restricts the comprehensive understanding of a phenomenon with physical and psychological aspects.

Table 7. Presence measurement scale.

Times Used	Ref.	Definition (Context of Study)	Authors	Data	Ref.
5	[1,5,22,26,69]	Independent Television Commission Sense of Presence Inventory (ITC-SOPI)	Lessiter et al.	2001	[29]
3	[12,21,31]	Presence Questionnaire (PQ)	Witmer & Singer	1998	[7]
3	[5,21,31]	Slater-Usoh-Steed Questionnaire (SUS)	Slater, Usoh & Steed	1994	[58]
2	[32,70]	Igroup Presence Questionnaire (IPQ)	Schubert et al.	2001	[75]
1	[1]	Reality judgment and presence questionnaire (RJPQ)	Baños et al.	2000	[76]
1	[24]	Presence-SAM	Schneider et al.	2004	[74]
1	[20]	Presence Subscale Questionnaire on User Experience in Immersive Virtual Environments (QUXiVE)	Tcha-Tokey et al.	2016	[77]
1	[9]	Adaptation of the Presence Questionnaire (Multiple references)	Barfield & Weghorst Slater & Usoh Hendrix & Barfield	1993 1993 1996	[78] [79] [80]
1	[19]	Adaptation of AR presence questionnaire	Regenbrecht & Schubert	2002	[81]
5	[5,12,22,23,59]	Presence brief verbal measure	-	-	-

3.3. Set-Ups (Support and Format)

This section discusses the supports and formats used for the simulation of built spaces in the analyzed studies, with the aim of identifying which have been the most used in relation to presence. The “support” category relates to the technological devices used during the experiments. The “format” category relates to the type of content offered, in terms of its technological characteristics. This systematic approach makes it possible to identify trends in the technologies used to simulate built environments and evaluate their connections with sense of presence. In the examination of formats, a distinction was made between auditory VEs, i.e., virtual environments experienced exclusively through hearing, and traditional VEs, environments that incorporate the visual experience. Three recurring subcategories were found in the traditional VEs: VE-MIPs, environments designed to induce a specific mood state; VE-DTs (Digital Twins), environments that replicate a physical built environment; and VE/PEs, scenarios developed to carry out tests in specific physical environments. On the other hand, the supports were identified based mainly on whether head-mounted displays (HMDs) were used; if they were, account was taken of whether accessories were used or if the purpose was to compare the devices with other supports. The results are shown in Table 9.

Table 8. Top 10 subscales and main complementary determinants.

Times Used	Ref.	Main Subscales	Times Used	Ref.	Main Complementary Determinants
12	[9,19,20,22,24,26,31,32,69,70]	Spatial Presence (SP)	5	[5,12,20,24,60]	Emotional and affective states
7	[19–21,23,24,32,70]	Attention/Involvement	4	[12,20,22,32]	Cybersickness
6	[1,5,12,23,32,70]	Realism	2	[19,23]	Spatial Memory
5	[9,12,22,23,59]	General Presence	2	[9,22]	Realism
5	[1,5,24,26,69]	Commitment/Engagement	2	[21,22]	Attentional Tendency
4	[1,5,26,69]	Cybersickness	2	[12,20]	Immersion
4	[12,20,21,60]	Sensory Fidelity	1	[26]	(Physiological) Heart rate (HR)
4	[1,5,26,69]	Ecological validity/naturalness	1	[26]	(Physiological) Electrodermal activity (EDA)
4	[20,21,23,60]	Immersion/Adaptation	1	[26]	(Physiological) Body temperature
3	[1,5,19]	Sense of Reality	1	[31]	(Physiological) Electroencephalogram (EEG)

Table 9. Main set-ups (formats and supports).

Times Used	Ref.	Format		Times Used	Ref.	Support
7	[1,9,19,20,23,69,70]	VE [1,2]	(Traditional)	5	[9,22,23,26,32]	HMD [3] + Accessories
3	[31,59,60]	AVE	(Auditory)	4	[5,19,20,24]	PC/Projection (No HMD)
5	[5,12,22,24,26]	VE-MIP	(Mood Induction Procedure)	3	[1,12,70]	HMD/Other supports
2	[12,21]	VE/PE	(vs. Physical Environment)	3	[31,59,60]	Only audio
2	[12,21]	VE-DT	(Digital Twins)	2	[21,69]	Only HMD

[1] References in these categories include only those results that differ from their specific subcategories (VE-MIP, VE-DT, VE/PE) [2] VE: Virtual Environment; [3] HMD: Head-Mounted Display.

The analysis revealed that traditional VEs were predominant, being used in 14 of the 17 studies. Within the VEs, most frequently they had no subcategory specifications, this being the case in seven studies, followed by the VE-MIP subcategory, used in five studies. Spatialized audio formats, physical vs. virtual environments and digital twins were observed less. HMDs were the main support for the virtual environments studied, being present in ten of the 17 works examined. Second in frequency of use were headphones/earphones, incorporated into five studies, three of which used only these devices. Other devices, such as motion trackers, smell systems and fans, were used in two or fewer studies. Although HMDs predominated, in only two works were they the only device used, in most cases they were combined with complementary supports, such as headphones, surround-sound systems, fans and heat lamps, with the aim of enhancing multisensory immersion. These results indicate that the HMD is the reference technology for the simulation of virtual environments in the study of presence levels, environmental variables and behavioral responses. However, many of the studies recognized the importance of complementing HMDs with other devices that stimulate sensory channels other than the visual.

3.4. Relationships between Sense of Presence and the Study Variables

In this section, the relationships between sense of presence and the sub-objectives are identified: (4) environmental stimuli, (5) built context, (6) technology conditions and (7) user profile. As in the analysis of the measurement methodologies, it was considered important to examine not only the direct results on presence, but also, as a complement, those relating to determinants and dimensions. This takes account of the fact that some constructs are operationalized as determinants in some studies, but in others are part of the actual presence scales. For example, attention/involvement was measured as a complementary determinant in some cases, for example [22], but as a sub-dimension of the presence scale in others, for example [21]. To perform a comprehensive analysis, the results on presence and its complementary determinants are tabulated together. Thus, in this section the relationships between presence and the four aforementioned variables are analyzed, taking into account both the direct findings on presence and those related to complementary constructs. This provides a more accurate understanding of how each study approached and conceptualized the results about sense of presence and its associated factors.

