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REVIEW ARTICLE

Intelligent Classrooms: How AI and IoT Can Reshape Learning Spaces

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ABSTRACT

This review examines the design and configuration of AI-powered 21st-century classrooms to align with modern pedagogical approaches. The objective was to identify the main characteristics of innovative classroom design through a systematic literature review analysing 90 articles from the Scopus database. The SPAR-4-SRL protocol guided the selection, organisation and assessment of articles, with analysis conducted using descriptive statistics and topic modelling in AtlasTi. Key findings include (a) determinants like acoustics, lighting, temperature, ventilation and dimensions impact learning; (b) flexible furniture arrangements promote collaboration and active learning over traditional row seating; (c) inclusive designs consider sensory needs of students with disabilities; and (d) technology integration is crucial, including smart boards, cameras and connectivity. This comprehensive synthesis highlights some insights into the effect of the use of Artificial Intelligence and the Internet of Things on the architectural principles and environmental factors that optimise classroom spaces for evolving educational practices. Educators, designers and policymakers can apply these insights to create student-centred, technology-enhanced learning environments fostering engagement and inclusivity.

1 | Introduction

The current society, undergoing rapid technological changes that are contributing to a progressively more uncertain and fluctuating world, has been the subject over the last decades of numerous pedagogical and technological frameworks proposed with the intention of realigning education to match these emerging realities (Burridge and Buchanan 2022; Celik et al. 2024) and whose result converges in what is referred to as '21st-century education'. However, in the everyday practice of educational institutions, dynamics show no substantial changes making them increasingly outdated, and one of the aspects that seem immune to innovation is the physical teaching-learning spaces, that is, the 'classroom' (Berezi 2024; Lebasi and Talischi 2024).

Reflections on 21st-century education based on principles of educational innovation have begun to identify key elements such as inclusion, accessibility, sustainability, integration of technologies and equity, whose incorporation into the design of current teaching and learning environments represents one of the main challenges for those who think about present-day education (González-Salamanca, Agudelo, and Salinas 2020; Patiño, Ramírez-Montoya, and Buenestado-Fernández 2023). In this sense, Trask et al. (2023) indicate that it is necessary to rethink the classroom as a flexible, collaborative and integrative space consistent with active and student-centred pedagogies, to bridge the gap between innovative discourse and traditional practices that still prevail.

In the present century, these spaces still continue to incorporate furniture and ergonomic as main considerations of the educational setting. However, additional factors, such as the overall environment and educational considerations, have also emerged as critical in the ongoing pursuit of innovation by professionals responsible for constructing and conditioning school environments.

Regarding the above, architects rather than educators have been played a crucial role in configuring learning spaces that are influenced by cultural, social and pedagogical factors. As mentioned by Töpper and Isensee (2021), dating back to the 19th century, experts like Lancaster provided recommendations for classrooms housing around 300 children, arranged in rows of tables under a panopticon model controlled by a teacher positioned in front of a blackboard, as a mirror of an era in which the focus was primarily knowledge transmission and skill development, employing methods centred on repetition, memorisation, iron discipline and obedience, often enforced through physical and other punitive measures to maintain order.

A century later, Raynsford (2020) exposes that in the early 1970s, a new generation of architects began to critique the perceived constraints of the classroom's rigid ideological structure, evident in its fixed seating arrangements, furniture, lesson schedules and strict hourly divisions. Over time, these perspectives gave way to the recognition of the need for creative designs that better align with a diverse range of learning activities. Moreover, Ahamer (2024) indicates that Montessori's pedagogical concepts like her vision of highlighting student autonomy boost the need for designed spaces to support it, recommending elements like mirrors, beds and specialised furniture to create an ideal learning environment.

In the same direction, Wellner and Levin (2024) indicate that decades ago, Papert advocated for flexible classrooms and physical environments facilitating students' engagement with digital objects to build and express their ideas safely, enhancing individual thought development. Also, Nair (2019) focused on designing flexible educational spaces promoting collaboration, creativity, adaptability and inclusion of students, teachers and the broader community. This approach also embraced the non-disruptive adoption of technological means, to align with the trends of a rapidly evolving society.

In the realm of current educational research, the intricate task of designing optimal educational spaces is demanding meticulous planning and execution, requiring collaboration among stakeholders such as students, teachers, directors and the surrounding community.

Regarding this, the advent of fourth industrial revolution technologies, notably Artificial Intelligence (AI) and Internet of Things (IoT) present both a significant promise and a formidable challenge to the design of school spaces and classrooms.

Artificial Intelligence refers to the simulation of human cognitive processes by computer systems, which enables them to perform tasks that typically require human intelligence, such as learning, reasoning, problem-solving, perception, language understanding and decision-making (Giudici, Centurelli, and Turchetta 2024; Martin, Zhuang, and Schaefer 2024; Novelli, Taddeo, and Floridi 2024). These capabilities are achieved through algorithms and models that process vast amounts of data, recognise patterns and make predictions or decisions. AI encompasses various subfields, including machine learning (Wang, Wang, and Zhang 2024), natural language processing (Singh, Manju, and Jatain 2024), computer vision (Zhao et al. 2024) and robotics (Akpuokwe et al. 2024), and plays a crucial role in diverse domains, such as healthcare, finance, education and autonomous systems, significantly impacting society and industry through its transformative potential.

Meanwhile, the Internet of Things describes the network of physical objects ('things') that are embedded with sensors, software and other technologies in order to connect and exchange data with other devices and systems via the Internet. These devices range from common household objects to sophisticated industrial tools (Rejeb et al. 2024).

It is worth mentioning that the literature presents numerous ways in which AI and IoT relate to education, particularly oriented towards promoting the personalisation of various educational processes, the automation of tasks, the assistance and diverse issues related to inclusion, almost all as possibilities or promises, very rarely described in a concrete way how these can materialise in concrete realities in the classroom (Bahroun et al. 2023; Kassab, DeFranco, and Laplante 2020; Shin 2021; Tissenbaum and Slotta 2019).

