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Learning Environment Design and Use

Edited by
Pamela Woolner and Paula Cardellino

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Cover image courtesy of Pamela Woolner.

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About the Editors

Pamela Woolner

Pamela Woolner, PhD, Reader in the Use and Design of Educational Space at Newcastle University, has been researching educational environments for nearly two decades. Her research includes investigations of underlying issues for the design of learning environments and examinations of the use and development of space in schools and universities. Through a range of collaborative and participatory projects, she has developed knowledge and experience of methods to support the engagement of stakeholders, including staff, students, and the wider community. Pam's published work includes an interdisciplinary edited collection, School Design Together (2015), which explores the participatory design of school spaces, and her recent collaboration with the Council of Europe Development bank (CEB), Constructing Education (2021), proposes a framework to guide collaborative activities through planning and building educational premises.

Paula Cardellino

Paula Cardellino, PhD, is a Senior Lecturer in the Faculty of Architecture at Universidad ORT Uruguay (since 2010) and an educational infrastructure specialist. She studied Architecture at Universidad de la República, Uruguay (diploma 2000), finished her MSc in Intelligent Buildings (2007) at University of Reading, UK, and received her PhD (2016) in Architecture and Urban Planning at Universidad del Bio Bio (Concepcion, Chile). She has been actively involved in the design, research, and improvement of school facilities for the last 20 years. She works with schools (including students, teachers, and non-teaching staff) and architects to align the vision of education with the teaching and learning curricula and the physical space. She has also become increasingly interested in the development of experiential analysis techniques, including mapping and photographic recording activities, that can facilitate the usability of the physical environment for learning.

Preface to "Learning Environment Design and Use"

Amid the burgeoning international interest in the built environment of education, this Special Issue examines the research, policy, and practice behind the global trends in architecture and pedagogy. It explores and discusses the multiprofessional and multidisciplinary landscape of educational spaces as they are planned, built, and used. Reflecting the diversity of the area, the papers feature empirical work using a range of methodologies, transdisciplinary work and novel theoretical framing. We are delighted to include co-authored papers whose authorship bridges academic disciplines, research and practice, or research and policy.

The over-arching aim was to capture the diversity of research related to learning environments, and we would like to acknowledge with thanks the contributions all the authors have made to this achievement.

Pamela Woolner, Paula Cardellino

Editors

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Editorial

Learning Environment Design and Use

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Reflecting a global trend of increased school construction, research into the built environment of education has multiplied over the last two decades. It seems unlikely that there are many counties where the assessment made in 2002 by education researcher, Helen Clark [1], in relation to the UK, would still hold: 'The neglect of school buildings in the past quarter of a century corresponds with a lack of educational research into their use' (Clark, 2002: 3). Some would argue, however, that the limited scope of much of the research in this area, which has been noted on various occasions through the last 20 years (e.g., Blackmore et al., 2011 [2]), remains an issue [3]. We will therefore consider what the contents, disciplinary backgrounds, and methodologies of the set of papers that comprise this Special Issue suggest about the state of this research area.

Our over-arching aim was to capture the diversity of research related to learning environments, and depending on exactly how diversity is judged, we have done that to a greater or lesser extent. It is certainly international and interdisciplinary. The authors, who are architects, educationalists, but also acknowledged learning environment researchers, are based in a range of countries across most continents, investigating learning spaces and design processes in China [4,5], Australia [6], Europe [7–9], South America [8], and the Nordic countries [10–12]. Interestingly, the contribution from Australia [2], where so much school building has occurred recently, presents a transdisciplinary review of the international literature to develop an understanding of affordance theory related to school design. This is then used to explain the challenges innovative learning environments (ILEs) can present for users and to suggest ways to enable better communication between designers and users. The authors use of theory to address, but reach beyond, specific aspects of the southern hemisphere's ILE landscape answers Benade's [3] contention that this research area is still dominated, to its detriment, by studies centered on 'descriptively documenting the performance of building fabric or attitudes of teachers' (Benade, 2021: 519). That said, we were always keen that our Special Issue would consider practice as well as theory, and this orientation is evident through the papers centered on pedagogical practices [8,11], student practices [5,7,9], and participatory design processes [8,10,12].

Looking across the educational contexts of the contributions, a range of educational sectors are evident. Educational spaces and resources in schools and universities feature catering for younger children [8,11], older children [7,10,12], and adults [4,5,9]. The papers include some that focus particularly on ILEs [6,10–12], but others that investigate other spaces for learning and teaching [4,5,7–9], which seems important when it is considered that ILEs, although much discussed, are still out-numbered by more traditional settings, even in countries where they are being embraced [13].

Turning now to the stage of the design and use timeline that the papers address and bearing in mind the criticism of Blackmore and colleagues back in 2011 [2] of the neglect of stages beyond initial planning and designing, it is good, and encouraging, to see a range. Although some papers do indeed focus on the design phase [6,8,10,12], others investigate spaces in use [4,5], particularly presenting approaches to post-occupancy evaluations, POE [9,11], and users' reflections on buildings in use [7].

Moving on to the methodologies presented in the different papers, a case study approach is the most used [7,9,11,12]. These papers merge perspectives from various theories, and overlap with empirical studies using a range of designs and methods to focus on the learner perspective represented in different age groups, genders, and cultural contexts and its relationship with the built environment [4,5,7,9,10,12]. Most of the studies evidence a focus on qualitative data [7,11,12], or establishing a qualitative understanding of design issues [6,8,10], but quantitative data are also evident [4,5,9], with several suggesting a broadly mixed methods research approach [5,7,9,10]. Within and beyond these studies, multiple methods dominate across the papers, with methods including observations, interviews, questionnaires, and focus groups, although with a preponderance of qualitative methods of analysis. Taken as a whole, the Special Issue therefore demonstrates the range of research designs, methods, and data that can be used to investigate the use of educational spaces. There is much here for developing researchers but also for premises managers and regional authorities hoping to evaluate their educational buildings and address the neglect, or narrowness, of POE that has been criticized for many years [14].

Alongside this empirical endeavor, however, all the papers appeal to more generalized knowledge, abstract understandings, or theoretical ideas. Although some contributions are more explicitly theory-driven than others, all attempt to reach conclusions beyond their immediate contexts, while still informed by these contexts. Therefore, we feel they answer Benade's concerns about research in this area, although perhaps not entirely as he had in mind [3]. He sees opportunity in, 'Focussing on space and the significance of spatiality as a theoretical project . . . [and so] . . . , elevating the concept above the purely empirical or abstract, locating spatial questions in a wider socio-political context' (Benade, 2021: 524). We are confident that these papers, through their range of methods, perspectives, and settings, do just that, underlining that 'the issues of space are not ordered or orderly and thus do not submit to simple analyses of effects or outcomes' (Benade, 2021: 524).

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Article

Affordances, Architecture and the Action Possibilities of Learning Environments: A Critical Review of the Literature and Future Directions

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Abstract: This paper critically reviews the body of literature on affordances relating to the design and inhabitation of school buildings. Focusing on the influence of learning spaces on pedagogical practices, we argue that links between affordances, architecture and the action possibilities of school-based environments have largely been overlooked and that such links hold great promise for better aligning space and pedagogy—especially amidst changing expectations of what effective teaching and learning 'looks like'. Emerging innovative learning environments (ILEs) are designed to enable a wider pedagogical repertoire than traditional classrooms. In order to transcend stereotypical understandings about how the physical environment in schools may afford teaching and learning activities, it is becoming increasingly recognised that both design and practice reconceptualisation is required for affordances of new learning environments to be effectively actualised in support of contemporary education. With a focus on the environmental perceptions of architects, educators and learners, we believe affordance theory offers a useful framework for thinking about the design and use of learning spaces. We argue that Gibson's affordance theory should be more commonly applied to help situate conversations between designers and users about how physical learning environments are conceived, perceived and actioned for effective teaching and learning.

Keywords: affordances; architecture; learning environments; learning spaces; innovative learning environments; action possibilities; affordance ecologies; forms of life

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1. Introduction

Traditionally, school buildings have been designed largely to support teacher-centred instruction. However, in Australia, New Zealand and parts of northern Europe, many new learning spaces are being designed to enable a wider range of pedagogies. These may be identified as innovative learning environments (ILEs) [1].

With an emphasis on the affordances of ILEs, Cleveland [2] (p. 93) characterised these environments as "learning spaces that provide a greater degree of spatial variation, geographic freedom and access to resources for students and teachers than traditional classrooms". Subsequently, Imms, Mahat, Byers and Murphy [3] identified ILEs as the product of innovative space designs and innovative teaching and learning practices, highlighting the importance of relations between space and behaviour. This and related discourse [4,5] reveals parallels with Gibson's [6] affordance theory—which describes the complementarity of the environment and user in perceiving a range of action possibilities—and indicates developing recognition in the literature that learning spaces and pedagogies are intrinsically linked.

Analysing the relationships between architectural spaces and pedagogical practices is salient at a time when educational objectives are being reviewed in schools around the world amidst shifting economic, political, cultural and social agendas. For example, the Organisation for Economic Co-operation and Development (OECD) has promoted innovative learning environments [1] and innovative learning systems [7] as key components of reforms needed to support learners to thrive in the 21st century. Concurrently, educators of global influence have promoted the need for change, particularly with respect to pedagogies aimed at supporting 21st century skills development. Fullan and Langworthy [8] and Fullan, Quinn and McEachen [9] advocated for 'deep learning' climates that may help generate new relationships with and between learners, their families, communities and teachers and that deepen human desire to connect with others to do good—contributing to the development of the skills needed to thrive in a modern world.

Monahan's [10] 'built pedagogy' construct has also aided recent interpretations of space–pedagogy relationships. He suggested that, throughout history, the creation of school spaces has been closely aligned with educational philosophies. He commented that:

> *"Architects, educational philosophers and teachers know well the force that spatial configurations exert on people—how they shape what actions are possible, practical, or even conceivable. Because space constrains certain actions and affords others, the design and layout of space teaches us about our proper roles and places in society"*
>
> ([10], p. 8).

The concept of 'affordances' was coined by James Gibson in the 1970s. Since then, his theory that the environment may offer 'the animal' a range of 'action possibilities' has been applied and re/interpreted by researchers from varying fields. Commonly, these have included psychology [6,11–22], technology/Human–Computer Interaction (HCI) design [23–31] and anthropology [32].

However, prior to Gibson's development of the term and theory of 'affordances', the principles behind the theory can be recognised in the approaches of school architects: principally Herman Hertzberger [33,34], who promoted school typologies that varied from traditional classroom designs to enable more diverse pedagogical practices. In 1969, Hertzberger [33] specifically discussed relationships between 'users' and 'things' when describing his approach to the architectural design of the innovative Montessori Primary School in Delft. He wrote:

> *"The aim of the architecture is then to reach the situation where everyone's identity is optimal, and because user and thing affirm each other, make each other more themselves, the problem is to find the right conditioning for each thing. It is a question of the right articulation, that things and people offer each other. Form makes itself, and that is less a question of invention than of listening well to what person and thing want to be"*
>
> ([33], p. 64).

The discourse generated by Hertzberger [33] about the relationships between the environment and users reveals synergies with Gibson's later descriptions of affordances, including his most cited definition found in *The Ecological Approach to Visual Perception* [6]:

> *"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill. The verb to afford is found in the dictionary, but the noun affordance is not. I have made it up. I mean by it something that refers to both the environment and the animal in a way that no existing term does. It implies the complementarity of the animal and the environment"*
>
> ([6], p. 127).

This paper critically reviews the body of literature on affordances as it relates to the design and pedagogical inhabitation of school buildings. In doing so, links between education, architectural design and affordance theory are explored within the context of shifting perspectives on what constitutes effective teaching and learning practices in schools.

By critiquing applications of affordance theory conducted by researchers from varying disciplines, contested ideas surrounding the theory are highlighted, including varying and sometimes contradictory interpretations of Gibson's original concept [27,29,35]. Opportunities for applying Gibson's theory to develop new insights into the relationships between space and pedagogy are also discussed, offering a foundation for future research into the action possibilities of learning spaces for school teachers and students.

To provide context, we begin by discussing recent developments in the creation of ILEs. We then explore affordance theory discourse, as interpreted through the lens' of architecture and learning environment design. Finally, we conclude with suggestions for future research at the intersections of space, pedagogy and affordance theory.

2. Innovative Learning Environments (ILEs)

Formal schooling, as we know it, was established in the nineteenth and early twentieth centuries, based on a subject-focused curriculum delivered didactically in traditional classrooms [36]. Since then, school buildings have largely been designed to reflect and enable teacher-centred instruction. However, many newer learning spaces, as may be identified as ILEs, are being designed to enable a wider range of pedagogies [37].

Intended to enable a shift from teacher-centred instruction to student-centred learning [1,38,39], the pedagogies within these new socio-spatial environments are anticipated to feature collaborative, participatory, and agentic teaching and learning approaches that may help engage students as "active participants in their own learning" [40] (p. 74) and "encourage and enable students to learn in ways that allow them to attain their personal academic and social potential" [41] (p. 65).

Physically, ILEs often exhibit an array of different spaces, learning materials and ways for people to interact with each other [40]. To illustrate the distinction between traditional classrooms and ILEs, an example is shown in Figures 1–3 (below). These depict a small secondary school building that was re-developed into an ILE at a school in Sydney, Australia. The re-development transformed a 1980s classroom block into an ILE featuring a variety of interconnected learning spaces or settings, each expected to afford different modes of teaching and learning.

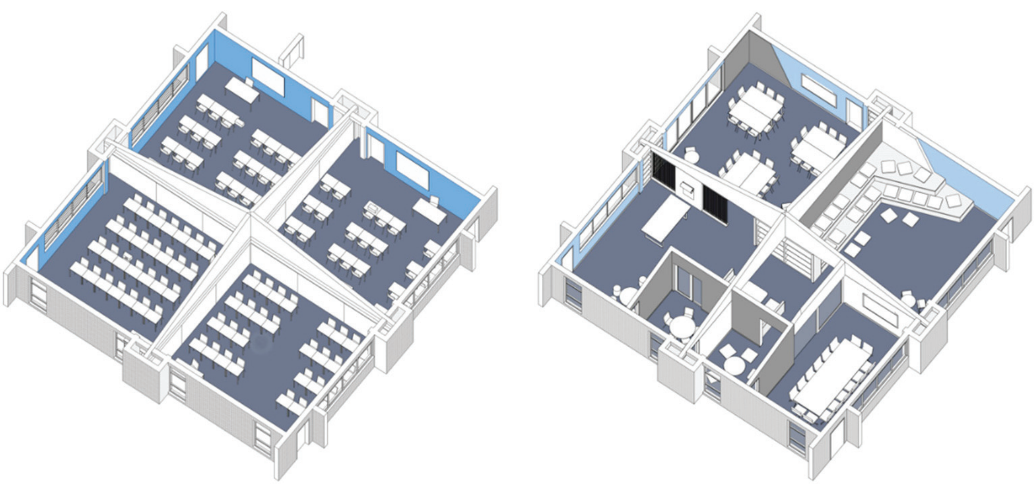

Figure 1. Before and after floor plans of a re-developed learning space, a school in Sydney, Australia (Image courtesy of Hayball architects) [42].

Figure 2. Writeable walls and table-tops enable students to brainstorm and share thinking with each-other (Image courtesy of Hayball architects).

Figure 3. A range of settings to accommodate different teaching and learning modes, and activities (Images courtesy of Hayball architects).

This new environment at the school can accommodate up the 75 students (equivalent to three classes, as opposed to the original four) and provides opportunities for the collaborative teaching of multiple classes. The building features zones for large group gatherings and explicit teaching as well as smaller areas for small group and independent work. Spaces include writeable surfaces (walls and table-tops) that enable students to work in groups and to share their thinking (see Figure 2). A range of setting types, including tiered seating areas, settings defined by high tables, booth seating areas and a boardroom-style space, provide students with options to pursue varied learning activities (see Figure 3).

As shown in this example, ILEs tend to be rich with affordances for learning. However, research suggests that these may not be well understood generally by designers or teachers [43,44]. Therefore, whilst there is widespread understanding about how traditional classrooms 'work', it appears that there is not common understandings about the pedagogical possibilities of ILEs [43].

