buildings

Review

Systematic Review of Factors Influencing Students' Performance in Educational Buildings: Focus on LCA, IoT, and BIM

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Abstract: In the evolving field of civil engineering studies, a significant transition is evident from fundamental to new-generation research approaches. This paper presents a systematic literature review aimed at analyzing these shifts, focusing specifically on the performance of students in educational buildings thought the integration of modern technologies such as the Internet of Things, life cycle assessments, and building information modeling. Covering the literature from the late twentieth century to the early twenty-first century, the review emphasizes advancements in sustainable infrastructure, eco-friendly designs, digitalization, and advanced modeling. A comparative analysis reveals that while the fundamental articles are primarily focused on indoor air quality parameters, the new-generation articles prioritize technological integration to address broader environmental concerns and for improved building performance. Challenges in the education sector, such as insufficient energy use, high maintenance costs, and poor working conditions, are also discussed, showcasing their impact on student learning outcomes. The methodology employed for this review included a comprehensive search in databases such as Scopus and Web of Science, using keywords such as "school buildings", "IoT", "BIM", and "LCA", ensuring a robust and diverse collection of academic articles. The findings show that new trends supplement existing topics, suggesting an integration rather than a replacement of traditional practices. Consequently, future research efforts will need to include a broader range of information to fully account for the evolving landscape in this field.

Keywords: LCA; BIM; IoT; CiteSpace; schools

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1. Introduction

People spend 87% of their lifetime inside buildings [1], with approximately 30% of that time being spent by primary and secondary school students in a space dedicated to their learning, which is called the classroom [2]. Extensive research has demonstrated the negative impact of air pollution on health [3–9] and student academic accomplishments [10–12]. The classroom indoor air quality (IAQ) can influence the time students spend in classrooms and their academic performance due to illness-related attendance [13–17]. Multiple research studies have conducted assessments of classroom IAQ [18], revealing problems in poorly ventilated classrooms [19]. Many classrooms discussed in these studies did not have enough fresh air circulation. The circulation was below the levels recommended by the American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) for maintaining good indoor air quality [18,20].

A group of studies [21–26] looked into how the environment and features of school buildings affect student learning and success. In these previous studies, it was found that if indoor conditions such as ventilation [15,27–33] are inadequate, this could lead to health issues for students and staff, which can also result in reduced concentration, attendance, and academic performance. Air pollution has been shown to harm cognitive abilities, affecting memory, attention, visual processing, and problem-solving. In a recent study, it was discovered that if students are taught in premises with bad air quality, they are more likely to get lower grades, and this exposure to air pollution is linked to decreases in academic performance [32]. These findings indicated that environmental aspects such as indoor air quality and air pollution play a crucial role in student learning and success. It is suggested that making improvements in the quality of the school environment could enhance student outcomes and test scores [23,24,31]. Studies conducted in Europe and the USA have also shown a connection between students' academic performance and the ventilation rates in classrooms [34,35]. Wargocki et al. (2013) discovered that indoor air conditions, using CO_2 levels as an indicator of ventilation rates, affected student performance by causing more errors and slower task completion [35]. Additionally, the findings of Crosby et al.'s study emphasized the advantages of prioritizing energy efficiency in school infrastructure. They highlighted how this approach not only enhances the educational quality but also fosters a healthier learning environment, yielding numerous benefits [36]. Studies that highlighted the importance of various factors for student performance are shown in the Table 1.

The research by Economidou et al. (2011) revealed that within the European Union, educational structures encompass approximately 17% of the non-residential building inventory in terms of square meters. According to this statistic, educational buildings represent the third most substantial sector, trailing behind wholesale and retail buildings (at 28%) and offices (at 23%) [37]. However, not as many studies have looked into how the indoor environment affects well-being and work productivity in educational buildings compared to other types of structures. Mendell et al. (2005) [15] and Wargocki et al. (2013) [35] reviewed the existing research, combining the results from practical tests and experimental studies. They connected negative health effects and lower student performance to inadequate indoor temperature or air quality conditions [15,35]. This article extends their work by integrating modern technological trends such as IoT, BIM, and LCA, which were not the focus of earlier studies. While both this article and the earlier studies are focused on educational buildings, the key differences lie in the timelines and technological advancements, as the previous articles are over 10 years older. In contrast to office buildings, which are designed for the purpose of profit, educational buildings, created for non-profit purposes, have not been as thoroughly examined from the perspective of a life cycle cost/life cycle assessment (LCC/LCA) [38].

The fundamental articles primarily focused on parameters related to indoor air quality, particularly heating and ventilation. The earliest discussions about school ventilation dated back to the late 1800s, originating mainly within the medical field. While the authors of these articles primarily addressed heating and ventilation factors [39–41], they laid the background knowledge that would later influence discussions on indoor air quality in educational settings. However, only in the mid-1900s did articles specifically devoted to school ventilation begin to appear in engineering and environmental science journals. Since then, there has been a significant growth in the number of articles on this topic, and there have been two notable increases (Figure 1). The first increase occurred between 2007 and 2011; that is, around the time the era of Industry 4.0 began. Schwab (2017), in his book *The Fourth Industrial Revolution*, defined Industry 4.0 as the fourth industrial revolution, which involves the integration of smart, interconnected machines and systems (such as automated manufacturing robots and smart grids), the Internet of Things (IoT), and network-based operations (such as real-time data analytics and cloud computing) in various industries, including construction and education [42]. Next, there was a decrease, possibly because many researchers moved on to the Industry 4.0 field and started writing about that instead. The second increase occurred in 2019, during the time when the COVID-19 pandemic was affecting the world.

Sustainability aspects are important in all fields, including research. They are important because they help us balance the economy, people's well-being, and taking care of the environment. This represents an ability to meet today's needs without compromising the ability of future generations to meet their needs [43].

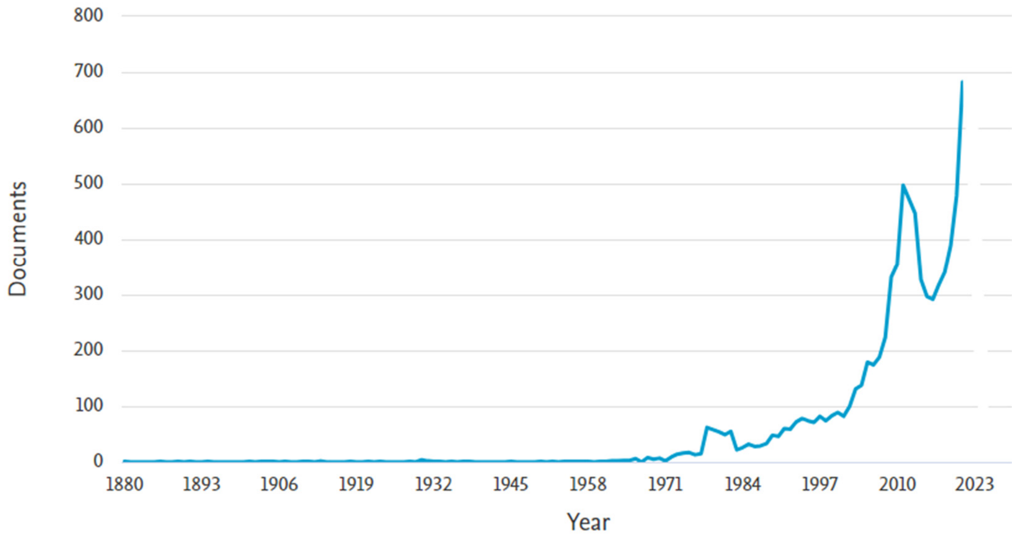

Figure 1. Number of publications by year in the Scopus database (keyword "school ventilation").

The usage of sustainable methods is crucial for schools. These methods help create schools that care about the environment and use resources wisely. There are different building certification systems such as Leadership in Energy and Environmental Design (LEED) [44], the Collaboration for High Performance Schools (CHPS) [45], the Building Research Establishment Environmental Assessment Method (BREEAM) [46], Green Star—Education V1 [47], and WELL [48] that give guidelines to make sure that the school environment is more sustainable. When certifying buildings using the mentioned systems, factors such as saving energy, using water wisely, using environmentally friendly materials, and making sure the IAQ is clean are taken into consideration.

The authors of this article conducted a systematic literature review, discussed in the Materials and Methods section, and looked into 25 published studies (Table 1), analyzing the various factors that affect students' academic performance. These 25 articles were selected based on the criteria listed in Table 1, which were chosen by the authors of this article. The table is part of an introduction and review of already existing articles to highlight the importance of investigating more parameters under one field of study in the future, as one parameter alone cannot impact students' performance as significantly as the combined effect of multiple parameters. The table could have included more articles if additional investigated parameters had been considered. The chosen articles specifically addressed parameters that influence students' performance, while other articles that were not included discussed topics such as the school surroundings, structures, BIM, and IoT in schools but did not focus on their impact on students' performance, addressing schools in general instead. However, no author has covered all of the factors mentioned in the table together in one study. The analyzed parameters were the reverberation time (RT), lighting (LI), indoor air quality (IAQ), temperature (T), CO_2 level, student testing (ST), short-term academic performance (S-TAP), cognitive performance or learning efficiency (CP), acoustics (A), air velocity (AV), and relative humidity (RH). Of the 25 published studies, two studies included a total of eight parameters, which was the highest number of parameters included. Additionally, three studies each covered seven, six, and five parameters, while two studies only covered four things. Three studies covered three parameters and one study covered two parameters, while eight studies covered one parameter.

After looking more closely, the authors found that different studies focused on different parameters (Table 1). The reverberation time was discussed in two publications, while lighting received attention in seven publications. Among the parameters studied, short-term academic performance and acoustics were addressed in four publications each, indicating a lower level of focus. The air velocity received slightly more attention and was discussed in five publications. CO_2 levels and student testing were equally covered, which were mentioned in 10 publications each. Moreover, the relative humidity was covered in 10 publications. Indoor air quality ranked third in popularity among the parameters studied and was discussed in 14 publications. The most popular parameter, however, was cognitive performance or learning efficiency, receiving extensive coverage across 17 publications; it was of critical importance in the academic research. These findings underscore the diverse exploration of parameters influencing student performance within the academic literature.

Table 1. Published studies about parameters that affects students' performance.

