

Review

A Ten-Year Review of Primary School Flexible Learning Environments: Interior Design and IEQ Performance

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Abstract: Flexible Learning Environments (FLEs) arose as enablers for implementation of student-centric pedagogical approaches. Interior design is the key to the success of FLEs, providing the physical infrastructure needed for students to engage on several learning activities, from individual to group work, which take place in a variety of zones ranging from low to high energy. Therefore, a harmonious synergy between the interior design and subsequent Indoor Environmental Quality (IEQ) performance of FLEs' physical configuration and learning activities is needed. The objective of this paper is to systematically review (in accordance with the PRISMA method) existing literature related to FLEs within primary school settings, typically catering to children aged 5–12 years old, to understand the body of work investigating the design and performance of FLEs over the last decade (2010–2020). Key findings suggest that the proximity and acoustic and visual permeability of zones found in FLEs may give rise to inadequate IEQ conditions delivered to students. In addition, it could be inferred from the results of the literature review that interior design and IEQ have not been sufficiently investigated in an integrated manner.

Keywords: flexible learning environment(s); primary schools; interior design; Indoor Environmental Quality; PRISMA



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1. Introduction

Over the last two decades, there was a significant transformation of educational models around the globe to enable a student-centric approach to teaching and learning [1]. There is evidence that 'learning environments' (LE) play a pivotal role in supporting this educational transformation, via manifold changes to pedagogical practices, spatial design and configuration of classrooms, as well as digital affordances. The transition towards a student-centric pedagogical model has led to classrooms moving away from the idea of a 'static container' to a dynamic and interactive learning environment [2,3].

The term 'LE' embodies a multitude of concepts which differentiate them from traditional classrooms, both in physical and functional attributes. The term 'LE' is known to less frequently refer to the physical learning environment or space than to the social, psychological, or conceptual environment [4]. This definition is different somewhat from a previous version by [5], as they defined LE as "the physical and digital settings in which learners carry out their activities, and also include the socio-cultural settings for such activities". The OECD's definition [6] is by far more precise, as LE is defined as "an organic, holistic concept that embraces the learning taking place as well as the setting: an eco-system of learning that includes the activity and outcomes of the learning".

Despite the lack of agreement on an universally accepted definition for LEs [7,8], "flexibility" remains their key characteristic, becoming inseparable from learning spaces [9]

in the pursuit of transitioning from traditional classrooms. More recently, LEs have been progressively referred to as Flexible Learning Environments (FLEs) which combine characteristics associated with flexible delivery of instruction and learning, enabling learners to have choices in terms of what, where, when, why, and how they learn [10]. As the basis for this study, FLEs are considered to be contextualizing learning, in terms of time, activity, and interaction, within the context of indoor built environment.

2. The Open-Plan Configuration of FLEs and Its Challenges for Indoor Environmental Quality (IEQ) Performance

Physical design plays a crucial role in classroom management [11] and in mediating the teaching and learning process [12], and physical configuration is fast becoming a key classroom resource for meeting learning outcomes [13]. In terms of ‘design’, FLEs can be categorized using Dovey and Fisher’s typologies [14], that are comprised of five types of layout configurations, of varying openness and convertibility, ranging from traditional egg-crate to large open-plan configuration. Their typologies describe FLEs as a design trend that involves adaptive usage of an assemblage of spaces, to support bespoke iterative pedagogical practices.

In comparison to traditional classrooms, FLEs are capable of simultaneously supporting a diverse range of learning activities, such as collaboration, discussion, feedback and reflection, guided, explicit, demonstration, experiential and independent learning [15,16]. As a result, the interior design and physical configuration of FLEs normally cater for the variety of learning activities, by providing students with several zones within the classroom intended to support their task at hand. Classrooms are open-plan, depicting different types of furniture intended to be moved around to reconfigure the space depending on needs. The teaching and learning practices within FLEs offer students an opportunity to move from one zone to another, in order to find the best location that suits their learning-activity, and for interacting with teachers, peers, and technology [15].

Experts are becoming increasingly aware of the physical environment’s significant role [4], and for the better utilization of this resource, schools have begun to redesign classrooms [13] to be able to create adaptable and often re-configurable learning settings [11]. An influential study [8] points out that this issue triggers the possibility that school leaders may jump on the bandwagon of opening up and fitting out classrooms with modern furniture, without adapting their teaching approaches to ones suited to flexible learning. The lack of design guidance and of a consistent definition is also challenging for the teachers, as they are expected to effectively manage environments that cannot be clearly described [7]. In this context, increasingly, interior design is understood to play a central role in the creation of LEs, and a lack of flexibility in a space would prevent even ordinary changes, such as increasing the number of students in the classroom [17].

Indoor Environmental Quality (IEQ) Performance of FLEs

IEQ refers to thermal, lighting, acoustics, and indoor air quality conditions observed indoors. IEQ performance in traditional classrooms has been heavily investigated and continues to draw significant interest. Much has been learned about daylight traditional classroom environments and student performance in maths and reading, especially when students have window views. In a follow-up study [18], access to higher amount of daylighting was found to improve students’ test performance by 7% to 18%, showing the benefits of higher illuminance levels and connection to the outdoors. Research also shows that an incorrect layout of windows, the materials, and colors of the walls, and the material of the floors and curtain styles had a significant effect on the lighting of FLEs [19]. Insufficient illumination in FLEs can lead to a drift of the circadian rhythm and affect hormone-levels and the sleep-wake cycle [20].