Insights into the relationships between the environment and user may be considered central to how learning environments are perceived and productively used (inhabited). When writing about Gibson's ideas about perception in *Anthropology and/as education*, Ingold [45] (p. 31) stated that "the perceptual system of the skilled practitioner resonates with the properties of the environment". He suggested that an 'education of attention' may be undertaken as educators notice and "respond fluently to environmental variations and to the parametric invariants that underwrite them" (p. 31). As such, understandings about affordances and how they relate to school design and educational practice is needed in support of effective teaching and learning. Adopting an affordance-based approach to design is likely to help generate shared understandings between architects and users, aiding in the creation of spaces that are not only well-designed but also well-used in practice. The following critical review of the literature seeks to highlight the usefulness of affordance theory in understanding space–pedagogy relations.

3. Affordance Theory as Interpreted through the Lens' of Architecture and Learning Environment Design

Whilst affordances have often been discussed in fields such as psychology, environmental psychology and technology (e.g., Human–Computer Interaction (HCI) design), affordance theory has been less present in architectural discourse. Figure 4 (below) depicts a selected timeline of affordance theory discourse and development. It represents parallel discourses with respect to the application and development of 'affordance thinking' and highlights the varied trajectories of the theory within selected domains over past decades.

Authors from psychology/philosophy, technology/HCI design, children's outdoor environments, engineering/product design, architectural/interior design and learning environments contexts are represented. As can be deducted from the number of citations, it is clear that the discourse in psychology/philosophy and technology/HCI design is far more extensive than in other domains.

3.1. *Affordance Theory in Architectural Discourse*

Mention of affordance theory in architectural discourse is sparse yet not completely absent. With respect to the design of physical environments, Heft [46] suggested that there is a strong argument for a more affordance-based approach to design yet a lack of literature exists about the experience of users within spaces. He wrote:

> *"Designers interested in how particular environments are utilized and experienced quite reasonably might turn to the environmental psychology research literature for guidance. They are likely to be disappointed. Although there is an extensive literature addressing how individuals assess environments (or rather environmental surrogates) on rating scales, information is sorely lacking about how environments are experienced by users in the course of action"*
>
> ([46], p. 22).

Over recent decades, affordances have been discussed and explored within the fields of technology/HCI design [26,28,47], architecture [48–52], interior design [53,54] and product design [55]. However, as noted by Heft [46], affordance theory has been less present in architectural discourse than in many other design fields. This is perhaps surprising given that Gibson [6] challenged architects and designers to adopt a theory of affordances to encompass their understanding of materials into a system. Heft [56] also noted this as being curious, given that the architectural design process is based around understandings of how building elements provide function for users. Furthermore, Maier et al. [51] argued that the lack of references to affordances within architecture relates to historical separations of form and function dating back to the writings of Vitruvius, in which form (firmitas), function (utilitas) and beauty (venustas) were considered separate but competing requirements. They proposed that affordance theory could be deployed to unite the originally separate Vitruvian ideas of form and function.

Similarly, Koutamanis [50] and Sporrel, Caljouw and Withagen [57] discussed designers' competing considerations with respect to form and function. Koutamanis [50] suggested that there is a perception that architects intuitively address affordances as part of their training and practice but noted that this is not necessarily the case as they primarily perceive design through a visual and aesthetic lens, generating differences between designer's and user's perspectives and perceptions. He felt that "users can be flexible, adaptable and tolerant to design limitations despite constant irritation and frustration" [50] (p. 357). This, he suggested, allows architects to be selective in what they deem important and "insensitive to practical problems that conflict with higher, usually aesthetic norms" (p. 357). Sporrel et al. [57] (p. 136), too, noted that "designers are often driven by aesthetic motives". In discussing playground design, they concluded that designers' motives may not always align with children's perspectives on the playability of play equipment.

Koutamanis [50] argued that the adoption of an affordance perspective could help correlate designers' and users' perceptions, promoting opportunities for design innovation and reducing "the danger of falling back to stereotypical solutions and arrangements" [50] (p. 357). He concluded that "the main target of affordances in architectural design is the enrichment of the architects' perception" [50] (p. 361).

Heft [59] suggested that, if design professionals better understood the nature of affordances, including the relationship between latent affordances and the actual use of environments, they may pay more attention to the ways in which environmental cues can be designed into settings to enable use. He also noted that, whilst designers do consider function as part of their work, the descriptive language they often use is largely form-oriented. He went on to suggest that this may hinder their ability to adequately incorporate function into their designs [60].

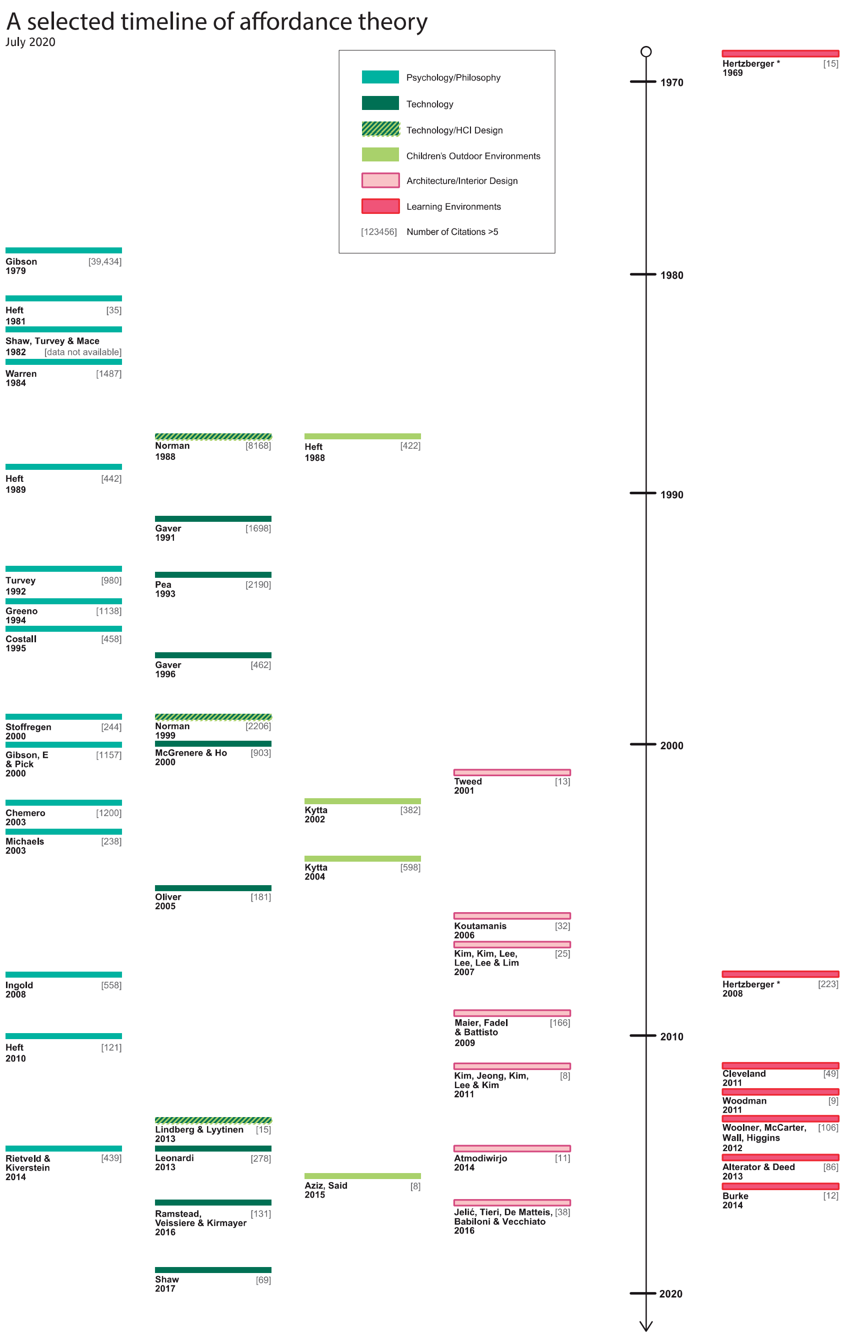

Figure 4. A selected timeline of affordance theory application and development [58].

3.2. Applications of Affordances in Architecture

A small number of researchers within the architecture and interior design disciplines have suggested various ways that affordances could be understood in relation to buildings [48,51–54]. It must be said, however, that a number of these suggestions have strayed (possibly too far) from the origins of affordance theory, with its emphasis on psychological perception.

Beek and de Wit [61] classified affordances within three dimensions of architecture: organismic personal, socioeconomic and cultural aesthetic. The organismic-personal level refers to Gibson's foundational understanding of affordances, i.e., the relationship between the environment and the user. However, the socioeconomic level refers to the interaction between humans in the realisation of common goals and the cultural-aesthetic level refers to the culturally situated aesthetic dimensions of architecture. Beek and de Wit felt that architects needed to design and connect affordances across all three levels and suggested that "architectural flaws are often the result of an emphasis on one level to the neglect of the other levels" [61] (p. 34).

Some years later, Maier et al. [51] defined both direct and indirect affordances within architecture. They suggested that artefact-user affordances (AUA) are direct affordances that reflect Gibson's original ideas about relations between the environment and the user. However, stretching Gibson's theory beyond what might be justified, they also proposed artefact–artefact affordances (AAA). These, they suggested, were indirect affordances related to the components required for buildings to function, e.g., walls afford support to roofs. The later (AAA) appears to be more akin to what Stoffregen [19] (p.15) identified as 'events', i.e., "static and dynamic properties of objects and surfaces defined without reference to behaviour". Maier, Ezhilan and Fadel [62] also applied these definitions as part of the development of an Affordance Structure Matrix (ASM), which they proposed to enable the analysis of environments based on the AUA and AAA concepts.

Similarly, Galvao and Sato [55] developed a Function–Task Interaction Method to analyse affordances in product design. Kim et al. [53] subsequently adapted this to suit interior design contexts. They proposed three key aspects to consider:

1. *Space*—including building components such as floors; ceilings; columns; walls; and door and window openings, which enable the flow of movement between spaces;
2. *Objects*—including fixtures, fittings and furniture as well as technological equipment and personal belongings, such as pens and paper; and
3. *Social activities and tasks*—including a range of diverse interactions between people (human–human interactions), including communication, socialising, discussion and presentations.

The affordance analysis framework developed by Kim et al. [53] represents perhaps the most sympathetic interpretation of Gibson's theory with respect to a built environment. Nevertheless, the range of interpretations of affordances across multiple disciplines, including within architecture, remains a source of confusion, with some researchers even questioning the validity of the concept [29].

3.3. Affordance Theory in Learning Environment Design

Within the world of architecture, affordance theory has received perhaps more attention in educational facility design [63–67] than in any other built environment sector. However, its application in 'learning environment research' has not been immune to the uncertainty identified above, and there remains limited discourse about its suitable interpretation and application.

Of the academic papers that refer to affordances in the context of learning environments, Alterator and Deed [67] referenced Greeno [14] (p. 2) to define affordances as "aspects of an environment that enable, contribute to, or constrain the kinds of interactions that subsequently occur". Taking their cue from the affordance analysis framework by Kim et al. [54], Young et al. [43] (p. 697) subsequently offered a definition that identified 'learning environment affordances' as "qualities of the environment (space, objects and people) which may be perceived to enable teaching and learning activities and behaviours".

To aid the interpretation and application of affordance theory in learning environment research and school design, we summarise some key affordance theory concepts, or ideas, below. Our intention here is to offer accessibility and clarity to some of the key concepts, as discussed in the literature, for researchers and practitioners in the domains of architecture and education.

4. Affordance Theory—A Review of Some Key Concepts

4.1. Relationships, Perception and Action Possibilities

Foundational to the concept of affordances is the relationship between the environment and the user, and the action possibilities that may result. People's perceptions are also fundamental to affordances. Gibson [6] suggested that an affordance needs to be perceived for an action possibility to occur yet affordances may exist regardless of whether they are used or not. He wrote:

> *"The affordance of something does not change as the need of the observer changes. The observer may or may not perceive or attend to the affordance, according to his needs, but the affordance, being invariant, is always there to be perceived. An affordance is not bestowed upon an object by a need of an observer and his act of perceiving it. The object offers what it does because it is the object it is"*
>
> ([6], p. 138).

However, the role of perception has been debated in the affordance literature. For example, Norman [28] proposed a definition of affordances from an HCI design perspective, which included both perceived and actual (or real) properties. He argued:

> *"... the term affordance refers to the perceived and actual properties of the thing, primarily those fundamental properties that determine just how the thing could possibly be used . . . Affordances provide strong clues to the operations of things. Plates are for pushing. Knobs are for turning. Slots are for inserting things into. Balls are for throwing or bouncing. When affordances are taken advantage of, the user knows what to do just by looking: no picture, label, or instruction needed"*
>
> ([28], p. 9).

Norman's interpretation of affordances diverges from the tenet of direct perception that was central to Gibson's view. This has been the cause of some confusion, as it implies that (a) an affordance needs to be perceived in order for it to exist and (b) that an affordance might be perceived but not be real. Recognising the ambiguity of his early definition, Norman [47] revised his definition to refer to 'perceived affordances', noting that HCI designers care "more about what actions the user perceives to be possible than what is true" [47] (p. 39). Furthermore, Noman [28,47] and others have suggested that assisting users to perceive the affordances of computer interfaces is core to how designers should approach HCI design.

An affordances matrix developed by Gaver [23] provides some insight into how these differing affordance perspectives may be understood (see Figure 5). Relating affordances and perceptual information, it defines four categories of affordances (perceptible, hidden, false or correct rejection) and identifies whether an actual (real) affordance and/or perceptual information exists. Aligning with Gibson's [6] definition, Gaver noted that affordances "exist whether the perceiver cares about them or not, whether they (are) perceived or not, and even whether there is perceptual information for them or not" [23] (p. 2). Norman's definition of 'perceived affordances' invariably includes what Gaver [23] identified as 'false affordances', i.e., perceived information that, in reality, does not afford an action possibility.

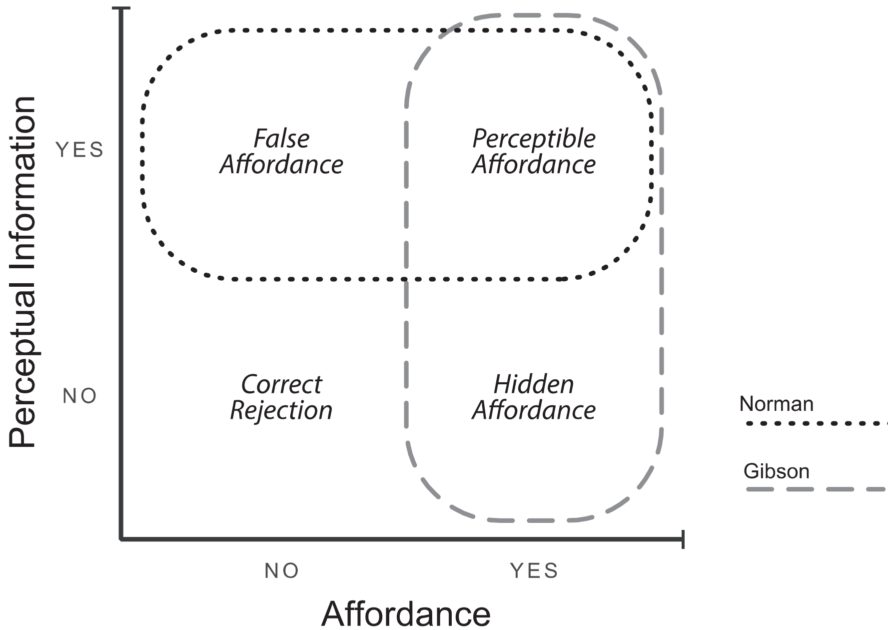

Figure 5. Gibson's and Norman's affordance perspectives, adapted from Gaver's [23] affordance matrix [42].

4.2. Abilities and Intentions towards Affordances

Individuals' abilities to perceive and subsequently use affordances is thought to relate to both their physical and mental capabilities. Warren's [22] empirical study on the affordances of stair climbing showed that an individual's ability to recognise affordances is body-scaled. He demonstrated that the ability to utilise affordances of stair climbing were related to the ratio between riser height and peoples' leg length. Translating these findings into the context of schools, it would appear obvious that designers should consider the differences in scale of smaller children, as opposed to older children or adults, when designing new learning spaces.

