EVALUATING TOOLS FOR ASSESSING SENSORY EXPERIENCES IN PHYSICAL LEARNING SPACES: A LITERATURE REVIEW

R.A.A. Mikhail, A. Barbara

Politecnico di Milano (ITALY)

Abstract

The paper is a comprehensive literature review that critically examines existing evaluation tools used in interior space evaluation studies that aim to design and assess the sensory performance of physical learning spaces. With the growing recognition of the impact of sensory experiences on learning outcomes, there is a need to understand and utilize effective evaluation methodologies, metrics, and approaches. By synthesizing findings from a wide range of research articles and publications, this review provides a thorough overview of the current landscape of evaluation tools in the field. The objective is to identify the strengths, limitations, and gaps in existing approaches, with a particular focus on sensory aspects in physical learning spaces.

The review explores various evaluation methodologies, including Pre- and Post-Occupancy Evaluation (POE) tools. These methodologies encompass both qualitative and quantitative approaches, offering insights into the subjective experiences of users as well as objective performance metrics. Furthermore, the review examines multi-modal evaluation approaches that integrate multiple sensory modalities, acknowledging the holistic nature of sensory experiences in learning environments.

Within each evaluation methodology, the review delves into specific metrics and indicators used to assess sensory performance. These metrics cover a range of sensory modalities, including visual, acoustic, tactile, olfactory, and gustatory experiences. By examining these metrics, the review highlights the importance of factors such as lighting quality, noise levels, furniture ergonomics, material selection, air quality, and ambient scents in designing optimal learning environments that support users' sensory needs.

Drawing from case studies and best practices, the review identifies the successful implementation of evaluation tools and highlights lessons learned and challenges faced in assessing sensory performance. Additionally, it addresses limitations and gaps in current evaluation tools, emphasizing the need for further research and development to address emerging research areas and technological advancements.

In conclusion, this literature review provides a comprehensive overview of evaluation tools used in interior space evaluation studies for designing and assessing the sensory performance of physical learning spaces. The findings offer valuable insights to architects, designers, and researchers, enabling them to make informed decisions in creating educational environments that optimize sensory experiences, enhance learning outcomes, and promote overall well-being. The identified gaps and future research directions pave the way for the advancement of innovative evaluation tools, contributing to the field of sensory design in physical learning spaces.

Keywords: Physical Learning Spaces, Sensory Experiences, Interior Space Evaluation, Performance-based Assessments, Spatial Behavior.

1 INTRODUCTION

In the realm of interior design and architecture, the quest to craft optimal learning environments that resonate with users' sensory experiences stands as an enduring pursuit. Acknowledging that our spaces profoundly influence our well-being and educational outcomes, designers and architects have increasingly turned to pre- and post-occupancy evaluations as indispensable tools in their creative arsenal.

The pre-occupancy phase is crucial in the design process, where designers gather insights from potential users before occupying a space. As shown in Figure 1, methods like sensory design theory, surveys, questionnaires, interviews, focus groups, and virtual and augmented reality simulations help refine and optimize sensory dimensions. Post-occupancy evaluations continue to refine and optimize design, focusing on the design's ability to meet evolving user needs. Tools like occupant surveys,

interviews, focus groups, sensor technology, Augmented reality (AR), and Building Information Modeling (BIM) systems help monitor and improve sensory experiences. Integrating these evaluation tools into design practices facilitates the creation of dynamic, inclusive, and engaging learning environments and empowers designers to adapt and enhance these spaces over time. By centering their efforts on the sensory experiences of users, interior designers, and architects can craft environments that transcend the mundane, fostering better educational outcomes and an overall sense of well-being.

In this research paper, we embark on a comprehensive exploration of pre- and post-occupancy evaluations, shedding light on their significance, methodologies, and the transformative potential they hold in shaping the future of learning environments. By comprehensively examining these tools and methods, the paper contributes to the body of knowledge guiding the design and evaluation of learning environments.