3.4.1. Relationships between Sense of Presence and Environmental Stimuli

The analyzed studies revealed that different environmental stimuli had significant effects on the intensity of presence experienced. The results are shown in Tables 10 and 11. Regarding biological stimuli, seven studies established that relationships existed between environmental stimuli and the experience of presence. One study [21] found greater presence at warm temperatures than at cold. Studies [22,26] showed increases in presence when smells congruent with the virtual scenario were incorporated. Studies [23,32] agreed on the positive relationship between smells and sense of presence but differed in terms of tactile stimulation. Study [32] found no differences in presence when wind-based tactile stimuli were added, while [23] established that a relationship existed between tactile stimuli and presence. The authors of study [24] proposed that a closer relationship existed between tactile (using textiles) and presence than existed between smell and presence, although it should be noted that they used a less advanced smell stimulation medium (aromatic oil) than [23,32]. Regarding auditory stimuli, [23,59] found increases in presence when sounds were presented, with [23] making a presence/absence examination of audition; [59] examined different audio configurations, finding that monoaural and artificial sounds should be avoided.

Table 10. Effects of environmental stimuli on the sense of presence.

Ref.	Categories			Human Responses (HR)	HR Behavior		
Environmental Stimuli with Effects on HR				Presence Dimension	HR is (< / ≡ / >) in (A) than in (B)		
[21]	Stimulus	Biological,	Tactile (Temperature)	Presence	(Heat)	>	(Cold)
[22]	Stimulus	Biological,	Smell	Presence	(Dissonant Smell)	≡	(Control)
				Presence	(Consonant Smell)	>	(Dissonant Smell), (Control)
[26]	Stimulus	Biological,	Smell	Spatial Presence	(Smell)	>	(Control)

Table 10. *Cont.*

Ref.	Categories			Human Responses (HR)	HR Behavior		
[23]	Stimulus	Biological,	Auditory	Presence	(Auditory), (Temp, Wind)	>	(Control)
	Stimulus	Biological,	Tactile (Temp, Wind)	Presence	(Smell) [1]	>	(Control)
	Stimulus	Biological,	Smell				
[24]	Stimulus	Biological,	Smell	Presence	(Smell), (Texture), (Both)	>	(Control)
	Stimulus	Biological,	Tactile (Texture)	Presence	(Texture) [1]	>	(Smell), (Both), (Control)
	Stimulus	Biological,	Smell + Tactile				
[32]	Stimulus	Biological,	Tactile (Wind)	Presence	(Wind)	≡	(Control)
				Spatial Presence	(Wind)	≡	(Control)
	Stimulus	Biological,	Smell	Presence	(Smell)	>	(Control)
				Spatial Presence	(Smell)	>	(Control)
[59]	Stimulus	Biological,	Auditory	Presence	(Fixed)	>	(Motion), (Artificial)
[69]	Stimulus	Sociocultural,	Affordances	Spatial Presence	(Interactive)	>	(Control)
[70]	Stimulus	Sociocultural,	Affordances	Spatial Presence	(Navigation)	>	(Control)
	Stimulus	Sociocultural,	Co-presence	Spatial Presence	(Animations)	≡	(Control)
	Stimulus	Sociocultural,	Semantic	Spatial Presence	(Yes interaction)	>	(No interaction)

Note. [1] This result is indicated as a trend by the authors.

Table 11. Effects of environmental stimuli on the sense of presence indicators.

Ref.	Categories			Human Responses (HR)		HR Behavior		
Environmental Stimuli with Effects on HR				Presence Indicators		HR is (< / ≡ / >) in (A) than in (B)		
[21]	Stimulus	Biological,	Tactile (Temp.)	Invol./Att., S. Fidelity		(Heat)	>	(Cold)
				Immersion/Adaptation		(Heat)	>	(Cold)
[22]	Stimulus	Biological,	Smell	Realism, S. Reality		(Consonant Smell)	>	(Dissonant Smell), (Control)
[26]	Stimulus Scenery Condition	Biological, MIP, User	Smell Benign/Terror New/Repeated	Cybersickness (CS)		(Smell)	≡	(Control)
				Engagement (En)	M	(Smell) + (Horror Scenario) [1]	>	(Control) + (Horror Scenario)
				Naturalness (Nat)	M	(Smell) + (Horror Scenario) [1]	>	(Control) + (Horror Scenario)
				RH, Temperature	M	(Smell) + (New Scenario)	>	(Control) + (New Scenario)
				EDA	M	(Smell) + (New Scenario)	<	(Control) + (New Scenario)
[32]	Stimulus	Biological	Tactile (Wind)	Realism, Implication		(Wind)	≡	(Control)
	Stimulus	Biological	Smell	Realism, Implication		(Smell)	≡	(Control)
				CS		(Wind), (Smell)	≡	(Control)
[23]	Stimulus	Biological,	Auditory	Spatial memory		(Auditory)	>	(Control)
	Stimulus	Biological,	Tactile (Temp.,	Object Memory		(Temp., Wind), (Smell)	>	(Control)
	Stimulus	Biological,	Wind) Smell					
[59]	Stimulus	Biological,	Auditory	Realism		(Fixed), (Motion)	>	(Artificial)

Table 11. *Cont.*

Ref.	Categories			Human Responses (HR)	HR Behavior		
Environmental Stimuli with Effects on HR				Presence Indicators	HR is (< / ≡ / >) in (A) than in (B)		
[24]	Stimulus Stimulus Stimulus	Biological, Biological, Biological,	Smell Tactile (Texture) Smell + Tactile	Anxiety	(Smell) [1]	>	(Control), (Texture), (Both)
				Relaxation	(Texture) [1]	>	(Control), (Smell), (Both)
				Excitement	(Texture) [1]	<	(Control), (Smell), (Both)
				Joy, AV	(Smell), (Texture), (Both)	≡	(Control)
				Decrease of Sadness	(Smell), (Texture), (Both)	≡	(Control)
[20]	Stimulus Scenery	Sociocultural, Comparative,	Co-presence External/Internal	Invol./Att.	(NPC)	>	(Control)
				Emotion (Fear)	(NPC)	>	(Control)
[69]	Stimulus	Sociocultural,	Affordances	Engagement	(Interactive)	>	(Control)
				Naturalness, CS	(Interactive)	≡	(Control)
				motor responses	(Interactive)	≡	(Control)
[70]	Stimulus Stimulus Stimulus	Sociocultural, Sociocultural, Sociocultural,	Affordances Co-presence Semantic	Realism	(Navigation)	>	(Control)
				Invol./Att.	(Navigation)	≡	(Control)
				Realism, Invol./Att.	(Animation)	≡	(Control)
				Realism, Invol./Att.	(Yes interaction)	≡	(No interaction)

Note. [1] This result is indicated as a trend by the authors. M: Moderator effect; S: Sensation; CS: Cybersickness; En: Engagement; Nat: Naturalness; Invol./Att.: Involvement/Attention; AV: Affective Valence.