People's abilities may also be influenced by a range of external factors. Some prominent theorists (including Gaver [23] and Norman [47]) have suggested that observers' cultures, social settings and experiences influence their ability and intentions towards using affordances. To this end, Kyttä [68,69] added the notion that affordances may be 'shaped' by a range of environmental, cultural and policy influences, helping to determine whether affordances may become available and relevant to users.

When describing objects that offer multiple affordances, Heft [56] noted that affordances do not cause behaviours. He suggested that there is a need for intentionality on the part of the perceiver to take up action possibilities by enabling them. For example, a lit candle may offer multiple affordances, including illuminating a dark space or heating a liquid. As the context in which a user and their environment co-exists may influence what a user requires (e.g., light or heat), the intentionality around which affordance is actualised may guide precedence.

Here, we begin to recognise the interconnectedness of space and practice. On one level, affordances are dependent on physical ability and body-scale. On another level, peoples' abilities to actualise affordances are determined by their mental ability, shaped by cultures, social settings and experiences. This was recognised in the context of learning environments by Halpin [70], who noted that open-plan school designs are just as likely to "act as containers for conventional as much as for more enlightened modes of teaching and learning" (p. 251) and that the key variable for the success of such environments "is not space, but teachers' intentions and educational aims in terms of how they go about using it" (p. 251).

4.3. Learning to Perceive Affordances and Sociocultural Contexts

Researchers in the field of children's environments [56,60,68,69,71] differentiate between *potential* affordances, which may remain latent in the environment and not seen by individual users, and *actualised* affordances. The notion of actualisation was introduced by Heft [56], who suggested that, of all potential affordances, only some are perceived and utilised at any given time depending on individual's intentions. He clarified that, in order for affordances to be utilised, they must first be perceived.

Eleanor Gibson (who was married to James Gibson and also a prominent psychologist) and Pick suggested that perceptual learning can help individuals discover affordances in some instances, but "may require much exploration, patience, and time" [13] (p. 17). Other researchers have also described peoples' perceptions and understandings of affordances as being culturally specific, such as when learning how to use particular objects takes place through direct instruction or observing others [56], or when learning to actualise affordances through playful discovery [30].

Further to the discourse on learning to perceive affordances, a number of researchers have discussed the influence of socio-cultural contexts on individual's understandings of affordances [12,17,23,25,28,47,72]. Costall [12] (p. 472) posited that we "experience objects in relation to the community within which they have meaning" and later noted that understanding affordances would "not be achieved by fixation upon the object in isolation, nor the individual-object dyad" [73] (p. 92). He suggested that objects need "to be understood within a network of relations not only among different people, but also a 'constellation' of other objects drawn into a shared practice" [73] (p. 92). Similarly, Rietveld and Kiverstein [17] (p. 340) suggested that affordance perception may be considered relative to an individual's abilities "acquired through training and experience in sociocultural practices". Drawing from Wittgenstein [74] (1953), Rietveld and Kiverstein [17] introduced the concept of affordances being part of socio-cultural 'forms of life' and suggested the following:

> *"We believe it is more precise to understand abilities in the context of a form of life. In the human case, this form of life is sociocultural, hence the abilities that are acquired by participating in skilled practices are abilities to act adequately according to the norms of the practice"*
>
> ([17], p. 330).

Further advancing a holistic conceptualisation, Ingold [21] (p. 1805) described affordances in the context of "an ecology of threads and traces". He suggested that Gibson's perspective should be described as "not a network but a meshwork" (p. 1807) and positied that affordances should be considered within an 'entanglement' of factors.

Promoting similar ideas, Lindberg and Lyytinen [26] introduced the concept of 'affordance ecologies', suggesting that affordances may be comprised of three domains: infrastructure, organisation and practice. Here, the ecology metaphor invokes thinking about complexity and dynamicity [35]. Working from a technology design perspective, Lindberg and Lyytinen [26] suggested that the infrastructure domain refers to basic information technologies and associated organisational structures that provide a field of tools available for use; that the organisational domain comprises institutional arrangements that guide how technologies are understood and used; and that the practice domain refers to the practices associated with how technologies are actualised.

Additionally, in this context, Ramstead et al. [72] defined 'cultural affordances' as comprising 'natural affordances' and 'conventional affordances', where 'natural affordances' refer to direct relationships between the environment and the user, and 'conventional affordances' relate to possibilities for action influenced by expectations, norms, conventions and cooperative social practices. While the distinctions put forward by Ramstead et al. [72] may not align neatly with the more holistic conceptions of authors such as Ingold [32], and Lindberg and Lyytinen [26], they do highlight a trend in the literature acknowledging the influence of socio-cultural contexts on affordance perception.

5. Future Directions for Affordance Theory in Learning Environment Research and Practice

This review of the literature shows that affordance theory has been used by researchers from a range of fields with varying interpretations. Its application in learning environment research has not been immune to uncertainty. Although Gibson's theory has received increased attention during the past decade, there remains little discourse in learning environment research around its suitable application. Here, we suggest opportunities to better appreciate and extend affordance theory to advance the design and use (inhabitation) of learning spaces and to better align space and pedagogy. We posit that affordance theory offers a useful framework for improving the action possibilities of learning spaces, and subsequent actualisation of affordances by teachers and students, especially when the environmental perceptions of designers, educators and learners are all considered.

The key affordance theory concepts outlined above, i.e., environment-user relationships, perceptions, action possibilities, actualisation, abilities and intentions, learning and socio-cultural contexts, may all be translated into the learning environment context. Figure 6 (below) represents our interpretation of the relationships between these key concepts, as may be applied in the context of learning environments.

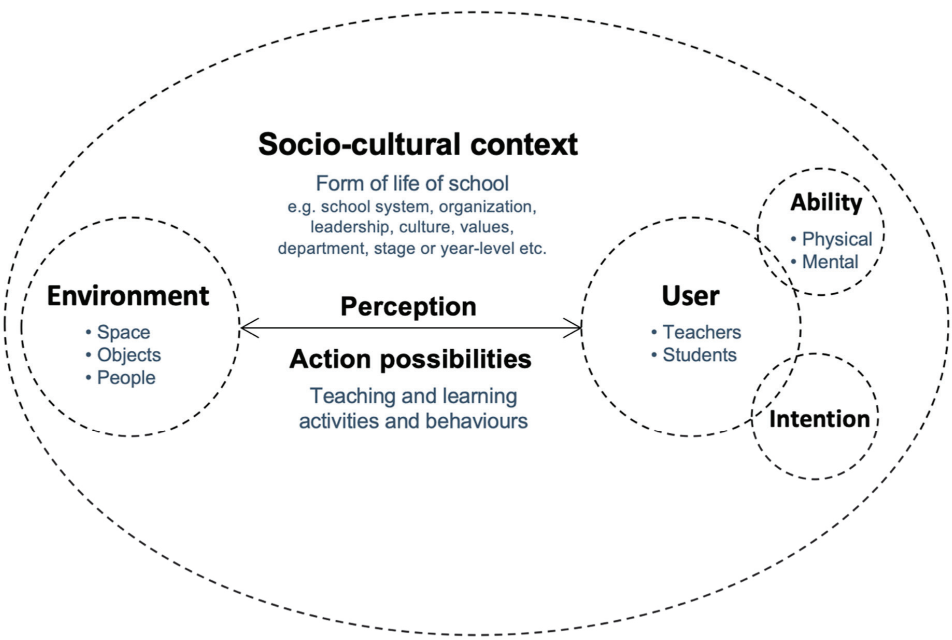

Figure 6. Learning environment affordance framework [42].

The idea of affordance ecologies [26] raises particularly interesting ways of thinking about affordances in the school context. Figure 7 (below) highlights the three interrelated domains of organisation (e.g., school organisation and culture), infrastructure (e.g., school environment–space relationship, objects and people), and practice (e.g., teacher and student practice) that Lindberg and Lyytinen [26] proposed as a framework to consider affordances within contextualised settings, again as may be applied in the context of learning environments.

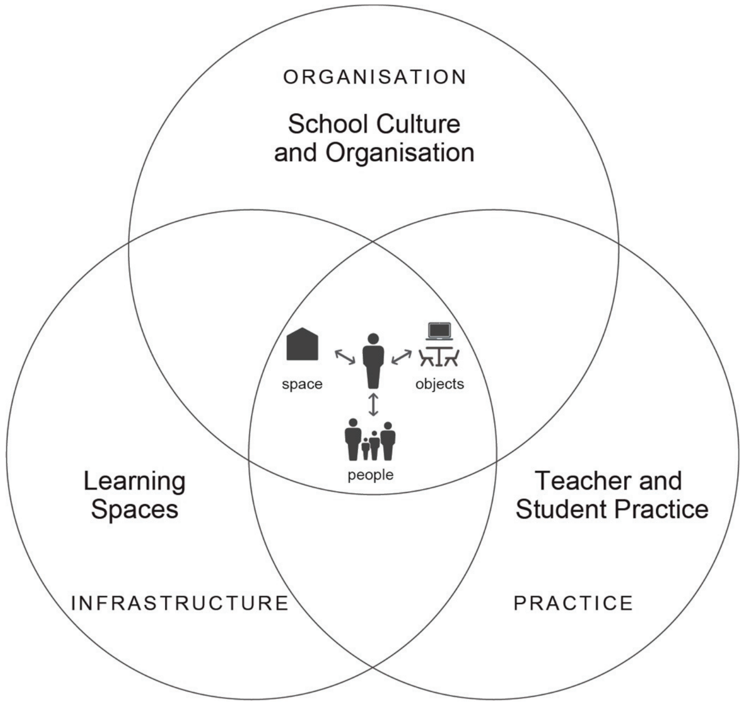

Figure 7. Learning environment affordance ecology, adapted from Lindberg and Lyytinen [25,42].

Predominantly, the discourse about affordances in learning environment research and practice has explored the relationships between the infrastructure and practice domains, focusing on direct relationships between the school environment, and teacher and student practice. Expanding this focus to attend to the organisation domain may reveal important insights into the cultural-situatedness of affordances, as influenced by the ways schools are organised and culturally led. For example, a school's organisation and culture may contribute to its 'form-of-life' [17], influencing teachers' and students' abilities to actualise affordances within school spaces. As such, individuals' abilities to actualise affordances may be influenced by the collective understandings about the potential and protocols of the spaces occupied. Re-visiting Gaver's [23] categories of affordance (see Figure 5 above), an example of how the socio-cultural context of a school may influence perceptible and hidden affordances in a learning space could be understood as outlined in Table 1 (below).

Table 1. Perceptible and hidden affordances in a learning space as influenced by socio-cultural context—the example of a pinnable wall surface.

Category of Affordance	Context	Example of a Display Wall in a Shared Learning Space	
		Affordance	Socio-Cultural Context
Perceptible Affordance	Perceptual information is available for an affordance—it can be easily seen.	A wall lining is pinnable to display student work.	There is an understanding about how the display wall will be used by teachers and students, including who has access, what types of materials may be pinned and who can remove/replace items.
Hidden Affordance	Affordance exists but is not obvious to find.	A wall lining is pinnable to display student work; however, as there are no pins made available, it is not considered a useful display surface.	There is no understanding about how the display wall could be used by teachers and students; thus, the affordance is hidden.

The example in Table 1 (above) highlights the important role of perception within an affordance landscape, where multiple potential affordances may remain latent depending on the 'form-of-life' that governs teacher and student practice within an environment.

In the context of ILEs, in which the environment may offer greater spatial variation, geographic freedom, and access to resources for students and teachers than is common in traditional classrooms [2] (p. 93), understandings about how space can support teaching and learning requires teachers and students to 'learn' to perceive new affordances [13,30,56]. Designers, too, must develop deeper insights into what action possibilities should be afforded in schools during the process of their creation. Affordance theory should 'participate' in this discourse.

Realising the potential for space to support teaching and learning activities beyond the affordances of traditional classrooms appears certain to require an evolution of individual and collective understandings about how space can enhance pedagogic practice. The benefits of an affordance lexicon that encourages users' perceptions to shift and evolve in order to pick-up more 'effective' affordances [23,26] suggests that the language used to describe and share affordances plays an important role in developing socio-cultural contexts that are supportive of the conception, perception and actualisation of affordances for teaching and learning.

With a word of warning, Norman [47] also described conventions as potential constraints on the affordances developed within communities of practice, noting that many conventions take time to be adopted and are slow to evolve. Further study of teacher and student practices in relation to affordances appears to be needed to 'shed light' on the influence of Lindberg and Lyytinen's [26] organisational domain and how this may be leveraged to enable school inhabitants to take fuller advantage of their environments—particularly in ILEs.

The design of ILEs is fundamentally based on the premise that broader pedagogical opportunities can be offered through the integration of more varied features within the environment. However, fulfilling the design intentions/aspirations of new learning spaces is clearly dependent on the ability of teachers (as leaders of learning activities) to perceive, utilise and shape the affordances of the environments they occupy—and to support students to act similarly. Learning through professional development may enhance teachers' 'individual ability' to take advantage of the affordances around them (although further studies are required to show this), while strategies and resources that can support group understandings also appear needed to enhance the 'collective ability' of teachers to actualise the affordances of new environments.

Figure 8 (below) suggests a hypothesised relationship between 'individual ability' and 'collective ability', suggesting that learning in both realms will aid higher chances of actualisation of learning environment affordances by teachers.

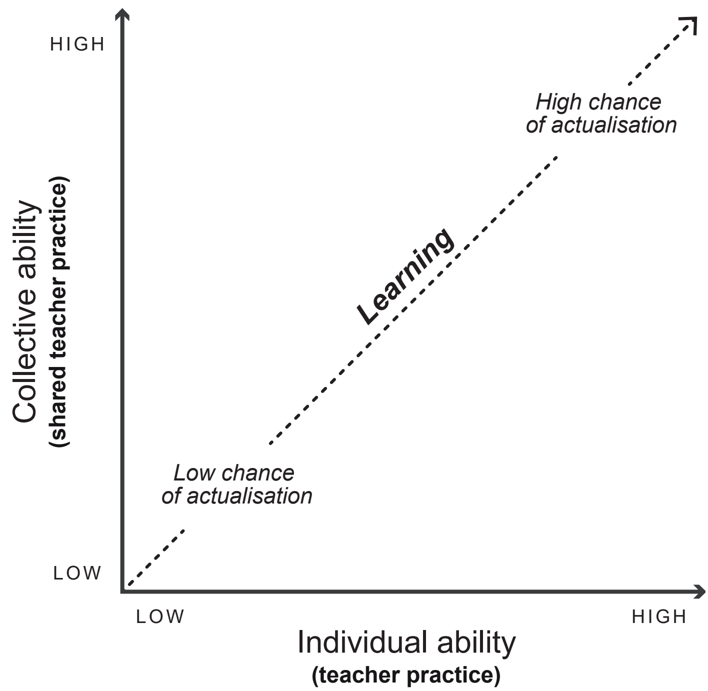

Figure 8. Affordance actualisation relative to individual and collective teacher practice [42].

We posit that paying attention to two key 'moments' in the creation of new learning environments may assist in the process of developing a shared affordance language, or lexicon:

1. The architectural design process; and
2. Initial inhabitation of new learning spaces.

First, the language chosen to discuss the design of new school facilities is likely to significantly influence the language that will persist as these facilities become inhabited by users. Labels applied to architectural drawings and the terminology used during design presentations may have a powerful influence on what affordances are perceived. The literature suggests that not paying attention to such matters can have unintended consequences. Heft [59] (p. 240) commented that "it must be disconcerting for professionals working on a design problem to learn (much less to believe) that the environments they are constructing are not perceived veridically by their clients". Similarly, Koutamanis [50] promoted the use of a functional rather than form-based language in the practice of architectural design, suggesting that using an affordance-based language can maximise the likelihood that the intent of the design carries through to how inhabitants use the environment.

Second, embedding a shared language early in the 'life' of a new learning environment may assist in consolidating understandings of the action possibilities associated with the form and features of spaces. We posit that this can help embed a common language and understandings about how school spaces may be re/configured and actualised for teaching and learning activities.