In the context of the review of published research on the use of technologies from the fourth industrial revolution in education, an emerging theme has been identified that is of particular interest and that is just beginning to produce reactions in the academic community. This theme has to do with the possible effects that technologies such as AI and IoT can have on influencing both the classroom design and the configuration of educational spaces in different ways, under the idea of creating more efficient and sustainable learning environments, providing safety and support for students (Coelho and Reis 2023; Onesi-Ozigagun et al. 2024; Pham and Sampson 2022; Zhang and Chen 2021).

In this sense, the combination of Internet of Things and Artificial Intelligence represents a powerful tool with enormous potential to transform educational spaces. As Abdel-Basset et al. (2019) point out, the convergence of IoT and AI can lead to intelligent and adaptive learning environments that respond to individual students' needs.

All these promises are creating an opportunity for the creation of new educational spaces where human cognition and data processing from digital technologies are intertwined, thereby generating new forms of learning experiences that are more effective, flexible and adaptable to the needs and characteristics of students, not as groups but as individuals (Williamson 2020). Thus, the rapid advancement of AI and IoT technologies has introduced new possibilities and challenges in the structure of education inviting the need for changes and adaptations in teaching spaces driving the transformation characterised by creative environments that offer novel opportunities and inspiring environments.

As we navigate these uncharted territories, it becomes imperative to recognise the evolving landscape of educational spaces influenced by AI and IoT with the objective of identifying the main characteristics or determinants, configurations and key elements to consider when designing classrooms. Based on the above, it will be possible to analyse their relevance within the framework of 21st-century education and how the use of AI and other related technologies such as IoT strengthen these characteristics and better leverage the potential of such configurations and key elements.

In this regard, undertaking a comprehensive literature review emerges as a critical step in advancing our understanding and clarifying the panorama of IoT and AI's utility in school spaces. This literature review not only addresses the present implications but also lays the groundwork for envisioning the future possibilities that disruptive technologies such as IoT and AI hold for the transformation of educational environments, contributing to the ongoing discourse surrounding the reshaping of school spaces and classrooms.

2 | Method

Literature reviews are documented as a type of research per se that, among its objectives, aims not only to identify what is known about a defined topic but primarily to explore the unknown aspects of the researched field. According to García-Peñalvo (2022) and Paul et al. (2021), the review is considered systematic when a rigorous, clear method has been followed, and is susceptible to validation and reproduction by other researchers.

The particular review reported in this article is called a 'semi-systematic' or 'narrative' review, which has been developed for addressing topics with different conceptualisations or across various disciplines (Snyder 2019), as is the case with this study.

Considering pertinent to the review's purpose, the SPAR-4-SRL protocol (Scientific Procedures and Rationales for Systemic Literature Reviews) was applied to configure the review process (Paul et al. 2021). This protocol is composed of three steps (known as the 3 A's due to their initials: assembling, arranging and assessing), and each of these steps is further broken down into two sub-steps, as shown in Figure 1.

2.1 | Assembling

The first stage includes the sub-steps of identification and acquisition. Identification involved establishing the domain of the review, which, in this study, is confined to the configuration of 21st-century classrooms. From there, the review question was formulated as: What are the main characteristics and configurations of 21st-century classrooms in which AI and IoT might have positive educational effects?

In this sub-step, the source type was narrowed to research articles published in indexed journals, and the quality was established by selecting Scopus as the search database source. The justification for selecting this database is based on its extensive list of journals, its multidisciplinary nature, the ease of searching on a specific topic, its rigorous peer review protocols, its versatility in research approaches, the possibility of downloading articles with open access system, the availability of useful metrics and the frequency of updating (Dorta-González and Santana-Jiménez 2018). On the other hand, the content coverage and practical usefulness of Scopus have been analysed in comparison with other databases (PubMed, Web of Science and Google Scholar), evidencing in the results that, for citation analysis, Scopus offers about 20% more coverage and also covers a wider range of journals, which is useful for both keyword search and citation analysis (Falagas et al. 2008).

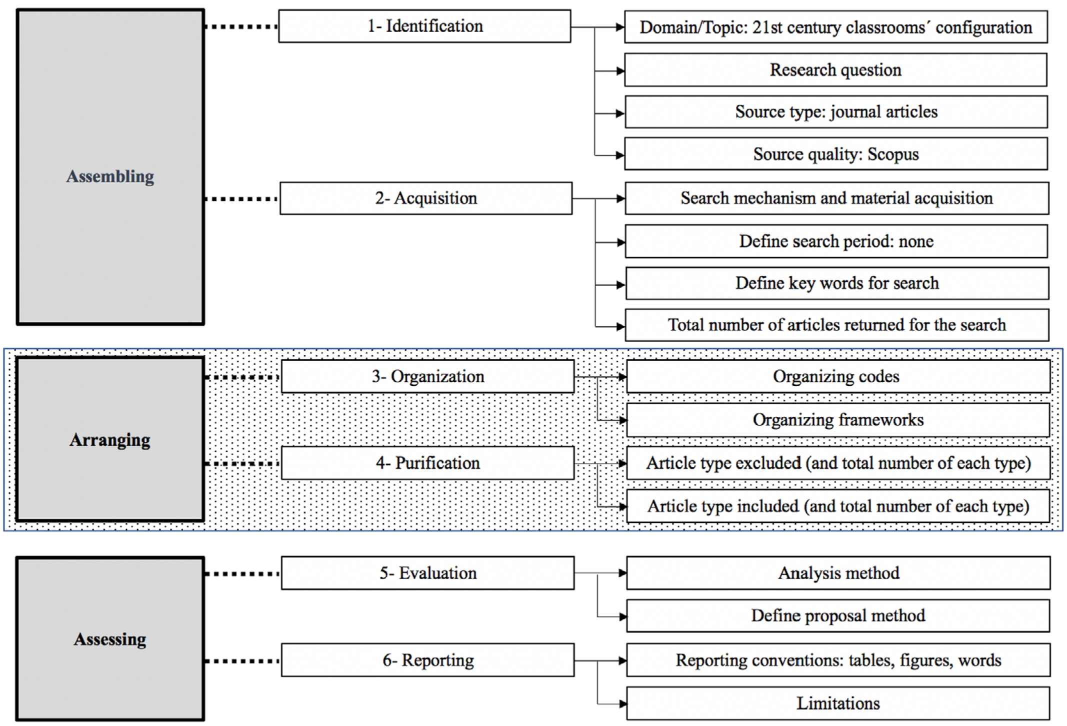

FIGURE 1 | Applied SPAR-4-SRL protocol.