Only three studies addressed sociocultural environmental stimuli. Studies [19,69] found that copresence and interactive affordances had positive effects on intensity of presence. However, [70] did not observe any changes when animation was added, which had been expected to generate a greater sense of place in the user. It is important to note that the animations went unnoticed by some participants, highlighting that the method used did not have the desired impact on users. These findings emphasize the importance of examining presence in interrelation with the physical and sociocultural attributes of the simulated environment, given its modulating influence on the subjective experience. To construct successful virtual environments, it will be key for the built space discipline to gather empirical evidence on how different environmental configurations affect sense of presence.

When examining the indicators used to evaluate presence it can be seen that several studies focused on biological stimuli, such as smells, sounds and temperature [21,22,59], consistently finding that perceived realism increased when these environmental variables were manipulated. These findings provide solid evidence supporting the modulating role of biological stimuli in terms of the subjective experience of realism in virtual environments. In addition, research focused on the interaction between smells and emotional scenarios [26] provided novel results, revealing that the effects of smells on engagement and cybersickness are mediated by the threatening or tranquil nature of the simulation. Study [23] is notable in that it registered improvements in spatial memory in response to stimuli affecting different sensory channels (auditory, tactile, smell), underlining the potential of multisensory configurations to reduce cognitive biases in virtual environments. Regarding emotional responses, [24] noted trends in specific changes in anxiety, sadness and relaxation, in relation to stimulation type (smell or tactile). The lack of significance in the results found by these authors shows that more evidence is needed to establish solid patterns in the evocation of emotions by the environmental stimuli used in virtual environments. Study [20] examined the effects on presence of including an avatar in the virtual environment. The results revealed that users felt more fear when an avatar was present than in the control condition without the avatar. However, the authors suggested that this was due to the role of the avatar, a police officer chasing the user. Nonetheless, this finding highlights the emotional impact that a feeling of copresence with other virtual actors can exert. Study [69] evaluated interactive versus non-interactive affordances, noting that, although affordances may increase sense of presence, their effect critically depends on the level of interactivity of the VE, which in turn can improve engagement.

Along the same lines, [51] found that the mere fact of believing they can interact within a VE has no effect on participants' sense of presence: the effect is only enhanced when the participants carry out interactions successfully. It is important to highlight that [26] was the only study to establish relationships between environmental variables and physiological responses in the study of presence as a construct. Its results showed that when the user had previously experienced the scenario (in this case due to the procedural methodology of the study), this mediated the relationships between the physiological measures heart rate (HR), electrodermal activity (EDA), body temperature and the influence of incorporating smells consistent with the scenario in a terror context. However, it should be highlighted that in a MIP environment, the repetition of the experience plays an important role in the uncertainty related to the emotion of fear. Together, these results emphasize the importance of studying complementary presence indicators to comprehensively understand their role as modulators in different environmental configurations. The capacity of biological and sociocultural stimuli to impact directly not only on presence, but also on perceptions of realism, emotional and physiological responses, and cognitive and motor performance, is evident.

3.4.2. Relationships between Sense of Presence and Scenarios

The scenarios or contents represented in virtual environments constitute a key element that can modulate the intensity of sense of presence experienced. The results showed that beyond the physical attributes of the simulated environment, the emotional and semantic qualities of the recreated situations influenced the level of sense of presence experienced. In this section, the studies that examined the relationship between different types of scenarios and presence are analyzed. The results are shown in Tables 12 and 13.

Table 12. Effects of scenarios on the sense of presence.

Ref.	**Categories**			**Human Responses (HR)**	**HR Behavior**			
Scenarios with Effects on HR				**Presence Dimension**	**HR is (< / ≡ / >) in (A) than in (B)**			
[5]	Scenario	MIP,	Relaxation	Presence		(Relaxation), (Anxiety)	>	(Control)
		MIP,	Anxiety	Spatial Presence		(Relaxation)	>	(Anxiety)
[1]	Scenario	MIP,	Sadness	Presence	M	(Sadness) + (HMD)	≡	(Control) + (HMD)
	Condition	Tech,	Support (Display)	Presence	M	(Sadness) + (PC)	>	(Control) + (PC)
[20]	Scenario	Comparative,	External/Internal	Presence		(External)	>	(Internal)

Note. M: Moderator effect.

Only three studies found that relationships existed between sense of presence and the built environment. Study [5] found that greater presence was evoked in simulations designed to induce relaxation and anxiety than was evoked by neutral scenarios. This highlights the importance of emotional stimuli in enhancing presence in VEs. In line with study [5], study [1] found that an interaction exists between emotional scenarios and the technological supports used: sadness increased presence only when a PC was used, not with HMDs. This result highlights the importance of taking into account combinations of technical and content factors. On the other hand, study [20] reported greater presence in outdoor than in indoor scenarios, which the authors suggest may be due to the greater realism and sensory richness of natural open environments.

Table 13. Effects of scenarios on the sense of presence indicators.