We suggest that further research into the relationships between the descriptive language used and peoples' perceptions of affordances should focus on these two key 'moments' in the creation of new school facilities. Situating such studies within the socio-cultural contexts of schools, as framed by Lindberg and Lyytinen's [26] affordance ecologies model, may assist in the development of new affordance thinking in connection to schools and the action possibilities they offer.

6. Conclusions

This paper highlighted the relevance and value of affordance theory in relation to school-based learning environments. The review of the literature identified a number of key affordance theory concepts, helping to bring clarity to Gibson's theory and subsequent re/interpretations. Suggestions for future research were also offered, towards developing new insights into the affordances of school-based learning environments, including generating understandings about how architects, educators and students perceive them and how the relationships between the environment and action possibilities can enhance both the design of new learning environments as well as the practices of the teachers and students inhabiting them.

In summary, we argue that the value of an affordance-based approach to learning environment design and use is beneficial for the following reasons:

1. From a designers' perspective, using an affordance-based lexicon may better align the perspectives of architects and users, promoting a greater likelihood that new learning spaces are designed to reflect and support teachers' and students' needs. Further to this, a shift in the use of affordance-based insights may enable more rigorous and in-depth briefing processes, helping to align the visions and expectations of educators and designers around evidence-based design features that offer the types of affordances that are genuinely useful to teachers and students in their daily practices. Further research should investigate how designers' and educators' perceive learning environment affordances and the language they use to articulate and communicate the design of schools.
2. For school leaders, teachers and students, newly built learning environments may be considered successful when pedagogical practices align with a school's educational aspirations and vision. For this to occur in the context of ILE's, teachers as individuals and as members of collective groups, need to better perceive and utilise the affordances of the environments available to them. Further investigations should explore how teacher professional learning can be used to enhance educators' spatial literacy, and their ability to individually and collectively use the action possibilities of new learning environments (i.e., spaces, objects and people) to support effective teaching and learning practices.
3. Enabling a shift to new teaching and learning practices within new spaces is likely to benefit from consideration of the three interrelated domains of organisation, infrastructure and practice [26]. Facilitating ongoing and sustained actualisation of learning environment affordances, particularly in ILEs, appears to certainly require more aligned understandings between designers (architects and interior designers), users (teachers and students) and those who influence the organisation of schools (school leaders). Further research should address how best to facilitate and strengthen these interrelated and cross-disciplinary understandings.

Therefore, as Hertzberger [33] suggested, "the aim of the architecture is . . . to reach the situation where everyone's identity is optimal" (p. 64). For this to occur, it appears that a return to relational thinking about the design and inhabitation of learning spaces is needed to accommodate the types of pedagogies that are believed to support learners to thrive in the 21st century. To this end, Gibson's affordance theory and subsequent developments offers great promise for better aligning space and pedagogy—especially amidst changing expectations of what effective teaching and learning 'looks like'.

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Article

Crossing Contexts: Applying a System for Collaborative Investigation of School Space to Inform Design Decisions in Contrasting Settings

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Abstract: This paper presents a system for participatory appraisal and idea generation by a school's users to enable interdisciplinary collaboration between educators and architects, producing school designs appropriate to the needs of the school at the time and into the future. Our uses of this system in two contrasting educational settings in England and in Uruguay are described. We show how the visual-spatial activities supported the educators to consider education in spatial terms, build a shared understanding and produce representations that could be used to convey ideas to architects and designers. Given that participation and cross-disciplinary collaboration in school design is known to be challenging, but vital, we consider the features of our approach that enabled its success and make it viable on each and every occasion of school design or redesign. Further, addressing the critiques of attempted international transfer of architectural designs, educational policies, practices and buildings, we argue that our system avoids these problems through seeking to transfer not a project but the means to enable participation in a project.

Keywords: school design; participatory design; knowledge transfer; education; architecture

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1. Introduction

In our increasingly connected world, the transfer of knowledge, understanding and ideas seems to promise effectiveness and efficiency. However, research into school design, and to differing extents within the underpinning disciplines of education and architecture, demonstrate the evident disadvantages of uncritical transfer of policies, designs, and buildings. In this introductory section, we first discuss these issues, within and across architecture and education. Following this and responding to the problems we outline of an over-emphasis on generalized approaches to particular situations, we briefly consider the challenges of participatory approaches to designing tailored solutions. This is particularly applied to any attempt to involve educational practitioners in meaningful collaboration with architects and designers to produce school spaces that support the practices and values of that specific school community, currently and into the future. In Sections 2 and 3 of the paper, we present our contribution of a system for developing shared understandings of pedagogical and spatial needs and possibilities to inform a school design process, together with the two contrasting cultural contexts in which we have used it. Finally, in discussing its performance and apparent success, we examine the aspects of our contribution that enable it to travel, as well as to withstand the challenges of participation that we identify.

1.1. Troubles with Transfer

1.1.1. Architecture

The transfer of knowledge or ideas in architecture and design is common practice [1]. The idea of precedent has been used in design, and it is seen by designers as an important part of their knowledge upon which they are able to draw in a 'designerly' way [2]. A key design characteristic of precedents is the fact that they can demonstrate different ways of doing things in design. Throughout the history of professional design such knowledge has played an important role.

At times, however transferring knowledge between nations and regions within the architectural arena has shown faults. For example, the case of the Modern Movement in architecture during 1950s and 1960s and its implementation in different contexts and cultures. One of the central objectives of this style of architecture was to meet the need for public housing during the post-war era. Following design precepts of modernist architect Le Corbusier in Europe, several public housing projects in the United States were built in a stripped-down modernist style. Several authors suggest that the insensitivity of the modernist design to the needs of residents and the incompatibility between high-rise housing solutions and social housing were to blame for the decline of these type of projects in this country. An emblematic example of this was the Pruitt-Igoe development in Missouri, United States, that since its demolition has remained as a symbol of the failure of the Modern Movement [3].

From a construction point of view, transfer of ideas has also experienced drawbacks. For example, materials and finishes developed in United States, such as the 'curtain wall', were used in the 1950s in regions of Latin-America with no real consideration for the local climate and a lack of technology to manufacture the product [4]. As one architect stated 'The region was not technologically ready to take on the curtain wall'. Eager to exhibit the building's operating mechanisms, especially the bearing structure, local architects used alternative finishes to resemble the curtain wall solution, that ended up being not fit for purpose.

Considering the architecture of education, school buildings, wherever constructed, generally mirror contemporary architecture rather than educational imaginaries, often leading to the reproduction of the industrial model of classrooms. This indicates little recognition of the significance of context for any particular school. Some notable exceptions to this are Reggio Emilio, Montessori and Dewey, where the designs are derived from particular educational philosophies [5–7].

An emergent theme is the significance of the design process [8,9]. Whyte and Cardellino [10] analyzed the role of visual representations in school design. Overall, the study tracked the political, cultural, and aesthetic judgments made around visual representations within the English Building Schools for the Future (BSF) programme (2003–2010). The conclusion highlights the significant role architects play in developing discourses and images associated with school design. There are pressures that exert an influence on the design—visual representations are used to show the desired outputs, convey precedents and exemplars, and develop the professional attitudes and approaches through professional activities. The visual representations circulate design ideas across context and enroll stakeholders into a broad set of ideals. This circulation and enrolment can be both intended and unintended, for example as elements of the user brief become quite literally interpreted in an architect's bid; or through different interpretations of the images shown as precedents and exemplars.

1.1.2. Education

In some contrast to the perspective from architecture, history and more recent experience within education demonstrate the flaws in transferring ideas between nations and cultures to influence policy or practice. Scholars who practice cross-national comparisons within education, and in social science more generally, have long engaged in nuanced and careful discussion about exactly how studies of social phenomena across cultures should be conducted and understood [11]. Alexander's immensely detailed study of primary schooling across a number of contrasting national contexts [12] is similarly careful to delineate the conclusions that should be drawn or the uses to which his research can be put:

> *Though there are undoubted cross-cultural continuities and indeed universals in educational thinking and practice, no decision or action which one observes in a particular classroom, and no educational policy, can be properly understood except by reference to the web of inherited ideas and values, habits and customs, institutions and world views which make one country, or one region, or one group, distinct from another*. ([12], p. 5)

Yet, historically policies, curricula, and sometimes whole educational systems have been transferred, typically from more economically and politically powerful nations to those they colonized [13], and this trend continues in, for example, moves towards a 'learner centred' approach to schooling in sub-Saharan Africa in the 1990s [14] and recent curriculum reform attempts in Saudi Arabia mathematics education [15]. The popularity of international education league tables, based on assessments such as the Programme for International Student Assessment (PISA), Trends in International Mathematics and Science Study (TIMSS) and Progress in International Reading Literacy Study (PIRLS), can particularly encourage simplistic comparisons between culturally very distinct systems and attempted adoptions of aspects of practice or policy, as governments seek to emulate the approaches of countries that are successful [16,17].

To illustrate how this phenomenon occurs, and the consequences of 'borrowing' [18], we turn to a recent example in the UK educational context. This is the drive to adopt a so-called 'mastery' approach to primary mathematics since this approach is seen as underpinning the success of Shanghai and Singapore in the international league tables. Clapham and Vickers are critical of how the challenges of 'implementing and internalising borrowed policy', that conflicts quite explicitly with many aspects of existing educational organisation and practice, are passed down from policy-makers, who do not appreciate the complexity, to practitioners who are not positioned to enact the 'root-and-branch reorientation of systems and practices' ([18], p. 802).

Relating to school architecture, specifically, there is similarly a suspicion of ill-judged attempted transfer, nonetheless combined with continued attempts to reproduce design ideas across the globe. Historically, a determination to build schools appropriate for the local culture and climate is discussed in Uduku's presentation of the Nigerian 'Unity Schools' [19], as well as the lingering influence of missionary provision on assumptions about the necessity of physical space and material accommodation for technology subjects.

More recently, Wood found school principals of new builds in England explaining design decisions by referring to "Australia and Scandinavia" or "Australia and America", leading him to remark that buildings, despite their physical stability, have a 'surprising capacity for travel' ([20], p. 476). He explains this tendency through noting the 'seductive' representations of buildings in plans and photographs which are easily transported, reflecting our discussion of visual representations in architecture in the previous section. Wood's central argument, however, paralleling the critique of curricular transfer, is that importation of a school design developed elsewhere for particular cultural and historical reasons will produce contradictions and mismatches. Although the desire to take systems, practices and indeed buildings that produce success in a specific context and generalize across contexts continues to be attractive, there is plenty of warning in education of the problems that ensue at various scales, from between school influences to international borrowing.

1.2. Perils of Participation

If searching for general solutions and standardised designs to apply to school construction is problematic, as the above consideration of international transfer suggests, we need then to consider how we design for local needs. An impetus for rejecting attempted generalisation in school design is also to be found in recent research of the impact of space on learning. This body of evidence shows that, once basic environmental comfort levels have been achieved, the success of a spatial design will be mainly determined by how well it accommodates the activities of the occupying school community and aligns with the values and ethos that underpin those educational practices [21–23].

The means to achieve this fit of design and use which is usually suggested within this literature is the participation of school users in the planning and designing process [9,24,25]. However, while examples exist of successful collaboration of school communities with architects and designers [26–28] there is also plentiful description and discussion of the challenges of participation, and of the failed school designs where participation in the design process does not occur or is not successful [22,29]. Here it is just necessary to briefly mention these acknowledged challenges of participation, which center on finding the time to collaborate and to plan, both towards the design and for any changes to practice that will be required to make the new design work [25,30,31]. Professional development opportunities to enable teachers to understand and use their spaces more effectively are also suggested [32,33] as is the use of relevant external expertise, in the form of facilitators to guide the participatory process [34]. An overarching issue is the apparent necessity of enacting this collaborative engagement with school space within each and every school community where change, rebuilding or redesigning is attempted [28] (pp. 398–399), with the considerable demands on people's time and energy that this brings, as well as the financial implications of this commitment.

2. Materials and Methods: Our System

Our system was developed to support a school community to review their school premises, considering the suitability of the building for their current practices and also thinking about new possibilities for the design and use of their space. Fundamental to the approach is the understanding, not surprising to architects and now quite established within research of educational space, that the design and use of the space are inevitably interlinked (see e.g., [35,36]). Thus, the totality of the learning environment experienced by students is produced by the mix of material, social and organizational elements that the school provides; central to the success of this environment is the alignment between these different aspects [23,25].

The system we present and discuss here is intended to support a review involving many different people, which could include students and staff with a range of teaching, leadership, and other roles, so needs to accommodate a diverse range of background interests and knowledge to ensure that many views are fully represented and can contribute to proposed solutions. It is based on a series of activities where participants work with visual-spatial materials, producing items that can then be used to mediate conversations about specific aspects of their existing premises and provoke discussions about physical spaces and educational activities. The use of visual materials and products that are literally on the table for all participants to see, discuss and contribute to, facilitates the development of a collective understanding, which is important in the context of developing a single school environment. These activities draw on understandings and practices that have developed in social science where approaches broadly defined as 'visual methods' have been found to support engagement with participants, provide them with more opportunities to influence a process and enable them to convey ideas that might be difficult to articulate, as well as bringing to light different information from investigations relying on words alone [37–39]. Two of the three activities have been used as part of consultations with school communities about their educational environment [29,40,41] and all three activities share features with approaches that have been proposed and developed to the exploration of users' experiences of school space [24,42].

In planning the progression through the activities, we accepted that users of a space will first want to consider their existing environment, but we wanted to move them beyond the salience of the current space and its use to consider alternatives. Therefore, we began with an activity to share users' experiences of their existing school space, then we used an activity with photographs of learning spaces to open discussion about the relationship between learning and space, before moving onto an activity focused on designing solutions to problems identified within the existing premises.

First, in mapping a day, each participant draws a line on a plan of the school to represent their movements on a typical day. Comments are added and colored stickers are used to indicate 'places that work' and 'places that do not work'. The aim is not only to gain an impression of the participants' movements and use of the school, although this can be interesting in itself (see [40] p. 13 for a notable contrast between movements of teacher and a student in a UK secondary school). The annotations, and resulting discussion between participants, also illuminate the intertwining of spatial, organizational, and cultural factors [41] that makes understanding a community's use of their space so challenging. Next, participants work in groups to 'diamond rank' photographs of learning environments, according to whether they represented a 'good place for learning' or a 'poor place for learning' (see Figure 1). The intention with this activity is to enable participants to connect their beliefs and values about education with spatial possibilities, addressing Halpin's critical comment that, 'thinking anew about spaces for learning cannot be sensibly commenced in the absence of deliberations about purpose' ([43], p. 251).

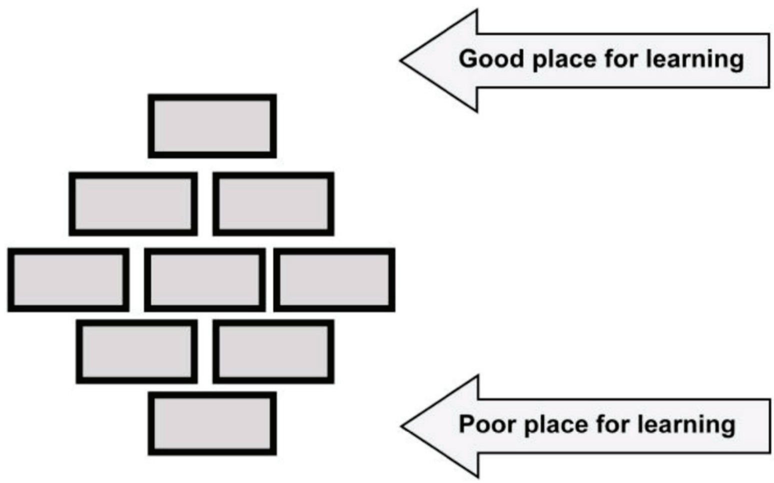

Figure 1. Instructions for 'Diamond Ranking' nine images according to opinions about suitability for learning.

The final activity calls for groups to produce ideas for development of the school premises, through a structured activity where they first choose two or three statements from a bank of suggestions answering the question 'What should be done here?' Using a variety of images and a plan of the school, they work together to create collages of needs and proposed solutions (see Figure 2). This structured approach to participatory design, making use of some provided materials and clear objectives, has been noted as succeeding with both adults and children through the provision of 'time and permission to pause and think' ([44], p. 8) with opportunities for movement, all underpinned by a focus to keep participants centered.