Reference	Investigated Parameter										
	RT	LI	IAQ	T	CO_2	ST	S-TAP	CP	A	AV	RH
Brink et al. (2023) [49]	+	+	+	–	+	+	+	+	–	–	–
Choi et al. (2014) [50]	–	+	+	+	–	–	+	+	–	–	–
Brink et al. (2021) [51]	–	+	+	+	+	+	+	+	+	–	–
Kim et al. (2012) [52]	–	+	+	+	–	–	–	–	+	–	–
Xiong et al. (2018) [53]	–	+	–	+	–	+	–	+	+	–	–
Calderón-Garcidueñas et al. (2008) [54]	–	–	–	–	–	–	–	+	–	–	–
Gardin et al. (2023) [55]	–	–	–	–	–	–	–	+	–	–	–
Duque et al. (2022) [56]	–	–	–	–	–	–	–	+	–	–	–
Kabirikopaei et al. (2021) [57]	–	–	+	+	+	–	–	+	–	+	+
Gaihre et al. (2014) [13]	–	–	–	+	+	–	–	+	–	–	+
Kielb et al. (2015) [14]	–	–	+	–	–	–	–	–	–	–	–
Mendell et al. (2005) [15]	–	–	+	+	+	+	–	+	–	–	+
Shendell et al. (2004) [16]	–	–	+	+	+	–	–	–	–	–	–
Wargocki et al. (2017) [17]	–	–	+	+	+	+	–	+	–	+	–
Requia et al. (2022) [58]	–	–	–	–	–	–	–	+	–	–	–
Guo et al. (2010) [59]	–	–	+	+	–	–	–	–	–	–	+
Richmond-Bryant et al. (2009) [60]	–	–	-	+	–	–	–	–	–	+	+
Rivas et al. (2014) [61]	–	–	+	–	–	–	–	–	–	–	–
Martínez-Lazcano et al. (2013) [62]	–	–	–	–	–	–	–	+	–	–	–
Forns et al. (2017) [63]	–	–	–	–	–	+	–	+	–	–	–
Benka-Coker et al. (2021) [64]	+	+	+	+	+	+	–	+	–	–	+
Choi et al. (2022) [65]	–	-	+	-	+	+	–	+	–	–	+
Wang et al. (2020) [2]	–	+	–	+	–	+	–	+	+	+	+
Shan et al. (2018) [38]	–	–	+	+	+	+	+	–	–	+	+
Ryan et al. (2022) [66]	–	–	–	+	–	–	–	–	–	–	+

The aim of this study was (i) to analyze patterns and trends in the scientific research related to school buildings, with a particular focus on thermal comfort and IAQ, as well as the integration of LCA, IoT, and BIM; (ii) to highlight the differences between the fundamental generation and new-generation articles; and (iii) to point out new trends in the research on school buildings in the civil engineering field, emphasizing the roles of LCA, IoT, and BIM.

2. Materials and Methods

We adopted a systematic literature review (SLR) approach [67,68] to establish a reliable evidence base for future research in schools. The systematic literature review approach is characterized as "a scientific process governed by a set of explicit and demanding rules oriented towards demonstrating comprehensiveness, immunity from bias, and transparency and accountability of technique and execution" [69]. This method has been criticized because it oversimplifies the research evidence, which might have reduce the results we obtained [70]. However, recently, there has been a tendency to include strong qualitative studies along with quantitative ones [71], which helps deal with this criticism to some extent.

The research question was formulated using the PICO method as outlined in Table 2. The complete research query was delineated as follows: "What differentiates the fundamental and new-generation approaches in the research of school buildings?" Additionally, in conducting the search, consideration was given to various filters pertinent to the investigation. These filters encompassed the research field, including engineering, construction, and technology, with a focus on publications in the English language, without restriction on the year of publication. In our methodology, we selected key themes such as LCA, IoT, and BIM to guide our systematic literature review. These themes were chosen due to their significance in the current research on school buildings and their potential to influence factors such as thermal comfort and indoor air quality (IAQ). The inclusion criteria were based on the relevance of these themes to the civil engineering field and their impact on educational environments. These themes were chosen to capture a broad spectrum of research studies related to technological advancements and methodologies in the construction and operation of educational facilities, ensuring comprehensive coverage of the relevant literature. The types of studies and publications included in the search were review papers, field studies, research papers, and technical reports to encompass both theoretical and practical insights.

Table 2. PICO table.

P	Population; problem; source of information	What population? What is the database? What is the source of the information?	Population: School buildings Database: Scopus and WOS Sources: Review papers, field studies, research papers, and technical reports
I	Intervention; factors	What interventions or factors are you interested in?	Differences between fundamental and new-generation topics in school buildings
C	Comparison; circumstances; situation	What circumstances are you interested in? What will you compare it to?	Comparison of fundamental and new-generation topics in school buildings.
O	Outcome; main point of interest	What do you expect to learn about? Dependent variable? Main focus?	To find out the differences and similarities between fundamental research topics and new-generation research topics. The main focus is parameters tested in schools and performance of students.

The search for relevant texts was conducted across databases including Scopus and Web of Science (WOS). Scopus was chosen for its extensive coverage of peer-reviewed literature in the fields of science, technology, and engineering, while Web of Science was selected for its multidisciplinary indexing and high-quality sources, providing a robust and diverse collection of academic articles [72]. These databases are widely recognized and respected in the academic community, ensuring that the search results are comprehensive and reliable.

The filters and key words were carefully selected to include relevant research studies from diverse but related fields, focusing on studies that explore the integration of advanced technologies in educational settings and their potential impact on various parameters affecting students' performance. By not restricting the year of publication, we ensured that both historical and contemporary perspectives were considered, allowing for a thorough understanding of the evolution and current state of research in this area.

The eligibility and inclusion and exclusion criteria were based on the relevance and quality of the selected studies. For the research area, only studies related to civil engineering (engineering, environmental sciences, and energy) were included. This focus ensured that the selected studies were related to the technical and environmental aspects of educational buildings, encompassing critical factors such as building design, construction materials, sustainability practices, and energy efficiency, which directly impact students' performance and well-being. Studies not related to civil engineering were excluded to maintain this article's connection to the field of civil engineering. Regarding the topic, the inclusion criteria encompassed studies on LCA, BIM, IoT, and educational buildings, as these areas are central to understanding how advanced technologies and methodologies can improve the design, operation, and impact of educational buildings and the performance of students. Studies focused on non-educational buildings, such as those related to industry, commercial, and residential buildings, were excluded to ensure this article was targeted and pertinent to its primary objective—educational buildings. The years of publication ranged from 1800 to 2023, allowing for a comprehensive historical perspective on the development and evolution of the research in this field, thereby identifying trends, advancements, and shifts in focus over time. The language criterion included only English-language publications, as English is the predominant language of the scientific literature in engineering and technology, ensuring accessibility and consistency in comprehension and interpretation. Non-English studies were excluded to avoid potential challenges related to translation and interpretation that could have affected the accuracy and consistency of this article. The inclusion criterion for the publication source specified peer-reviewed academic journals and technical reports to ensure the inclusion of high-quality, strictly checked research. While other sources such as conference papers can provide valuable insights, they often lack the same level of peer-reviewed scrutiny essential for maintaining the integrity and reliability of a literature review. Peer-reviewed journals and technical reports are recognized for their methodological rigor and scientific validity, which is crucial for a comprehensive and accurate analysis of the factors affecting students' academic performance. The inclusion and exclusion criteria are shown in Table 3.

Table 3. Eligibility and inclusion and exclusion criteria.

Criterion Type	Inclusion Criteria	Exclusion Criteria
Research area	Related to the civil engineering	Not Related to the civil engineering (e.g., the arts or humanities).
Topic	LCA, BIM, IoT, educational buildings	Not educational buildings (e.g., industrial, commercial, and residential buildings)
Year of publication	1800–2023	Outside the set range
Publication source	Peer-reviewed academic journals, technical reports	Other type of sources
Language	English	Other languages
Type of publication	Review papers, field studies, and research papers	Other types of publication

The following search string was used in the Scopus database to search for the articles: (TITLE-ABS-KEY (educational AND building AND bim) OR TITLE-ABS-KEY (school AND building AND bim) OR TITLE-ABS-KEY (school AND building AND iot) OR TITLE-ABS-KEY (educational AND building AND iot) OR TITLE-ABS-KEY (educational AND building AND lca) OR TITLE-ABS-KEY (school AND building AND lca). In the Scopus database, 895 documents were found before using the filters. In order to decrease the number of documents, several filters were applied. These included the subject areas of engineering, environmental science, and energy. Only articles and reviews written in English were considered. After the filters were applied, 304 documents were found. The search of the Scopus data base was performed on 17 March 2024.

When searching for documents in the WoS database, a slightly different query string was required compared to the one used in the Scopus database due to variations in their field tags. In WoS, the following string was used: "educational building bim" (All Fields) OR "school building bim" (All Fields) OR "school building iot" (All Fields) OR "educational building iot" (All Fields) OR "educational building lca" (All Fields) OR "school building lca" (All Fields). The search was carried out on 20 March 2024. In the WoS database, 8993 results were found. After the initial search, additional filters were applied. Specifically, document types such as articles, review articles, and data papers were included. Moreover, for the WoS categories, fields including civil engineering, construction building technology, environmental sciences, green sustainable science technology, engineering environmental, engineering multidisciplinary, and environmental studies were selected. After applying the filters, 3524 documents were found. Following the second search, additional filters were applied to further refine the results. Specifically, filters were applied to publication titles such as *Sustainability*, *Buildings*, *Journal of Cleaner Production*, *Journal of Building Engineering*, *Energy and Buildings*, *Journal of Construction Engineering and Management*, *Engineering Construction and Architectural Management*, and *Building and Environment* to reduce the number of documents to 1311.

Both the Scopus and WoS databases contained a total of 2206 publications, with only 59 duplicates identified. These duplicates were detected and excluded from the future SLR processes with the assistance of the Mendeley reference manager tool.

The second step of the database search was the title and abstract screening. Only the first 300 of the most relevant articles from the Scopus and WoS databases, with 150 from each database, related to IAQ and academic performance, which were included for further review. In Scopus and WoS, relevance is determined by the databases' built-in algorithms, which prioritize articles based on factors such as keyword matching, citation counts, publication recency, and overall impact in the field [42]. By selecting the most relevant articles, we ensured that the included studies were highly related to the research topic and likely to contribute valuable insights. This relevance sorting helped in identifying the most significant and influential studies, thereby enhancing the quality and focus of the review. The title and abstract selection process in the Scopus and WoS databases resulted in 150 publications from each database. Selecting 150 articles from each database, for a total of 300, was a strategic choice that balanced the need for comprehensiveness with practical limitations, ensuring a manageable yet representative and high-quality review process.