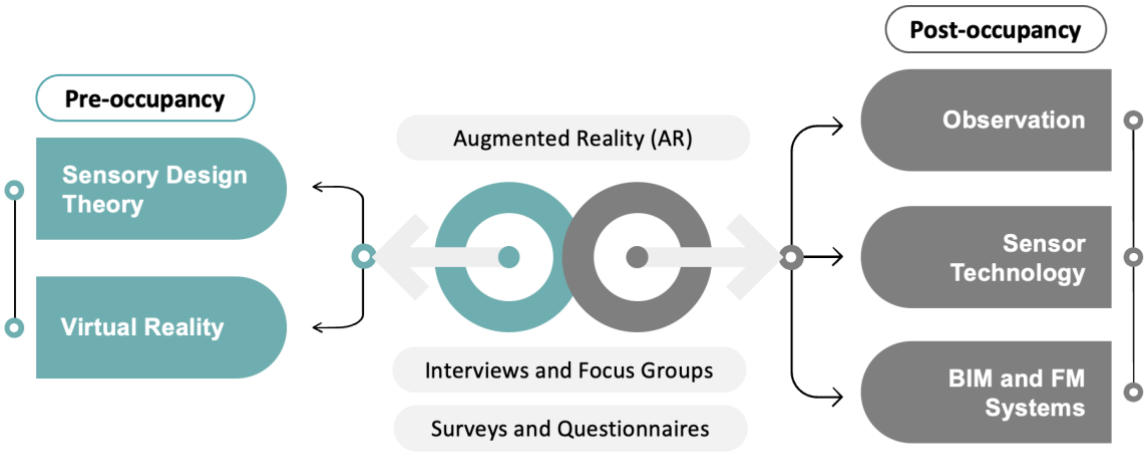

Figure 1. Pre- and post-occupancy evaluation tools, source: by the authors

2 METHODOLOGY

The research methodology utilized for the paper encompassed a systematic and comprehensive approach. An extensive literature search was conducted across various academic databases and scholarly resources to initiate the study, employing specific keywords related to sensory experiences, assessment tools, and physical learning spaces. Inclusion criteria were established to select peer-reviewed articles, books, reports, and relevant publications. Once the sources were identified, a thorough evaluation of their quality, methodology, and relevance was performed, considering factors such as research design, data collection methods, and the authors' expertise. The literature was then synthesized, categorizing and analyzing the field's findings, trends, and emerging patterns. Finally, the paper critically discussed the gaps and implications identified in the literature, offering valuable insights into assessing sensory experiences in physical learning spaces and guiding future research in this domain.

3 PRE-OCCUPANCY EVALUATION TOOLS

Pre-occupancy evaluation is crucial in assessing users' sensory experiences in physical learning spaces. It allows designers to gather feedback before the space is occupied, enabling them to make informed design decisions that enhance the overall sensory experience [1]. A study by Vo et al. highlighted the importance of pre-occupancy evaluation in assessing occupant satisfaction with various aspects of the built environment, including sensory experiences. The study conducted pre- and post-occupancy evaluation surveys in a renovated space to assess occupant satisfaction with indoor environmental quality (IEQ) metrics. The evaluation provided valuable feedback on sensory aspects that were harder to quantify, such as environmental satisfaction, comfort, health, and performance [1].

In addition to sensory experiences, pre-occupancy evaluation can also assess users' preferences and design needs. For example, a study by Sadia explores the design preferences of neurodivergent populations for quiet spaces [2]. The findings suggest that the design of quiet spaces should consider

users' diverse perspectives and sensory profiles to create neutral environments for the most sensitive users while providing optional stimulating design features for the least sensitive.

User pre-occupancy evaluation can also aid in designer-client communication in the early design stage, better understanding users' sensory preferences and requirements. This information can be used to create designs that align with users' needs and enhance their sensory experiences in the learning space [3].

3.1 Sensory Design Theory

This tool acts as a catalyst for developing design criteria based on the sensory qualities of the environment. It emphasizes manipulating sensory components such as space, shape, color, pattern, textures, lighting, and acoustics to enhance the overall user experience [4]. This theory recognizes that the sensory experiences of users in physical learning spaces can significantly impact their learning processes and outcomes. The evolution of design studio learning spaces, from physical to virtual and online, has sparked debate on designing, using, and evaluating learning environments for practice-based design disciplines. Sensory Design Theory offers a lens to understand students' experiences, allowing designers to analyze and interpret the impact of the learning environment on their experiences [5].

Sensory Design Theory has been applied in various fields, including autism classroom design, which is used to meet the sensory needs of individuals with autism [6]. It recognizes that fulfilling individuals' sensory needs is essential in designing physical learning environments that meet students' basic needs. By considering factors such as acoustic properties, color, smell, lighting, accessibility, wayfinding, compartmentation, building scale, quiet rooms, safety, gardens, and alternatives, designers can create environments conducive to learning for individuals with autism [7].

3.2 Surveys and Questionnaires

Surveys and questionnaires are valuable tools for designers to gather quantitative and qualitative data, ensuring that learning environments align with users' sensory requirements. For instance, a study by Peng et al. found that indoor physical space comfort and indoor acoustic environment comfort positively impact library visits [8]. Another study by Zeivots and Schuck used surveys and interviews to understand research students' needs and expectations in a new learning space. The data was analyzed to identify themes related to physical, virtual, and hybrid spaces, distraction-free environments, and a sense of belonging [9].

Surveys can also evaluate the impact of design interventions on users' sensory experiences. For instance, a study by Clement et al. assessed the effect of an active learning space on student success, highlighting the importance of incorporating active learning spaces in physical learning environments [10]. Additionally, surveys can be used to explore gender differences in student participation and experiences in active-learning classrooms, identifying gender gaps and understanding how men and women experience the classroom differently [11].