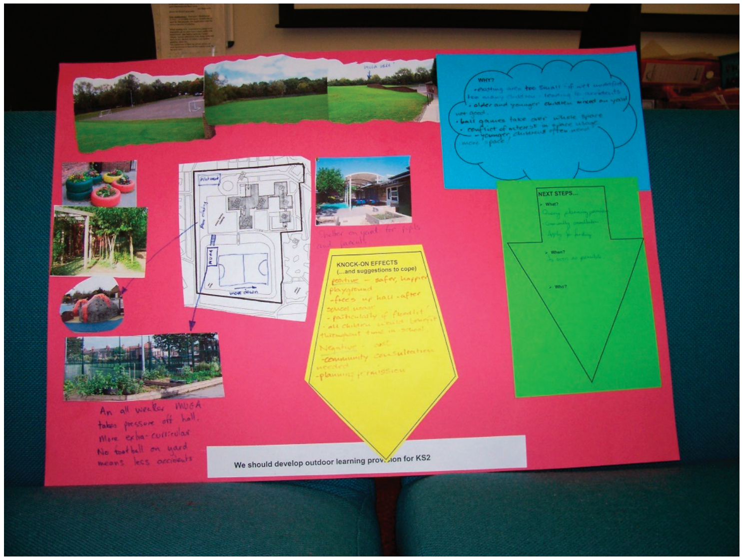

Figure 2. Collage presenting a priority for change and design suggestions from staff.

3. Results: Use of the System within Two Contrasting Contexts

3.1. In England

England has an educational system with power and decision-making distributed through levels of management from the individual school to the national government. During much of the 20th century, lots of control rested at the local (i.e., city or county) council level, with counties organizing and funding education in schools in a geographical area through local authorities (LAs). However, a series of education policy reforms in the late 20th and early 21st centuries, moved funding and control away from LAs [45]. This has resulted in a much more mixed provision of schools inside and outside the LA, 'multi academy trusts' chains of schools, 'free schools' answering directly to the national department for education, alongside the continued existence of faith schools with their own local structures. Although the extent to which the claimed intention of increasing autonomy for individual schools has been achieved is arguable, head teachers (principals) have become more aware of possibilities for school-level development.

This is the background to the invitation received in 2013 by the Centre for Learning and Teaching (CfLaT) team at Newcastle University from a newly appointed head teacher in a local primary school. The school was a LA school, and it was to this body that the head would need to appeal for funding for any refurbishment, but the head teacher was motivated by his own observations of the use of the school and funded a half-day staff workshop from the school's budget.

Built originally as a primary school (for children aged between 4 and 11), this was still the school's purpose, although there had been some additions and development of nursery space to accommodate 3–4-year-old children. At this time there were 411 children on roll in Reception to Year 6, mainly organized into two classes of approximately 30 children per year group, and the nursery facility. The premises date from the early 1980s, which was the beginning of a downturn in school building in the UK [46]. The school was built to serve a new community between former mining villages as part of a 'new town' and opened in 1980 with a small roll that grew rapidly as the local housing was built. Although quite traditional in external appearance, with brick walls and tiled, pitched roof, internally there were four semi-open plan learning spaces, with the few internal walls non-loadbearing. This original design had however, by 2013, been reconfigured to provide a mix of mainly enclosed classroom of differing sizes with some spaces used for class learning and circulation space.

During an initial half-day workshop, we facilitated the collaborative activities with school staff (including teachers, a school governor, teaching assistants, deputy and head, administration, and support staff). The 33 participants each produced an individual map (see Figure 3 for an example). Written comments showed appreciation of recent improvements in specific rooms and with newly refurbished toilets. The teaching spaces that were liked tended to be the self-contained classrooms, as opposed to the teaching spaces in open areas, which provoked more criticism. Teachers complained that these spaces were "noisy" if you were teaching or learning here but also worried about disturbing classes if they were passing through. Yet staff were also critical of the limited space in some of the enclosed classrooms. Mixed feelings were expressed about the various outdoor spaces. These ranged from inevitable issues with the outdoors ("mud"; "children hide in trees") through to assertions that some of these spaces could be much better used and should be developed. Specifically, some teachers expressed a desire for direct access to the outdoors from their classrooms, enabling more flexibility and spontaneity in how they use outdoor space for learning.

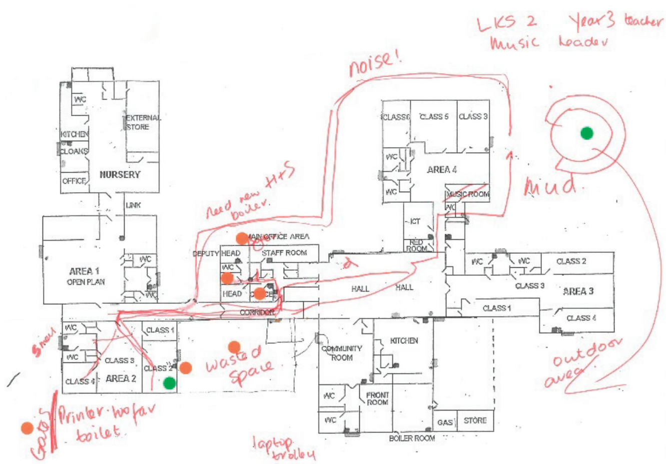

Figure 3. An example of a staff member's mapping of a typical day.

The second activity of diamond ranking by groups of staff, who, within their groups, had similar roles in the school, produced eight diamonds. These were then displayed for discussion between groups about what constitutes or contributes to a good educational space (see Figure 4). Ideas to emerge from the diamonds included the positive connotations for most staff of outdoor space for learning, although there was significant difference of opinion about what constitutes appropriate outdoor learning space. The indoor learning spaces were placed in very different positions by different groups, partly due to differences in the age of children they worked with. Wherever particular images were ranked, however, the accompanying comments suggested some shared values around providing appropriate spaces for different styles of teaching and to satisfy differing preferences of learners and teachers. Space to move, flexibility and having resources available to learners were also valued elements. The collages were very varied across the groups and were used by group members to initiate discussions between groups. Some consistent priorities emerged, however: reorganizing the location of classes of particular aged children, together with ideas for improving the entrance and outdoor spaces.

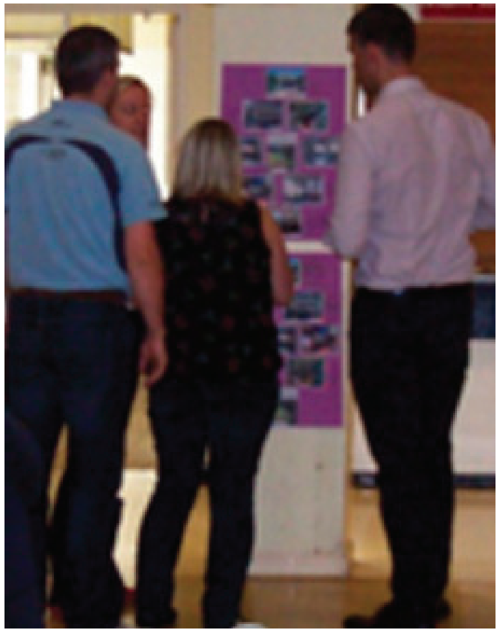

Figure 4. Staff discuss the diamonds the groups have produced.

We produced a report to the school, detailing what we had discovered about the use of the building and the views of the staff, as well as summarizing the ideas for change that had been generated. We went on to research the school use of space, working collaboratively with some of the teachers and including the student perspective. An outcome of these two phases of engagement was to produce a report to support the school's application to the LA for funding. The building work that was eventually completed in 2017 was based on a re-worked plan that accommodated some, but not all, of the design suggestions made.

Alongside these bigger changes in the school infrastructure, however, there were changes in how staff thought about school space. In the three and a half years that elapsed between the initial workshop and the building work, staff engagement with the environment was sustained and, in many cases, developed. In a visit during this period, we noticed that some organizational and spatial adjustments had been made within the existing physical environment. These included changes in the management of student arrival and departure, and rearrangement of furniture by teachers in two small, enclosed classrooms and within the unenclosed learning space to create usable 'carpet spaces'. Furthermore, the original LA architect's plan of providing a layout of enclosed classrooms, favored by teachers of the older children, quickly came to be seen by the head teacher and other staff as inappropriate for the younger children. The design for this block was redrawn to provide a mix of open and enclosed space.

It was this design, revised through discussions with the principal and teachers, that was built, and has been well-received by the staff. The enclosed classroom model was followed for the area for the slightly older students but included some adjustments to support the teacher communication and collaboration that was a benefit of the original school design. Staff reported that they were able to make suggestions through the planning and construction stages, such as aligning doors across a corridor to facilitate communication and circulation.

3.2. In Uruguay

Uruguay's education system can be described as traditional and centralized. Decisions are taken at a central level by the National Public Education Administration (ANEP), the organization responsible for formulating and implementing policies in school education. Curricula for all schools are defined at this central level and there is little scope for public or private schools to exercise autonomy. However, private schools have certain freedom on decisions about their physical learning environments, though following the 'private schools building regulations' [47].

In this context, in 2018 the headteacher of a local private school in Uruguay approached the research team at the Faculty of Architecture, University ORT for advice on the design of a new building for the school. The plan was to build a new preschool to replace the existing one located in the original building from 1950 situated in a mid-to high-income area in the city of Montevideo. At this time the school had 900 students on roll between the ages of 3 and 18 years old, including preschool, primary and secondary levels mainly organized into three classes of approximately 30 children per year group. The new preschool would be designed to host up to 300 students aged 3 to 5 years old.

The intention with the design of the new preschool was, according to the school board's vision, to create an open and inspiring environment for preschool children making the most flexible use of the spaces. Directly linked to the educational vision to introduce progressive pedagogical ideas, the idea was to push for pedagogical change through the design of an innovative learning environment.

Firstly, a meeting was held with the preschool coordinator, teachers, and teacher assistants where the pedagogical change proposal for the preschool was presented as well as the need to support it with a new building that would sustain the change. The participants were very positive and interested in the change proposal. Aspects related to the daily use of spaces, positive and negative aspects of the existing building and possibilities for the new space were discussed. During the meeting, photos and videos were shown that served to exemplify different types of spaces, in addition to encouraging educators to think outside the box.

Secondly, a walkthrough of the existing building was carried out with observations of the use of the different spaces in the existing building by teachers and students and informal talks with several teachers and teacher assistants. These were documented through photos taken during the visit. During this visit issues with the length and dullness of corridors, the layout of the classroom spaces and the location and level of noise in the dining area were discussed.

Finally, a half day workshop to facilitate collaborative activities was held with teachers, educational specialists, and teacher assistants. The 18 participants each produced a map of their movements on a typical day (see Figure 5 for an example). Written comments showed appreciation for the outdoor area and the psychomotricity room. However, access to the outdoor area was highlighted as problematic as it overlaps with the entrance to the toilets. The distances between classrooms and the gym area were considered too long and interfering with the school entrance. The dining areas was marked as noisy and difficult to access. In groups, educators worked in diamond ranking nine photographs of learning spaces that were then displayed amongst the rest of the groups for discussion (Figure 6). These photographs showed examples of spaces for younger aged children reflecting (or challenging) local norms and cultures. During this stage, six diamond rankings were produced. The teaching spaces that were most liked tended to be the teaching spaces in open areas with nooks and niches and with movable furniture, while the enclosed classroom photo was ranked last. The same groups had to then work with two propositions on what to do in the new space to create a collage of the needs and the solutions, making sure that the 'Why', 'Effect' and 'Next Steps' were answered. Six collages were produced during the last activity (Figure 7). The propositions that had more collages stated the need to open the space and do more group teaching. Though the comments in the collages also indicate the need for teacher training and work in collaboration.

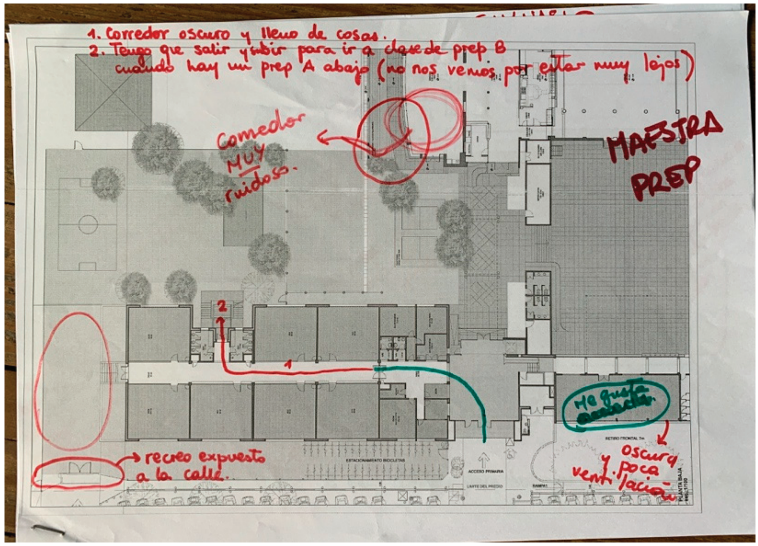

Figure 5. An example of a Uruguayan staff member's mapping of a typical day.

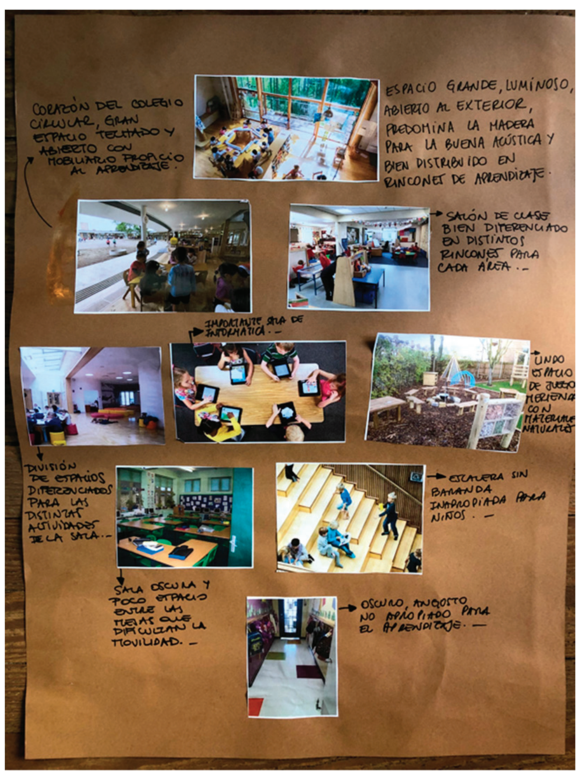

Figure 6. An example of the result of a diamond ranking exercise.

Figure 7. An example of a resulting collage by one of the groups.

A report with the findings was prepared for the school detailing what was found about the use of the existing building and the views of the teachers and staff considering its direct influence on the design of the new preschool space. The main findings show teachers' desire to break with the concept of "enclosed classroom" as well as an appreciation of the difficulties it entails, though seen as a positive change.

The original architects' plan with a layout of enclosed classrooms was redrawn in line with the report findings as it was seen by head teacher and school board as not appropriate. The new design for the preschool provided open and flexible spaces. During the construction process staff were offered various professional learning opportunities during after-school hours, including sessions with outside specialized speakers in line with the requests in the written comments during the workshop. Online learning resources were also made available. The coordinator also worked with the staff and experts to explore how to successfully use the space across a range of lessons.

4. Discussion and Conclusions

As evidenced above, the system for collaboration enabled, in both schools, the productive involvement of the school staffs in planning change to their educational spaces. They were able to engage at the time, building shared ideas and were able to convey these to the architects so that plans were adjusted. The participatory design process also led, in these two cases, to sustained collaboration between architects and educationalists through the construction stage and into use of the new spaces. There is also some suggestion, in these cases, of the educational staff, through their involvement in the design projects, developing their 'environmental competence' [33]. Given the considerable problems, outlined above, of transfer in education across cultures and nations, the fact that an approach developed in the

UK context, and used initially in a primary school in northeast England, was also successful in a nursery setting in Uruguay is significant. Therefore, we will first consider the reasons for the success of our system in facilitating collaboration in the design of educational space in these two contexts before proposing some suggestions for how it was able to overcome the challenges of travel between them.