Thermal comfort studies conducted in traditional classrooms have identified that elevated temperatures can significantly impact academic performance [21,22]. Children have a greater sensitivity to higher temperatures as compared to adults, possibly due to their metabolic rate and the limited available adaptive opportunities in classrooms [21,23–

25]. Further, air-conditioning was found to be the most favored thermoregulatory method amidst other adaptive options such as building or personal behavior adjustments [24,26]. In addition, Indoor Air Quality (IAQ) studies identified that children are more susceptible to air pollutants than adults because of immature lung growth, as well as metabolic and defence mechanisms [27], and mitigating poor IAQ in classrooms is a huge public health concern [28]. Low ventilation rates in classrooms, with CO₂ as an indicator, are found to significantly reduce pupils' attention and negatively affect memory and concentration [29]. In FLEs students move from zone to zone to develop their task at hand, but these zones may or may not provide appropriate thermal and IAQ conditions depending on the reconfigurable layout and air-conditioning outlets. Further, students' metabolic rate may also vary depending on the type of activity they are engaged with which again is different from a traditional classroom where students spend most of their time seated [30].

Good acoustic quality favors appropriate cognitive and processing of the gathered information [31]. Classroom noise is typically dominated by children's speech and activities, with approximately 20dB(A) difference between the quietest and noisiest activity [32], and unfavorable noise levels are found to negatively impact scores in the standardized tests [33]. In typical FLEs, children are often engaging in different activities within an open-plan configuration which may in turn require an increased effort in listening, compromising learning [34]. It is also observed that noise alters the linguistic and sociolinguistic patterns and processes employed for collaborative learning, and ironically, in rooms with potentially poor acoustics, collaboration can become an impediment rather than an aid to their learning [35]. Further, the variety of activities, often involving multi-tasks, taking place simultaneously may lead to clashes, for example, acoustics-related issues arising from activities that demand concentration versus collaboration [34]. Subjectively, external noise appeared to have little effect on the internal noise environment [33]; however, chronic exposure to external sources such as aircraft noise is found to cause impaired speech perception, which would lead to a noise-exposure-reading deficit link [36].

There is growing evidence that optimizing IEQ conditions within FLEs' is potentially more challenging than within traditional settings suggesting that the open-plan configuration and the variety of activities taking place simultaneously may lead to IEQ-related issues. While some of these IEQ-performance shortcomings observed in FLEs may be addressed via interior design considerations, normally research has focused on IEQ performance or interior design but seldom on the two together. This systematic review brings these two topics together by presenting findings related to the design and IEQ performance of FLEs from research conducted in primary school settings over the last decade (2010–2020).

3. Method

This systematic literature review was conducted in accordance with the guidelines set-out under the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) [37]. The search was conducted using three scientific databases—Scopus, ERIC, and PsycInfo. The relevant records were exported to an Excel spreadsheet for the screening of abstracts and to identify the most relevant publications. Studies were included only if they satisfied all the following inclusion criteria items:

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation, as well as the experimental conclusions that can be drawn.

- Full-text available in English;
- Peer-reviewed Journal article;
- Published between 2010 and 2020;
- Focused on non-traditional learning environments within primary schools;
- Identified interior design characteristics that support student-centric learning; and/or
- Measured or reviewed a specific outcome related to IEQ performance relevant to students' experience or performance.

Studies that exclusively addressed the impacts on teachers or teaching were excluded, as they were beyond the scope of the current paper. The authors identified a total of 28 keywords related to the categories of interior design and IEQ performance of FLEs, as depicted in Table 1. Each of the keywords from both categories were searched in combination with the following terms, in all selected databases:

- [Keyword] +
- [Primary (OR) Elementary] +
- [school] +
- [learning environment (OR) classroom]

Table 1. Keywords and categories used in the search strategy.

Keywords		
Category 1: Interior Design		Category 2: IEQ
Interior design	Innovative	Indoor Environmental Quality
Design	Project-based	Thermal comfort
Open-plan	Collaboration	Lighting
Flexible	‘New generation’	Visual comfort
Layout	Technology-infused	Air quality
Modern	Flex-class	Acoustics
Learner-centered	Agile	Wellbeing
Student-centered	Blended	Satisfaction
21st century	Smart	
Multi-modal	Non-traditional	

As per the PRISMA flowchart summarized in Figure 1, the keywords reviewed through the multiple databases resulted in a preliminary database of 14,641 articles. The first stage of screening involved scanning of the abstracts and titles and the removal of duplicates. Of the remaining 661 articles, 137 were removed as part of a second stage review in order to exclude papers that could not be obtained in full text. A further third stage review involved the elimination of non-relevant articles (i.e., did not satisfy the inclusion criteria) and to retain only peer-reviewed journal publications. A final set of 31 articles were included in the analysis.