In the subsequent acquisition sub-step, the definition of the search period and keywords were conducted simultaneously. The initially defined descriptors, '21st-century classroom' OR '21st-century learning environments', were reconsidered as they did not yield results connected to the focus of the study. Additionally, the number of articles found was not substantial. Following the recommendations of Paul et al. (2021), the start date was left open, and the closing date was set as 2023, considering the emerging nature of the topics and the limited literature. It is important to mention that, although initial attempts were made to search for terms related to Artificial Intelligence (AI) in combination with other relevant terms in the Scopus database, no documents were found that directly addressed the intersection of AI with the specific topics of 21st-century classroom design and configuration. Therefore, the search was focused on descriptors that were more directly aligned with the study's objectives, ensuring a more relevant and coherent collection of articles consistent with the research's purpose. Table 1 includes the search string (searching keywords) that has yielded a total of 136 articles to initiate the review process.

2.2 | Arranging

The next stage includes organisation and purification. Organisation refers to the list of codes that support researchers in the search and are directly related to the type of review being conducted. In this case, some codes have been determined, such as article type, keywords and abstracts, as these are considered the most effective means of locating the subject of study. Once the codes were defined, the purification stage was carried out, which determined the article types to be included or excluded. This step was directly linked to the previous codes, as filtering before this phase could lead to excluding relevant articles. Later, exclusion criteria were defined, to eliminate duplicate articles, editorial articles and articles from non-scientific journals or book chapters. Results of inclusion/exclusion criteria are shown in Table 2.

In synthesis, out of the total of 136 selected articles, 17 could not be retrieved, and 29, upon thorough examination, were not directly related to the topic, resulting in a total of 46 excluded documents.

2.3 | Assessing

In the last stage, covering the fifth sub-step called evaluation, the analysis method for the reviewed articles was defined, based on counting and frequency analysis and identifying topic relationships using the AtlasTi software, to conduct a descriptive analysis, focusing mainly on classroom design, learning environment design, space configuration and innovative learning spaces.

The analysis led to identifying gaps in the reviewed literature as well as good practices which were reported in the last and sixth sub-step of the review protocol.

3 | Results

3.1 | Bibliometric Analysis

The first result of the review is presented as a mechanism for assessing the quality of the sources used. In that sense, a fairly homogeneous distribution is recognised, in which 41% of the articles exclusively correspond to 16 publications.

TABLE 2 | Purification stage.

Article type included	Article type excluded
Research 87	Review 5
Conference Paper 26	Book chapter 2
	Book 1

TABLE 1 | Acquisition: Keywords for search-total articles and period search.

Keywords for search	N° art	Period search
TITLE-ABS-KEY ('classroom design' OR 'modern classroom architecture' OR 'physical features of 21st-century learning spaces' OR 'classroom layout and design' OR 'innovative classroom design' OR 'learning space design principles' OR 'classroom ergonomics' OR 'flexible learning environments' OR 'active learning spaces' OR 'collaborative classroom design' OR 'classroom architecture') AND (LIMIT-TO (DOCTYPE, 'ar')) AND (LIMIT-TO (SUBJAREA, 'SOCI')). Then the searching string was limited to include the following keywords (LIMIT-TO EXACTKEYWORD): 'Classroom Design', 'Classroom Environment', 'Teaching and Learning', 'Ergonomics', 'Learning Spaces', 'Perception', 'Building', 'Classroom Acoustics', 'Learning Experiences', 'Smart Classroom', 'Computer Aided Design', 'Environment', 'Furniture', 'School Design', 'Classroom Teaching', 'Flexible Learning Environment', 'Flipped Learning', 'Interior Design and Furnishings', 'Learning Space'	109	1969–2023
TITLE-ABS-KEY (learning AND spaces AND classroom AND design AND innovative AND learning AND architecture)	18	1984–2023
TITLE-ABS-KEY ('spaces for learning') AND (LIMIT-TO (OA, 'all')) AND (LIMIT-TO (EXACTKEYWORD, 'education') OR LIMIT-TO (EXACTKEYWORD, 'teaching and learning') OR LIMIT-TO (EXACTKEYWORD, '21st-century classroom'))	9	

Source: Own elaboration based on Scopus data.

The top 10 journals that contributed the most to the review are shown in Table 3.

It is known that the design of school spaces is not a new topic and that it has been researched and put into practice for a long time, which can be seen in Figure 2, which shows the growth of this topic in the publications indexed in Scopus, as well as research related to the Artificial Intelligence/Internet of Things and education.

Something interesting about this figure has to do with the fact that, on the one hand, concerns about the design of school spaces have been growing consistently, especially since the mid-90s, which coincides with the massification of the Internet and the beginning of its use in educational institutions. On the other hand, the number of publications per year is relatively low, which infers that there is a notable gap in research and development of new educational possibilities supported by the use of disruptive digital technologies.

Now, the vast majority of the characteristics and configurations of school spaces have historically been determined by architects, not educators or edTech experts. This has resulted in spaces that may not be optimally designed to facilitate modern, technology-enhanced learning. The exciting possibility moving forward is to place the design of school spaces in the hands of those who truly understand the needs of students and teachers—the educators and edTech professionals.