A fundamental reason why attempts at widening participation in planning the design and use of school space falter is the time such engagement and interactions require. Our system is quite quickly worked through since the activities can be completed comprehensively in a single session of 2–3 h. Additional time is required around the session to prepare the materials, informed by understanding of the context, and then to understand the resulting artefacts, in light of the conversations and discussions witnessed on the day. These associated actions, however, do not require more time from the professional educators and architects who are central to the collaboration, as long as the facilitator(s) of the workshop is independent of these groups. Such independence would be preferable, we argue, and this requirement for an external facilitator is indeed recommended for successful participatory design [34].

A strength of our system is that particular expertise, in either architecture and design or in education, is not required of the facilitator since the materials and activities convey some ideas and, more importantly, enable the professionals to draw on their own expertise. The mapping supports the educationalists to see their setting in spatial terms, while the images for the diamond rank and collages provide new ideas for furniture, layout and use of space. Thus, the process enabled the school staff to think visio-spatially about education, both in terms of their own practices and regarding possibilities for change. Meanwhile, the visual results of the workshops helped with conveying and sharing ideas, within the schools and beyond. In Uruguay, the architects appreciated the production of something they could translate into space, while, in England, it was observed that the teachers had more confidence to engage with the initial plans drawn up by the LA architect. The visual elements can be seen as a common language that can ease communication between designer and educator. It also helps with the travel of ideas since the different languages (Spanish and English in this cases) do not add to the difficulty of knowledge transfer, for example misinterpretations of educational or design ideas.

It appears that professionals are enabled to connect their knowledge across the disciplinary divide between education and architecture. The teachers feel that their voices have been heard, and therefore can have more certainty on what to expect as the end result. Their participation also contributes to the professional development of teachers that is advised to support their use of new, innovative spaces [32] and in order, more generally, to develop their 'environmental competence' [33] so that 'teachers to turn to material objects in full knowledge of the pedagogic possibilities they open up' ([35], p. 590).

This combination of activities that stimulate and activate existing knowledge, rather than requiring lots of prior learning, which can be facilitated by a non-expert and that are not excessively time-consuming, ensures that our system is manageable on each and every occasion that a school space is proving difficult to use or a rebuilding opportunity occurs. This practical utility is very valuable, given the need for interdisciplinary collaboration to occur each time [28] if the resulting design and use of the space is to be successful [26], avoiding mismatches between design intentions and actual use [22,25] that are expensive [48] as well as frustrating.

Some of the observations about the reasons for the success of our system are suggestive of why it was also able to travel, supporting collaborations over the design of educational space in two very different contexts. Essentially, its success is based on the fact that it is not educational or architectural ideas, policies or practices, that are being transferred, but instead the means for generating local ideas based on local knowledge. Rather than trying to transfer a project, we transferred the tool to enable participation in the project. This is a powerful approach, addressing the concerns discussed above about uncritical transfer of practices, curricula, and school buildings between differing contexts [16–18,20]. More generally, it also takes seriously the challenge outlined by Thomson and Hall for education research of managing the general and the specific, given that, 'There are things about schools which are the same, just as there are things about all of them that are distinctive' ([49], p. 7, italics in the original).

Finally, it is worth noting that in supporting our educator participants to produce their own visual representations of educational activities occurring in re-imagined physical spaces with chosen material resources, which can be shared and discussed, we are countering the tendency so critiqued by Wood [20] for school leaders to seize on 'seductive' visual representations of settings for educational cultures and activities quite at odds with their own. The images that are provided to the participants can be chosen so that they are appropriate to their social, cultural and pedagogical assumptions, but while also ensuring there is a range for them to choose from so that they have representations of new and different settings and materials to consider. Thus, ideas for the design and use of schools, visually represented, will only travel internationally through being discussed and reinterpreted, by local architects and educators, rather than imposed on systems where they do not fit.

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buildings

Article

Pedagogical Walks through Open and Sheltered Spaces: A Post-Occupancy Evaluation of an Innovative Learning Environment

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Abstract: This paper describes a post-occupancy evaluation of a school building in Iceland that combines open and confined spaces, designed for manifold pedagogical approaches and multiple uses. The school was built for students at the primary and lower secondary school levels and serves a neighborhood still under construction in a coastal town about 40 km from Iceland's capital area. The building will be an essential part of a larger complex, constituting the heart of its neighborhood, including a compulsory school tied into a preschool, a public library, sports facilities, and a site for local events. Our aim was to map how plans for this innovative learning environment have succeeded, as viewed by practitioners and students. Several research interviews with leaders of the building project and a method called pedagogical walk-throughs were used to collect data. Four focus groups of teachers, teaching assistants, and students were asked to review selected sections of the building. The results serve to show the strengths and weaknesses of the design, as perceived by participants, as well as commend the methodology applied. They provide insights and considerations of value for anyone involved in the design and application of educational spaces.

Keywords: school architecture; school design; school building; innovative learning environment; open plan school; post-occupancy evaluation; pedagogical walk-through

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1. Introduction

Building a new compulsory school to provide education of quality—by current standards and for an unforeseen future—is an investment involving risks at many different levels for any community, large or small. A growing research body on the physical learning environment as a factor of schooling has yet to deliver extensive and profound evidence that would help to explain to what extent and in which ways architectural design affects student learning and teaching patterns. A recent review of the literature [1], however, leads to the conclusion that the physical environment does indeed affect processes of teaching and learning and could be assumed to have an impact, for better or worse, on student outcomes [2,3]. To invest in innovative school buildings and try out new design forms, registering and analyzing their effects on teaching and learning, can be viewed as an opportunity to enhance learning processes and improve outcomes for students.

Recent advances in the design of school buildings in Iceland are well documented [4–6] and reflect paradigm changes from traditional 19th- and 20th-century design forms, based on conventional classrooms along corridors, towards open and flexible learning spaces designed for teamwork and more student-centered approaches. This development has not always been clear-cut nor free of difficulties, but most schools or school extensions built in this century have been designed to accommodate open and flexible approaches in school practices [6]. A similar trend has been apparent in other parts of the world, including Sweden [7], Finland [8], Australia [9], and many other countries [10], often involving considerable challenges for school leaders, teachers, and students [11]. Stapaskoli, a compulsory school designed by ARKÍS and inaugurated in 2020, is the subject of this study and a current case reflecting this national and international development. Our aim was to map how political, pedagogical, and architectural intentions behind its innovative facilities are succeeding, as viewed by different stakeholders—in particular, practitioners and students.

The following three research questions guided our investigation:

- What were the political, pedagogical, and architectural intentions guiding the design of the building?
- How do students and staff view the strengths and weaknesses of the building as an environment for teaching and learning?
- What do different stakeholders see as innovative features of significance in the new building?

The review of Duthilleul and associates [1]), as well as four themes developed by French and associates [12] to describe the conditions for a successful adaption of school practices into a new and innovative learning environment are used as points of reference in the review of our findings.

Academic interest in successful educational improvements has gone through several phases over time, leading to the current focus on a systemic approach, and emphasizing the complexity of educational systems and the significance of coherence and interdependency among their different components [13,14]. The physical learning environment is one such component that has to be in alignment with other components for educational efforts to succeed [12,15–17], which helps to underline how urgent it is to study new models of design and how they might support intended pedagogical approaches.

What counts as an innovative learning space is debatable and can be viewed from many perspectives, a physical point of view, of course, but also pedagogical, psychosocial, or perhaps technical angle [18]. We tend to classify as innovative any deviation from the traditional grammar of schooling, with classrooms of similar sizes lined up along corridors [7], and regard such design forms as open and flexible learning spaces, designed for collaboration and aiming to meet students with varied needs in optimal ways (see e.g., [5]). Bradbeer and associates [18] concluded, after reviewing twelve studies, that an innovative learning space would always be laid out to incorporate innovative pedagogies that aim to induce better learning outcomes and more competent students.

An interesting aspect to consider is where ideas about innovations come from; another is what the process from ideas to well-established practices looks like. Duthilleul and associates [1] found broad that collaboration between different stakeholders is essential at all phases of the design process. Collaboration takes place at the initial planning phase, before staff and students move in, as well as in the first months of practice, as students and staff adapt pedagogical work in their new environment. Collaborative post-occupancy evaluation, finally, serves to support such adjustments, evaluate how spaces suit educational needs, and assess whether facilities are used as intended. Deed and Blake [19] suggest a model that explains how teachers adapt their practice toward a flexible learning environment, starting with an awareness of the possibilities for change, then experiments, and finally, coherence. The last step includes the integration of spatial affordances and pedagogy, which calls for a purposeful interaction between teachers working together. Teacher agency and collaboration, obviously, are of the utmost importance in this process of adaption [7,8,20].

Different studies seem to suggest that changes in school spaces may have enhanced teaching and learning practice, but how this happens and to what effect remains debatable. Woolner and associates [17] maintained in a study on two schools in northern England that physical settings tend to influence pedagogical and social practice but could both support and constrain desired change. Australian teachers [21] reported a shift in pedagogy towards an increasingly student-centered approach as they changed their traditional classrooms into flexible learning spaces, while a case study in Iceland [5] showed how teachers of younger students adapted more easily to an open and flexible learning environment than teachers at a senior level. Researchers do, however, in spite of such evidence, seem to agree that more is needed to illuminate to what extent and in what ways physical changes in school buildings affect educational practices [7,12,16,17]. Giving teachers ample time and opportunities to prepare, adapt, and reflect upon their preferences and practices in different phases of a construction project, preferably in some context with academic research, is, therefore, essential.

French and associates [12] identified four main themes that represent factors that affected how the staff at four schools in Australia and New Zealand succeeded in adapting to innovative learning spaces. The first one concerns teacher culture, empowerment, and opportunities to try out different things based on teacher relationships, collaboration, and reflection. The second theme is focused on the creation of constraints that make it harder for staff members to fall back to conventional ways of working. The third theme emphasizes structures that embrace new and different processes but maintain, at the same time, ties to older and more familiar procedures to bridge old and new behavior (see also [7,18]). Finally, there is the need for an accountability system to ensure that the new space is used as expected and new methods are firmly incorporated into the school culture.

Assisting staff members and students, just like teachers, need to find their place in a new setting. Grannas and Frelin [22] are among the few who have reviewed the perception and wellbeing of staff members other than teachers in this respect. They revealed that the architecture can both enable and limit the opportunities assisting staff members have to conduct their work; the physical environment can determine not only what is done, but also how, when, and where it is done. Senygit and Memduhoglu [23], on the other hand, interviewed children in Turkey and found out that classroom design elements, such as brightness (daylight), spaciousness, density (number of students), flexibility, and functionality, were considered important.

Kariippanon and associates [21] noted positive changes in student engagement and wellbeing, as well as the level of student choice and self-regulated learning, as traditional classrooms in Australia were transformed into flexible learning spaces. Secondary school students in Iceland [24] valued classroom arrangements that gave them flexibility or power to make decisions about their learning preferences or environment, and did not appreciate rigid environments for learning, crowded classrooms, or those that were too hot or lacking in flexibility to allow them to affect the circumstances. Their views in this respect were in clear contrast to the arrangements offered to them at school. Another study in Iceland [25] revealed that students at the primary level were rather pleased with their environment, both in conventional and open plan schools. They also complained about noise and limited access to computers in both types of settings.

2. Materials and Methods

This was a single-case study comprising a post-occupancy evaluation of Stapaskoli, a new school in an Icelandic coastal township about 20,000 inhabitants. It was built for around 520 students, aged 6–of 15 years old. The school serves a new neighborhood still under construction and will be an essential part of a complex constituting its heart, including a compulsory school tied into a preschool, a public library, sports facilities, and a site for local events. It was inaugurated in the autumn of 2020 and is currently attended by a growing number of students—around 280 in total from the data that was gathered in the spring of 2021.

Participants in our study included focus groups of teachers, teaching assistants, and students, as well as selected representatives in charge of architecture and educational leadership. The study was, in essence, a post-occupancy evaluation conducted in the adaption phase, as staff and students have only recently moved in and were still molding their culture and practice in the new setting. Four types of data informed the results, including data derived from documents, photography, interviews, and pedagogical walk-throughs. Data was collected in 2021 as the school was completing its first year of practice.

Documents reviewed include a report from the initial planning group, announcements and local news about the building project, technical drawings, and complimentary texts from the team of architects. Photographs include pictures taken on site during a field visit to conduct pedagogical walk-throughs, as well as pictures published by the municipality and local media.

Interviews conducted with an architect from the team of designers behind Stapaskoli and the director in charge of schools in the municipality served to reveal political, pedagogical, and architectural intentions behind the new building. They were conducted at the offices of each individual and lasted for about one hour each. Bits and pieces from informal conservations with the school leader as we gathered other data were registered in short notes as was seen fit and deemed necessary to compliment findings in the study.

Pedagogical walk-throughs require focus groups, most often comprised of teachers, that are asked to walk through educational facilities and review the strengths and weaknesses of their physical environment from a pedagogical perspective. This is an inductive research method that was developed in Sweden to make participants more aware of their physical environment and educational opportunities in that respect [26]. The method can be applied in different contexts at any school level for both pre- and post-occupancy evaluations [15]. It is currently being tried out within the framework of a European research project on collaborative redesigns of school buildings [27] and was used in this study to reflect the conceived strengths and weaknesses of a construction that represents new trends in school building design. A walk-through should constitute a tour in which a focus group is asked to make about five stops in selected areas within a building and make written notes about how they accommodate educational activities [26]. This is followed up with recorded discussions after each stop, or as in our case, the tour as a whole. The tour is designed to provide insights and overview in key areas, but one should keep in mind that it has its limitations, as it neither includes every space of significance in the school building under evaluation nor involves every staff member and student who might have significant viewpoints to share with the researchers.

Four focus groups did walk-throughs the same day, and each group was supervised by one researcher. There were two groups of nine teachers, a group of assisting staff that was made up of the caretaker and five teaching assistants assigned to different grade levels, and finally, a group of 13 students representing all grade levels, accompanied by one teacher. Each group made stops in four or five selected locations, including a double classroom assigned to two grade levels, a classroom or workshop area for art and crafts, the library, the assembly hall, and the corridors. Each member had a paper with forms to fill at each stop. Recorded discussions, lasting 15 to 60 min, were conducted right after the walk-through and took place in a meeting room within the administrative facilities of the school building. Some notions about staff facilities and the school playground were also recorded and reviewed.

Interviews and focus group discussions were recorded and transcribed up to a point that was deemed necessary for a thorough analysis of their content. Thematic analyses of the data were then used to illuminate the ideas and intentions behind the new building, as well as review conceived strengths and weaknesses of the areas visited in the school. Photographs were used to recall the perceived features of the building and examine them in more detail.

3. Results

The results are presented in three main parts that reflect the political and pedagogical intentions behind the new building, the design features of the new school and the architectural intentions behind them, and finally, the strengths and weaknesses of the new environment as viewed by the pedagogical walk-through focus groups.

3.1. Political and Pedagogical Intentions behind the Building

The municipality of Reykjanesbaer had been growing fast and was struggling with serious financial setbacks when it had to tackle the need for a new school, the building under review in our study. Ideas from drawings from two school buildings erected in the municipality several decades prior were, nevertheless, put aside, with the underlying notion that innovations that emerged since the time these older schools were designed called for a fresh start. With that in mind, the municipal directors of education and planning, together with the mayor, went to visit three newly built and innovative schools in Reykjavik and surrounding areas. A group representing different stakeholders from the neighborhood, municipal authorities, and prospective leaders of the school complex was then established to determine the underlying values, overall structure, and emphasis in pedagogy for the new building.

The preparatory group was to "take into account the needs of children, their families, the local community, and society as a whole" in accordance with the design down process, which was developed in Minnesota around the turn of the century and has been applied in Iceland in several school building projects since then [5]. The group included neither architects nor technical engineers but followed the method in other respects. It described in its report a school that was to be built in alignment with "modern needs", placing special emphasis on creativity and the arts, as well as flexibility and variation in educational practice. The school complex, including a preschool, a compulsory school spanning grades 1 to 10, and a music school, was to serve the local community as a communal and cultural center, with strong relations between the two school levels, teachers and parents, the school and the neighborhood, as well as ties to its natural surroundings—the open sea and fields along a low coastline, with lava spread out in the distance. The concept was illustrated as a heart in an initial report [28] and not defined in any detail as to how to go about teaching and learning. A more elaborate document was produced in continuation [29] that reflected ideas about round cores, wet areas, and workshops for art, tied into classroom areas for children from 2 to 16 years of age. Preconceived classrooms were not seen as "open plan" but rather as open and flexible spaces with a round core with upholstered benches, digital displays, a wireless network, and a number of breakout cells for each age group.