Further, the complete texts were read to evaluate whether the studies mentioned factors influencing students' performance. Following a thorough review, 58 publications were excluded. Ninety-two publications were chosen for the SLR.

Later, the data collection process involved using the bread-crumbing method, which is a technique where the references of a publication are checked to find additional relevant publications. Twenty-eight more publications were included.

After completing all data collection steps, a total of 120 publications were included in the SLR and analyzed (Figure 2).

The CiteSpace program was used to create visualizations. These visualizations were developed using data from the Web of Science database, focusing on exploring the dynamic landscape of life cycle assessments (LCAs), the Internet of Things (IoT), and building information modeling (BIM). A broader perspective was gained through a general visualization that encapsulated key aspects such as authorship, references, and cited authors. The study covered the period from January 2020 to December 2023, allowing for a comprehensive understanding of trends and contributions over time. Importantly, the scholarly impact assessment used a g-index with a scale factor of k = 25, adding a nuanced layer to the evaluation of significance in the fields of LCAs, IoT, and BIM. This method, combined with the visualization capabilities of CiteSpace, contributed to a deeper comprehension of the interconnected aspects in these fields, providing valuable insights for future research and strategic advancements.

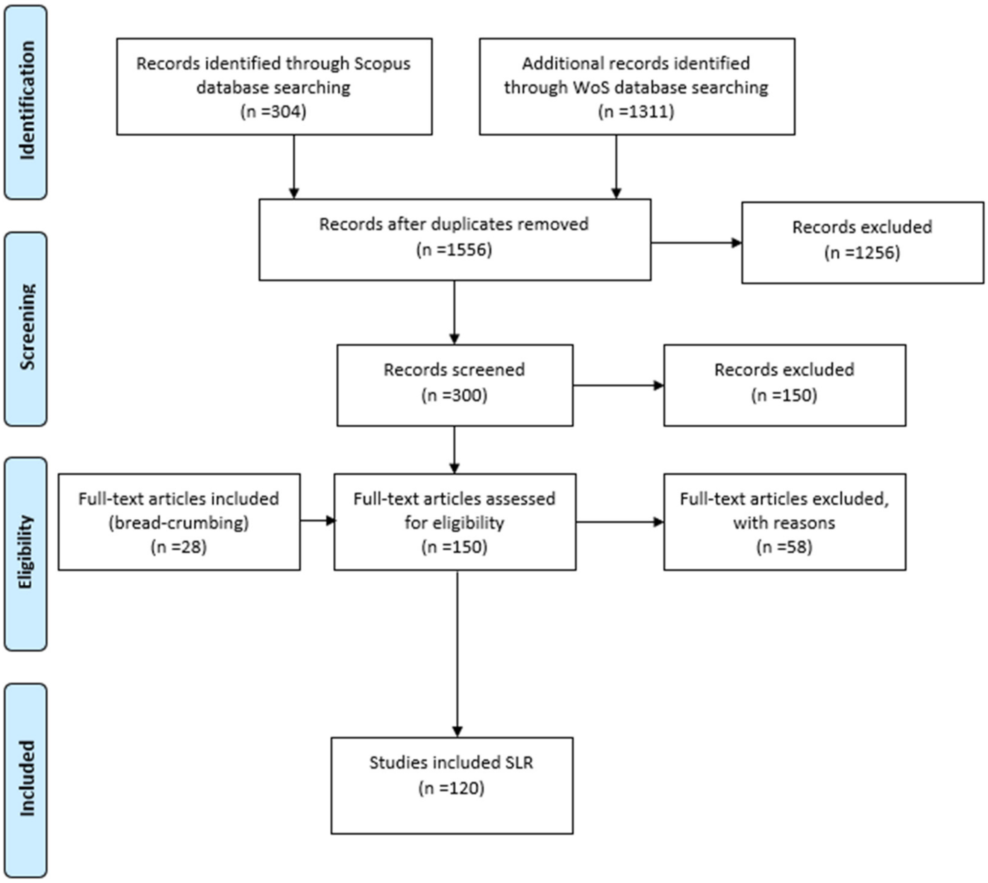

Figure 2. PRISMA 2009 flow diagram.

In the CiteSpace program, there are a few important concepts that help us understand scholarly networks and how they change. Clusters are groups of closely connected nodes, showing themes or research communities [73–75]. A burst, according to CiteSpace, is a sudden increase in the frequency of a particular type of events. It helps us see when there is a lot of activity or significance in a dataset. Centrality points out nodes that are important in the overall network, indicating their central position among many connected nodes. Lastly, CiteSpace uses the Sigma metric to measure the importance of a node in a network of cited references [76,77]. Sigma helps highlight structurally important nodes, showing rapid growth in citations, which is known as citation abundance [47]. This temporal aspect helps researchers identify nodes with growing influence, giving a detailed understanding of how specific scholarly works become more impactful and prominent over time.

Mongeon et al. (2016) screened the WoS and Scopus databases to see whether there were any unfair preferences. They found that both of these databases favored topics related to natural sciences, engineering, and biomedical research rather than social sciences and the arts and humanities [49]. Despite both of these databases having other advantages, such as WoS having good coverage going back to 1990, with most of its journals being in English and granting broader access to readers, Scopus covered more journals in total, which mostly included recent articles.

The literature review was carried out using both the WoS and Scopus databases. However, the visualizations were created only using the WoS database because it has more English publications. We chose to focus on visualizing IoT, BIM, and LCAs because these are significant trends influenced by Industry 4.0, reflecting current developments. The visualizations aimed to provide insights into these key areas, recognizing their importance in today's world.

3. Results

In the literature review, we distinguished two types of scientific papers for the analyzed topic—fundamental and new-generation articles (Figure 3). The term "new-generation articles" has come about as technology has advanced, particularly with the influence of the era of Industry 4.0. In contrast to the fundamental research focusing on basics such as CO_2, ventilation, heating, and IAQ, the new-generation articles highlight current trends such as IoT, digital twins (DTs), LCAs, BIM, and more. This categorization highlights the shift in research focus and emerging trends in the study of school buildings.

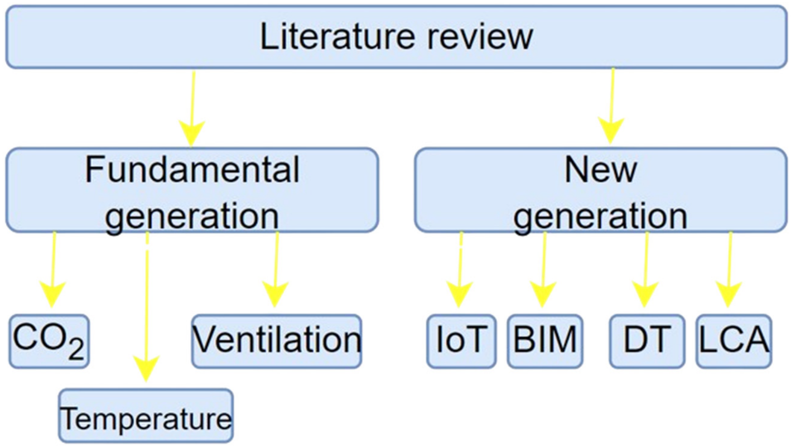

Figure 3. Differences between fundamental and new-generation articles.

3.1. Life Cycle Assessment (LCA)

Evaluating schools' sustainability and its impact on human well-being often involves an LCA, which is a method that helps achieving certifications such as the BREEAM and LEED. Vigovskaya et al. (2018) underlined the significance of LCAs in evaluating environmental impacts, emphasizing the crucial role of assessment results in adjusting the design and construction methods for improved energy efficiency and reduced environmental footprints [78]. Alshamrani et al. (2014) integrated LCAs with LEED to assess sustainability in 109 LEED-certified schools, revealing insights into energy, materials, and design choices. Their study recommended revisions in LEED integration for better functionality and proposed enhancements such as indoor air quality analyses and broader applicability across diverse climates and building types [79]. Meanwhile, Changyoon Ji et al. (2016) studied 23 buildings across South Korea, utilizing an LCA to evaluate impacts such as the global warming potential (GWP) and acidification potential (AP), finding that factors such as the gross floor area (GFA) and geographical location significantly influence these impacts [80].

Brás et al. (2015) researched mortars used in a 1980s school in Portugal, targeting thermal bridge issues. Their study compared various mortar types (cement–cork, cement–EPS, and hydraulic lime–cork), assessing the building's energy performance using original and new mortars, examining factors beyond the operational energy. According to their study, traditional mortars such as cement-based and hydraulic lime mortars significantly contributed to global warming, while cork-infused mortars, especially those with a 70% cork content, notably reduced CO_2 emissions by 30%. Cork-based mortars possessed lower embodied energy values, contrasting with EPS, which caused escalated energy consumption. Their research indicated that using mortars with less embodied energy, such as cement cork, helped reduce the operational energy requirements. Additionally, it emphasized a rapid decrease in heating needs and CO_2 emissions over time with cork-based options. In the initial eight years, embodied energy accounted for 30% of the school's operational energy [81].

The comparison by Pachta et al. (2015) of modern and historic school buildings revealed that the environmental performances vary, despite the similar location and operational demands. A modern school exhibited a significantly higher environmental impact, while a historic school consumed more operational energy due to its extended lifespan and absence of insulating materials [82]. Additionally, Gamarra et al. (2018), in their LCA research, examined a high school student's environmental impact over a school year, highlighting transport and mobility as the most significant contributors to climate change impacts (69%). Their study linked different impacts to material and energy consumption, emphasizing the role of educational activities in influencing various environmental aspects. Another study by Gamarra et al. (2018) focused on two pilot schools in Madrid, Spain, assessing the cumulated energy demand (CED), water resource depletion (WRD), and carbon footprint (CF) per student and per built gross area. The mentioned study stressed the importance of enhancing the conditioning and lighting efficiency to mitigate global warming effects and lower the overall energy consumption [83]. Furthermore, the analysis by Munoz et al. (2017) of an educational building's construction and operational aspects identified challenges in meeting the nZEB standards due to contributions from embodied materials and limitations in power generation. Their recommendations were intended to improve sustainability through a life cycle energy analysis (LCEA), advocating for materials with lower embodied energy levels and establishing clear classifications for non-residential buildings (NRBs) encompassing various types and energy services [84].