3.3 Interviews and Focus Groups

Interviews are a qualitative research method used in interior design to gain in-depth insights into users' sensory experiences and perceptions. They involve one-on-one conversations with participants, allowing designers to ask open-ended questions to explore subjective experiences, emotions, and preferences related to the physical learning space [12]. In addition, walk-with interviews provide a more holistic understanding of users' associations and experiences with physical and social environments. This method involves accompanying users on a walk through the learning space and asking them to talk about their sensory experiences and perceptions [13].

Focus groups, another qualitative research method, involve bringing together a small group of participants to discuss a specific topic. In the context of interior design, focus groups allow participants to share their thoughts, opinions, and experiences related to the physical learning space, generating rich discussions and insights. This method provides a broader perspective on users' sensory experiences and allows for exploring different viewpoints [12].

3.4 Virtual Reality (VR) and Augmented Reality (AR) Simulations

VR technology creates an immersive virtual environment replicating real-world sensory experiences, allowing users to navigate and interact with the virtual space. It can simulate visual, auditory, and tactile stimuli, allowing designers to evaluate the visual aesthetics of the learning space, such as furniture arrangement, color schemes, and lighting conditions [14]. VR also helps assess acoustic environments, allowing adjustments to optimize sound quality [15]. It provides a sense of presence and spatial awareness, allowing users to experience the scale and proportions of the space [16].

AR technology overlays virtual elements onto the real-world environment, enhancing the sensory experience of the physical space. It can visualize and assess object placement and ergonomics [17] and provide real-time information, enhancing users' understanding of the space [18]. AR is beneficial for individuals with special needs, such as children with autism, as it supports their non-verbal communication skills [19].

4 POST-OCCUPANCY EVALUATIONS

Post-occupancy evaluation (POE) is a process that evaluates the performance of a building after it has been occupied for a certain period [20]. It provides valuable insights into the effectiveness of the design and helps identify areas for improvement [21]. In the context of physical learning spaces, POE allows designers to understand how the environment impacts users' sensory experiences and how it can be optimized to enhance learning outcomes.

Various evaluation methods and tools can be employed to conduct a comprehensive post-occupancy evaluation of physical learning spaces. These include occupant surveys, focus groups, interviews, and physical measurements [22]. Occupant surveys, in particular, are commonly used to gather feedback on users' satisfaction, comfort, and overall experience [23]. By analyzing the data collected through these evaluation methods, designers can gain valuable insights into the strengths and weaknesses of the space and make informed decisions for future improvements.

Post-occupancy evaluations can also be applied to the design of special needs classrooms. By manipulating the physical environment to assist specific functions and elicit desired behavior, interior designers can create spaces that respond to the sensory needs of students with exceptionalities. Sensory Design Theory provides a flexible and adaptable tool for developing design criteria based on the sensory qualities of physical environments [4].

4.1 Observation

Observation is a valuable tool for designers to understand how users perceive and experience environments. Studies have shown that observation can be a post-occupancy tool to assess users' sensory experiences in physical learning spaces.

Zeivots and Schuck used observation methods to understand the needs and expectations of research students in a shared activity-based learning space, identifying physical, virtual, and hybrid spaces that were important to their learning experiences [9]. Ibrahim et al. assessed a physical informal learning environment at a public university in Malaysia, using observational and field inventory survey techniques to investigate space conditions and utilization that support informal learning activities outside formal lecture hours [24].

Observation can also be used to assess the impact of soundscape on users' sensory experiences, as discussed by Aburawis and Yorukoglu [25]. Cho and Kim explored the measurement of user emotion and experience in interaction with space, highlighting the use of observation in combination with other methods to capture and analyze user experiences in architectural spaces. Integrating observation with other data collection techniques, such as surveys or interviews, can provide a more holistic understanding of users' sensory experiences [26].

4.1.1 Types of observation

Various observation techniques are employed to comprehensively understand users' experiences within a learning space, as illustrated in Figure 2. First, behavioral observation entails systematic documentation of users' actions and behaviors, shedding light on their interactions with the environment, movement patterns, and responses to sensory stimuli [25]. Spatial observation, on the other hand, delves into the physical layout and arrangement of the learning space, assessing the impact of furniture and equipment distribution on sensory experiences [27]. Sound observation involves listening and

documenting the auditory environment, considering factors like ambient noise levels and acoustic quality [25]. Visual observation focuses on lighting, color schemes, and visual stimuli, examining users' engagement and comfort with visual elements [13]. Social observation centers on users' social interactions, communication patterns, and dynamics within the space [28], while user experience observation captures users' subjective experiences, emotions, and satisfaction levels. These diverse observation methods collectively provide valuable insights into the multifaceted nature of users' sensory experiences within the learning environment, offering opportunities for design enhancements and optimization [29].