By leveraging the expertise of these stakeholders, alongside the application of technologies like Artificial Intelligence and the Internet of Things, we can transform school spaces in ways that better support the evolving needs of 21st-century teaching and learning. The results of this review highlight the opportunity to rethink the design of school environments, shifting away from the traditional architectural approach and towards an education-centric model that prioritises the needs of the end users—the students and teachers.

TABLE 3 | Top 10 sources of the review.

Journal name	2022 SJR Imp.Factor	CiteScore quartile
Building and Environment	1.584	Q1
Learning Environments Research	1.187	Q1
Journal for Advancement of Marketing Education	0.127	Q4
Computers and Composition	0.711	Q1
New Zealand Journal of Educational Studies	0.282	Q3
Computer Applications in Engineering Education	0.651	Q1
Frontiers in Architectural Research	0.592	Q1
Higher Education	1.952	Q1
Interactive Learning Environments	1.170	Q1
International Journal of Emerging Technologies in Learning	0.536	Q1

3.2 | Determinants for School Space Design: What Do IA and IoT Have to Say?

The determinants of school space design are pivotal in creating environments that align with the evolving pedagogical needs of the 21st century. In this context, integrating cutting-edge technologies such as Artificial Intelligence and the Internet of Things has opened up transformative possibilities for classroom configurations and functionalities. These determinants, encompassing environmental factors, space flexibility, furniture arrangements and inclusion considerations, significantly influence learning outcomes. By automating and optimising

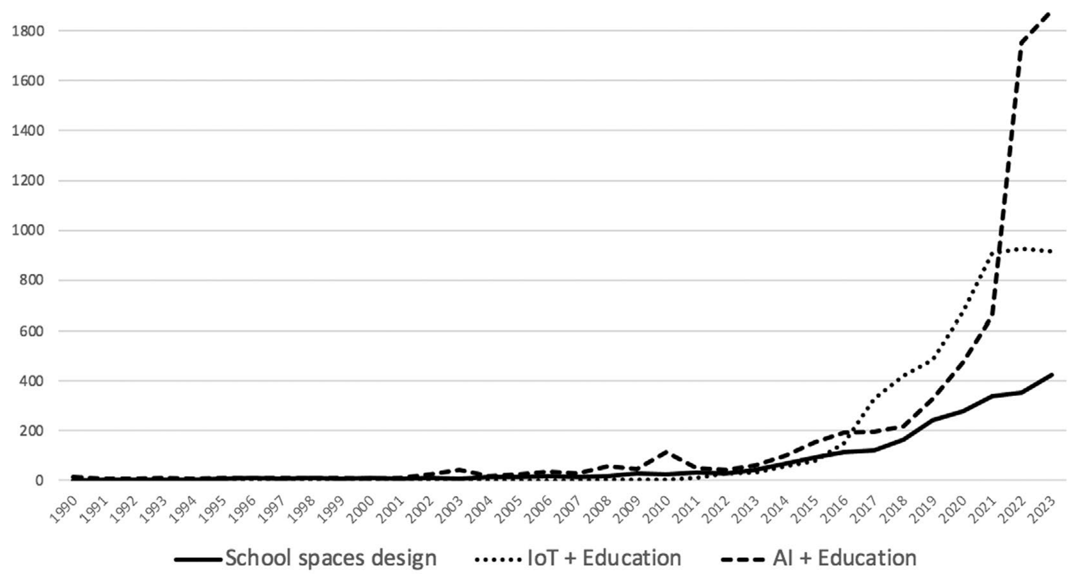

FIGURE 2 | Research on IoT/AI in education and school spaces design (published in Scopus-indexed journals).

aspects like lighting, acoustics and temperature, AI and IoT foster adaptive learning environments that cater to diverse educational activities and individual student needs. Furthermore, these technologies not only enhance collaboration and engagement but also promote inclusivity by addressing the sensory and accessibility needs of all learners. This section delves into these determinants, highlighting their relevance and interplay with AI and IoT in reshaping educational spaces to support innovative, student-centred learning experiences.

The studies reviewed show a great diversity of attributes or aspects that determine the design and organisation of school spaces, which is aligned with what the OECD mentions in this regard (Carvalho et al. 2020), as shown in Figure 3.

3.2.1 | Environmental Conditions: Automating for a Good Mood

The first group of studies refers to environmental factors (28.70%), including work by Knaub et al. (2016), Mercier, Higgins, and Joyce-Gibbons (2016) and Valtonen et al. (2021), focusing on the management of acoustics, lightning, temperature and ventilation as four of the main elements when designing spaces oriented to learning and teaching.

The review highlights the importance of environmental factors in creating optimal learning environments, particularly focusing on lighting, noise levels and ventilation. While proper lighting, especially natural light, significantly impacts student performance by improving memory, attention and mood (Castilla, Higuera-Trujillo, and Llinares 2023; Llinares, Castilla, and Higuera-Trujillo 2021), poor lighting, however, can impair focus. Additionally, noise levels also play a crucial role; excessive or unwanted noise in classrooms can hinder concentration and communication, negatively affecting both students and teachers (Burfoot et al. 2020; Martin 2016). Also, ventilation is essential, as inadequate air quality, particularly high CO_2 levels, can reduce students' ability to concentrate (Andamon, Rajagopalan, and Woo 2023; Barrett et al. 2015). Furthermore, using plants in the classroom can improve the indoor climate and well-being, provided they are chosen to avoid allergic reactions (Danielski et al. 2022). These factors collectively contribute to designing effective educational spaces.

The integration of AI and IoT in school spaces offers significant pedagogical advantages by creating responsive learning environments tailored to educational needs, as evidenced by Shi et al. (2024) in their 'smart classroom' which highlights the fusion of technologies to enhance the learning experience by dynamically adapting the classroom environment. Works such as Yağanoğlu et al. (2023) or Fatehi et al. (2024) highlight the use of Near Field Communication (NFC) and other systems from the IoT ecosystem for the continuous monitoring of classroom conditions so that changes in lighting, acoustics or temperature favour students' attitude towards learning, where these changes can be automatically adjusted by an AI that also takes into account other parameters, allowing classrooms to be personalised in real time, improving student concentration, mood and participation by aligning environmental conditions with specific teaching activities.