Firstly, content analysis was done to group the studies under Interior Design and IEQ-relevant themes. Second, the paper’s findings of the relationship between interior design, indoor environment, and aspects of student satisfaction and/or behavior were identified. From the full-text papers, key data as well as conclusions of these articles have been considered for this review.

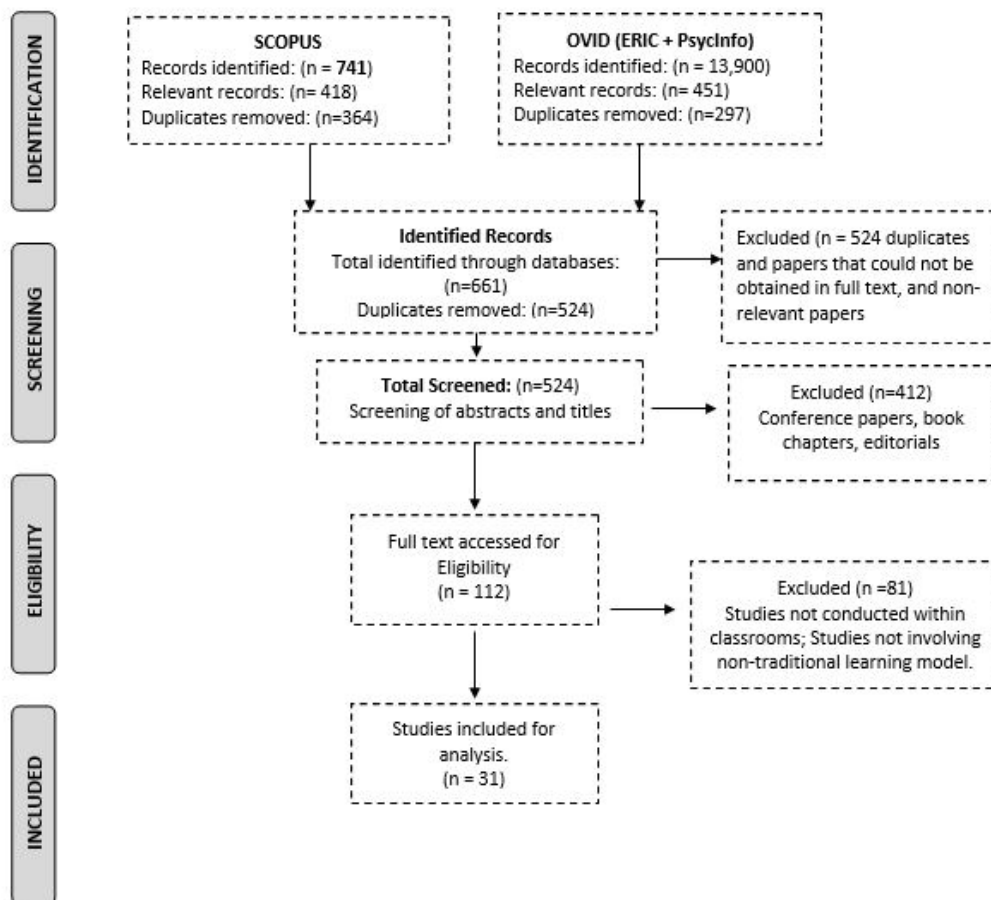


Figure 1. PRISMA Flow diagram to summarize the study selection.

4. Results

A total of 31 papers met the inclusion criteria for this review, and the publication trend indicates that these have emerged from multiple geographical locations, and 19 of the studies were published within the last five years, suggesting that there is a rising interest on the topic of FLEs. Of the final selection, interior design was most researched, with a total of 23 studies, and the remaining eight focused on IEQ. In terms of geographical distribution, Australia is at the forefront in number of recent publications (11), followed by the USA (7), with research encompassing both interior design and IEQ, and the Netherlands (3) with a high focus on IEQ.

The first stage of this review focused on investigating the interior design transformation arising from the move from traditional to flexible typology. The second stage of this review focused on literature pertaining to IEQ performance within FLEs. Table S1 provided as supplementary material, provides a tabular summary of the 31 selected papers in regards of their research design, method(s), sample size, aim, and category of findings. The identified findings are categorized under distinct headings of interior design and IEQ and presented in detail.

4.1. Interior Design

The majority of the papers included in this review reported findings associated with interior design under the themes of (1) layout as well as (2) furniture and technology. Much of this published research is based on empirical studies involving qualitative research methods.

The significance of having a flexible interior design for supporting 21st century learning needs was studied by comparing traditional and flexible settings and identifying

shortfalls of the former [12,38]. A shift towards a more open and dynamic model, where the design is guided by flexibility, flow, openness, and teamwork, has been observed in recent designs in Iceland [39]. Similar studies conducted in Australia have identified that, when designed and used effectively, FLEs are found to offer increased autonomy to students and appear to positively impact teaching, learning, and student-wellbeing outcomes [30] as well as students' spatial perception and experience [8]. A further study [40] investigated space and elements in a blended classroom (i.e., one with a physical and digital space) and identified that they support the orchestration of classroom activities across tools and resources, while also leveraging students' engagement in reciprocal teaching and collaborative learning. Another study reviewed the elements of the physical FLE [41] and developed a hypothetical Model (MoPLE21) as a simple tool for evaluating existing school environments or designing new ones. The need for having analytical tools to support educational designers (such as teachers and architects) was highlighted in a study conducted in Australia, in order to promote correspondence between pedagogy, people, and place [42]. The intent of the framework is to ensure that the designable elements (comprising of set-design, epistemic design, and social design) would recognize and support the learning activities that are 'spatiotemporal' in nature.