Five architectural firms were asked to participate in a closed competition on the basis of these preparations, and two of the competing teams were asked to take their ideas further. The architects from ARKÍS, who eventually won the competition, proved able to bring to the table profound insights into school building design, which were welcomed by the directors in charge of the project, as well as the school leader, who would later get deeply involved in design decisions, such as the choice of furniture and technologies to support innovative modes of teaching and learning.

3.2. Architectural Intentions behind Design Features of the New Building

The team of architects at ARKÍS was determined from the outset to design Stapaskoli as a bright and colorful building and a light and inviting construction, with clear ties to its natural surroundings and neighboring community, as well as a compulsory school set in a carefully intertwined complex of constructs for different needs and services, allowing for flexibility and multiple uses. Team members wanted the building to promote and maintain teamwork, collaboration, and a communal spirit, reflect ties to the natural environment, and be a venue for the neighboring community at large. Transparency and natural lighting from above and as many sides as possible were also issues of particular concern.

The leading architects were able to reach back to an era of attempts to build open plan schools in the seventies and eighties and recall how school building design had later taken a step back to more conservative design forms with conventional rows of standardized classrooms with groups of up to 30 students sitting in regular rows. They had been involved in a number of school building projects, competitions, and consultation assignments of a more progressive nature over the last two or three decades and were able to elaborate the design project at hand and its manifold features in light of their extensive experience, rather than focusing on any one model or building project from the past.

The following subchapters reflect our own review of the building and their notions about "hearts within hearts", with the school building constituting the heart of its neighborhood, open and flexible classrooms representing the hearts of teaching and learning for cohorts at different grade levels, and a brightly lit oval core resembling a heart in the middle of each room. The idea of a heart filled with life was what the architects highlighted as the signature concept and leading idea behind their design, as well as, perhaps, the most innovative aspect of the whole project.

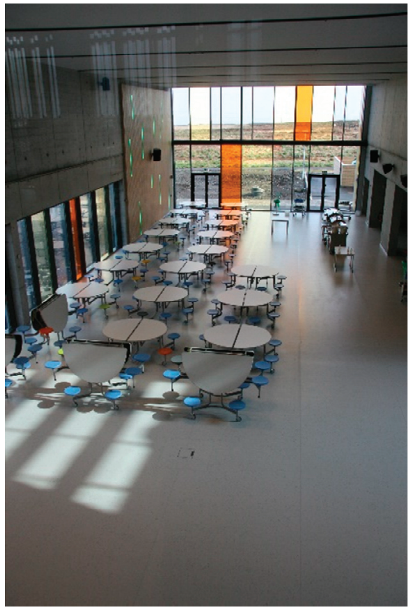
3.2.1. Heart of the Neighborhood

Buildings already built and those about to be built in a unified complex on the site of Stapaskoli constitute not only a compulsory school spanning grades 1 to 10, shown in Figure 1, but also a preschool for children from 2 to 5 years old and a community center with a public assembly hall, a school library, a building extension for sports, and a richly equipped playground open to the public after school hours. Spaces for lessons in music are in place, as are areas assigned to home economics or art and crafts. A church is also planned for the premises, opposite the entrance to the school.

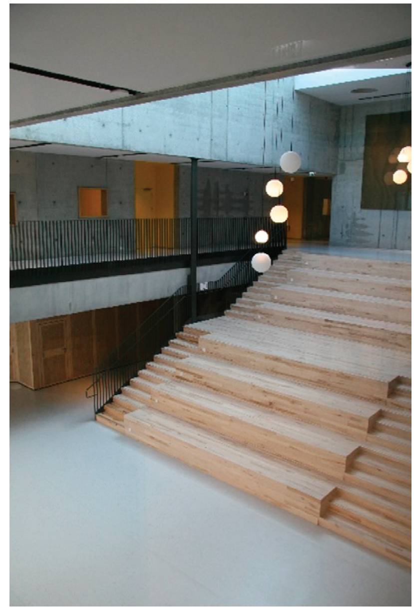
Figure 1. Stapaskoli, compulsory school in Reykjanesbaer. The main entrance and entrance hall are underneath a grand library on the upper floor. The administrative section can be seen to the right, protruding southwards, on top of a classroom unit for grades 5 and 6.

3.2.2. Heart of the School and Community Center

The assembly hall, shown in Figure 2, is wide and open, reaching from the lower floor to the upper ceiling, with an abundance of different spaces and services in its immediate periphery. It was designed to be the combined heart of the whole complex, both the school and the community center. This constellation of spaces is bound together with light and flow from all directions, with a big staircase and indoor balconies towering over the hall, allowing audiences to view this brightly lit space from above. A wide entrance hall on the lower floor, a school kitchen and a lower floor hall for multiple uses, and extended space behind removable walls enrich the facilities. Also within reach are a storage room and a classroom assigned to lessons in music and backstage activities, as well as four soundproof cells for lessons on musical instruments.



(**a**)



(**b**)

Figure 2. The assembly hall. (**a**) View from above to the north. An extension for sports will be built on the left side. An adjoining kitchen and a lower hall lie hidden to the right. (**b**) Balconies and giant steps are used to accommodate audiences and walls on the lower floor can be removed.

A school library, already in function on the upper floor and overlooking the hall, will be open to the public after school hours. Furthermore, yet to be built is a large extension construct assigned to sports. It will be tied into the library on the upper floor and open into the assembly hall at a lower level for special events, making it possible to use the assembly hall and adjoining spaces to accommodate visitors in great numbers. It will contain sophisticated facilities for both public use and educational purposes, including a weight gym, a swimming pool, and a sports hall of an acknowledged size, with dressing rooms elaborate enough to have the complex certified for official sports competitions.

Tied into all of this is the compulsory school itself, with its bright walls, long and wide entrance hall, extensive hallways running through the length of the building on both floors, administrative offices, open and flexible classroom areas, classrooms for special subjects, such as sciences or art and crafts, and a colorful playground stretched out along the southern side.

A preschool extension will be built at the far end of the school building. It will be tied into classroom sections assigned to the youngest students on the lower floor, as well as classroom facilities for home economics. A part of the playground is already confined by a fence in reserve for children at the preschool level, who are currently stationed in preliminary housing next to the school. Figure 3 illustrates the complex as a whole.

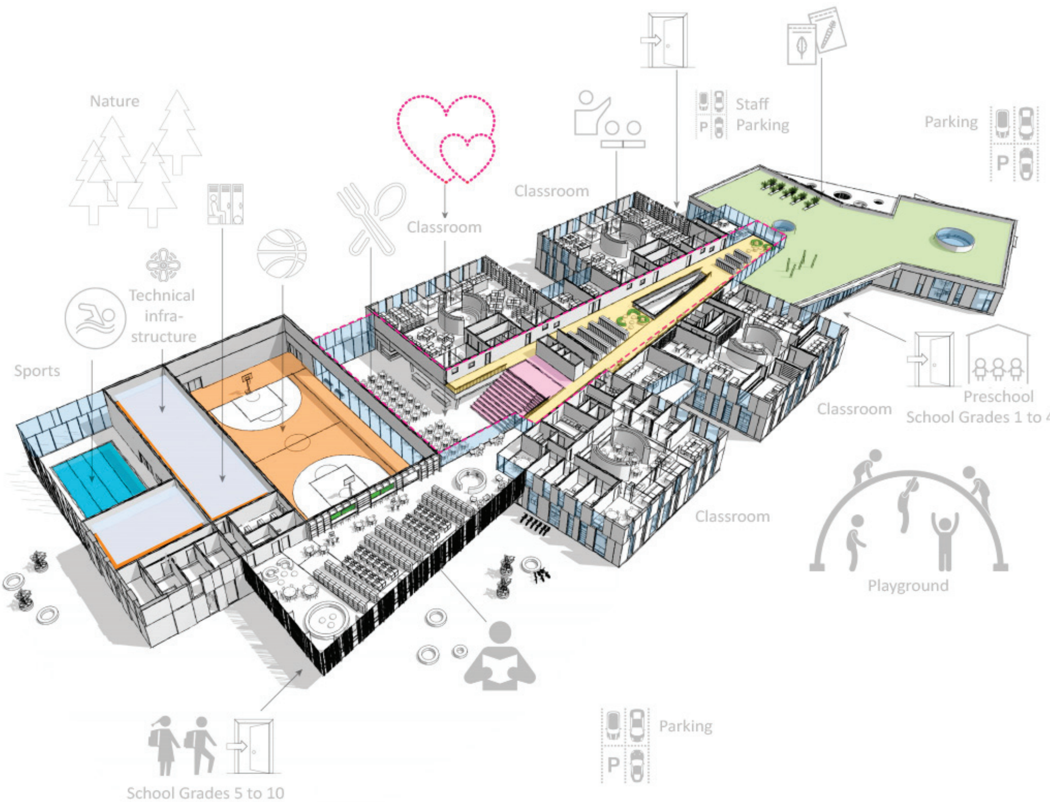


Figure 3. An early illustration of Stapaskoli from ARKÍS architects [30]. Sports facilities on the western end of the building complex, as well the preschool extension on the eastern end, have yet to be built. Two upper-floor classroom sections can be seen on the northern side. The library, a section for administrative functions, and a classroom section for art and crafts face the south. Three additional classrooms, a multifunctional hall, and music facilities lie hidden and out of sight on the lower floor.

3.2.3. Hearts of Teaching and Learning

Staff members at Stapaskoli use the Icelandic word *tvennd* (plural: *tvenndir*), meaning two of the same, when referring to open space classroom areas in the school building. Each classroom or *tvennd* is designed in a symmetric fashion to accommodate two cohorts of students and their teachers from two different grade levels, one in each half of the room. The idea is to let grades 1 and 2, 3 and 4, 5 and 6, 7 and 8, and 9 and 10 work together and share learning experiences up to a point determined by the teaching staff and, to some extent, the students themselves. The rooms, then, are five in all, with each classroom constituting the heart of teaching and learning activities for two cohorts or grade levels. Classrooms in the eastern part of the lower school level, the part of the playground reserved for younger children, together with the preschool construct yet to be built, constitute a hub or heart for preschool children and students in their early years.

The classrooms or *tvenndir* are spacious enough to be called open and flexible, yet divided in part by curved walls, a partly open circle constituting an oval core in the middle of the room. Four breakout cells behind glass walls are lined up along a wall separating the classroom from its hallway, two cells side by side in each half of the room. Between the two pairs of cells are two doorways leading out to the hallway, while restrooms are hidden behind a counter with cabinets facing the classroom. Tall windows with benches and cupboards with shelves reaching the ceiling, mostly empty for the time being, but with built-in seating, cover both sidewalls of the room. On the wall opposite to the counter, doorways, and cells are more windows with benches for optional seating, and two relatively large breakout rooms, one in each corner, confined behind colored glass. Figure 4 shows one of these breakout rooms and the oval core. A drawing from ARKÍS representing a *tvennd* is shown in Figure 5.

(**a**) (**b**)

Figure 4. A classroom or *tvennd*. (**a**) One of two larger breakout rooms in a *tvennd*. (**b**) The oval core residing in the middle of the classroom.

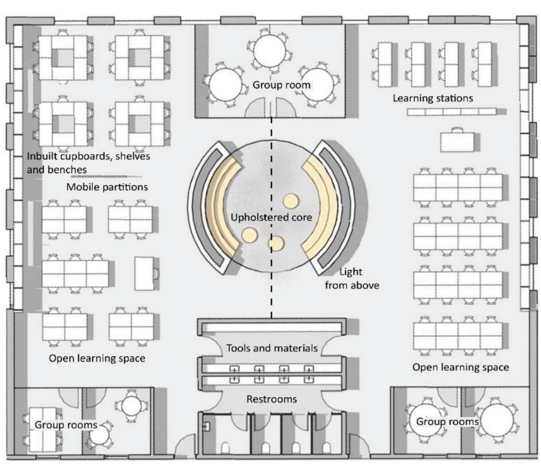


Figure 5. A draft illustration of a classroom or *tvennd* by ARKÍS architects [30].

Curved steps or benches that allow groups of students to be seated in three escalating rows are placed inside the core facing a curved constellation of nine digital displays connected to a sound system. Hovering over the core is a white cloth stretched over a round frame illuminated from above, while more conventional lights and a filtering cloth, hiding sound-absorbing materials, cover the ceilings in other parts of the room. Moveable and colorful furniture, including bean bags, cushions, desk chairs, and tables, are scattered all over the room. Podium stands on wheels serve as mobile work and storage stations for the teachers, while four large displays—two for students working in the open space and one for each breakout room—can be moved around at will. A set of iPads is also in store for each and every grade level.

3.2.4. Heart of Art and Crafts

A sixth *tvennd* or classroom is assigned to art and crafts in an open and flexible setting, subtly divided into three areas and used by students from all grade levels for creative work in subject areas including art, textiles, and woodworking, as well as creating with digital devices, such as for drawing, laser cutting, designing, and printing. The confined and more conventional space, which makes up approximately one-fourth of the *tvennd*, is used for lessons in natural sciences, computing, and digital programming. Restrooms, as well as breakout sections for heavy machinery, storage, and scientific experiments, are also in place.

3.2.5. Heart of Administration and Staff Facilities

Hallways running through the building on both floor levels are, in part, divided by a few rooms into two walkways. Three or four of these rooms are used for special subjects, while one is reserved for teachers stationed on the lower floor. A bright room for teachers working on the upper floor lies next to the administrative section, which resembles a *tvennd* and houses the school reception, offices of the administrative staff, meeting rooms, restrooms for staff members, and a teacher lounge placed in a round and stylish core resembling cores in the classrooms, with small tables for coffee and meals.

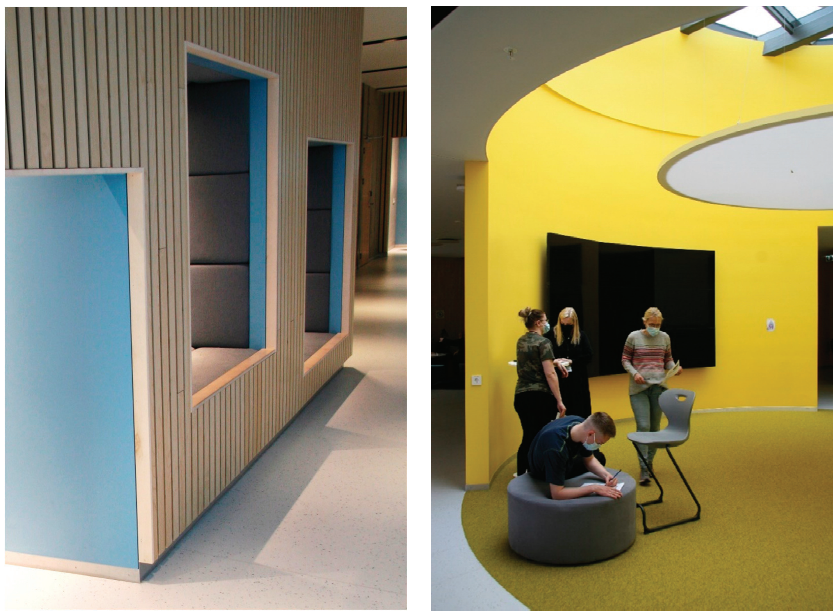
3.3. Strengths and Weaknesses as Viewed by Focus Groups

Our focus group of assisting staff appeared quite proud of their new school building, yet a bit more critical than members of the two focus groups representing teachers in our study when it came to the practical aspects of the facilities. Students made up the fourth focus group and appeared somewhat hesitant to share their views with the researcher or perhaps other members of their group. They did, nevertheless, put forward a number of positive viewpoints about the school building and the learning opportunities it had to offer, as well as some critical notions calling for "more calm and quiet" in their everyday school environment.