Ref.	Categories			Human Responses (HR)	HR Behavior			
	Scenarios with Effects on HR			Presence Indicators	HR is (< / ≡ / >) in (A) than in (B)			
[5]	Scenario Scenario	MIP, MIP,	Relaxation Anxiety	Tranquility, Happiness		(Relaxation)	>	(Control), (Anxiety)
				Affections (−)		(Relaxation)	<	(Control), (Anxiety)
				Sadness, Anxiety		(Anxiety)	>	(Control), (Relaxation)
				Affections (+)		(Anxiety)	>	(Control), (Relaxation)
				Tranquility; Happiness		(Relaxation)	>	(Control), (Anxiety)
				Anxiety		(Anxiety)	>	(Control), (Relaxation)
[1]	Scenario Condition	MIP, Tech,	Sadness Support (Display)	Realism, S. Reality	M	(Sadness) + (HMD)	≡	(Control) + (HMD)
				Interactivity, En.	M	(Sadness) + (HMD)	≡	(Control) + (HMD)
				Emotional Engagement	M	(Sadness) + (Videowall)	>	(Control) + (Videowall)
				Commitment, EV.	M	(Sadness) + (PC)	>	(Control) + (PC)
				S. Reality, EE.	M	(Sadness) + (PC)	>	(Control) + (PC)
[12]	Scenario Condition Scenario Condition	Comparative, Tech, Comparative, Tech,	Physical/Virtual Support (Display) Urban/Nature Hardware (Graphic)	Affection (+/−)		(Physical), (Video)	≡	(VR)
				Serenity		(Physical)	≡	(VR)
				Enjoyment		(Physical)	>	(VR 3)
				CE		(Natural)	≡	(Urban)
				Affection (+)	M	(Natural)	>	(Urban)
				Serenity		(Natural) + (LR)	>	(Urban)+(LR)
[20]	Stimulus Scenario	Sociocultural, Comparative,	Co-presence External/Internal	Immersion (Invol./Att.)		(NPC)	>	(Control)
				Emotion (Fear)		(NPC)	>	(Control)
				Motion Perception		(External)	>	(Internal)
				User Experience		(External)	>	(Internal)
				Immersion (Invol./Att.)		(External)	>	(Internal)
				Flow		(External)	>	(Internal)
				Emotion		(External)	>	(Internal)
				(EN, CS, Usability, Judgment, Adoption)		(External)	≡	(Internal)

Note. S: Sensation; E: Enjoyment; CS: Cybersickness; En: Engagement; Invol./Att.: Involvement/Attention; EV: Ecological Validity; EE: Emotional Engagement; CE: Connection with the environment; LR: Low Realism.

The examination of the indicators used to evaluate presence revealed that only four studies examined the relationships between sense of presence and scenarios. Studies [1,5] consistently showed that scenarios designed to induce specific emotions (relaxation, anxiety, sadness) increased positive and negative affective responses. They also enhanced dimensions such as engagement and emotional connection more than did neutral scenarios. These findings provide solid evidence for the ability of virtual content to modulate emotional states, which is related to greater experienced presence [24]. On the other hand, studies [12,20], in comparing physical with virtual scenarios and exterior with interior scenarios, reported that virtual and open environments improved perceptions of realism, attentional involvement and user affective responses. Study [12] highlighted that certain technical aspects, such as graphic realism, can mediate the relationships between environment typologies and users' affective responses. Although more work is required, these results suggest that certain types of virtual scenarios have the potential to overcome the limitations set by closed, physical environments. It is clearly important to consider both the physical–spatial design and the emotional and semantic qualities of virtual scenarios to optimize the subjective experience of sense of presence.

3.4.3. Relationships between Sense of Presence and Conditions (Technology and User Profile)

The technical attributes of virtual environment systems and the individual characteristics of users can modulate the intensity of presence they experience. In this section, studies that investigated these interrelationships in the context of the analysis of environmental variables are examined. The results are shown in Tables 14 and 15.

Table 14. Effects of conditions (technology and user profile) on the sense of presence.

Ref.	Categories			Human Responses (HR)	HR Behavior			
	Conditions with Effects on HR			Presence Dimension	HR is (< / ≡ / >) in (A) than in (B)			
[23]	Condition	Tech,	Hardware (Resolution)	Presence		(Low resolution)	≡	(Control)
[31]	Condition	Tech,	Support (Audio Channels)	Presence		(Stereo)	>	(Mono)
				Presence		(Stereo) [1]	>	(2D)
				Presence		(2D)	>	(Mono)
[59]	Condition	Tech,	Support (Audio Channels)	Presence		(Triple)	>	(Mono)
	Condition	Tech,	Support (Audio Spatialization)	Presence		(Spatialized)	>	(Anechoic)
[9]	Condition	Tech,	Support (Audio Spatialization)	Presence		(Spatialized)	>	(Control), (Non-spatialized)
				Presence		(1)	≡	(Control)
[60]	Condition	Tech,	Support (Audio Channels)	Presence		(6 Speakers)	>	(Mono), (Stereo)
[1]	Scenario Condition	MIP, Tech,	Sadness Support (Display)	Presence	M	(HMD) + (Control)	>	(PC) + (Control)
				Presence	M	(VideoWall) + (Control)	>	(PC) + (Control)
				Presence	M	(PC) + (Sadness)	>	(HMD) + (Sadness)
				Presence	M	(VideoWall) + (Sadness)	>	(HMD) + (Sadness)
				Presence	M	(VideoWall) + (Sadness)	≡	(PC) + (Sadness)
[12]	Condition	Tech,	Support (Display)	Spatial Presence		(VR)	>	(Video)
	Condition	Tech,	Hardware (Graphic Realism)	Presence		(High realism)	>	(Low realism)
[19]	Condition Condition Condition Condition	Tech, Tech, Tech, Tech,	Hardware (PoV) Hardware (CoP) Hardware (Visual field) Support (Display)	Presence	M	(Center) + (CoP Front)	>	(Right) + (CoP Front)
				Presence	M	(Zoom) + (CoP Front)	>	(Right) + (CoP Front)
				Presence	M	(Center) + (CoP Front)	>	(Left) + (CoP Front)
				Presence	M	(Zoom) + (CoP Front)	>	(Left) + (CoP Front)
				Presence	M	(Right) + (CoP Center)	>	(Center) + (CoP Center)
				Presence	M	(Left) + (CoP Center)	>	(Center) + (CoP Center)
				Presence	M	(Right) + (CoP Center)	>	(Zoom Out) + (CoP Center)
				Presence	M	(Left) + (CoP Center)	>	(Zoom Out) + (CoP Center)

Note. [1] This result is indicated as a trend by the authors. M: Moderator effect; PoV: Point of View; CoP: Center of Projection.

Table 15. Effects of conditions (technology and user profile) on the sense of presence indicators.