Despite the current trend where classrooms are 'out' and FLEs are 'in', there is no single identifiable approach used across the school, as different FLE models can function simultaneously and effectively within one school, such as open-spaces, double-spaces, and single-cell classrooms [43]. Similarly, the connection between space, power, and pedagogical practice was examined and identified that contemporary educational practices observed in their case-study were not restricted to the constitution of a simple 'opening' or 'dissolving' of boundaries, but rather a specific use of areas different for each student [44].

The design of the physical FLE has been found to play a prominent role in successfully supporting a school's pedagogical ideas; however, the open and transparent designs encouraged by FLEs have been identified to negatively impact privacy afforded to individuals in the name of openness and the negative impact of increased transparency on certain students' distraction and behavior [17]. To determine the impacts of physical design on children's learning performance, the HEAD study in the UK [45] evaluated the impact on the basis of three design principles that were split into 10 parameters as follows: (1) Naturalness: Light, Sound, Temperature, Air Quality, Links to Nature; (2) Individualization: Ownership, Flexibility, Connection; (3) Level of Stimulation: Complexity, Color. Findings from this study identified that, at the classroom level, flexibility offered via dynamically reconfigurable spaces is a significant factor in improving learning outcomes for all three subjects of reading, writing, and maths, with larger impact on math progress, and the combined effect of classroom design on students' "overall" learning progress is 16%.

While non-traditional spaces clearly enable student-centric learning, there are still limits that are yet to be defined in terms of what students can or cannot do in the LE [46]. It has also been conclusively shown that a gap exists in how students perceived their actual innovative LE, in comparison with a preferred one [47], and which characteristics predicted students' cooperation (out of 10 characteristics of their classroom learning environment—student cohesiveness, teacher support, involvement, task orientation, investigation, cooperation, equity, differentiation, computer usage, and young adult ethos). Results indicated a gap between the actual and the preferred states for all characteristics.

Another study developed an Innovation Configuration (IC) Map based on the Concerns-Based Adoption Model of Change (CBAM) [7]. This study identified two configurations, one being more traditional and content-based, and the other a project-based approach, both included technology use which the researchers considered as the catalyst for learning as it is often claimed as a means for creating opportunities for collaboration, creativity, critical thinking, and communication. However, it was found that the culture of the environment, and the interactions between individuals and the space, is the key factor to promote FLEs.

Layouts: FLEs vs. Traditional

Existing literature has established that ‘flexibility’ means more than just the popular idea of removing desks and chairs and providing more informal furnishings within a space previously known as a classroom [43]. Within traditional classrooms, ‘space’ has been a constraint as it restricted the layout to a linear configuration within a rectangular profile of approximately 60 m² in size to accommodate around 30 students [8]. Changes to classroom layouts appear to be an inevitable consequence of moving towards future-focused LEs that emphasize freeing up of space via the removal of standard rows of desks and chairs [8], and creating different learning settings around the room, comprising of spatial typologies such as general learning areas, breakout areas, individual pods, presentation spaces, along with no distinct ‘front of classroom’ [30]. The idea of the conventional classroom—with its four walls, blackboard, ‘closed’ door, teacher-centered pedagogy—is being radically renegotiated [46].

Clusters of classrooms or open spaces, transparent or movable boundaries, as well as shared spaces allowing for manifold interactions in flexible groups seem to be emerging [39]. This new design conceptualization leads to the possibility of moving away from the doctrine of a seat for each student, towards a form of ‘hot desking’, whereby students no longer claim territorial ownership of a specific desk and chair, but rather have the freedom to select a suitable seat [38]. The teacher’s desk, often a dominant feature in a traditional classroom with a perceived ‘no-go zone’ around it, is either removed altogether or replaced with a small, unassuming table in FLEs [30]. Instead of dedicated teacher’s desks, or blackboards in each learning group’s area, there are white boards and flip charts [13,44]. ‘Space’ has become a key consideration for accommodating needs from flexible ways of teaching and learning; however, its impact on student performance and learning outcomes is largely hypothetical and requires further investigation [48].

One study [44] observed zoning and territorialisation practices by the students and established that the educational practices were not restricted to the constitution of a simple ‘opening’ or ‘dissolving’ of boundaries, but rather a specific use of areas and places different for each student. A study in Poland conclusively suggested that the traditional corridor and classroom layout is oversimplified, inflexible in design, and found to work against learner-centered pedagogies that stress diversity and multiplicity [12]. Flexibility, flow, openness, and teamwork seem to guide recent school design [39], and FLEs often have the capacity to hold more students than a traditional classroom [30]. The flexibility of the classroom interior, its versatility, and adaptability to change, is an important contemporary architectural issue [41]. Transparency is a significant characteristic of FLEs [38,44] along with a high degree of acoustic permeability [44].