Figure 4 illustrates the principal clusters identified in the LCA visualization. The network discerns a total of six clusters, each encapsulating distinct facets of LCA research. This visualization provides a valuable overview, allowing for an in-depth exploration of the multidimensional landscape of LCA research, covering areas such as environmental sciences, materials science, construction and building technologies, and energy and fuels.

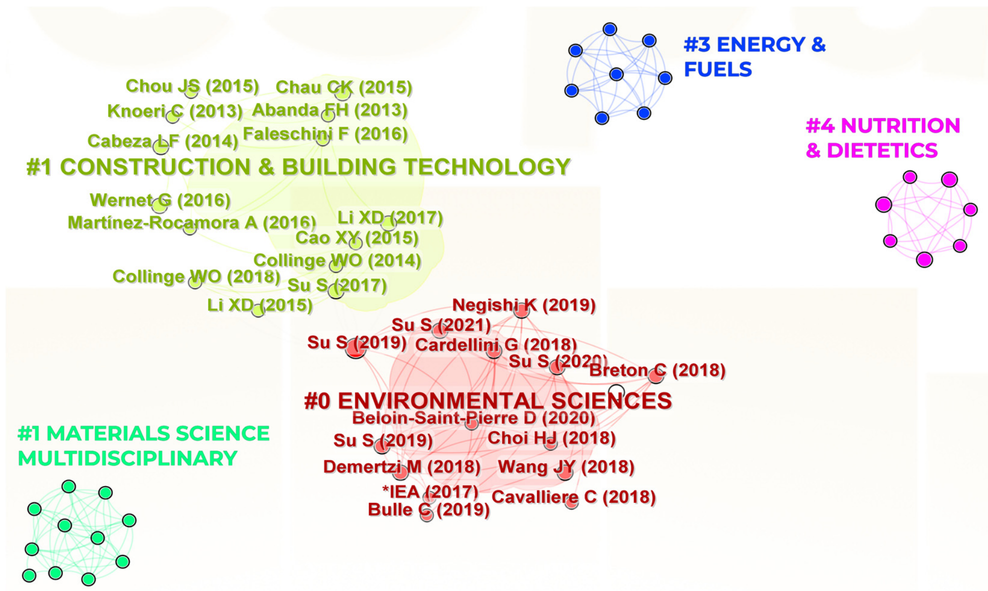

Figure 4. CiteSpace visualization of the multidimensional fields of LCAs and cluster analyses for SLR research [85–88].

The examination of the provided data revealed significant patterns in categories such as citation counts, bursts, degrees, centralities, and sigma values across various clusters. In clusters #0 and #2, as shown in Figure 4, the most cited author was Su et al. (2019) [85], Li et al. (2017) [86], Su et al. (2020) [87], and Su et al. (2021) [88], accumulating a total count of 16 citations. The citation for Su emphasized their considerable influence in environmental, construction, and building technology sciences. Notably, Su was consistently mentioned in each visualization category, indicating that Su held the utmost relevance in the field of LCA research.

3.2. Building Information Modeling (BIM)

In the architecture, engineering, and construction (AEC) sector, BIM serves various purposes, such as for 3D visualization; clash identification; feasibility assessments; cost estimations; scheduling; environmental, BREEAM, LEED, and other analyses; shop drawing generation; and facilities management [89–92]. BIM plays a role in simulating emergency scenarios such as fire evacuations, helping optimize school layouts for occupant safety and swift evacuations [93,94]. Additionally, BIM facilitates early-stage activities such as code compliance assessments, cost estimations, and sustainability analyses. It fosters collaborative efforts and empowers designers to evaluate building element performance and the environmental implications of sustainable design methods [92,95–97].

The study conducted by Zhuang et al. (2021) [98] introduced a framework called performance-integrated building information modeling (P-BIM), which focuses on designing for energy efficiency and environmental optimization. This framework organizes environmental data into various dimensions throughout the life cycle of a green building, ensuring standardized storage and interactions of this information. P-BIM is notable for freeing BIM platforms from data type constraints, allowing the integration of diverse performance data. It enhances the capacity of BIM for handling localized, customized, and big data, ensuring adaptability to evolving project requirements. The prototype demonstrated significant improvements in indoor environmental quality and cost reductions, highlighting the importance of detailed digital performance evaluations. By bridging the gap between the initial and late design stages, P-BIM empowers architects to better control the project life cycle. However, the study identified limitations, calling for further refinements, including refining the IEQ indicators, expanding the occupant satisfaction research, integrating more variables into the optimization model, broadening the application of P-BIM in the early design stages, and exploring energy efficiency during the construction and operation phases.

The challenge in this study was in managing fluctuating engagement levels and input across various stages of user participation in school design. While AEC professionals maintained a consistent and vested interest throughout (for instance, structural engineers overseeing the school building's structure at all phases), the involvement of school management professionals, teachers, and students proved significant in offering insights during development. For example, in an article written by Liu et al. (2018), during the design phase, students actively engaged in shaping the building's design through 3D walkthroughs, contributing ideas that influenced the final structure [92,99]. However, their participation tended to decrease during the realization phase, leading them to primarily receive what AEC professionals had crafted during the operational stage [100,101]. Ensuring the continual presence of management professionals, teachers, and students remained crucial in enhancing the efficacy and dependability of user engagement in the design process.

Figure 5 illustrates the main clusters identified through the BIM visualization. The complex network consists of a total of 11 clusters, each representing a different aspect of BIM application and research. In order to focus on the most significant contributors, the subsequent analysis zeroes in on the seven largest clusters, identified as #0 (FEMA p-58), #1 (building technology), #2 (industry foundation classes), #3 (risk assessments), #4 (educational training), #5 (team-based learning), and #6 (geometric quality inspections). These clusters cover various dimensions of BIM, ranging from its applications in risk assessments and building technology to educational training and team-based learning.

When looking into the details of each cluster, cluster #0, centered around FEMA p-58, addresses the complexities of disaster response and management within the BIM framework. Cluster #1 explores the realm of building technology, delving into innovative applications and advancements within the construction domain. The industry foundation classes in the cluster #2 highlight standardization and interoperability, playing a crucial role in enhancing collaborative efforts across BIM platforms.

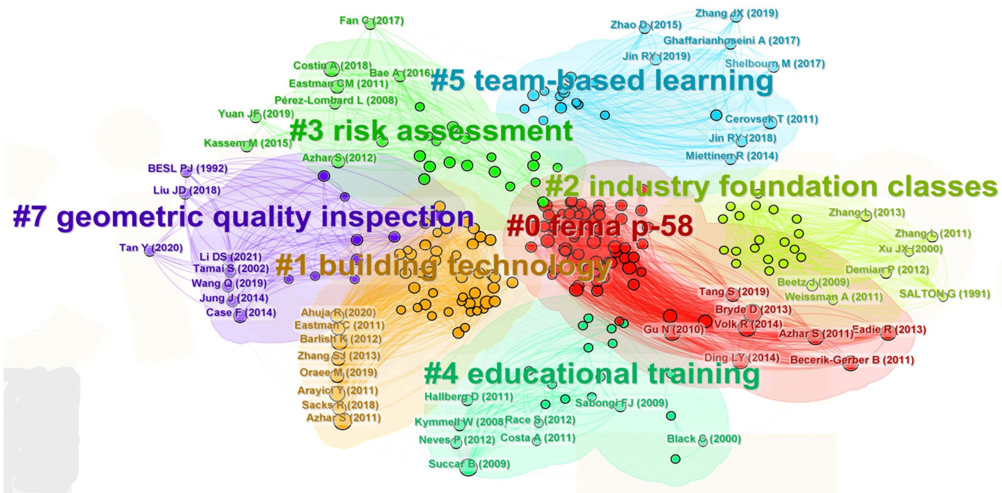

Figure 5. CiteSpace visualization of the multidimensional fields of BIM and a cluster analysis for SLR research [102–104].

Risk assessments, featured in the cluster #3, address the evaluation and mitigation of potential risks in BIM applications. When moving to cluster #4, the focus shifts to educational training, shedding light on the pedagogical aspects of BIM adoption and knowledge dissemination. The team-based learning in cluster #5 emphasizes collaborative practices within BIM, promoting effective teamwork in the industry. Lastly, cluster #6 delves into geometric quality inspections, unraveling the intricacies of BIM's role in ensuring precision and quality in geometric representations.

Based on the visualization in Figure 5, three of the most significant authors in the BIM category were identified. Succar (2009) [102] was notable in cluster #4 for educational training, Volk (2014) [103] in cluster #1 for FEMA p-58, and Azhar (2011) [104] in cluster #1 for building technology. These three authors were consistently the most mentioned in each visualization category.

3.3. Internet of Things (IoT)

The incorporation of IoT technology, including wireless sensors and computer networks, significantly advanced the concept of the smart environment during the recent technological revolution [105]. IoT technology has undergone extensive development and increased usage across various sectors such as social networks, infrastructure, security, business, and healthcare [106]. Integrating IoT-based intelligent monitoring systems, such as environmental and energy monitoring systems, with human involvement has emerged as a promising approach within the smart city framework, aiming to improve human health and overall well-being [107].

Amaxilatis et al. (2017) [108] conducted research focusing on measurements by IoT devices in two primary areas—power consumption and environmental comfort within school buildings. Power consumption meters, strategically placed on the general electricity distribution board of each building, assessed both the apparent and average power usage levels across the three-phase power supply. During another study, Amaxilatis et al. (2017) [108], using environmental comfort meters, evaluated factors crucial to occupants' well-being, including thermal satisfaction, visual comfort in terms of available light perception, and overall noise exposure. Room occupancy was tracked using passive infrared sensors (PIR). Beyond the building, weather and atmosphere stations provided comprehensive data on outdoor atmospheric conditions, including precipitation levels, wind dynamics, atmospheric pressure levels, and concentrations of specific pollutants. The insights from these atmospheric meters offered a clear view of pollution levels around the school buildings.

Hossain et al. (2020) [109] and Martínez et al. (2021) [110] both explored the monitoring of environmental parameters in educational and office settings using IoT technologies and sensor networks. They measured key factors such as CO_2, relative humidity, and temperature levels. Hossain et al. (2020) specifically targeted parameters such as the dry bulb temperature, illuminance, and sound pressure levels, while Martínez et al. (2021) focused on a broader set of measurements, including the light intensity, presence detection, and energy consumption. Both studies emphasized the importance of sensor placement for accurate data collection and recognized the value of historical and real-time data visualizations for managing building performance. Differences arose in the parameters measured, with Hossain et al. (2020) including sound pressure levels, which were not addressed by Martínez et al. (2021), who delved deeper into user-centric services and security protocols at the user level. Kamel et al. (2022) [111] adapted IoT technology for smart fire systems. Paganelli et al. (2019) [112] described IoT monitoring endpoints within classrooms, utilizing a mix of commercial hardware, sensor vendors, and open-source solutions, regularly collecting measurements such as power consumption values, environmental data, weather conditions, and air pollution levels.