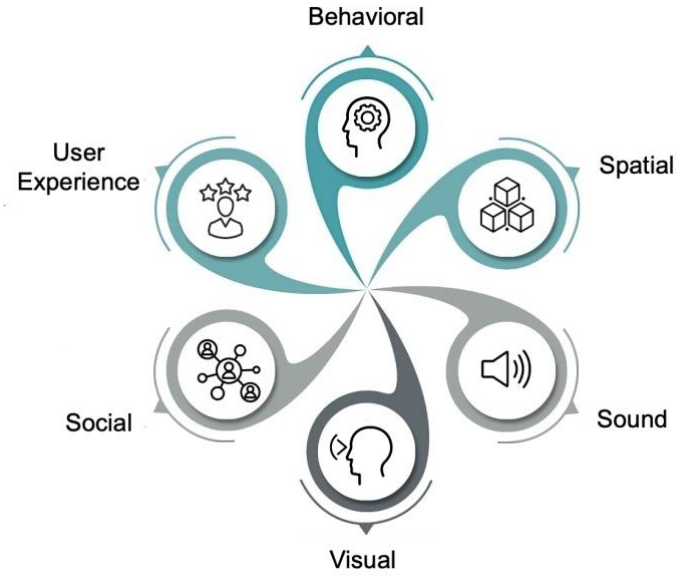

Figure 2. Observation Types, source: by the authors

4.2 Occupant Surveys and Questionnaires

The Center for the Built Environment's (CBE) Occupant Survey is an online tool that assesses occupants' satisfaction with indoor environmental quality parameters [23]. It provides a structured framework for gathering user feedback regarding their sensory experiences, comfort levels, and overall satisfaction with the learning space. The survey includes questions related to factors such as lighting, temperature, acoustics, air quality, and spatial layout. Users can provide ratings and comments on these parameters, allowing designers to gain insights into the effectiveness of the design in meeting users' sensory needs and preferences.

Surveys and questionnaires can be designed to target specific aspects of sensory experiences, such as visual aesthetics, acoustics, lighting, thermal comfort, and overall satisfaction. Using Likert scales or rating systems, users can rate their satisfaction or agreement with statements related to these sensory aspects [23].

The advantage of using surveys and questionnaires is that they allow for the collection of data from a large number of users, providing a broad perspective on the sensory experiences in the learning space. This data can be analyzed to identify patterns, trends, and areas for improvement, as well as to understand the specific sensory needs and preferences of different user groups, such as students with sensory sensitivities or disabilities [30].

Statistical analysis of the data collected from surveys and questionnaires can identify significant trends or correlations between different sensory aspects and overall satisfaction, providing valuable insights into the strengths and weaknesses of the learning space design and allowing designers to make informed decisions for future improvements or modifications [31].

4.3 Interviews and Focus Groups

Post-occupancy interviews and focus groups are two methods used to assess users' sensory experiences in a learning space. Post-occupancy interviews involve one-on-one conversations between the designer and individual users, allowing them to express their thoughts, feelings, and experiences related to the sensory aspects of the space. Designers can ask open-ended questions to explore users'

sensory perceptions, comfort levels, and any issues they may have encountered. This allows for a deeper understanding of how users interact with and experience the space, allowing for more informed design decisions [13].

Focus groups involve a group of users discussing their experiences in the learning space, allowing for group dynamics and interactions. Designers can facilitate discussions by asking questions related to sensory experiences, such as the impact of lighting, acoustics, colors, and textures on their learning experiences. This method provides a platform for users to share their thoughts, compare experiences, and generate new insights that may not have emerged in individual interviews [28].

Both methods offer advantages for assessing users' sensory experiences, providing a direct line of communication between designers and users, exploring subjective experiences, and identifying specific sensory elements contributing to positive or negative experiences [9]. However, they should be conducted sensitively and inclusively, considering cultural and contextual factors influencing users' sensory experiences and interpretations [32].

4.4 Sensor Technology

Sensor technology enables real-time data collection, allowing designers to monitor users' sensory experiences in various conditions. Temperature and humidity sensors can monitor thermal comfort levels [33]. Noise level sensors can assess acoustic quality [34]. Light sensors measure lighting intensity and quality [33]. Color sensors evaluate color temperature and rendering [35]. Pressure sensors measure comfort and support provided by seating furniture, aiding in selecting ergonomic seating options [36]. Texture sensors evaluate the tactile qualities of surfaces and materials used in the learning space [37].

Incorporating multiple sensors and using sensor fusion techniques can provide a more comprehensive understanding of users' sensory experiences. By combining data from different sensors, designers can gain insights into the interactions between different sensory modalities and how they collectively contribute to the overall user experience [38]. For example, combining data from temperature, humidity, and lighting sensors can help designers understand the relationship between thermal comfort, visual comfort, and the overall sensory experience in the learning space.

Machine learning algorithms can be employed to analyze sensor data, identifying patterns and correlations. These algorithms can identify optimal ranges for temperature, lighting, and acoustics [39]. They can also develop predictive models that anticipate users' sensory needs and adjust environmental conditions accordingly. Sensor technology is crucial in designing and implementing effective learning environments [40].