Ref.	Categories			Human Responses (HR)	HR Behavior			
	Conditions with Results			Presence Indicators	HR is (< / ≡ / >) in (A) than in (B)			
[26]	Condition	User,	New/Repetition	En, Nat, Cybersickness		(New)	≡	(Known)
[59]	Condition Condition	Tech, Tech,	Support (Audio) Support (Audio)	Sensation of sound location		(Single)	>	(Triple)
				Realism	M	(Triple) + (Fixed)	>	(Single) + (Fixed)
				Realism	M	(Triple) + (Movement)	>	(Single) + (Movement)
				Realism	M	(Single) + (Artificial)	>	(Triple) + (Artificial)
				Sensation of sound location	M	(Spatialized) + (Fixed)	>	(Anechoic) + (Fixed)
				Sensation of sound location	M	(Anechoic) + (Movement)	>	(Spatialized) + (Movement)
[9]	Condition	Tech,	Support (Audio)	Realism		(Spatialized),(Non-spatialized)	≡	(Control)
				Interaction Fidelity		(Spatialized)	>	(Control),(Non-spatialized)
				Sensation of sound location		(Spatialized)	>	(Control),(Non-spatialized)

Table 15. *Cont.*

Ref.	Categories			Human Responses (HR)	HR Behavior			
	Conditions with Results			Presence Indicators	HR is (< / ≡ / >) in (A) than in (B)			
[60]	Condition	Tech,	Support (Audio)	Emotional Reaction		(Stereo),(6 Speakers)	>	(Mono)
				Emotional Reaction		(Stereo)	≡	(6 Speakers)
				Emotional Reaction		(6 Speakers)	>	(Mono),(Stereo)
				Emotional Reaction		(Stereo)	≡	(6 Speakers)
				Spaciousness		(6 Speakers)	>	(Mono),(Stereo)
				Proximity to music		(3)	>	(Mono),(Stereo)
[1]	Scenario Condition	MIP, Tech,	Sadness Support (Display)	Cybersickness		(HMD)	>	(Videowall),(PC)
[12]	Scenario	CMP,	Physical/Virtual	Serenity, Enjoyment, S.R.		(VR)	>	(Video)
	Condition	Tech,	Support (Display)	Serenity	M	(High realism)	>	(Low realism)
	Scenario	CMP,	Urban/Nature	Affection (+)	M	(High realism) + (Natural)	>	(Low realism) + (Natural)
	Condition	Tech,	Hardware	Serenity		(Low realism) + (Urban)	>	(High Realism) + (Urban)
[19]	Condition	Tech,	Hardware (POV)	Perceived spatial depth		(Center)	>	(Zoom Out),(Right),(Left)
	Condition	Tech,	Hardware (CoP)	Perceived spatial depth		(Monocular)	>	(Binocular)
	Condition	Tech,	Hardware (VF)	Perceived spatial depth		(Projector)	>	(Reduced TV)
	Condition	Tech,	Support (Display)	Perceived Spatial Dimension	M	(Projector)	>	(Reduced TV)
				Perceived Distortion	M	(Behind) + (PoV Center)	>	(Center) + (PoV Center)
				Perceived Distortion	M	(Front) + (PoV Center)	>	(Center) + (PoV Center)
				Perceived Distortion	M	(Behind) + (Rear PoV)	>	(Center) + (Rear PoV)
				Perceived Distortion	M	(Front) + (Rear PoV)	>	(Center) + (Rear PoV)
				Perceived Distortion	M	(Behind) + (Right PoV)	>	(Center) + (Right PoV)
				Perceived Distortion	M	(Front) + (Right PoV)	>	(Center) + (Right PoV)
				Perceived Distortion	M	(Behind) + (Left PoV)	>	(Center) + ((Left PoV)
				Perceived Distortion		(Front) + (Left PoV)	>	(Center) + ((Left PoV)

Note. M: Moderator effect; CMP: Comparative; SR: Sense of Reality; En: Engagement; Nat: Naturalness; VF: Visual Field.

Regarding technology conditions, eight studies found that relationships existed between sense of presence and study conditions. Studies [31,59,60] found that using multiple audio channels increased presence over mono and stereo sound. This highlights the importance of auditory richness for enhancing sense of presence. In addition, [9,59] found that spatialized sound, which helps interpret sounds in relation to a space, potentially increases presence. However, in the absence of this characteristic, study [9] demonstrated that presence is enhanced by the use of sound. Similarly, studies [1,12] revealed that virtual reality evoked more presence than other, flat screen, media. Curiously, study [1] argued that this relationship can be mediated by the built environment used, where MIP scenarios of sadness produced higher presence results in flat screen media than was produced by HMDs. Study [19] also reported complex interactions between sense of presence and point of view mediated by the projection center in an indoor environment. The authors of this study also highlighted that participants had a slight preference for virtual environments with a shorter focal length, which generates a visual effect of greater depth.

The examination of indicators used to evaluate sense of presence identified seven studies that established relationships between presence and conditions (technology and user profile). Studies [9,31,60] revealed that users' perceptions of realism and sound localization were improved in spaces incorporating audio support with more channels and spatialization. Study [59] also found a similar positive relationship for emotional responses and even the recognition of emotional responses. This again highlights the importance of auditory richness in evoking different determinants of presence. The authors of study [12] suggested that participants experienced greater serenity in environments with high graphic design, both in terms of the quality of textures and the number of polygons. However, the authors also pointed out that this relationship between affective states and graphic design quality can be mediated by the environment typology, in this case, outdoor or indoor environments. In addition, study [19] reported that the perception of spatial characteristics, such as greater accuracy in the perception of depth and spatial dimensions, can be moderated by joint manipulations of point of view, center of projection and display type. Together, these findings emphasize the importance of considering both visual and auditory technological attributes to comprehensively enhance key dimensions of the experience of presence in virtual environments.

3.4.4. Other Predictive Relationships between Sense of Presence and Behavioral Responses in Relation to the Built Environment

Some research has established that notable relationships exist between sense of presence and its indicators and users' behavioral responses in the built environment. In some cases, these relationships are also predictive of behavioral responses in users. For example, study [21] found that a higher level of presence and involvement, sensory fidelity and immersion predicted that users would experience greater comfort. However, these relationships arose only under heat stimuli, not cold. It should be noted that the relationship with presence occurred before adaptive interactions took place, while for its indicators it was later. In the cold condition, the absence of relationships was associated with less behavioral adaptation. Study [22] found that greater presence predicted better smell detection. Curiously, this occurred only with the measures taken during the experience, not with the post-experience measurement. This underlines the importance of examining when measurements were taken. In addition, study [26] revealed that spatial presence predicted a better user experience. Similarly, [5] showed that the level of presence experienced predicted affective responses.