In their comprehensive research, Mylonas et al. (2018) [113] implemented a network of 880 sensing points across various categories. These were strategically organized into four distinct groups, including sensors for monitoring classroom environments, assessing outdoor atmospheric conditions, gathering data from the weather stations on rooftops, and tracking power consumption through meters connected to the main building's electricity panels. This extensive deployment aimed to capture diverse data crucial for their study's comprehensive analysis and insights.

This section provides detailed insight into the major clusters within the network, incorporating both citing articles and references (Figure 6). The significance of network nodes is thoroughly examined using diverse metrics to measure their impact. Citation-based metrics, such as counts and bursts, highlight the scholarly influence of nodes, while network-based metrics such as the degree centrality and betweenness centrality offer insights into their structural importance. Additionally, the sigma metric combines the burst and betweenness centrality to provide a holistic measure of node importance.

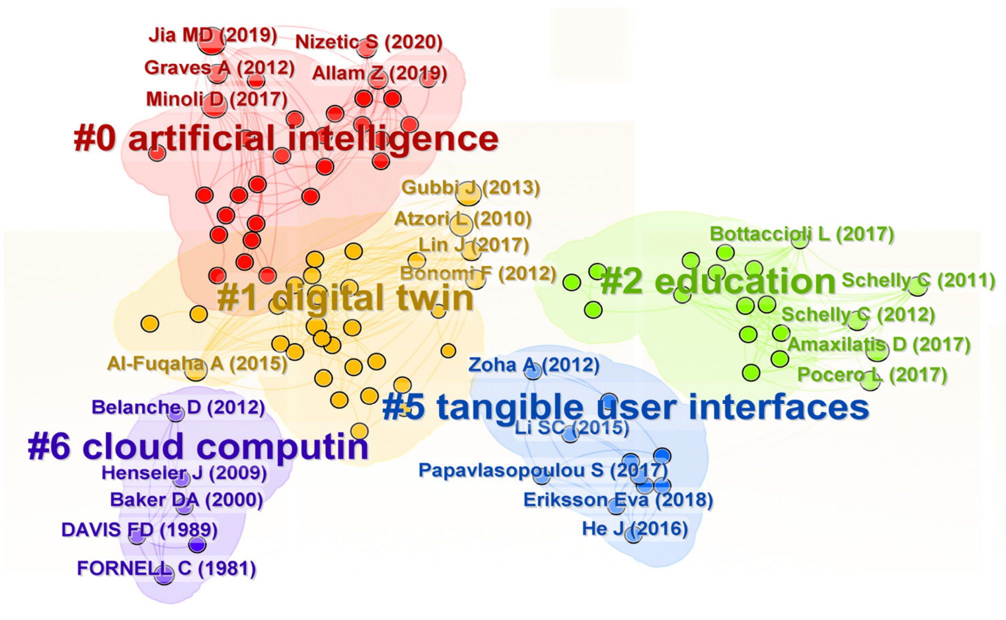

Figure 6. CiteSpace visualization of the multidimensional fields of IoT and cluster analyses for SLR research [114–116].

Figure 6 shows the main clusters of the IoT visualization, revealing the complex connections within the network. There were a total of 10 clusters in the network, each making a unique contribution to the extensive field of IoT-related research. These clusters covered various research areas, including artificial intelligence (#0), digital twins (#1), education (#2), big data analyses (#3), cloud computing (#4), tangible user interfaces (#5), digital libraries (#6), and educational materials (#7).

In the IoT field, several prominent authors appeared in the various visualization categories. For example, Jia (2019) [114] was a notable author in cluster #0, leading in citation counts (100in total). Additionally, Jia appeared in the degree and centrality categories. Such authors as Atzori (2010) [115] and Gubbi (2013) [116] from cluster #1 were also mentioned multiple times in various categories, including the citation count, degree, and centrality categories.

3.4. Digital Twins (DTs)

Digital twins represent a cutting-edge topic that is currently trending in various industries. However, within the scope of this SLR, it was observed that there is a lack of publications on school-related digital twins. Instead, the majority of publications on digital twins predominantly focus on aspects such as architecture, development, modeling, software platforms, and frameworks. This gap suggests a need for deeper and more comprehensive research and field studies to investigate how digital twins in school buildings affect student academic performance. Further exploration in this area could provide valuable insights into the application of digital twins in the educational field and the implications for enhancing the learning environment.

4. Discussion

4.1. Indoor Environment Factors

In this study, various authors examining factors related to students' academic performance considered different parameters. While many articles focused on external factors such as chemicals from streets and power plants, this study specifically looked at the indoor environment of schools and the factors influencing students within the school premises.

4.2. New-Generation vs. Fundamental Articles

When talking about the new-generation and fundamental articles, the first type focuses on modern technologies such as IoT, LCA, and BIM, while the second one concentrates on traditional aspects such as heating, ventilation, and IAQ. However, both types of articles remain relevant today. The research review indicated a significant growth in the number of articles on school ventilation, with notable surges over 2007–2011. The first increase occurred between 2007 and 2011; that is, around the time the era of Industry 4.0 began. Next, there was a decrease, possibly because many researchers moved on to the Industry 4.0 field and started writing about that instead. The second rise occurred in 2019, during the global impact of the COVID-19 pandemic, and no subsequent decrease was observed thereafter.

The comparison between fundamental and new-generation articles reveals a clear evolution in the research focus and methodology. Fundamental articles, dating from the late 19th century to the mid-20th century, primarily address basic and traditional aspects of IAQ, ventilation, heating, and microclimate. These studies provide essential environmental parameters such as CO2 levels, ventilation rates, and temperature values, offering foundational knowledge for maintaining healthy and comfortable indoor environments in school buildings. However, they are limited by the technology of their time, leading to challenges in implementation and a narrow focus that does not consider the broader impacts of technological integration and sustainability practices. Additionally, the earlier methods for collecting and analyzing data were less complex, potentially affecting the accuracy and comprehensiveness of the findings.

In contrast, new-generation articles, emerging from the late 20th century to the early 21st century, reflect the influence of Industry 4.0 and focus on modern trends such as

IoT, BIM, DTs, and LCAs. These studies emphasize sustainable infrastructure practices, eco-friendly designs, digitalization, and advanced modeling techniques. Despite their advantages, these articles face barriers in their technological adoption and resource allocation, with the complexity and cost associated with implementing advanced systems presenting significant difficulties. Nevertheless, integrating the foundational knowledge from fundamental articles with the innovative solutions from new-generation articles presents a comprehensive approach to improving school building environments. Future research should explore optimizing the integration of these technologies to overcome existing barriers, thereby enhancing the IAQ, energy efficiency, and overall sustainability in educational buildings.

4.3. Interdisciplinary Research Findings

This paper extensively combined diverse findings from clusters such as FEMA P-58, LCAs, environmental impacts, construction management, risk assessments, BIM education, and smart building. When analyzing citation metrics, bursts, centrality measures, and sigma metrics across these clusters, significant patterns and contributions by authors such as Su, Succar, Azhar, and Jia were identified, revealing their impact across various domains. This combination highlights the interdisciplinary nature of the research fields, showcasing interrelationships among environmental sciences, materials science, construction technology, and energy domains.

4.4. Focus on IAQ and Overlooked Aspects

Even though IAQ is a basic and vital subject, the contemporary new-generation articles are focused on digitalization and sustainability, often overlooking the impacts on students and teachers. It is interesting to note that there is a lack of scientific research on digital twins in schools in databases such as WoS and Scopus. The rise of new-generation articles began in the late 20th century and has continued into the early 21st century, while the fundamental articles can be traced back from the late 19th century to the mid-20th century.

Most of the articles that are related to LCA discuss important topics such as IAQ; heating, ventilation, and air conditioning (HVAC); and the global warming potential (GWP), and although the articles are different, all of them cover these listed topics [79,83,117–119]. However, it is interesting that not all of these papers thoroughly cover related subjects such as energy usage, sustainability, or the use of advanced modeling approaches such as 3D modeling and BIM, even though these are important in LCAs. This observation shows that the authors do not always grant equal importance to all aspects of am LCA. Some focus more on IAQ, HVAC, and GWP aspects, while not giving as much weight to things such as energy use, sustainability concerns, or the use of advanced modeling techniques such as 3D modeling or BIM.

4.5. Database Comparison and Article Selection

The research revealed that the WoS database contained a greater number of publications compared to the Scopus database when using the same search string. In particular, Scopus displayed 895 publications, whereas WoS exhibited 8993 publications, which amounted to a total of 9888. After applying various filters on the databases' search engines and identifying 59 duplicates using the Mendeley reference manager, a total of 1556 publications were included for the screening phase. Subsequently, during the screening phase, 1256 publications were excluded, leaving only 300 publications for detailed screening. From this detailed screening, half of the articles were selected for the full-text reading phase, also known as the eligibility phase. Within the full-text reading phase, 32 publications were excluded for various reasons, such as their focus on school surroundings rather than the schools themselves. Ultimately, only 118 publications were chosen for the systematic literature review (SLR).

When looking at scientific articles on databases such as Scopus and WoS, clear criteria must be established to distinguish next-generation articles from fundamental articles. This paper defines new-generation articles as those published from the late 20th century to the early 21st century. This distinction is based on a change in focus. Fundamental articles, from the late 19th century to the mid-20th century, mainly emphasized aspects such as CO_2, sustainability, IAQ, ventilation, and microclimates. On the other hand, new-generation articles focus on exploring modern trends and practical uses of technologies such as IoT, DTs, LCAs, and BIM. In order to identify these next-generation articles, publications that delve into the real-world impacts, progress, and integrative aspects of new technologies in various scientific fields are often sought. All of these factors differentiate these articles from the seminal discoveries and theoretical foundations found in the fundamental articles.

5. Conclusions

In terms of sustainability in schools, adopting eco-friendly methods is crucial. Programs such as LEED [44], CHPS [45], BREEAM [46], Green Star—Education V1 [47], and WELL [48] provide guidelines to ensure schools are more sustainable by emphasizing energy savings, efficient water usage, and maintaining clean IAQ.