Classroom arrangement to promote communication and collaboration occurs in multiple forms (clusters, dyads, groups), and students move to form such groups based on the unique learning activity occurring [7] and are provided with grouped table layouts and larger tables as an alternative to individual desks [8]. The modified flexible spaces were reportedly more enjoyable, comfortable, and inclusive and allowed greater interaction; however, students reported that they were more frequently distracted because of the increased focus on collaboration with their peers in class. Becoming distracted was further facilitated by the layout [30]. Similar findings were established by a multiple case-study analysis. It was apparent, however, that trade-offs are made on the amount of privacy afforded to individuals in the name of openness, along with ample evidence of the downside of increased transparency, in the form of students’ distraction and negative behavior. Extreme openness of the learning space was also not well received by the students, as it was hard to find concentration zones [17].

Flexibility was also considered as a measure of how well designed the classroom space is for the particular age of the students, with complex room shapes for younger students to enable the differentiation into different learning zones and larger and squarer rooms for older students, to enable flexible working for either group work or whole class learning. The optimal transition in reduction in the number of learning zones was found to

be gradual as the students' progress through the year groups [45]. In summary, the layout of FLEs consists of a strategic arrangement of interior elements to create the desired type and number of activity settings or zones, as desired by the class teacher(s).

The design-related papers reviewed for this study also identified other key design features that support flexibility, such as furniture and technological features. Furniture, both in terms of function and significance, is considered as the most interesting aspect of FLEs [38]. It is now well-established that FLEs, in order to facilitate both individual and collaborative learning, contain a variety of furniture options in a relatively open space [8,30] that is flexible and capable of multiple reconfigurations, as opposed to the traditional rows of desks and chairs [8,13]. Teachers are responsible for the arrangement of furniture, for creating an adaptable and often flexible setting in order to stimulate students' active involvement in the lessons [11].

Due to the clear distinction in their form and functional characteristics, furniture has begun to be classified as traditional and flexible. According to a definition provided by [13], flexible furniture was defined as furniture (work surfaces and seating) that provides and supports students' choice of seating, location, comfort, and classroom peer interaction, with the intent to foster collaboration. This approach contrasts with the regular classroom furniture which portrays a 'one size for all' scenario [38]. Flexible furniture is mainly comprised of modular and light-weight versions of conventional elements of a classroom environment such as seats and tables, along with less traditional furniture, such as couches, ottomans, beanbags, standing desks, writeable tables, and walls [8]. Mobility is another significant attribute of flexible furniture, with desks on wheels and mobile units (cupboards, shelving, and screen walls) that allow the home areas to be divided into smaller spaces [17] to create spaces within spaces and contribute towards creating highly modifiable internal layouts [44]. FLEs also attempt to replicate home and office environments, by mimicking furniture features from both, to make children feel comfortable, while preparing them for the future work environments [8]. Another key feature in most FLEs is the lack of a dedicated teacher's desk or blackboards, and instead providing white boards and flip charts [44] and walls that function as a canvas for writing and sketching [40].

4.2. IEQ Performance: FLEs Versus Traditional

From the selected literature, eight studies relate to IEQ, with acoustics being the most frequently studied parameter (four studies), followed by studies on the combined effects of IEQ parameters (three studies) on the occupants' comfort and satisfaction. One study evaluated children's visual demands in contemporary learning environments [49]. Detailed findings are presented below.

Three papers evaluated the combined effect of different environmental parameters on children's health, comfort, and satisfaction, and were all conducted in the Netherlands, and had common investigators and/or participants. Two of these were field-studies [50,51] to evaluate children's comfort preferences, and the third study [52] aimed at identifying teacher's actions for improving the classroom IEQ conditions.

Health and comfort in flexible settings was found to be better than in the traditional schools [50]; however, it was suggested that acoustical, air, and thermal conditions of classrooms need to be further improved. This study [50] also created a database in terms of children's health and IEQ perception, as well as classroom characteristics (including but not limited to, floor area per child—2.2 m² in non-traditional classroom and 2.5 m² in traditional classrooms; ventilation mode—mostly natural ventilation in traditional and mechanical ventilation in non-traditional classrooms). The other study that dealt with children's comfort perception [51] identified six clusters of children, of whom four clusters had specific concerns of 'Sound', 'Smell and Sound', 'Thermal and Draught', and 'Light', along with one 'All concerned cluster' and a 'Nothing concerned cluster'. Another study [52] indicated that teachers play an important role in maintaining the IEQ in classrooms by taking actions to control the indoor environmental conditions. Overall, these studies do not provide details on the various learning-activities that the participants

were involved in, nor the specific zoning and layout of the non-traditional classrooms at the time of data collection. The findings from the studies were attributed to the entire FLE rather than deriving specific findings that are representative of each activity-zone.

4.2.1. Acoustics

The current review has identified four studies that focused on acoustics within FLEs, with all conducted in Australia.