It is worth mentioning two studies, not included in the results analysis, that established that interesting predictive links exist between spatial/presence dimensions and behaviors. Study [27] found that social presence predicts greater socio-spatial interaction, establishing a circular relationship that feeds back depending on the intensity of the interactions and affective associations. Study [82] revealed that positive relationships existed between spatial presence, copresence and social presence, which become cross-predictors of each other. In addition, the users' tendency for involvement predicted greater spatial and copresence. Together, these findings highlight the value of examining predictive relationships between presence qualities and behavioral responses, which can reveal the existence of processes of mutual feedback between cognition, emotion and action in virtual environments. Figure 3 shows a graphic relationship between the types of environmental stimuli, scenarios and technology and user profile conditions that influence sense of presence, where the size of the circles is equivalent to the number of studies that explored the area.

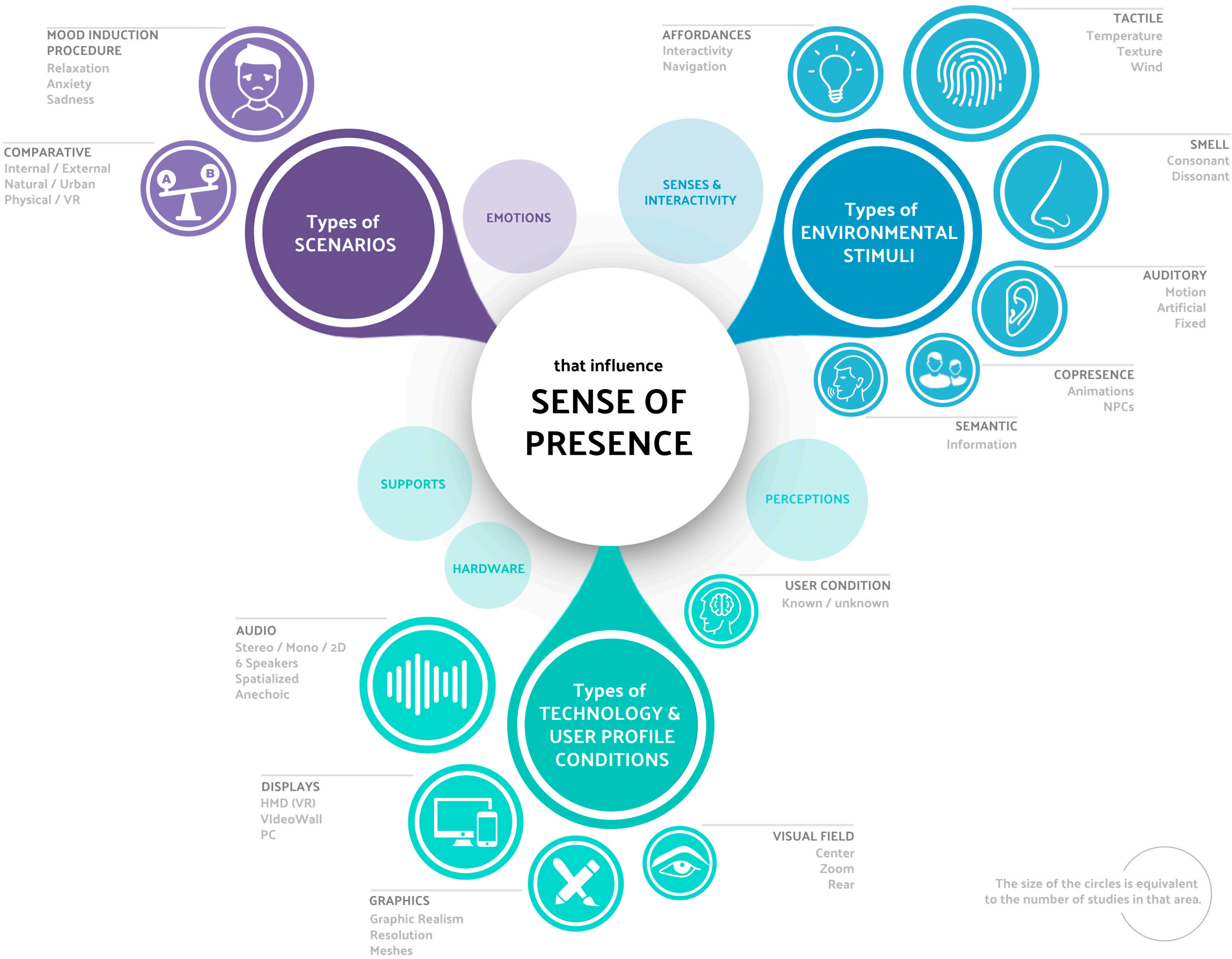

Figure 3. Types of environmental stimuli, scenarios and technology and user profile conditions that influence sense of presence. Note: The size of the circles is equivalent to the number of studies that explored the area.

4. Discussion

The results of this systematic review provide important evidence of the current state of use of sense of presence in research into human behavior in built space-related virtual environments. In this section, the main findings in relation to the study's conceptual framework and objectives are discussed. The aim is to integrate the identified contributions to identify the challenges and propose future perspectives in this line of work. Specifically, an analysis is made of the extent to which the primary studies provide a consolidated conceptualization of the phenomenon of sense of presence and solid techniques that can measure it in virtual environments. Similarly, an examination is made of whether the results reinforce the importance of continuing to investigate presence in interrelation with the attributes of built spaces. Finally, guidelines are proposed to advance toward a comprehensive understanding of the human experience in virtual environments that optimizes their ability to evoke a sense of presence.

4.1. Identification of the Dimensions of Presence

The results of the analyses support the notion that presence is a multidimensional phenomenon with various competing theoretical conceptualizations [5,12,32,82]. However, the diversity of definitions found during the analysis of presence dimensions shows that research in the field is in a preliminary phase, and that it is still far from having solid and agreed conceptual frameworks [3]. Work is needed to achieve greater definitional coherence to consolidate knowledge about this multidimensional concept. Thus, future studies should seek to integrate existing definitions to propose a more comprehensive conceptualization of the phenomenon, incorporating previous contributions. Similarly, researchers should make their adherence to any particular definition explicit and justify their position when carrying out studies into presence. It is key that future studies use the terminology on the dimensions of presence in a rigorous way, adjusted to the specific phenomenon they are examining. This will facilitate progress in the conceptual delimitation of each presence dimension and in the solid construction of knowledge in the field.