The digitalization of schools has the potential to enhance students' cognitive performance. However, more research is needed to establish a connection between digitalization, IAQ, and the impact on academic performance.

The incorporation of new-generation approaches addresses various challenges in the education sector, such as insufficient energy use, high maintenance costs, and poor working conditions. These improvements are crucial, as they directly impact classroom air quality and consequently student learning outcomes. This study underscores the importance of creating healthier and more efficient learning environments through advanced technological integration.

The comparison between fundamental and new-generation articles shows a clear shift in research focus. The fundamental articles were focused on IAQ parameters, while the new-generation articles emphasize using broader technologies, such as LCAs, BIM, and IoT, to address environmental issues and improve building performance. This indicates a more comprehensive approach to solving the diverse challenges in educational building environments.

This study offers important insights into how the civil engineering research has evolved, highlighting the use of modern technologies to tackle both old and new challenges in school buildings. The findings suggest that a balanced approach, which mixes traditional methods with new technologies, can boost sustainability and improve student performance.

For future research, it is recommended to explore the influence of new-generation topics, including BIM, IoT, and LCAs, and their implementation in schools on students' academic performance. Additionally, there are no articles in the WoS and Scopus databases about digital twins in schools and how they affect students' academic performance, so looking deeper into the use of digital twins in schools is recommended.

Overall, it is implied that the current topics will not be forgotten. Instead, they will be integrated and further developed. As a result, future research efforts will need to cover a wider range of information to tackle the evolving dynamics within the field effectively.

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References

1. Klepeis, N.E.; Nelson, W.C.; Ott, W.R.; Robinson, J.P.; Tsang, A.M.; Switzer, P.; Behar, J.V.; Hern, S.C.; Engelmann, W.H. The National Human Activity Pattern Survey (NHAPS): A resource for assessing exposure to environmental pollutants. *J. Expo. Sci. Environ. Epidemiol.* **2001**, *11*, 231–252. [CrossRef]
2. Wang, D.; Song, C.; Wang, Y.; Xu, Y.; Liu, Y.; Liu, J. Experimental investigation of the potential influence of indoor air velocity on students' learning performance in summer conditions. *Energy Build.* **2020**, *219*, 110015. [CrossRef]
3. Currie, J.; Neidell, M.; Schmieder, J.F. Air pollution and infant health: Lessons from New Jersey. *J. Health Econ.* **2009**, *28*, 688–703. [CrossRef]
4. Currie, J.; Reed, W. Traffic Congestion and Infant Health: Evidence from E-ZPass. *Am. Econ. J. Appl. Econ.* **2011**, *3*, 65–90. [CrossRef]
5. Knittel, C.R.; Miller, D.L.; Sanders, N.J. Caution, drivers! children present: Traffic, pollution, and infant health. *Rev. Econ. Stat.* **2016**, *98*, 350–366. [CrossRef]
6. Schlenker, W.; Walker, W.R. Airports, Air Pollution, and Contemporaneous Health. *Rev. Econ. Stud.* **2016**, *83*, 768–809. [CrossRef]
7. Deryugina, T.; Heutel, G.; Miller, N.H.; Molitor, D.; Reif, J. The Mortality and Medical Costs of Air Pollution: Evidence from Changes in Wind Direction. *Am. Econ. Rev.* **2019**, *109*, 4178–4219. [CrossRef]
8. Heft-Neal, S.; Burney, J.; Bendavid, E.; Voss, K.; Burke, M. Air Pollution and Infant Mortality: Evidence from Saharan Dust. Working Paper 26107, National Bureau of Economic Research. 2019. Available online: https://www.nber.org/papers/w26107 (accessed on 20 February 2024).
9. Simeonova, E.; Currie, J.; Nilsson, P.; Walker, R. Congestion Pricing, Air Pollution, and Childrens Health. *J. Hum. Resour.* **2019**, *56*, 971–996. [CrossRef]
10. Ebenstein, A.; Lavy, V.; Roth, S. The Long-Run Economic Consequences of High-Stakes Examinations: Evidence from Transitory Variation in Pollution. *Am. Econ. J. Appl. Econ.* **2016**, *8*, 36–65. [CrossRef]
11. Persico, C.L.; Venator, J. The effects of local industrial pollution on students and schools. *J. Hum. Resour.* **2021**, *56*, 406–445. [CrossRef]
12. Heissel, J.A.; Persico, C.; Simon, D. Does Pollution Drive Achievement? The Effect of Traffic Pollution on Academic Performance. *J. Hum. Resour.* **2022**, *57*, 747–776. [CrossRef]
13. Gaihre, S.; Semple, S.; Miller, J.; Fielding, S.; Turner, S. Classroom Carbon Dioxide Concentration, School Attendance, and Educational Attainment. *J. Sch. Health* **2014**, *84*, 569–574. [CrossRef]
14. Kielb, C.; Lin, S.; Muscatiello, N.; Hord, W.; Rogers-Harrington, J.; Healy, J. Building-related health symptoms and classroom indoor air quality: A survey of school teachers in New York State. *Indoor Air* **2015**, *25*, 371–380. [CrossRef] [PubMed]
15. Mendell, M.J.; Heath, G.A. Do indoor pollutants and thermal conditions in schools influence student performance? A critical review of the literature. *Indoor Air* **2005**, *15*, 27–52. [CrossRef] [PubMed]
16. Shendell, D.; Prill, R.J.; Fisk, W.; Apte, M.; Blake, D.; Faulkner, D. Association between class room CO_2 concentrations and student attendance in Washington and Idaho. *Indoor Air* **2004**, *14*, 333–341. [CrossRef]
17. Wargocki, P.; Wyon, D.P. Ten questions concerning thermal and indoor air quality effects on the performance of office work and schoolwork. *Build. Environ.* **2017**, *112*, 359–366. [CrossRef]
18. Fisk, W. The ventilation problem in schools: Literature review. *Indoor Air* **2017**, *27*, 1039–1051. [CrossRef]
19. Madureira, J.; Paciência, I.; Pereira, C.; Teixeira, J.P.; de Oliveira Fernandes, E. Indoor air quality in Portuguese schools: Levels and sources of pollutants. *Indoor Air* **2015**, *26*, 526–537. [CrossRef] [PubMed]
20. Deng, S.; Lau, J. Seasonal variations of indoor air quality and thermal conditions and their correlations in 220 classrooms in the Midwestern United States. *Build. Environ.* **2019**, *157*, 79–88. [CrossRef]
21. Twardella, D.; Matzen, W.; Lahrz, T.; Burghardt, R.; Spegel, H.; Hendrowarsito, L.; Frenzel, A.; Fromme, H. Effect of classroom air quality on students' concentration: Results of a cluster-randomized cross-over experimental study. *Indoor Air* **2012**, *22*, 378–387. [CrossRef]
22. Durán-Narucki, V. School building condition, school attendance, and academic achievement in New York City public schools: A mediation model. *J. Environ. Psychol.* **2008**, *28*, 278–286. [CrossRef]
23. Berman, J.D.; McCormack, M.C.; Koehler, K.A.; Connolly, F.; Clemons-Erby, D.; Davis, M.F.; Gummerson, C.; Leaf, P.J.; Jones, T.D.; Curriero, F.C. School environmental conditions and links to academic performance and absenteeism in urban, mid-Atlantic public schools. *Int. J. Hyg. Environ. Health* **2018**, *221*, 800–808. [CrossRef] [PubMed]
24. Evans, G.W.; Yoo, M.J.; Sipple, J. The ecological context of student achievement: School building quality effects are exacerbated by high levels of student mobility. *J. Environ. Psychol.* **2010**, *30*, 239–244. [CrossRef]
25. Crampton, F.E. Spending on school infrastructure: Does money matter? *J. Educ. Adm.* **2009**, *47*, 305–322. [CrossRef]
26. Haverinen-Shaughnessy, U.; Shaughnessy, R.J.; Cole, E.C.; Toyinbo, O.; Moschandreas, D.J. An assessment of indoor environmental quality in schools and its association with health and performance. *Build. Environ.* **2015**, *93*, 35–40. [CrossRef]
27. Shaughnessy, R.; Haverinen-Shaughnessy, U.; Nevalainen, A.; Moschandreas, D. A preliminary study on the association between ventilation rates in classrooms and student performance. *Indoor Air* **2007**, *16*, 465–468. [CrossRef] [PubMed]
28. Godwin, C.; Batterman, S. Indoor air quality in Michigan schools. *Indoor Air* **2007**, *17*, 109–121. [CrossRef] [PubMed]