The pedagogical implications are profound, as these technologies allow educators to design and implement lesson plans that are not only content-focused but also sensitive to the environment, such as that done by Trocquet et al. (2023), where ventilation and humidity conditions were varied depending on the topics of study to improve children's concentration. This adaptability supports differentiated instruction and creates optimal environmental conditions for various teaching methods, from group work to individual tasks (Brink et al. 2023). Moreover, the concept of 'Smart Healthy Schools' (SHS) has emerged, where AI and IoT technologies not only enhance learning but also ensure healthy, safe environments by monitoring and controlling factors like air quality and infection risks, ultimately fostering a conducive learning atmosphere (Zivelonghi and Giuseppi 2024).

3.2.2 | Education Level and Student's Age

In addition to the above, when designing a classroom, factors such as the level of education and the learners' ages (4.63%) appear less frequently but become relevant determinants of

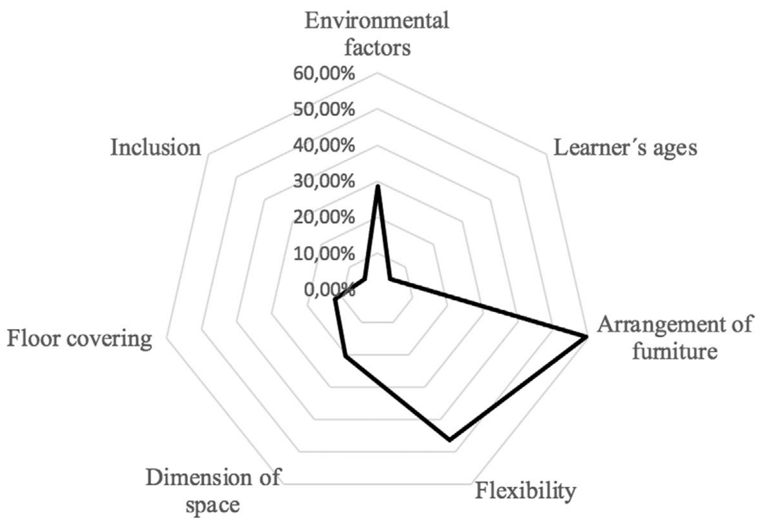

FIGURE 3 | Set of determinants found in the literature.

space design, as mentioned in Lee, Kim, and Kang (2019), Martin (2016) and Wilburn et al. (2019).

In this regard, the analysis carried out on the data did not show any significant effect of the use of AI or IoT on this determining factor in the design of school spaces.

3.2.3 | Distribution of Space and Furniture: New Possibilities of Information Display and Interaction

A third group of studies focuses on the arrangement of furniture (59.26%), as an aspect that has a direct effect on the facilitation of interaction, collaboration in general, on the development of 21st-century skills and student performance. Examples of the above are found in Carvalho et al. (2020), Krajewski and Khoury (2021), Lee, Kim, and Kang (2019), Llinares, Castilla, and Higuera-Trujillo (2021), Miller-Cochran and Gierdowski (2013), Perry, Adi-Japha, and Spektor-Levy (2023), Rönnlund, Bergström, and Tieva (2021), Thoring, Luippold, and Mueller (2012) and Wilburn et al. (2019).

While theorists prioritise physical characteristics based on population and education level, another recurring issue in the reviewed articles is the configurations inside spaces, especially in the arrangement of furniture and other equipment. Frameworks and models have been developed for this distribution, responding to certain pedagogical trends, especially in higher education.

The traditional classroom configuration, criticised by almost all authors, features a front with an atrium or teacher's desk and rows of seats and desks arranged unidirectionally, promoting a passive student–teacher relationship (auditorium type). Some authors have referred to this configuration as 'industrial teaching' due to fixed, row-aligned furniture (Walls, Schopieray, and DeVoss 2009), which is prevalent in secondary and higher education.

In contrast, other configurations place the student at the centre of the training process, promoting collaborative and discussion activities typical of active pedagogies. These configurations include U-shaped (horseshoe-shaped) or semi-circle designs (Knaub et al. 2016; Mercier, Higgins, and Joyce-Gibbons 2016; Wilburn et al. 2019).

Additionally, according to De Borba, Alves, and Campagnolo (2020), designs by workgroups facilitating interactions and collaboration are considered multifunctional, including L-shaped, small groups, work in pairs and distributed, among others. Many of the reviewed articles indicate that these configurations often align with the pedagogical model, training level and teaching methodology the instructor intends to implement. However, it is also noted that, in some cases, classroom organisation may simply adhere to local or national regulations or directives.

The primary effect of using 4.0 technologies, specifically IoT, in the distribution of space and classroom furniture focuses mainly on flexibility. Studies such as Castilla et al. (2017) focus on how effectively identifying the design and arrangement of elements in the classroom to improve functionality distribution generates positive affective responses from students. The incorporation of IoT allows assigning digital characteristics to work surfaces, tables, walls and even the classroom floor, eliminating the fixed orientation of furniture dictated by the location of predetermined points for the projection of information such as whiteboards, televisions or screens, which has been legitimised by Haleem et al. (2022) in their studies on facilitating more dynamic and collaborative learning environments, findings that align with the research of Chaichana, Wongkalasin, and Sanrutsadakorn (2022) who demonstrated the benefits of integrating these systems into different teaching methods. The fixed position of these elements creates a natural viewing axis that influences the placement of students, as illustrated in Figure 4.