The four papers were based on field studies and involved a wide range of open-plan flexible classrooms and included a typical enclosed classroom as a reference point. This approach led to more appropriate findings on problems and solutions for each open-plan configuration. Two of the papers [53,54] were part of a same broader study and were comprised of a same sample and study-location. They involved measurements within four classroom typologies of various sizes. In the first study [53], it was identified that open-plan classrooms with over 90 students are inappropriate for young children due to their high intrusive noise levels. Findings from the second study [54] suggest that acceptable listening conditions were revealed for enclosed and double classrooms, but only when the adjacent class was engaged in quiet activities. Furthermore, for the two larger open-plan classrooms, the noise levels were excessive irrespective of the activity of the other classes. It was also identified that the noise levels and children's speech perception scores were better in a semi-open space, compared to linear open-plan triple layout, despite it having over twice the number of children. This demonstrates that the semi-open FLEs are an improvement on the open-plan classrooms that simply add rooms together by removing walls.

Results also indicate that the speech perception of young children can be less efficient in open-plan classrooms [54], unless appropriate measures are taken to reduce such problems. FLEs have also been associated with high levels of unpredictable and variable background noise levels due to the presence of a large number of children involved in a variety of learning activities, and late reverberation times (due to large room volumes), and the proximity of noise from adjacent class bases.

Several solutions have been identified too. For instance, if open-plan FLEs are desired, they need to be acoustically designed to be appropriate for critical listening activities [53], and an appropriate arrangement of flexible purposeful settings were found to have better acoustic conditions, as compared to open-plan classrooms that were formed by adding adjacent rooms by simply removing partitions [54]. Enclosed classrooms that cater for critical listening activities, comprised of operable partition walls to enable connections to adjacent spaces, were found to provide flexibility and improved acoustic conditions [53]. This is especially important as children in these open-plan classrooms can still spend up to 40% of the time teaching in a traditional didactic-style method [53], so it is vital that children are able to hear the new concepts that are being taught.

4.2.2. Indoor Air Quality (IAQ) and Thermal Comfort

The current review identified three studies that analyzed the overall performance of indoor environmental parameters that constituted IAQ and thermal comfort as well, and determined the impact on children's health, comfort, and satisfaction. Of these, two [50,51] were field-studies to evaluate children's comfort preferences, and a third [52] involved field studies to identify teacher's actions for improving the classroom IEQ conditions.

For one of the studies, conducted in Netherlands during spring season, field studies involved the use of subjective questionnaires as well as building characteristic checklists [50], within 21 schools in 54 classrooms, of which nine classrooms were FLEs. The findings indicated that 63% of the children were bothered by smell, 38% by temperature, and 8% by draught. The most frequently reported smells were 'human' (56%) and 'stuffy' (27%), and the IAQ monitoring indicated that most of the classrooms had average CO₂ concentrations of above 1000 ppm. To improve the IAQ, it was identified that more attention should be paid to (local) source control and to the cleaning of flooring surfaces and components of building services. A strong correlation was found between mean air temperature and the

children's responses in relation to thermal discomfort and draught. A follow-up study [51] identified six clusters of children, based on the children's comfort perception, and the results indicated that children do have different annoyances and preferences related to IAQ, thermal comfort, as well as other IEQ parameters. Although these two studies provide valuable findings, their field studies are limited to the spring season and raises the need for further research to complement these findings.

A third study, involving the same schools as previous two studies, gathered information on teachers' actions for improving classrooms IEQ via questionnaire responses. It was identified that the most common action conducted by teachers was opening windows to address children's complaints of being 'too warm' combined with their most frequent request to open/close windows because of thermal discomfort. However, it should be noted that the teachers' actions were found to not impact the children's thermal perception, as such making it hard to establish the relationship between children' perception, their request, and teachers' actions. One of the recommendations from this study was to consider the possibility of permitting the children to adjust their IEQ themselves.

4.2.3. Lighting and Views

Four of the selected studies looked at the importance of light [45,49–51], of which only one study exclusively analyzed visual demands [49], and the remaining three studied lighting conditions under a broader study encompassing combined influence of design and/or all IEQ parameters.

One of the studies [49] indicated that, to perform efficiently in the modern primary classrooms, students require higher than expected levels of optometric-ability (i.e., in terms of visual acuity and contrast demands), and their visual demands are likely to differ as compared to traditional settings. One of the selected combined IEQ studies [51] identified six clusters of students based on their comfort perceptions and the importance of environmental factors. The smallest (in size) of the six clusters was the 'light concerned cluster' which implies that not many children were annoyed with the internal lighting levels. Students noted both sunlight and artificial light as sources of discomfort. Hence, the solution probably lies in the protection of sunlight, or the possibility to control the artificial light instead of just providing them light. However, it should be noted that these students also reported a high level of annoyance due to thermal discomfort. Future research is needed to narrow down any possible design solutions. Findings from another study [50] suggested that more research is required on the use of different lighting systems and use of different colors in classrooms, as these aspects seem to have not gotten much attention so far, despite being important for the health and comfort of students.

Another significant study [45] evaluated the design of classrooms against three principles of individualization, naturalness, and connectivity. Within the naturalness principle, much research has been carried out about optimum lighting levels and links to nature, and it was found that light and flexibility have significant influence on three core subjects of reading, writing, and maths, with light having a slightly larger impact on writing. In the same study [45], the light-factor was constructed by measures that identify a good amount of natural light, with no glare, and good light control by shading devices and electrical lighting.