29. Mendell, M.; Ekaterina, E.; Davies, M.; Spears, M.; Lobscheid, A.; Fisk, W.; Apte, M. Association of Classroom Ventilation with Reduced Illness Absence: A Prospective Study in California Elementary Schools. *Indoor Air* **2013**, *23*, 515–528. [CrossRef] [PubMed]
30. Daisey, J.M.; Angell, W.J.; Apte, M.G. Indoor air quality, ventilation and health symptoms in schools: An analysis of existing information. *Indoor Air* **2003**, *13*, 53–64. [CrossRef]
31. Haverinen-Shaughnessy, U.; Shaughnessy, R. Effects of Classroom Ventilation Rate and Temperature on Students' Test Scores. *PLoS ONE* **2015**, *10*, e0136165. [CrossRef]
32. O'Neill, D.; Oates, A. The Impact of School Facilities on Student Achievement, Behavior, Attendance, and Teacher Turnover Rate in Central Texas Middle Schools. *Educ. Facil. Plan.* **2001**, *36*, 14–22.
33. Simons, E.; Hwang, S.-A.; Fitzgerald, E.F.; Kielb, C.; Lin, S. The Impact of School Building Conditions on Student Absenteeism in Upstate New York. *Am. J. Public Health* **2010**, *100*, 1679–1686. [CrossRef] [PubMed]
34. Toyinbo, O.; Shaughnessy, R.; Turunen, M.; Putus, T.; Metsämuuronen, J.; Kurnitski, J.; Haverinen-Shaughnessy, U. Building characteristics, indoor environmental quality, and mathematics achievement in Finnish elementary schools. *Build. Environ.* **2016**, *104*, 114–121. [CrossRef]
35. Wargocki, P.; Wyon, D.P. Providing better thermal and air quality conditions in school classrooms would be cost-effective. *Build. Environ.* **2013**, *59*, 581–589. [CrossRef]
36. Crosby, K.; Metzger, A.B. *Powering Down: A Toolkit for Behavior-Based Energy Conservation in K-12 Schools*; Technical Report; U.S. Green Building Council (USGBC): Washington, DC, USA, 2012.
37. Economidou, M.; Atanasiu, B.; Despret, C.; Maio, J.; Nolte, I.; Rapf, O.; Laustsen, J.; Ruyssevelt, P.; Staniaszek, D.; Strong, D.; et al. *Europe's Buildings under the Microscope: A Country-by-Country Review of the Energy Performance of Buildings*; Technical Report; Buildings Performance Institute Europe (BPIE): Brussels, Belgium, 2011; ISBN 9789491143014.
38. Shan, X.; Melina, A.N.; Yang, E.-H. Impact of indoor environmental quality on students' wellbeing and performance in educational building through life cycle costing perspective. *J. Clean. Prod.* **2018**, *204*, 298–309. [CrossRef]
39. Reed, R.H. The heating and ventilation of the mansfield schools and churches: A Lecture delivered before the Mansfield Lyceum, February 13, 1889. *J. Am. Med. Assoc.* **1889**, *XII*, 469–478. [CrossRef]
40. Reed, R.H. Original articles. original investigations on the heating and ventilation of school buildings: Read in the Section of State Medicine, at the Forty-second Annual Meeting of the American Medical Association, at Washington, D.C.; May, 1891. *J. Am. Med. Assoc.* **1891**, *XVII*, 389–396. [CrossRef]
41. Wheatley, J. The ventilation of schools. *Public Health* **1894**, *7*, 373–374. [CrossRef]
42. Rovira, C.; Codina, L.; Guerrero-Solé, F.; Lopezosa, C. Ranking by Relevance and Citation Counts, a Comparative Study: Google Scholar, Microsoft Academic, WoS and Scopus. *Futur. Internet* **2019**, *11*, 202. [CrossRef]
43. U.S. Environmental Protection Agency. Sustainability and the ROE. 2023. Available online: https://www.epa.gov/report-environment/sustainability-and-roe (accessed on 20 February 2024).
44. Center for Green Schools. Leed certification for schools. 2023. Available online: https://centerforgreenschools.org/about/leed-certification-schools (accessed on 20 February 2024).
45. The Collaborative for High Performance Schools (CHPS). 2021. Available online: https://chps.net/ (accessed on 20 February 2024).
46. Bre Group. BREEAM—Education. 2022. Available online: https://bregroup.com/asset_type/breeam-education/ (accessed on 20 February 2024).
47. Green building council Australia. Green Star—Education v1. 2008. Available online: https://www.gbca.org.au/uploads/226/1762/Factsheet_Educationv1.pdf (accessed on 20 February 2024).
48. Kosasih, A. WELL v2 and Educational Spaces: Promoting Healthy Schools. 2018. Available online: https://resources.wellcertified.com/articles/well-v2-and-educational-spaces-promoting-healthy-schools/ (accessed on 20 February 2024).
49. Brink, H.W.; Krijnen, W.P.; Loomans, M.G.L.C.; Mobach, M.P.; Kort, H.S.M. Positive effects of indoor environmental conditions on students and their performance in higher education classrooms: A between-groups experiment. *Sci. Total Environ.* **2023**, *869*, 161813. [CrossRef]
50. Choi, H.-H.; van Merriënboer, J.J.G.; Paas, F. Effects of the Physical Environment on Cognitive Load and Learning: Towards a New Model of Cognitive Load. *Educ. Psychol. Rev.* **2014**, *26*, 225–244. [CrossRef]
51. Brink, H.W.; Loomans, M.G.L.C.; Mobach, M.P.; Kort, H.S.M. Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: A systematic literature review. *Indoor Air* **2021**, *31*, 405–425. [CrossRef]
52. Kim, J.; de Dear, R. Nonlinear relationships between individual IEQ factors and overall workspace satisfaction. *Build. Environ.* **2012**, *49*, 33–40. [CrossRef]
53. Xiong, L.; Huang, X.; Li, J.; Mao, P.; Wang, X.; Wang, R.; Tang, M. Impact of Indoor Physical Environment on Learning Efficiency in Different Types of Tasks: A 3 × 4 × 3 Full Factorial Design Analysis. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1256. [CrossRef] [PubMed]
54. Calderón-Garcidueñas, L.; Mora-Tiscareño, A.; Ontiveros, E.; Gómez-Garza, G.; Barragán-Mejía, G.; Broadway, J.; Chapman, S.; Valencia-Salazar, G.; Jewells, V.; Maronpot, R.R.; et al. Air polldogs. *Brain Cogn.* **2008**, *68*, 117–127. [CrossRef] [PubMed]
55. Gardin, T.N.; Requia, W.J. Air quality and individual-level academic performance in Brazil: A nationwide study of more than 15 million students between 2000 and 2020. *Environ. Res.* **2023**, *226*, 115689. [CrossRef] [PubMed]
56. Duque, V.; Gilraine, M. Coal use, air pollution, and student performance. *J. Public Econ.* **2022**, *213*, 104712. [CrossRef]

57. Kabirikopaei, A.; Lau, J.; Nord, J.; Bovaird, J. Identifying the K-12 classrooms' indoor air quality factors that affect student academic performance. *Sci. Total Environ.* **2021**, *786*, 147498. [CrossRef]
58. Requia, W.J.; Saenger, C.C.; Cicerelli, R.E.; Monteiro de Abreu, L.; Cruvinel, V.R.N. Air quality around schools and school-level academic performance in Brazil. *Atmos. Environ.* **2022**, *279*, 119125. [CrossRef]
59. Guo, H.; Morawska, L.; He, C.; Zhang, Y.L.; Ayoko, G.; Cao, M. Characterization of particle number concentrations and PM2.5 in a school: Influence of outdoor air pollution on indoor air. *Environ. Sci. Pollut. Res.* **2010**, *17*, 1268–1278. [CrossRef]
60. Richmond-Bryant, J.; Saganich, C.; Bukiewicz, L.; Kalin, R. Associations of PM2.5 and black carbon concentrations with traffic, idling, background pollution, and meteorology during school dismissals. *Sci. Total Environ.* **2009**, *407*, 3357–3364. [CrossRef] [PubMed]
61. Rivas, I.; Viana, M.; Moreno, T.; Pandolfi, M.; Amato, F.; Reche, C.; Bouso, L.; Àlvarez-Pedrerol, M.; Alastuey, A.; Sunyer, J.; et al. Child exposure to indoor and outdoor air pollutants in schools in Barcelona, Spain. *Environ. Int.* **2014**, *69*, 200–212. [CrossRef]
62. Martínez-Lazcano, J.; González Guevara, E.; Rubio, C.; Franco-Pérez, J.; Custodio, V.; Hernández-Cerón, M.; CARLOS, L.; Paz, C. The effects of ozone exposure and associated injury mechanisms on the central nervous system. *Rev. Neurosci.* **2013**, *24*, 337–352. [CrossRef] [PubMed]
63. Forns, J.; Dadvand, P.; Esnaola, M.; Alvarez-Pedrerol, M.; López-Vicente, M.; Garcia-Esteban, R.; Cirach, M.; Basagaña, X.; Guxens, M.; Sunyer, J. Longitudinal association between air pollution exposure at school and cognitive development in school children over a period of 3.5 years. *Environ. Res.* **2017**, *159*, 416–421. [CrossRef]
64. Benka-Coker, W.; Young, B.; Oliver, S.; Schaeffer, J.W.; Manning, D.; Suter, J.; Cross, J.; Magzamen, S. Sociodemographic variations in the association between indoor environmental quality in school buildings and student performance. *Build. Environ.* **2021**, *206*, 108390. [CrossRef]
65. Choi, N.; Yamanaka, T.; Takemura, A.; Kobayashi, T.; Eto, A.; Hirano, M. Impact of indoor aroma on students' mood and learning performance. *Build. Environ.* **2022**, *223*, 109490. [CrossRef]
66. Ryan, I.; Deng, X.; Thurston, G.; Khwaja, H.; Romeiko, X.; Zhang, W.; Marks, T.; Yu, F.; Lin, S. Measuring students' exposure to temperature and relative humidity in various indoor environments and across seasons using personal air monitors. *Hyg. Environ. Health Adv.* **2022**, *4*, 100029. [CrossRef]
67. Evidence for Policy and Practice Information and Co-ordinating Centre (EPPI-Centre). *EPPI-Centre Methods for Conducting Systematic Reviews*; EPPI-Centre, Social Science Research Unit, Institute of Education, University of London: London, UK, 2007.
68. Harden, A.; Thomas, J. Methodological Issues in Combining Diverse Study Types in Systematic Reviews. *Int. J. Soc. Res. Methodol.* **2005**, *8*, 257–271. [CrossRef]
69. Lamé, G. Systematic Literature Reviews: An Introduction. In Proceedings of the Design Society: International Conference on Engineering Design, Delft, The Netherlands, 5–8 August 2019; Volume 1. [CrossRef]
70. MacLure, M. 'Clarity bordering on stupidity': Where's the quality in systematic review? *J. Educ. Policy* **2005**, *20*, 393–416. [CrossRef]
71. Higgins, J.P.T.; Green, S. (Eds.) *Cochrane Handbook for Systematic Reviews of Interventions*; The Cochrane Collaboration: London, UK, 2009.
72. Chadegani, A.A.; Salehi, H.; Yunus, M.M.; Farhadi, H.; Fooladi, M.; Farhadi, M.; Ebrahim, N.A. A Comparison between Two Main Academic Literature Collections: Web of Science and Scopus Databases. *Asian Soc. Sci.* **2013**, *9*, 18–26. [CrossRef]
73. Chen, C.; Hu, Z.; Liu, S.; Tseng, H. Emerging trends in regenerative medicine: A scientometric analysis in CiteSpace. *Expert Opin. Biol. Ther.* **2012**, *12*, 593–608. [CrossRef] [PubMed]
74. Chen, C. Searching for intellectual turning points: Progressive knowledge domain visualization. *Proc. Natl. Acad. Sci. USA* **2004**, *101* (Suppl. S1), 5303–5310. [CrossRef] [PubMed]
75. Chen, C. CiteSpace II: Detecting and visualizing emerging trends and transient patterns in scientific literature. *J. Am. Soc. Inf. Sci. Technol.* **2006**, *57*, 359–377. [CrossRef]
76. Chen, C.; Song, M. Visualizing a Field of Research: A Methodology of Systematic Scientometric Reviews. *PLoS ONE* **2019**, *14*, e0223994. [CrossRef]
77. Chen, C. A Glimpse of the First Eight Months of the COVID-19 Literature on Microsoft Academic Graph: Themes, Citation Contexts, and Uncertainties. *Front. Res. Metr. Anal.* **2020**, *5*, 607286. [CrossRef]
78. Alshamrani, O.S.; Galal, K.; Alkass, S. Integrated LCA–LEED sustainability assessment model for structure and envelope systems of school buildings. *Build. Environ.* **2014**, *80*, 61–70. [CrossRef]
79. Ji, C.; Hong, T.; Jeong, J.; Kim, J.; Lee, M.; Jeong, K. Establishing environmental benchmarks to determine the environmental performance of elementary school buildings using LCA. *Energy Build.* **2016**, *127*, 818–829. [CrossRef]
80. Brás, A.; Gomes, V. LCA implementation in the selection of thermal enhanced mortars for energetic rehabilitation of school buil ings. *Energy Build.* **2015**, *92*, 1–9. [CrossRef]
81. Pachta, V.; Giourou, V. Comparative Life Cycle Assessment of a Historic and a Modern School Building, Located in the City of Naoussa, Greece. *Sustainability* **2022**, *14*, 4216. [CrossRef]
82. Gamarra, A.R.; Herrera, I.; Lechón, Y. Assessing sustainability performance in the educational sector. *A High Sch. Case Study. Sci. Total Environ.* **2019**, *692*, 465–478. [CrossRef]
83. Gamarra, A.R.; Istrate, I.R.; Herrera, I.; Lago, C.; Lizana, J.; Lechon, Y. Energy and water consumption and carbon footprint of school buildings in hot climate conditions. *Results Life Cycle Assess. J. Clean. Prod.* **2018**, *195*, 1326–1337. [CrossRef]