4.5 Building Information Modeling (BIM) and Facilities Management (FM) systems

Integrating Building Information Modeling (BIM) and Building Information Modeling (FM) systems is crucial for post-occupancy evaluations. BIM models comprehensively represent a building's physical attributes, such as layout, materials, and systems. By linking this information with real-time data from FM systems, designers can monitor factors like indoor air quality, temperature, lighting levels, and acoustics, identifying areas where sensory experiences may be compromised. This data can guide design interventions to improve the overall environment [41].

Integrating BIM and FM systems also allows for analyzing energy consumption in the learning space. By monitoring energy usage patterns and identifying inefficiencies, designers can make informed decisions to optimize energy performance and reduce environmental impact. This can include adjusting lighting systems, HVAC settings, and insulation to create a more comfortable and sustainable learning environment [42].

Occupant behavior is another crucial aspect that can be assessed through digital technologies. By analyzing data on occupant movement, space utilization, and interaction with elements, designers can gain insights into user engagement and sensory experiences. This information can inform design decisions related to spatial layout, furniture arrangement, and interactive features [43].

Digital technologies also enable designers to visualize and communicate findings of post-occupancy evaluations more effectively. BIM models can create virtual walkthroughs and simulations, facilitating discussions and collaborations among designers, clients, and users, leading to more informed and inclusive design solutions [44].

4.6 Augmented Reality (AR)

AR technology offers a more immersive and interactive experience for users to provide real-time feedback on their sensory experiences [45]. This allows designers to identify areas of improvement and make necessary adjustments to enhance the sensory experience [46]. AR also allows for visualization of design recommendations in the physical space, allowing users to see how these changes would look and feel in the actual space [47].

By integrating sensors into the AR system, AR technology enables collection of objective data on users' sensory experiences [48]. This data can provide valuable insights into how environmental factors impact users' sensory experiences and guide designers in optimizing the design to meet their needs and preferences.

AR facilitates collaboration and communication between designers and users, ensuring that the design meets the diverse sensory needs of users and aligns with the goals and objectives of the learning space [49]. It also enhances communication of design intent by providing a shared visual language that all stakeholders can understand and engage with.

A study by Scolere and Malinin explores the use of AR in post-occupancy evaluations to enhance user experiences in hybrid interior environments [12]. The findings suggest that AR has the potential to expand the goals of post-occupancy evaluations by teaching occupants about resources and urging them to utilize spatial features designed to enhance wellness.

5 RESULTS

The paper emphasizes the significance of assessing users' sensory experiences in physical learning spaces and provides insights into various evaluation tools and methods. These tools can be categorized into pre- and post-occupancy tools, each serving different purposes in the design process; collectively, these tools empower designers to create optimal learning environments that enhance educational outcomes and user satisfaction.

Additionally, the paper underscores a critical gap in the existing literature: the need for comprehensive research that identifies a unique set of Key Performance Indicators (KPIs) tailored explicitly to learning spaces based on sensorial metrics. This gap highlights the need to develop a comprehensive list of KPIs, which designers and businesses can employ to gauge and improve the sensory performance of learning spaces effectively. These KPIs would serve as valuable benchmarks, guiding the design and optimization of learning environments to enhance educational outcomes and user satisfaction. In summary, the research paper not only offers insights into sensory evaluation tools but also calls for creating a collective set of KPIs dedicated to sensory aspects in interior space evaluation studies.

6 CONCLUSIONS

Pre-occupancy and post-occupancy evaluations are invaluable tools for interior designers and architects striving to create optimal learning environments that cater to users' sensory experiences. Pre-occupancy evaluations enable designers to gather crucial feedback before a space is occupied, ensuring that design decisions are informed and aligned with users' needs and preferences. These evaluations encompass various methodologies, including sensory design theory, surveys, questionnaires, interviews, focus groups, and virtual and augmented reality simulations, all of which play pivotal roles in assessing and enhancing sensory experiences in physical learning spaces.

Sensory Design Theory emphasizes the manipulation of various sensory components to enhance the overall user experience, and its application spans diverse fields, including the design of spaces for individuals with autism. Surveys and questionnaires enable designers to collect quantitative and qualitative data on users' sensory preferences and experiences, shedding light on factors such as comfort, lighting, and acoustics. Interviews and focus groups provide in-depth insights into users' perceptions, emotions, and preferences, fostering a deeper understanding of sensory experiences. Virtual and augmented reality simulations offer immersive environments for evaluating sensory aspects such as visual aesthetics and sound quality.

In the post-occupancy phase, designers continue to assess and refine learning environments. Observation, occupant surveys, interviews, focus groups, sensor technology, and Building Information Modeling (BIM) systems allow for the ongoing monitoring and optimization of sensory experiences.

Augmented reality (AR) emerges as a promising tool, offering real-time user feedback and visualization of design interventions.

These evaluation tools facilitate the creation of sensory-rich learning environments and empower designers to adapt and improve spaces over time. By prioritizing users' sensory experiences, interior designers can create dynamic, inclusive, and engaging learning environments that foster better educational outcomes and overall well-being. As technology continues to advance, the integration of these tools in design practices will become increasingly vital for the continued enhancement of physical learning spaces.