Links-to-nature was found to be significant for improved 'writing performance' [45]. The measure of links-to-nature described in this study is a measure of natural elements in the classroom (wooden furniture and plants), views of nature from the windows, and whether there is direct access to an outdoor learning zone from the classroom. It should be noted that the improved levels of progress owing to links to nature were only found to be correlated with writing and not with either reading or math, which implies that the links to nature are having a greater influence on "creative" nature of writing rather than the more general "restorative" effect, which should have the effect of improving concentration and progress in all subject areas. Findings show that literature are inadequate in providing design guidance, in terms of optimum spatial configuration, required illumination levels

for each activity zone and the likelihood of visual distractions due to the proximity of multiple activities, combined with permeable boundaries between adjacent rooms.

5. Discussion

FLEs are typically designed to support a diverse range of learning modes and activities (Figure 2), such as collaboration, discussion, feedback and reflection, guided, explicit, demonstration, experiential and independent learning [16].

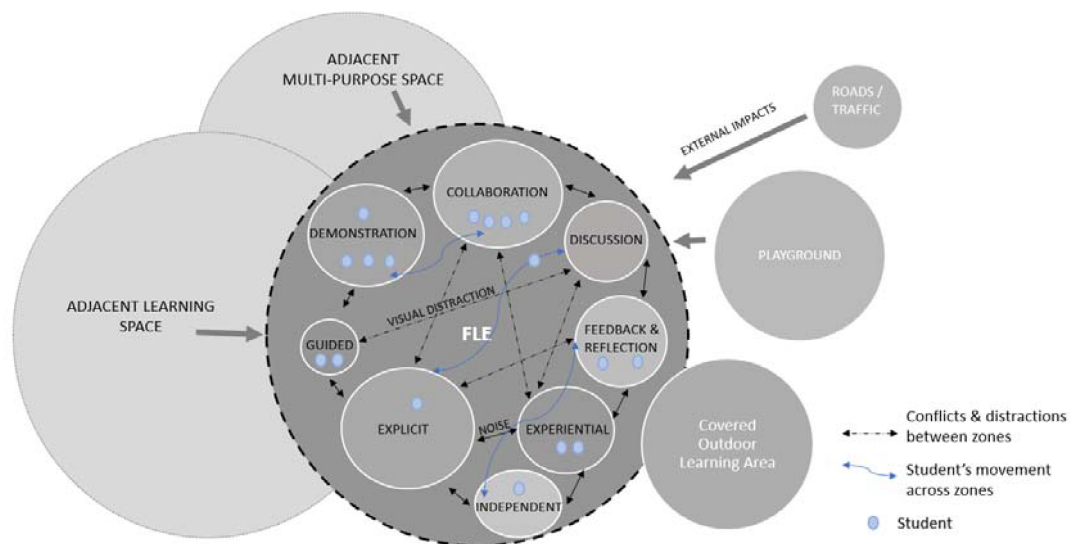


Figure 2. Design considerations need to address internal zoning and proximity of zones.

The first section of this review focused on transformation of classroom design, from traditional to flexible typology. It is identified that there is neither a ‘one-size-fits all approach’ for FLEs, nor is the design restricted to creating simple opening or dissolving of boundaries between learning settings [44]. The design intent is to be able to create FLEs with a potential for having multiple zones that are either permanent or fleeting, via a reconfigurable spatial sub-division, to simultaneously support multiple learning modes [8,30,48] via increased reliance on furniture that is light-weight, modular, and mobile due to their ability to be moveable and easily reconfigurable [8,17,38]. Despite their benefits, it is suggested that the furniture within FLE should be carefully selected, as potential challenges are identified, such as issues of glare associated with light-colored desk surfaces and issues of noise associated with the movement of furniture.

The second section of this review focused on the literature pertaining to IEQ performance within FLEs. From the current literature, it has been identified that the implementation of several zones generates challenges in terms of providing IEQ conditions within the different zones that are acceptable and do not clash. Research evaluating satisfaction within the entire FLE considers it as one homogeneous space which is not appropriate. In FLEs, groups of children perform a variety of learning tasks in parallel, and any potential IEQ clashes, such as acoustic permeability, might inhibit performance.

Further, studies dealing with the combined effects of all IEQ aspects are in its infancy and largely restricted to one single geographical location (The Netherlands). From the limited number of studies, it is revealed that the primary focus has been on acoustical conditions within open-plan settings, via field-studies, to develop evidence-based findings. FLEs were identified to be subject to generally poor “acoustic health”, due to their design and build. When compared to FLEs that simply add rooms together by removing walls, having enclosed rooms for critical listening activities, with operable partition walls, was found to provide flexibility and improved acoustic conditions. Furthermore, the study by [51] identified students’ preference for personal-control devices, with the ‘headphone’ being the most preferred device for around 60% of the students in classrooms of both

traditional and non-traditional schools. This highlights acoustics as a significant concern to the students. The remaining studies [50,52] evaluated the combined effect of different indoor environmental parameters on students' health, comfort, and satisfaction, and one study [45] investigated the impact of the overall physical design of classrooms specifically on students' learning performance.