When furniture, walls and floors are digitally interconnected, information can be distributed in ways that differ significantly from the unidirectional approach dictated by the classroom board. This would promote much more flexible design layouts and pedagogical approaches, such as Student-Centered Active Learning Environment with Upside-down Pedagogies (SCALE-UP), Active Learning Classroom (ALC) and Technology-Enhanced Active Learning (TEAL) (Ellern and

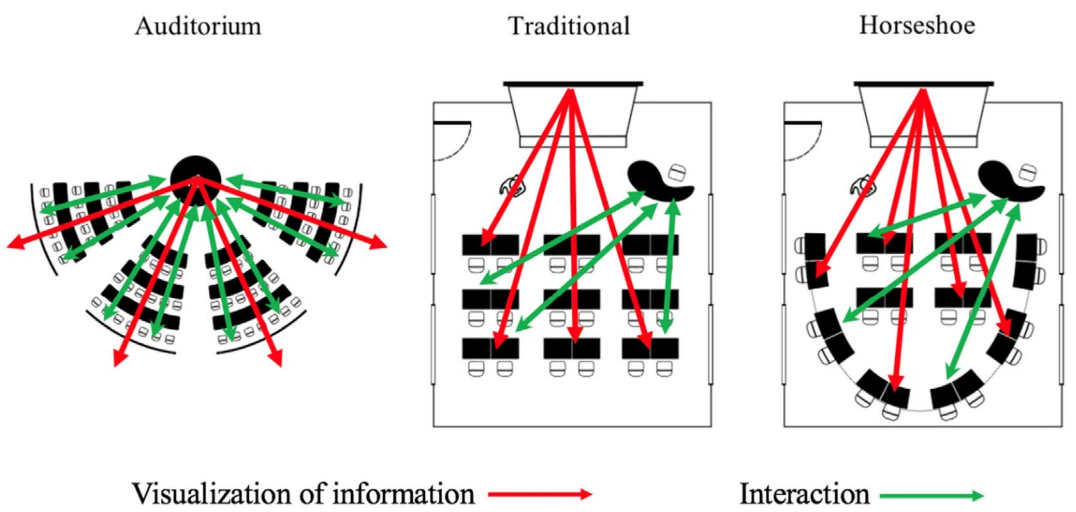

FIGURE 4 | Information display and interaction in low-flexibility classroom configurations.

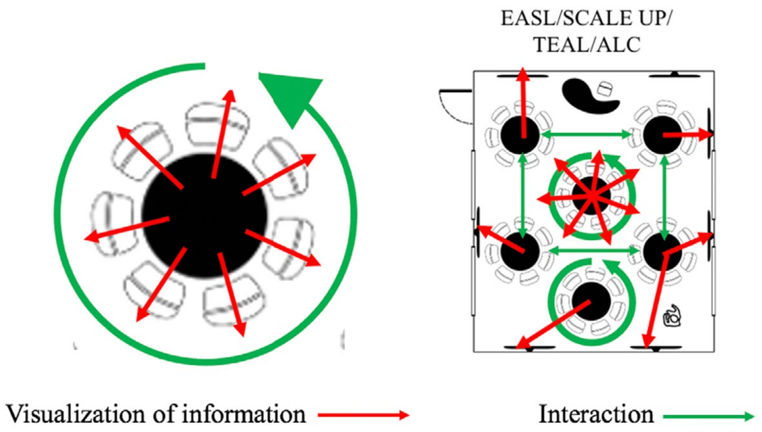

FIGURE 5 | Information display and interaction in IoT-powered high-flexibility classroom configurations.

Buchanan 2018; Farrow and Wetzel 2021; Knaub et al. 2016; Miller-Cochran and Gierdowski 2013; Pates and Sumner 2016), where the interactions and visualisation of class information would develop in diverse and varied ways (Han, Long, and Wang 2024), as shown in Figure 5.

Flexibility and mobility of 21st-century classrooms are issues partially dependent on the arrangement and versatility of furniture, allowing for various configurations, already mentioned previously, promoting active and collaborative learning, and facilitating the creation of diverse areas suitable for self-directed learning, group work or independent study (Benade 2017; Castilla, Higuera-Trujillo, and Llinares 2023; Ellern and Buchanan 2018; Holowka 2020; McKown et al. 2022; Mercier, Higgins, and Joyce-Gibbons 2016; Rincon-Flores et al. 2021; Valtonen et al. 2021). These aspects are essential to meet the changing needs of students, where the adaptability of space becomes a pillar for the enrichment of learning experiences (Barrett et al. 2015; Guetl et al. 2013; Lin et al. 2002; Walls, Schopieray, and DeVoss 2009; Wyatt, Todd, and Verbick 2006).

The results of this objective show how a learning system based on AI and IoT can be developed by means of a series of devices (e.g. cameras, amplifiers, etc.), which collect information from the students in a progressive way, which is then stored and decomposed. Subsequently, the transmission of information from the sensors to the devices with remote innovations (e.g. Bluetooth and ZigBee, among others) allows to manage the collected information with AI calculations, which enables a teacher to receive valuable information from the profile and study practices, or specific needs, to adjust their instructional methodology during education or assessments (Hameed et al. 2021).

3.2.4 | Flexibility: A Pedagogical Determinant of Space Design

Regarding the above, it is noteworthy that a prominent pedagogy-related characteristic that many authors emphasise is flexibility (46.30%). This attribute spans various concepts, encompassing movement within space, creating areas for different uses and pedagogies, and incorporating diverse equipment to enhance the teaching-learning process. The above can be seen in Barrett et al. (2015), Benade (2017), Knaub et al. (2016), Krajewski and Khoury (2021), Martin (2016), McKown et al. (2022), Miller-Cochran and Gierdowski (2013), Rönnlund, Bergström, and Tieva (2021), Thoring, Luippold, and Mueller (2012) and Valtonen et al. (2021).