Furthermore, the research paper highlights a significant gap in existing literature concerning the need for a comprehensive set of Key Performance Indicators (KPIs) specifically designed for assessing sensory aspects in learning spaces. This gap underscores the urgent need to develop a comprehensive list of KPIs tailored for use by designers and businesses to evaluate and enhance the sensory quality of learning environments effectively.

REFERENCES

[1] A. Asojo, H. Vo, and S. Bae, “The Impact of Design Interventions on Occupant Satisfaction: A Workplace Pre-and Post-Occupancy Evaluation Analysis,” *Sustainability*, vol. 13, no. 24, Dec. 2021, doi: 10.3390/SU132413571.

[2] T. Sadia, “Exploring the Design Preferences of Neurodivergent Populations for Quiet Spaces,” 2020, doi: 10.31224/OSF.IO/FKAQJ.

[3] W. Shen, X. Zhang, G. Q. Shen, and T. Fernando, “The User Pre-Occupancy Evaluation Method in designer–client communication in early design stage: A case study,” *Autom Constr*, vol. 32, pp. 112–124, 2013, doi: 10.1016/J.AUTCON.2013.01.014.

[4] T. Patel, J. Dorff, and A. Baker, “Development of special needs classroom prototypes to respond to the sensory needs of students with exceptionalities,” *Archnet-Ijar: International Journal of Architectural Research*, vol. 16, no. 2, 2022, doi: 10.1108/ARCH-07-2021-0196.

[5] L. Marshalsey and M. Sclater, “Supporting students’ self-directed experiences of studio learning in Communication Design: The co-creation of a participatory methods process model,” *Australasian Journal of Educational Technology*, vol. 34, no. 6, pp. 65–81, 2018, doi: 10.14742/AJET.4498.

[6] R. binti Ghazali, S. R. Md Sakip, I. Samsuddin, and H. Samra, “The Relationship of Sensory Design towards the Physical Learning Environment for Autism Classroom,” *Environment-Behaviour Proceedings Journal*, vol. 6, no. 18, pp. 85–90, Dec. 2021, doi: 10.21834/EBPJ.V6I18.3070.

[7] R. Ghazali, S. R. Md. Sakip, and I. Samsuddin, “Preliminary Study on Sensory Design for Autism Centre,” *Environment-Behaviour Proceedings Journal*, vol. 3, no. 8, p. 46, Jun. 2018, doi: 10.21834/E-BPJ.V3I8.1392.

[8] L. Peng, W. Wei, Y. Gong, and R. Jia, “University Library Space Renovation Based on the User Learning Experience in Two Wuhan Universities,” *Int J Environ Res Public Health*, vol. 19, no. 16, p. 10395, Aug. 2022, doi: 10.3390/IJERPH191610395.

[9] S. Zeivots and S. Schuck, “Needs and expectations of a new learning space: Research students’ perspectives,” *Australasian Journal of Educational Technology*, vol. 34, no. 6, pp. 27–40, 2018, doi: 10.14742/AJET.4516.

[10] K. A. Clement *et al.*, “Reading, writing, and running? Assessing active space in libraries,” *Performance Measurement and Metrics*, vol. 19, no. 3, pp. 166–175, Oct. 2018, doi: 10.1108/PMM-03-2018-0011/FULL/PDF.

[11] S. M. Aguillon, G. F. Siegmund, R. H. Petipas, A. G. Drake, S. Cotner, and C. J. Ballen, “Gender differences in student participation in an active-learning classroom,” *CBE Life Sci Educ*, vol. 19, no. 2, Jun. 2020, doi: 10.1187/CBE.19-03-0048/ASSET/IMAGES/LARGE/CBE-19-AR12-G003.JPEG.

[12] L. Scolere and L. Malinin, “The Building That Teaches: Exploring Augmented Reality Affordances in Academic Incubators,” *J Inter Des*, vol. 48, no. 1, 2022, doi: 10.1111/JOID.12229.

[13] A. M. Cox, “Space and embodiment in informal learning,” *High Educ (Dordr)*, vol. 75, no. 6, pp. 1077–1090, Jun. 2018, doi: 10.1007/S10734-017-0186-1.

[14] B. K. Prahanı, H. V. Saphıra, F. C. Wıbowo, Mısbah, and N. F. Sulaeman, “Trend and Visualization of Virtual Reality Augmented Reality in Physics Learning From 2002-2021,” *Journal of Turkish Science Education*, vol. 19, no. 4, pp. 1096–1118, 2022, doi: 10.36681/TUSED.2022.164.

[15] K. T. Huang, C. Ball, J. Francis, R. Ratan, J. Boumis, and J. Fordham, “Augmented versus virtual reality in education: An exploratory study examining science knowledge retention when using augmented reality/virtual reality mobile applications,” *Cyberpsychol Behav Soc Netw*, vol. 22, no. 2, pp. 105–110, Feb. 2019, doi: 10.1089/CYBER.2018.0150.