4.2. Methodologies Used to Quantify Sense of Presence

One of the findings of this review was that subjective self-reported measures had overwhelming predominance over objective indicators in the evaluation of sense of presence [32]. While post-experience virtual questionnaires are useful, several authors warn that they provide a limited view by relying completely on participants' conscious judgments [31]. This is because presence involves multiple cognitive, affective and physiological processes [4] that operate outside the individual's conscious deliberation [32]. Therefore, it is key to complement questionnaire analyses with objective measures that address automatic responses such as facial expressions, physiological responses and emerging behavior patterns [31]. It will be essential to increase the use of this type of objective indicator, together with the triangulation of subjective and objective techniques, to achieve a more comprehensive and solid understanding of the complex phenomenon of sense of presence. This will also require methodological advances to improve the viability and analysis of objective measures in virtual environment contexts.

The systematic literature review revealed that there is great diversity of methodological approaches and a general lack of standardization in measuring sense of presence. This situation was observed across many investigations into this complex, multidimensional phenomenon [1,5,7,9,12,19,20,22,29,31,32]. The results showed that a wide variety of scales and questionnaires have been used to measure sense of presence in the examined studies, and that there has been little coincidence in the measuring instruments. The scale most utilized was the ITC-SOPI [29], employed in five of the works, followed by the Presence Questionnaire (PQ) of Witmer and Singer [7] and the Presence Questionnaire (SUS) of Slater, Usoh and Steed [58], both used in three studies. The authors of five articles developed their own sense of presence measures. The most examined subdimensions were spatial presence (12 times), involvement/user attention (7 times) and subjective sense of realism (6 times).

Even in research using the same scale, such as the ITC-SOPI, different questionnaires were employed, based on the conceptual frameworks used, for example, to evaluate attention/involvement [22] and affective responses [5,12,20,24,26].

This situation hinders the tabulation and categorization of methodologies, as some constructs (e.g., attention) appear in the presence scale in some studies, while in others they are complementary determinants.

The variety of scales, techniques and operationalized constructs makes it difficult to directly compare studies and systematically replicate results. As the instruments used to measure sense of presence differ, and there is no unified definition of its dimensions, it is unclear to what extent the various investigations are examining the same phenomenon. This hampers coordinated advancement in building knowledge about sense of presence and its determinants. Overcoming these conceptual and methodological limitations will be key for consolidating research in the field. Greater standardization of psychometric and physiological scales and techniques is required. This will facilitate the more precise measurement of sense of presence and allow effective comparisons to be made between studies.

4.3. Set-Ups (Support and Format) and Technology Conditions

The results of the analysis of the set-ups used provide a framework for future studies aimed at determining the differential impact of different immersive supports and formats on the intensity and qualities of sense of presence. It has been demonstrated that device type can influence reported levels of presence and, in turn, that the influence of the device depends on the characteristics of the virtual environment being viewed [1]. Thus, future research should continue to examine the differential impact of different virtual environment configurations and user profile characteristics on the intensity and characteristics of sense of presence. Similarly, the spectrum of supports examined needs to be expanded beyond the predominant HMD, and explore emerging technologies such as augmented reality, mixed reality and 360° video spheres, barely incorporated so far into this field of study. In addition, noting that HMDs are an emerging technology in continuous evolution, different HMD supports should be compared with the aim of analyzing the influence of their different features on users' perceptions of environmental variables and experience of sense of presence. This would make it possible to detect technological qualities beyond the type of support used, examining aspects such as ergonomics, interpupillary distance (IPD), optical quality, spherical and chromatic aberrations, focus distance and external light isolation.

On the other hand, there is growing interest in more complex and hybrid formats that seek to increase multimodal immersion and activate emotional responses in participants. It is noteworthy that only two studies [12,21] examined the case of a digital twin of a physical built environment. Researchers should incorporate a greater variety of multimedia formats, such as more detailed architectural simulations, extended reality environments and BIM methodologies to expand knowledge about the possibilities offered by different technologies in the architectural discipline. This will provide evidence on how different technological and architectural specific characteristics can affect the intensity and qualities of sense of presence.

Other research has examined the effect of different multisensory configurations on sense of presence, agreeing on the importance of perceptual richness. It has been shown that using multiple audio channels [31,59,60] and adding spatial features to sound and spatialized audio [9,59] increase sense of presence. Similarly, research has highlighted that the quantity and consistency of sensory outputs in a simulated environment are determinants of presence [23,24,32]. These results emphasize the importance of comprehensively studying the multiple sensory attributes of virtual environments to increase our understanding of sense of presence. It is clear that, irrespective of the device used, aspects such as visual, auditory and multisensory richness provide more immersive experiences. Therefore, future research should examine the interrelationships between technological qualities and the perceptual, cognitive and affective responses of different user profiles.

4.4. Sense of Presence, Environmental Stimuli and Scenarios

Several primary studies revealed that different environmental variables and spatial attributes have significant effects on the intensity and qualities of presence experienced. Specifically, presence was modulated when manipulating sounds [23,59], smells [22,23,26,32,70], temperature [21,23], texture [24], spatiality [19], socio-spatial qualities [20,70], etc. Taking a more global approach, a solid line of research related to the interactions between the different landscape typologies of scenarios and sense of presence was also found [1,5,12,20].

These results emphasize the need to study the experience of presence in interrelation with the characteristics of the built context, since they directly affect its spatial presence dimension, the subjective feeling of "being there" in a virtual environment, as well as other dimensions. Therefore, researchers should go beyond investigating presence as an isolated phenomenon, and to move toward conceiving it within a comprehensive framework of interaction between the properties of the simulated environment and the internal processes of users and their individual characteristics. Only through an ecological approach will it be possible to identify optimal design principles for virtual environments that will make them capable of evoking high levels of spatial presence. This will also make it possible to understand how different built space configurations impact on the cognition, affectivity and behaviors of users.

4.5. Sense of Presence and User Profile

Some studies showed the existence of individual differences in responses to sensory stimuli based on variables such as previous familiarity with the built environment [26]. These results emphasize the need to take into account users' profiles when investigating the presence experience, and not only the attributes of the medium. Aspects such as age, gender, spatial abilities, personality traits and perceptual–cognitive abilities can modulate the intensity and qualities of presence experienced in the same virtual environment [1]. Therefore, these individual variables should be examined to adequately explain the differential responses of different users. Incorporating this more comprehensive perspective will allow virtual environments to be optimized to evoke presence based on the specific needs and characteristics of the target users. Similarly, it will enable more effective personalization of immersive experiences.