In basic education, flexibility is linked to providing differentiated spaces for activities such as learning by doing, play, art and science, and rest, aiming to enhance activity and facilitate varied experiences. It is also emphasised that spaces should be easy to understand and guide for children, promoting autonomy and development, directly linked to accessibility through single-level spaces and the elimination of impediments or obstacles (Barrett et al. 2015; Martin 2016).

Otherwise, for young people, flexible spaces should facilitate both group and individual work, ensuring tranquillity and concentration (Valtonen et al. 2021).

Some pedagogical implications of applying AI and IoT to promote flexibility in space arrangement are manifested in four key aspects: adaptability to diverse teaching methods that allow spaces to be reconfigured for different pedagogical styles, from traditional classes to active learning; support for varied learning activities through movable furniture and interactive surfaces; increased student engagement through spaces that adjust to individual and group needs; and the ability to keep educational spaces relevant and effective in the long term without requiring costly renovations, as shown in Figure 6.

3.2.5 | Space Dimensions and Coverings: When a Floor Is More Than a Floor for Learning

Other physical determinants of space, such as dimensions (20.37%), are crucial, with amplitude potentially impacting attention levels, behaviours and interactions with the teacher (Burfoot et al. 2020; Clarke, Nelson, and Gallagher 2020; McKown et al. 2022; Pates and Sumner 2016; Widiastuti, Susilo, and Nurfinaputri 2020). This is explicitly stated by certain authors who link classroom dimensions to the management of students' attention and memory, discovering that larger spaces are associated with lower performance (Knaub et al. 2016; Llinares,

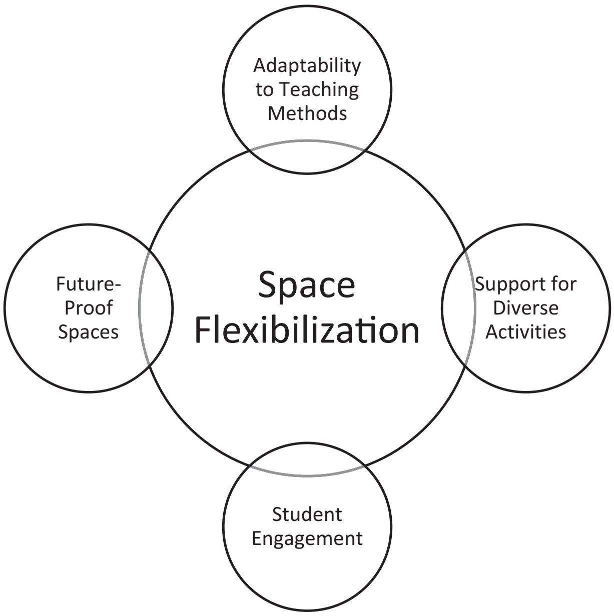

FIGURE 6 | Implications of AI and IoT to promote space flexibilisation.

Castilla, and Higuera-Trujillo 2021). Regarding dimensions, other factors are articulated, such as the heights of the roof and windows, their shapes, sizes, and arrangement. It can be inferred that, to varying degrees, children and young people must have a direct relationship with nature through patios or windows. This is because these elements influence moods and, more importantly, the ability to concentrate, which typically benefits from access to environments with natural light (Barrett et al. 2015; Carvalho et al. 2020; McAllister and Maguire 2012; Widiastuti, Susilo, and Nurfinaputri 2020).

While neither AI nor IoT can make learning spaces larger or smaller, it is possible to influence students' perception of these spaces. Very narrow spaces can be perceived differently depending on what the walls or ceiling project onto their surface, as Brown et al. (2020) highlight by incorporating mixed reality (MR), augmented reality (AR) and AI to significantly transform learning environments to create more immersive, engaging and effective experiences. Let us imagine then the possibilities of a wall and ceiling covering with digital connectivity and image projection capabilities on the perception of space or on the motivation or engagement of a group of students who interact digitally with everything in the school space. The possibilities are endless.

On the other hand, complementary elements of the space, such as floor covering (12.04%), are details insufficiently investigated, although they directly or indirectly affect aspects like temperature and acoustics, impacting the well-being of students and teachers (Bautista Pérez, Rubio Hurtado, and Sánchez-Martí 2022; Burfoot et al. 2020; McCreary et al. 1998).

Furthermore, a floor that reacts to students' footsteps or that can be programmed to light up in a certain way and in certain directions at certain times would become a factor in enriching learning experiences. If this were taken to a technological extreme, the floor could even become a display surface for information, thus making the classroom an immersive space for interaction and interactivity.

3.3 | Inclusion Beyond Architectural Barriers

Another aspect developed in the literature was the design of inclusive classrooms (4.63%), focusing not only on the architectural barriers that design professionals usually deal with but also on the needs of a population that has become increasingly visible in recent decades. Although the articles identified in the review paid particular attention to children with Autism Spectrum Disorder (ASD), the emphasis was on environmental requirements to avoid overstimulation or anxiety due to the visual, tactile, auditory and olfactory sensitivity characteristic of this population (Benade 2017; Martin 2016; McAllister and Maguire 2012). The lack of knowledge about these particularities in classroom design has been a constant issue; the information is available to their families, health professionals, psychologists and therapists but is not handled by professionals responsible for school space design.

4 | Discussion and Conclusions

The results of this review suggest that the relationship between AI, IoT and the design and preparation of school spaces can be viewed from at least two different perspectives: one in which flexibility is conditioned by the extent to which these technologies automatically react to environmental or external factors or changes in the classroom, and a second one, in which flexibility is achieved through support for the teacher's work in decision-making and process execution before or during the interaction with students. In this regard, it is noteworthy to mention that both perspectives present some effects on learning conditions.

4.1 | Discussion of Results on Determinants of School Space Design

AI and IoT can automatically control classroom parameters such as acoustics, temperature and lighting to enhance concentration, while also being able to optimise the use of furniture to support various pedagogical strategies, adapting space to educational needs rather than restricting pedagogy to spatial constraints.