[16] S. Oberdörfer, S. Birnstiel, M. E. Latoschik, and S. Grafe, “Mutual Benefits: Interdisciplinary Education of Pre-Service Teachers and HCI Students in VR/AR Learning Environment Design,” *Front Educ (Lausanne)*, vol. 6, Jun. 2021, doi: 10.3389/FEDUC.2021.693012.

[17] O. G. Mcgrath, “AR/VR Strategy Considerations for Academic Computing Services,” 2019, doi: 10.1145/3347709.3347783.

[18] J. G. Lee, J. O. Seo, A. Abbas, and M. Choi, “End-Users’ augmented reality utilization for architectural design review,” *Applied Sciences (Switzerland)*, vol. 10, no. 15, Aug. 2020, doi: 10.3390/APP10155363.

[19] I.-J. Lee, “How to use the Advantages of AR and VR Technique to Integrate Special Visual Training Strategies in Non-Verbal Communication Skills Training for Children with Autism,” *Types of Nonverbal Communication [Working Title]*, Nov. 2020, doi: 10.5772/INTECHOPEN.94587.

[20] P. Li, T. M. Froese, and G. Brager, “Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review,” *Build Environ*, vol. 133, pp. 187–202, Apr. 2018, doi: 10.1016/J.BUILDENV.2018.02.024.

[21] C. M. Zimring and J. E. Reizenstein, “Post-Occupancy Evaluation,” *Environ Behav*, vol. 12, no. 4, pp. 429–450, 1980, doi: 10.1177/0013916580124002.

[22] B. Cleveland and K. Fisher, “The evaluation of physical learning environments: a critical review of the literature,” *Learn Environ Res*, vol. 17, no. 1, pp. 1–28, Apr. 2014, doi: 10.1007/S10984-013-9149-3.

[23] L. T. Graham, T. Parkinson, and S. Schiavon, “Lessons learned from 20 years of CBE’s occupant surveys,” *Buildings and Cities*, vol. 2, no. 1, pp. 166–184, 2021, doi: 10.5334/BC.76.

[24] N. Ibrahim, N. H. Fadzil, and M. Saruwono, “Learning Outside Classrooms on Campus Ground: A case study in Malaysia,” *Asian Journal of Behavioural Studies*, vol. 3, no. 9, p. 131, Jan. 2018, doi: 10.21834/AJBES.V3I9.68.

[25] A. A. M. Aburawis and P. N. Dokmeci Yorukoglu, “An integrated framework on soundscape perception and spatial experience by adapting post-occupancy evaluation methodology,” *Building Acoustics*, vol. 25, no. 1, pp. 3–16, Mar. 2018, doi: 10.1177/1351010X18758478.

[26] M. E. Cho and M. J. Kim, “Measurement of user emotion and experience in interaction with space,” *Journal of Asian Architecture and Building Engineering*, vol. 16, no. 1, pp. 99–106, 2017, doi: 10.3130/JAABE.16.99.

[27] A. Ozbil Torun, D. Yesiltepe, S. Erten, O. Ozer, T. Gurleyen, and E. Zunbuloglu, “Measuring the relationship between spatial configuration, diversity and user behavior: A Post Occupancy Evaluation study in Istanbul’s peripheral districts,” *Journal of Design for Resilience in Architecture and Planning*, vol. 1, no. 1, pp. 84–102, Dec. 2020, doi: 10.47818/DRARCH.2020.V1I1006.

[28] A. K. Sigurðardóttir, T. Hjartarson, and A. Snorrason, “Pedagogical Walks through Open and Sheltered Spaces: A Post-Occupancy Evaluation of an Innovative Learning Environment,” *Buildings*, vol. 11, no. 11, Nov. 2021, doi: 10.3390/BUILDINGS11110503.

[29] A. M. Cox, “Learning bodies: Sensory experience in the information commons,” *Library &Amp; Information Science Research*, vol. 41, no. 1, pp. 58–66, Jan. 2019, doi: 10.1016/J.LISR.2019.02.002.

[30] S. Elijah-Barnwell and B. Friedow, “Development and psychometric testing of a post-occupancy evaluation,” *Health Environments Research and Design Journal*, vol. 8, no. 1, pp. 115–121, Oct. 2014, doi: 10.1177/193758671400800109/ASSET/IMAGES/LARGE/10.1177_193758671400800109-FIG1.JPEG.

[31] D. Ikediashi, G. Udo, and M. Ofoegbu, “Post-occupancy evaluation of University of Uyo buildings,” *Journal of Engineering, Design and Technology*, vol. 18, no. 6, pp. 1711–1730, Oct. 2020, doi: 10.1108/JEDT-11-2019-0303/FULL/PDF.

[32] M. Coulter, D. Scanlon, A. MacPhail, W. O’Brien, S. Belton, and C. Woods, “The (mis)alignment between young people’s collective physical activity experience and physical education curriculum development in Ireland,” *Curriculum Studies in Health and Physical Education*, vol. 11, no. 3, pp. 204–221, Sep. 2020, doi: 10.1080/25742981.2020.1808493.