4.6. Sense of Presence and Architecture, Neuroscience and Environmental Psychology

Several studies highlighted the high potential of virtual environments for testing architectural design concepts, allowing researchers to easily evaluate alternatives before building commences [20,69]. However, to fully take advantage of these possibilities, built environment representations capable of evoking a strong sense of spatial presence in users must be created. Although these works provide certain preliminary guidelines, there are still no solid principles and consolidated evidence on how to optimize spatial presence in virtual environments [69]. Identifying effective guidelines for the optimal design to evoke a sense of presence therefore is a key challenge that must be overcome to realize the potential advantages of virtual environments in architecture and urban planning. In this sense, a promising path is the integration of disciplines such as architecture, neuroscience and environmental psychology: this can provide complementary perspectives on the human experience in built environments [10]. However, this integration is nascent and must be reinforced to comprehensively understand the cognitive, affective and behavioral processes that underlie sense of presence. Only by taking a holistic approach, with multidisciplinary contributions, will it be possible to identify and implement optimal design solutions that provide spatial experiences with heightened sense of presence.

Some previous research has explored combinations of theoretical perspectives and complementary methodologies in fields such as architecture, environmental psychology and neuroscience, setting important precedents. It has been shown that relationships exist between physiological responses and reported levels of sense of presence, such as body temperature and electroencephalogram measurements [26,31]. Similarly, it has been established that relationships exist between the evocation of sense of presence and users' behavioral responses in the built environment [5,21,22,26,27,82]. These studies highlighted the importance of adopting interdisciplinary and transdisciplinary perspectives to investigate complex phenomena such as sense of presence and its dimensions. Taking advantage of neuroscience, psychophysiology and design sciences, among others, will provide a more comprehensive understanding of the human experience in virtual media.

5. Future Lines of Research

More systematic reviews that integrate advances in understanding sense of presence across disciplines are needed to update the state of the art on conceptualized dimensions, measurement and associated factors. Quantitative meta-analyses are also necessary to synthesize the quantifiable effects of different environmental and technological variables on sense of presence. Future research could also qualitatively assess the varying definitions and theoretical models proposed, identifying points of convergence to develop integrative frameworks.

Although this systematic review provides important evidence on sense of presence in virtual environments, it also reveals several research gaps and key challenges that need to be faced to comprehensively advance this field. One pending task is to achieve a more unified conceptualization of sense of presence, integrating dimensions such as spatial presence, social presence and copresence, as well as differentiating the frameworks used to examine these dimensions from a global concept of presence (e.g., overall sense of presence). Further empirical work is needed to determine the relationships between the dimensions. Similarly, more robust explanatory models are needed to understand the cognitive and neurological processes underlying each type of presence.

Another important challenge is to identify further objective measurements of sense of presence, such as facial expressions, physiological responses and emerging behavioral patterns. This would help to explain aspects of presence not accessible through conscious self-reports. This will require not only greater application of existing measures, but also the design of new, viable objective indicators usable in virtual environments. It will also be key to broaden the environmental variables and spatial attributes studied in relation to sense of presence, to examine the precise effects of lighting, acoustics, spatial distributions and materials. Furthermore, more comparative studies are needed on the differential impact of the various immersive technologies.

Identifying specific design principles for virtual environments that optimize spatial presence is another core challenge. This would enable them to be more effectively applied in architecture, urban planning and related disciplines. Finally, more multidisciplinary approaches must be pursued, integrating design research, experimental work, computational modeling, cognitive neuroscience and associated fields. Only through comprehensive integration can an integral understanding of sense of presence be achieved.

6. Limitations

Systematic reviews synthesize all of the available evidence, including the strengths and weaknesses of the identified studies, the study populations, the interventions used and the specific study outcomes [35]. However, there is a risk of bias in syntheses (such as meta-analyses) due to the exclusion of relevant studies. It is possible that studies with statistically non-significant results may not have been submitted for publication (publication bias), or results that were statistically non-significant may have been omitted from study reports (selective non-reporting bias) [83,84], which can compromise the validity of results. Future research might use advanced systems such as the revised Cochrane 'Risk of bias' [85].

Others limitations of this review were the restriction in scope to studies written only in English or Spanish, the exclusion of gray literature, and the lack of examination (in terms of their application to building research) of emerging immersive technologies, such as augmented and mixed reality, digital twins, the metaverse, BIM, etc. [86–89]. Reviews focused on non-architectural applications of sense of presence in virtual environments are also needed. Overcoming these restrictions would provide a broader vision of the current state of knowledge on this phenomenon.

7. Implications

Research on sense of presence enhances the understanding of human experience in interactions with the environment, and human beings' underlying internal processes, for example, cognitive processes. Advances in conceptualizing and measuring sense of presence can help researchers identify principles to optimize immersive experiences in domains such as psychology and neuroarchitecture, and aid professionals interested in the user experience in virtual environments. In architecture and urban planning, specifically, this could help professionals create more innovative designs that allow them to evaluate built spaces, using virtual, augmented and mixed reality and related technologies; this would facilitate the application of more efficient, sustainable and human-centered processes. Understanding this phenomenon can help in the development of enhanced simulated environments for analyzing digital twins of cities (traffic, public participation, emergency drills, etc.) and architectural projects (restoration, therapeutic environments, accessibility, human well-being, etc.). In addition, deepening knowledge of sense of presence can advance the understanding of an individual´s experience of inhabiting virtual environments, for example, walking through a virtual park and having a home in the metaverse, and how these new environments can transform people´s daily lives.

8. Conclusions

This systematic review examined the use of sense of presence in research on human behavior in virtual environments representing built spaces. The results allow us to advance the definition of the phenomenon and provide evidence of its dimensions, measurement, simulation technologies and associated factors. A diversity of approaches that address presence was identified, underlining the need to agree on integrative frameworks. Similarly, the importance of expanding the study of objective indicators was confirmed, as well as the need to complement them with subjective measures to achieve a more comprehensive understanding of the concept.

The results showing the effects exerted by different environmental variables and spatial attributes reaffirm the importance of conceiving presence in interrelation with the built context. Harnessing the potential of virtual environments in architecture requires optimizing the experience of spatial presence, for which even more evidence is needed. In summary, the value of studying presence from a multidisciplinary orientation is highlighted: this will allow researchers to identify principles that will help them virtualize built environments capable of evoking sense of presence. This will be cross-cuttingly useful for the various disciplines involved in researching and modeling human experience through virtual environments.

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