84. Munoz, P.; Morales, P.; Letelier, V.; Munoz, L.; Morad, D. Implications of Life Cycle Energy Assessment of a new school building, regarding the nearly Zero Energy Buildings targets in EU: A case OF study. *Sustain. Cities Soc.* **2017**, *32*, 142–152. [CrossRef]
85. Su, S.; Zhu, C.; Li, X. A dynamic weighting system considering temporal variations using the DTT approach in LCA of buildings. *J. Clean. Prod.* **2019**, *220*, 398–407. [CrossRef]
86. Li, X.; Su, S.; Zhang, Z.; Kong, X. An integrated environmental and health performance quantification model for pre-occupancy phase of buildings in China. *Environ. Impact Assess. Rev.* **2017**, *63*, 1–11. [CrossRef]
87. Su, S.; Wang, Q.; Han, L.; Hong, J.; Liu, Z. BIM-DLCA: An integrated dynamic environmental impact assessment model for buildings. *Build. Environ.* **2020**, *183*, 107218. [CrossRef]
88. Su, S.; Zhang, H.; Zuo, J. Assessment models and dynamic variables for dynamic life cycle assessment of buildings: A review. *Environ. Sci. Pollut. Res.* **2021**, *28*, 26199–26214. [CrossRef] [PubMed]
89. Lee, S.; Yu, J.; Jeong, D. BIM acceptance model in construction organizations. *J. Manag. Eng.* **2015**, *31*, 04014048. [CrossRef]
90. Gheisari, M.; Irizarry, J. Investigating human and technological requirements for successful implementation of a BIM-based mobile augmented reality environment in facility management practices. *Facilities* **2016**, *34*, 69–84. [CrossRef]
91. Wang, J.; Wang, X.; Wang, J.; Yung, P.; Jun, G. Engagement of facilities management in design stage through BIM: Framework and a case study. *Adv. Civ. Eng.* **2013**, *2013*, 189105. [CrossRef]
92. Liu, Y.; van Nederveen, S.; Wu, C.; Hertogh, M. Sustainable infrastructure design framework through integration of rating systems and building information modeling. *Adv. Civ. Eng.* **2018**, *2018*, 8183536. [CrossRef]
93. Zhang, J.; Issa, R. Collecting fire evacuation performance data using BIM-based immersive serious games for performance-based fire safety design. In Proceedings of the 2015 International Workshop on Computing in Civil Engineering, Austin, TX, USA, 21–23 June 2015; pp. 612–619.
94. Vaughan, E. *"Elementary School", Whole Building Design Guide*; National Institute of Building Sciences: Washington, DC, USA, 2017. Available online: https://www.wbdg.org/buildingtypes/education-facilities/elementary-school (accessed on 20 February 2024).
95. Eastman, C.; Teicholz, P.; Sacks, R.; Liston, K. *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers, and Contractors*, 2nd ed.; John Wiley and Sons: Hoboken, NJ, USA, 2011.
96. Bynum, P.; Issa, R.R.A.; Olbina, S. Building information modeling in support of sustainable design and construction. *J. Constr. Eng. Manag.* **2013**, *139*, 24–34. [CrossRef]
97. Lee, K.; Choo, S. A hierarchy of architectural design elements for energy saving of tower buildings in Korea using green BIM simulation. *Adv. Civ. Eng.* **2018**, *2018*, 7139196. [CrossRef]
98. Zhuang, D.; Zhang, X.; Lu, Y.; Wang, C.; Jin, X.; Zhou, X.; Shi, X. A performance data integrated BIM framework for building life-cycle energy efficiency and environmental optimization design. *Autom. Constr.* **2021**, *127*, 103712. [CrossRef]
99. Neasden Primary School. *Application of BIM in Energy Management of Individual Departments Occupying University Facilities*; Neasden Primary School: Hull, UK, 2019. Available online: https://neasdenprimary.org.uk/school-new-build/ (accessed on 20 February 2024).
100. Konings, K.D.; Bovill, C.; Woolner, P. Towards an interdisciplinary model of practice for participatory building design in education. *Eur. J. Educ.* **2017**, *52*, 306–317. [CrossRef]
101. Van Merrienboer, J.J.G.; McKenney, S.; Cullinan, D.; Heuer, J. Aligning pedagogy with physical learning spaces. *Eur. J. Educ.* **2017**, *52*, 253–267. [CrossRef]
102. Succar, B. Building information modelling framework: A research and delivery foundation for industry stakeholders. *Autom. Constr.* **2009**, *18*, 357–375. [CrossRef]
103. Volk, R.; Stengel, J.; Schultmann, F. Building Information Modeling (BIM) for existing buildings—Literature review and future needs. *Autom. Constr.* **2014**, *38*, 109–127. [CrossRef]
104. Azhar, S. Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry. *Leadersh. Manag. Eng.* **2011**, *11*, 241–252. [CrossRef]
105. Gaur, A.; Scotney, B.; Parr, G.; McClean, S. Smart City Architecture and its Applications Based on IoT. *Procedia Comput. Sci.* **2015**, *52*, 1089–1094. [CrossRef]
106. Sethi, P.; Sarangi, S.R. Internet of Things: Architectures, Protocols, and Applications. *J. Electr. Comput. Eng.* **2017**, *2017*, 1–25. [CrossRef]
107. Li, S.; Xu, L.D.; Zhao, S. The internet of things: A survey. *Inf. Syst. Front.* **2015**, *17*, 243–259. [CrossRef]
108. Amaxilatis, D.; Akrivopoulos, O.; Mylonas, G.; Chatzigiannakis, I. An IoT-Based Solution for Monitoring a Fleet of Educational Buildings Focusing on Energy Efficiency. *Sensors* **2017**, *17*, 2296. [CrossRef] [PubMed]
109. Hossain, M.; Weng, Z.; Schiano-Phan, R.; Scott, D.; Lau, B. Application of IoT and BEMS to Visualise the Environmental Performance of an Educational Building. *Energies* **2020**, *13*, 4009. [CrossRef]
110. Martínez, I.; Zalba, B.; Trillo-Lado, R.; Blanco, T.; Cambra, D.; Casas, R. Internet of Things (IoT) as Sustainable Development Goals (SDG) Enabling Technology towards Smart Readiness Indicators (SRI) for University Buildings. *Sustainability* **2021**, *13*, 7647. [CrossRef]
111. Kamel, S.; Jamal, A.; Omri, K.; Khyyat, M. An IoT-based Fire Safety Management System for Educational Buildings: A Case Study. *Int. J. Adv. Comput. Sci. Appl.* **2022**, *13*, 765–771. [CrossRef]

112. Paganelli, F.; Mylonas, G.; Cuffaro, G.; Nesi, I. Experiences from Using Gamification and IoT-Based Educational Tools in High Schools Towards Energy Savings. In *Ambient Intelligence. AmI 2019*; Lecture Notes in Computer Science; Chatzigiannakis, I., De Ruyter, B., Mavrommati, I., Eds.; Springer: Cham, Switzerland, 2019; Volume 11912. [CrossRef]
113. Mylonas, G.; Amaxilatis, D.; Chatzigiannakis, I.; Paganelli, A.A.F. Enabling Sustainability and Energy Awareness in Schools Based on IoT and Real-World Data. *IEEE Pervasive Comput.* **2018**, *17*, 53–63. [CrossRef]
114. Jia, M.; Komeily, A.; Wang, Y.; Srinivasan, R.S. Adopting Internet of Things for the development of smart buildings: A review of enabling technologies and applications. *Autom. Constr.* **2019**, *101*, 111–126. [CrossRef]
115. Atzori, L.; Iera, A.; Morabito, G. The Internet of Things: A survey. *Comput. Netw.* **2010**, *54*, 2787–2805. [CrossRef]
116. Gubbi, J.; Buyya, R.; Marusic, S.; Palaniswami, M. Internet of Things (IoT): A vision, architectural elements, and future directions. *Future Gener. Comput. Syst.* **2013**, *29*, 1645–1660. [CrossRef]
117. Hoda, I.; Elsayed, M.S.; Wael, S.M.; Abdou, H.M. Functional analysis as a method on sustainable building design: A case study in educational buildings implementing the triple bottom line. *Alex. Eng. J.* **2023**, *62*, 63–73. [CrossRef]
118. Peng, C. Calculation of a building's life cycle carbon emissions based on Ecotect and building information modeling. *J. Clean. Prod.* **2016**, *112*, 453–465. [CrossRef]
119. Schwab, K. *The Fourth Industrial Revolution*; Penguin Books Limited: London, UK, 2017. Available online: https://books.google.lt/books?id=ST_FDAAAQBAJ (accessed on 20 June 2024).