[33] Y. Wang, “Real-Time Collection Method of Athletes’ Abnormal Training Data Based on Machine Learning,” *Mobile Information Systems*, vol. 2021, 2021, doi: 10.1155/2021/9938605.

[34] J. Gong, J. Geng, and Z. Chen, “Real-time GIS data model and sensor web service platform for environmental data management,” *Int J Health Geogr*, vol. 14, no. 1, Jan. 2015, doi: 10.1186/1476-072X-14-2.

[35] S. Nittel, J. C. Whittier, and Q. Liang, “Real-time spatial interpolation of continuous phenomena using mobile sensor data streams,” *Proceedings of the 20th International Conference on Advances in Geographic Information Systems*, pp. 530–533, 2012, doi: 10.1145/2424321.2424407.

[36] H. Maosa, K. Ouazzane, and V. Sowinski-Mydlarz, “Real-Time Cyber Analytics Data Collection Framework,” *International Journal of Information Security and Privacy*, vol. 16, no. 1, 2022, doi: 10.4018/IJISP.311465.

[37] W. Suh, “Application of Real-time Sensor Data to Evaluation of Performance of Ad Hoc Distributed Traffic Simulation,” *Sensors and Materials*, vol. 31, no. 5, pp. 1477–1488, 2019, doi: 10.18494/SAM.2019.2265.

[38] J. Yan, Y. Huang, and L. Song, “Research on Real-Time Data Transmission and Feature Analysis Technology of Smart Tool Holder,” *J Phys Conf Ser*, vol. 2419, no. 1, 2023, doi: 10.1088/1742-6596/2419/1/012102.

[39] K. Lee and K. Gilleade, “Generic processing of real-time physiological data in the cloud,” *International Journal of Big Data Intelligence*, vol. 3, no. 4, p. 215, 2016, doi: 10.1504/IJBDI.2016.079974.

[40] M. A. Lilo, L. A. Latiff, A. B. H. Abu, Y. I. Al Mashhadany, and S. M. A. Al-Obaidi, “Design of Industrial Wireless Sensor System for Real-Time Data Collection in Steam Turbines,” *International Journal of Electronics and Electrical Engineering*, pp. 439–442, 2016, doi: 10.18178/IJEEE.4.5.439-442.

[41] I. Tripathi, T. M. Froese, and S. Mallory-Hill, “Applicability of BIM-IoT-GIS integrated digital twins for post occupancy evaluations,” *Front Built Environ*, vol. 9, Jun. 2023, doi: 10.3389/FBUIL.2023.1103743.

[42] S. Terreno, C. J. Anumba, and C. Dubler, “BIM-Based Management of Building Operations,” *Construction Research Congress 2016*, pp. 1855–1865, 2016, doi: 10.1061/9780784479827.185.

[43] J. Marley, M. C. Nobe, and C. M. Clevenger, “Utilization of Post-Occupancy Evaluations in LEED Certified K-12 Schools,” *Icsdec 2012*, pp. 862–868, 2013, doi: 10.1061/9780784412688.103.

[44] F. Kadir, M. B. Ogunleye, and A. O. Otunola, “Post Occupancy Evaluation of Students’ Satisfaction with Hostel Facilities in Federal Polytechnic Offa, Kwara State, Nigeria,” *Journal of Education, Society and Behavioural Science*, pp. 78–89, Dec. 2021, doi: 10.9734/JESBS/2021/V34I1230385.

[45] S. A. Yoon and J. Wang, “Making the Invisible Visible in Science Museums Through Augmented Reality Devices,” *TechTrends*, vol. 58, no. 1, pp. 49–55, Jan. 2014, doi: 10.1007/S11528-013-0720-7.

[46] K. H. Cheng and C. C. Tsai, “Affordances of Augmented Reality in Science Learning: Suggestions for Future Research,” *J Sci Educ Technol*, vol. 22, no. 4, pp. 449–462, Aug. 2013, doi: 10.1007/S10956-012-9405-9.

[47] V. T. Phan and S. Y. Choo, “Interior Design in Augmented Reality Environment,” *Int J Comput Appl*, vol. 5, no. 5, pp. 16–21, Aug. 2010, doi: 10.5120/912-1290.

[48] J. A. Muñoz-Cristóbal, L. P. Prieto, J. I. Asensio-Pérez, I. M. Jorrín-Abellán, A. Martínez-Monés, and Y. Dimitriadis, “GLUEPS-AR: A System for the Orchestration of Learning Situations across Spaces Using Augmented Reality,” *Lecture Notes in Computer Science*, vol. 8095 LNCS, pp. 565–568, 2013, doi: 10.1007/978-3-642-40814-4_59.

[49] B. Sanii, “Creating Augmented Reality USDZ Files to Visualize 3D Objects on Student Phones in the Classroom,” *J Chem Educ*, vol. 97, no. 1, pp. 253–257, Jan. 2020, doi: 10.1021/ACS.JCHEMED.9B00577.