For open-plan classrooms with dynamic learning activities and varying intrusive noise levels, it is more appropriate to use a design criterion such as Speech transmission index (STI) which combines both speech-to-noise ratio and reverberation in a single parameter. They should also be designed in a semi-open-plan style and have at least 6.5 m between class bases where there is an open wall [55]. Key lighting related findings from a future-focused study [56] indicate that (a) simple solutions such as dimming the lighting across a classrooms are no longer appropriate; (b) the interactive whiteboard is the most common cause of visual problems with reflections, yet is not addressed in current guidance; (c) changes in screen technology, such as the use of antiglare coating, have introduced new problems such as haze reflection, which is not adequately addressed in guidance; and (d) glossy screens are popular, but can suffer from disturbing reflections. It is also recommended that the use of large pre-existing data sets can be a successful and powerful tool for investigating the effects of the physical environment on human performance [57]. This recommendation underlines the findings of the current review that suggests further evidence-based research to be carried out, to better identify the IEQ preferences of students within FLEs. If left unaddressed, this knowledge gap would result in insufficient information for informing future primary school FLE designs in terms of addressing the students' IEQ preferences while meeting their pedagogical needs.

Until new research findings are gathered, some of the existing findings from non-flexible classrooms could be utilized, as the problems identified and the suggested recommendations from these studies seem very relevant to the context of FLEs. Providing opportunities for adaptive behaviors, for both teachers and students, should be considered as part of the design process and operational protocols for both newly-built and refurbished [58], along with a careful consideration for thermal comfort thresholds [59] and the decision to install air-conditioning [26]. For optimizing indoor air quality, school designers and managers could consider on-going IAQ monitoring as part of performance assessment which could inform operational practices. Recommendation from research in traditional settings can be used to inform ventilation rates and recommendations for TVOCs, VOCs, particulates, and others [29].

The findings from this review, while highly significant, are yet inadequate to inform future spatial design and configurations, due to the limited number of studies, and also due to the lack of reporting on the specific zoning, layout, and usage patterns of the FLEs, as the findings are reported following a broad classification of traditional versus non-traditional. In summary, the review highlighted several shortcomings in existing literature and the urgent need for more evidence-based research.

6. Conclusions

This systematic literature review aimed to bring together empirical findings related to FLEs within primary schools, published over the last 10 years, encompassing aspects of interior design and IEQ. The objective of the review was to identify the benefits and challenges arising from the open-plan design of FLEs and its IEQ performance in particular. The review indicates that FLEs are an emerging topic of research, with increased interest over the last five years.

The need for developing design guidelines is urgent, since globally governments have committed to heavily invest in the creation of FLEs over the coming decades, due to the perceived benefits for the student-led learning approach. However, the overall number of studies are limited and insufficient to provide directions for consideration by designers and school leaders in refining the design of their FLEs specifically within primary school developments. Utilizing taxonomies such as those developed by Dovey and Fisher

(2014) [14], seems to be highly beneficial, as that enables school leaders to make informed decisions in terms of preferred layouts, arrangement, and proximity of zones, and preferred occupant-density within each zone in order to appropriately meet the specific needs of the school's pedagogical model, and also ensure that the interference between zones would be minimal in terms of visual or acoustic clashes.

Further, findings from this paper suggest that additional research needs to be conducted to establish a robust empirical database in order to inform design guidelines for future primary school FLE developments, specifically, in terms of enabling flexibility and adaptability to suit the changing nature of pedagogy, while maintaining adequate IEQ conditions. Nevertheless, non-flexible primary schools are a heavily investigated topic. There is potential for their findings to be partially utilized to inform the FLEs. To be able to utilize these current findings, extra research is required to discover exactly the 'what, when, and where' activities that happen in FLEs, and map similarities, if any, between non-flexible and FLEs.

It has been identified that one of the key challenges when designing and implementing the several zones needed by FLEs is to provide IEQ conditions within the different zones that are acceptable and do not clash. The proximity of zones (such as noisy group work located adjacent to quiet independent learning), and the acoustic and visual permeability between zones, may give rise to inadequate IEQ conditions delivered to students, due to a potential clash of high-energy and low-energy activities, with diverse acoustic and visual demands. This may have an influence on the students' perception and satisfaction with their overall IEQ. In addition, within the limited FLE research database, it is identified that lighting and visual comfort within FLEs has been an under-researched topic and warrants the need for more detailed investigations, especially for identifying the simultaneous needs of the various learning zones and any clashes that may arise due to the proximity of distinct learning settings.

IEQ conditions within an open-plan FLE configuration are far more challenging than traditional classrooms because students, rather than being seated still, are mobile and active as they move between various learning activities and zones, although further evidence is required to establish the frequency of student movement. The literature indicates that problems concerning all IEQ factors and the consideration of mobile occupants within FLEs have hardly been addressed, as the body of research conducted in FLEs is still young [51].

A potential shortcoming of this review is its limited research base due to the shortage of studies in relation to IEQ performance of FLEs. Further limitations include a restriction to peer-reviewed journal publications, from within the Scopus, ERIC, and PsycInfo scientific databases. The review could further be expanded in future to include other publication types.

Supplementary Materials: The following are available online at <https://www.mdpi.com/article/10.3390/buildings11050183/s1>, Table S1: Tabular summary of papers selected for this review.

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