In this sense, classroom layouts can be managed through AI-driven teaching, processing information about student characteristics and learning needs. Within the framework of the fourth industrial revolution, AI and IoT can create adaptable and personalised learning environments that move away from traditional models, maximising active learning processes (Al-Moqaram and Al-Amara 2020). This aligns with Gislason's (2009) claim that some physical classroom designs facilitate collaborative teaching practices.

Open architecture supported by principles of flexibility could have a positive impact on the social climate by promoting broader peer-to-peer relationships—here AI systems could suggest furniture arrangements or adjust environmental factors to optimise student interaction, collaboration and performance based on specific needs. The integration of intelligent, reconfigurable furniture controlled by AI and IoT can improve the flexibility of the learning space, allowing the dynamic creation of areas for different pedagogies and facilitating movement within the learning environment.

In this regard, Selwyn (2024) states that AI and IoT can contribute to designing spaces that promote student autonomy through smart interfaces and personalised guidance systems that are easy to understand and that can also facilitate the monitoring and analysis of student interaction patterns. In addition to the above, we want to place special emphasis on the possibilities in the field of educational inclusion that would open up with the integration of AI and IoT in the design and organisation of the school space.

4.2 | Discussion of Results on Inclusion Beyond Architectural Barriers

The review highlights the potential of AI and IoT to promote inclusion by overcoming traditional architectural barriers. These technologies enable adaptive learning environments, especially for students with sensory disabilities, by dynamically adjusting to their needs. IoT sensors, for instance, can collect real-time data to manage factors like lighting, temperature and noise, minimising overstimulation and anxiety for students with special sensitivities. This integration of AI and IoT equips stakeholders with the insights to design advanced classrooms.

Additionally, it advances the conversation on how technology can reshape the future of education, emphasising the importance of flexible and collaborative approaches in classroom redesign. Such approaches are crucial for creating environments that meet diverse needs and avoid costly failures, both economically and socially. Ultimately, this review underscores the necessity of a shared vision in designing educational spaces that motivate teachers and students, contributing to the evolution of schools.

4.3 | Discussion of Challenges and Considerations for Implementing IoT in Educational Settings

The implementation of IoT in schools involves various costs that must be considered, where the most relevant represents a significant financial burden for educational institutions, particularly those with limited budgets or unclear plans for this type of implementation, since it demands the purchase of devices, sensors and technological infrastructure to guarantee continuous and efficient connectivity.

In addition, additional costs arise from software and integration with existing management platforms, which require developing custom applications or adapting existing solutions, consulting services and specialised licences. Furthermore, institutions must prepare for the costs of replacing outdated equipment, updating systems and ensuring security.

Also, it is essential to consider the costs of training teachers and administrative staff too, because to use IoT technologies effectively, workforce needs to learn how to use these tools and make the most of the data they generate to improve educational experiences. Finally, it is worth noting that using these devices initially consumes more energy, increasing short-term energy costs, despite potential long-term savings through automation.

4.4 | Discussion of Pedagogical Transformation Through Intelligent and Adaptive Environments

The use of AI and IoT in educational environments allows the teaching-learning process to be continuously personalised and adapted, automatically adjusting classroom conditions, creating more favourable environments for the concentration and academic performance of students, while their statistics can be obtained and analysed in real time by their teachers or the professional in charge. This facilitates more informed pedagogical decision-making and allows teaching strategies to be adjusted to individual needs.

In this regard, AI and IoT also favour interaction and collaborative learning within the classroom by creating dynamic spaces where students can interact with each other and with smart objects by participating in immersive activities that encourage the development of key skills such as critical thinking and problem-solving. By automating routine tasks such as assessment or data management, these technologies allow teachers to focus on more strategic aspects of teaching and on personalised attention to students, which is essential to promote a more inclusive and effective education.

However, for the implementation of these smart spaces to be effective, it is crucial that there is adequate planning that involves collaboration between teachers who are experts in technology and other professionals, which would generate a coherent integration of these technologies with traditional pedagogical methodologies, ensuring that learning environments are truly inclusive and adaptive and capable of significantly improving the educational experience.

This review has examined the growing body of research on the design of school spaces, with a particular focus on the role of emerging technologies like artificial intelligence and the Internet of Things in shaping these environments. The analysis reveals several key insights. First, the design of school spaces has traditionally been dominated by architectural considerations, with insufficient input from educators and edTech experts who best understand the evolving needs of students and teachers. In this regard, by integrating AI and IoT, there is significant potential to transform learning environments in ways that better support 21st-century pedagogy, enabling intelligent, adaptive spaces that can dynamically adjust factors like lighting, temperature and acoustics to optimise conditions for concentration, collaboration and overall well-being.

Beyond environmental conditions, AI and IoT also unlock new possibilities for the physical configuration and flexibility of learning spaces. It is noteworthy that by embedding connectivity and smart capabilities into furniture, walls and even floors, classrooms can become highly adaptable, accommodating diverse teaching methodologies from traditional lectures to active, project-based learning. This flexibility empowers educators to create differentiated learning experiences tailored to students' unique needs.

Regarding the above, the integration of these advanced technologies also holds promise for enhancing inclusion and accessibility in school design. AI-powered systems can monitor environmental variables and automatically adjust to support students with sensory sensitivities or other special requirements, breaking down traditional architectural barriers. Besides, while the reviewed research highlights the significant pedagogical advantages of applying AI and IoT to school space design, it also cautions that successful implementation requires careful planning and collaboration between educators, technologists and design professionals. Ongoing challenges around cost, training and system integration must be addressed to realise the full transformative potential of intelligent, adaptive learning environments.

Overall, this review underscores a critical opportunity to rethink the design of educational spaces, moving beyond conventional architectural models to create flexible, technology-enhanced facilities that truly elevate the teaching and learning experience. Further research is needed to explore innovative applications of AI and IoT, as well as to develop holistic frameworks for designing the classrooms of the future.

Author Contributions

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The authors have nothing to report.

Consent

The authors have nothing to report.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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