3.3.1. Open and Flexible Classrooms

Both teachers and the assisting staff described the classrooms as accommodating and spacious places for learning and commended a wide selection of comfortable seating options within the room. Teachers celebrated the variety of approaches they were able to apply in their everyday practice and related how dynamic the environment was in terms of allowing staff members to work together and create all kinds of learning opportunities for students. The assistants pointed out restrooms behind a wall of cabinets and a small area assigned to wheelchairs or other similar aids when not in use. Breakout cells and other confined spaces, both small and large, were generally seen as great assets; sometimes they were overcrowded, too warm, or too exposed, but they were quite useful on an everyday basis.

The round cores placed in the middle of classrooms were generally considered helpful shelters for individual students or small study groups, as well as spaces where a teacher would be able to interact with students in small or large numbers. Initial difficulties with the audio system and the set of displays in these areas were being resolved. Thick curtains, sliding doors, or foldable walls, which allow teachers to close the core at will, were seen as an optional and perhaps feasible addition to the facilities. Compartments and open spaces in hallways outside the classrooms were also in use and considered yet another opportunity to provide students with an empowering selection of places for learning. Compartments in an open hallway and assisting staff members, reviewing a round core in one of the classrooms, can be seen in Figure 6.



(**a**) (**b**)

Figure 6. Focus groups and sheltered spaces. (**a**) Compartments and open areas in hallways were celebrated as optional settings for learning. (**b**) Oval cores in classrooms were also commended.

The assistants maintained that the tables and chairs in the classroom, which are assigned to the oldest students, would have to be adjusted or replaced to make an adequate fit for teenagers. Classroom doors were considered heavy and difficult to open. Heating and ventilation had proven to be problematic, in particular in the upper floor classrooms and the smaller break-out cells, as shown in Figure 7. Initial difficulties of that kind were said to be expected in a new building of this scale and staff members pointed out that shades or protective films placed in the windows would probably help to solve such problems. A simple but important fault, when it came to lighting in the classrooms, was also revealed—teachers and other staff members were not able to turn on and dim lights from the ceiling in their half of the room without affecting the lights in the other half. This, of course, would be easy to fix. Hooks or hangers for wet coats were deemed as something that could be added and placed behind the counter and wall of cabinets separating the restroom section from other parts of the room.

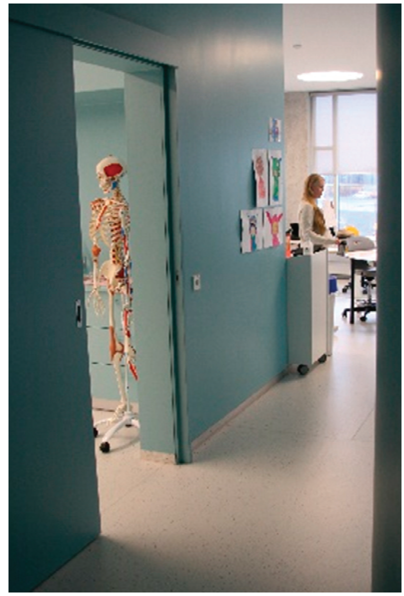
Figure 7. Breakout cells with recording devices and a selection of furniture. Windows connect the cells with the hallway areas outside the *tvennd* or classroom.

The variety of furniture offered was the feature that students liked most about their classrooms, with the opportunities they had to choose their own seating arrangements: "If you get tired of sitting on a chair, you can (always) have it cozy on one of the bin bags." They celebrated the technology in place and considered it much more advanced than in other schools they had been to, while also questioning the money put into a curved constellation of displays: "Who needs thirteen TV screens in one room?" When asked about negative aspects, they mentioned how noisy they sometimes found the classroom and that it was irritating not to have more space to hang things up on the walls. When asked for suggestions about conceivable improvements, some proposed a set of walls to split the learning space into two parts and provide each cohort with a classroom of its own.

3.3.2. Art and Crafts Classroom

Teachers in our focus groups celebrated the acoustics, spaciousness, dynamic flow, and emancipating freedom they had experienced in the open space classroom unit assigned to art and crafts. Students were reportedly allowed to move from one teacher and subject field to another and decide for themselves, to some extent, how to go about their work. They were not only able to collaborate with partners of their choice but also apply combined approaches and a broader selection of tools than in a more conventional setting that focuses on one subject area within art and crafts at a time. Communication between the teachers of art, textiles, and woodworking appeared to be lively and the teachers were able to send students over to their colleagues whenever they deemed fit. The room, shown in Figure 8, was considered bright and spacious, and the general atmosphere was both lively and relaxed. One teacher, praising the acoustics and flexibility in the classroom, pointed out how a big display on wheels would suffice as a convenient divider between groups occupied with different tasks.

(a)



(b)

Figure 8. Classroom or *tvennd* for art and crafts. (**a**) Students attending a class in woodworking in an open space. The oval core is behind them. (**b**) Beyond the core is a room confined behind sliding doors assigned to natural sciences and digital programming. An open area for classes in art is in the far back.

The core, reportedly, would be used for short lectures, introductions, and discussions, but most often would serve as a central shelter where students could take a short break or find a relatively quiet place for the task at hand. A confined space behind a sliding door was assigned to lessons in natural sciences and digital technologies, making it approachable to tie experiments and programming to digital devices in the workshop areas. The teachers also proclaimed that they would never hesitate to send their students over to the art and crafts classroom whenever they wanted to extend some project work to include activities that involve hands-on tasks and which require particular tools or workshop materials.

The teaching assistants found the selection of seating in the classroom area for art and crafts too limited and the level of noise and back and forth motion among younger students in large groups somewhat frustrating. Some of the children apparently tended to roam without a clear aim from one area or group to another. More chairs, tables, and a few movable dividers, if not fixed or foldable walls, were thought to be helpful for students who might find the facilities for art and crafts compromising in this respect.

On a more positive note were notions commending the spacious facilities, a relaxed atmosphere, adjustable furniture, and the selection of tools used for woodworking, digital cutting, and 3D printing. Older students were said to be making extensive use of all this equipment, while the younger students were less likely to be applying such devices. Students, reportedly, were allowed to leave the area and take a short break in the hallway or rest for a while within the core residing in the middle of the room. This was seen as reasonable and helpful for tired or perhaps listless students in the course of long classroom sessions. Some concerns about absent-minded and unattended students, conceivably hiding away from their teachers or fellow students, were also noted.

Students praised the level of freedom they had in their open space art and crafts classroom. They would not only be allowed to seek out a chair, a table, or a spot on the window shelves to their liking—to be, up to a point, in charge of their own learning environment—but also choose what to work on, often by applying tools and methods from different subject areas. They related the selection of tools they had to choose from and the fun they had working on their projects. They maintained, on the other hand, that some of the machinery and digital tools provided could be applied more often or to a greater extent. Some members of their focus group also suggested that a couple of walls erected within the classroom might help to make the environment more efficient and user-friendly.

3.3.3. Halls and Hallways

A long and wide entrance hall, running from the main entrance towards the assembly hall, was highly appreciated by members of the assisting staff, as it provided low shelves and excessive space for students in great numbers to take off and put away shoes when entering the school. Other hallways running through the whole building on both floor levels were also considered spacious, bright, and inviting by all focus groups. It was repeatedly pointed out how they provided students with extended areas and smaller spaces to interact, study, and play. Small booths or compartments along the corridors for small study groups, individual work, or social leisure during breaks appeared to be in particularly high regard, and they constitute symbolic features of design that aims for flexible school practices. Hooks or hangers to dry outdoor clothing were mentioned as a feasible addition to improve hallway facilities, as well as perhaps a small cell assigned to the assisting staff to dry their outdoor clothing after breaks in the open on a wet or snowy day.

The assembly hall, with adjoining spaces, giant steps, and upper floor balconies, was reportedly used for meals, social events, performances, and eventually, exhibitions, and generally regarded as a big success in terms of both design and practicality. High levels of noise in lunch hours had been seen as a potential problem factor when the assembly hall was first put into use, but staff members had quickly grown accustomed to the tumult characterizing the large groups of youngsters enjoying their meal. Students, in particular, described their appreciation of the hall, its beauty and bright walls, the round tables allowing them to chat with friends, and the view through extensive windows to a natural environment outside the building. They expressed their wish for more time at the tables after meals and were told by a teacher accompanying the group that the shape of the tables had been chosen to encourage just that, chatting and shared quality time over meals. The students also uttered wishes to have some background music playing during lunch hours and the distance between tables to be extended to allow for a more relaxed atmosphere and increased elbowroom in the hall.

The students liked the giant steps, shown in Figure 9, as a place to exercise, have a chat with friends, or even to learn without too many people around. They also mentioned the advantage of being able to charge computers and cell phones on the steps and reported how they would like to have more compartments in the hallways to enjoy with a small group of friends, study in private, or just have access to a learning environment different from their usual spot. A few of them mentioned a pleasant scent of baking or cooking coming from a room in the hallways currently used for home economics. A wall area designed for climbing, located outside the classrooms assigned to younger students, appeared to also be appreciated. Students expressed their wish to have it extended and supplied with a softer mattress. They also complained about the limited access to elevators running between the two floors, as only handicapped students were allowed to use them. The caretaker and teaching assistants told us how students would often claim to be sick or injured, in their attempts to use the elevators despite such restrictions.

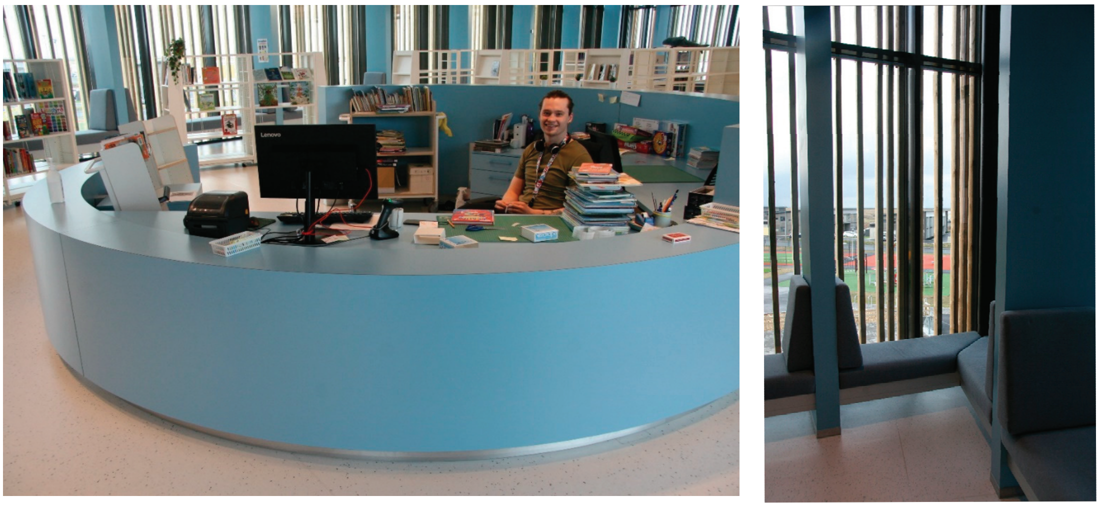
(**a**) (**b**)

Figure 9. Hall and hallways. (**a**) The giant steps facing the assembly hall can be used for studying, as well as charging digital devices. (**b**) A living tree on the lower floor. Booths and compartments for students are in the back. Note the window and doorway into a classroom unit.

3.3.4. Library

The library was seen as an exceptionally bright, spacious, and inviting environment supplied with abundant seating options and workstations for multiple uses. It was considered very popular and well attended by students and staff, reportedly for studying, project work in groups, leisure reading, chess and board games, and performances and readings involving students, staff, preschool children, parents, and eventually other guests. Teachers described visits to the library with groups of students from different grade levels and students made positive remarks reflecting how good it was to hang out in the facilities. A round reception desk, shown in Figure 10, as well as a bench that forms a circle and is used for readings and group discussions, were seen as clever efforts of design, echoing oval cores in other sections of the building.

Sunlight coming in at a low angle through large windows that surround most of the library was proclaimed to be difficult to deal with. Wooden bars lined vertically in a grid-like fashion outside the glass appeared to be of limited help in this regard. Teaching assistants found them decorative when seen from the outside but of little use from inside the building, even obstructing an otherwise pleasant view. The library had sometimes become overheated, as well as cold when attempts had been made to adjust the heating. This was seen as something that would be solved over time. A large breakout room behind glass walls was seen as an ideal learning space for project work but was currently being used by a study consultant to conduct interviews due to a lack of an office for such sessions.



(**a**) (**b**)

Figure 10. The library. (**a**) An oval reception desk resides in spacious facilities filled with light. The school is new, and many shelves are still empty. (**b**) Upholstered benches run along the walls. Wooden bars on the outside forming a striped pattern can also be detected.

3.3.5. Staff Facilities

The administrative section or *tvennd* did raise some contemplative remarks about staff members taking a break could conceivably disturb staff members attending to administrative tasks and vice versa, but it was generally seen as a pleasing and stylish environment. Two bright and relatively spacious rooms assigned to the teaching staff, one on each floor, appeared to be highly appreciated by all staff members alike and reflect a joyful atmosphere. We could see how these rooms were used to share mobile podium stands and other equipment among the teaching staff on a daily basis, and how markers with washable ink had been used to write both practical and playful bits of info and communications on the walls.

3.3.6. Playground

The playground was neither visited nor covered in any detail with our focus groups. A few remarks, however, made by members of the assisting staff, illuminated how popular it has become far beyond the school district. It draws in groups of youngsters and parents with young children coming from as far as the other end of the municipality. A colorful design, the choice of materials, and the bounty of equipment to play with appear to have hit their target. Teaching assistants overlooking the playground, as younger students went out for breaks between class hours, also commended how easy it was to look over the premises with the whole playground stretching out on the southern side of the school, rather than surrounding the whole building.

4. Discussion

The aim of this study was to map how political and architectural intentions for Stapaskoli have succeeded as applicable and innovative school facilities in the eyes of teachers, teaching assistants, and students. Our three research questions in this regard are discussed below in Sections 4.1–4.3, followed by a discussion about the overall aim of the paper as well as conclusive remarks.

4.1. Intentions Guiding the Design

Intentions guiding the design of the new building seemed relatively open and somewhat unclear, as documented in a preparatory report produced at the initial stage of the building project. A more elaborate and informative document was later established by municipal authorities leading the project. The overall political aim was to build a school and community center to meet the perceived demands of a new neighborhood in current times, but the pedagogical intentions were perhaps rather vague in terms of defining in detail how to organize teaching and learning in the new school. A text describing the winning design proposal from ARKÍS reflected the idea of a school as a heart of a community and classrooms as hearts of teaching and learning, but without much clarity when read with care. The proposal itself, as illustrated in drawings, on the other hand, appears carefully thought out in terms of showing how an open and flexible learning environment might help to sustain teaching and learning in teams and allow for variable learning and teaching conditions for everyday school practice. The team of architects had gained insight into school building design over decades and was able to produce a viable concept for the new school that was welcomed by the municipal directors of schooling and planning, as well as the prospective school leader.

4.2. Conceived Strengths and Weaknesses

Conceived strengths and weaknesses of the learning environment found in the data were many, as related in Section 3, which seems to commend pedagogical walk-throughs as a research method [26]. We are also able to confirm that the walks and discussions served to raise the awareness of a noteworthy school building offering opportunities for new ways of teaching and learning. Teachers and students agreed that the variety of spaces and furniture that allow students to choose their learning conditions for themselves could be considered the greatest strength of their new learning environment. The weaknesses often had to do with technical difficulties that were expected at the initial stages and were likely to be eliminated to some extent over time, while other weaknesses had more to do with disturbances that are likely to get worse as the number of students increases over the next few years. A comparative study in a few years might prove interesting in that regard.

A sense of empowerment and the will to grasp opportunities to try out different things based on teacher relationships, collaboration, and reflection—one of the requirements for the success of putting an innovative learning environment to use, as laid out by French et al. [12]—was sometimes detected as we walked or talked with teachers and teaching assistants in our focus groups or visited classes included in our scheduled walks through the building.

We were also able to identify physical constraints that make it harder for staff members to fall back to conventional ways of working—another theme from the same source as above [12]. The sheer ambition, beauty, and strength of the physical design in the halls and hallways was a feature likely to prevent people from tampering with or fragmenting these environments, while oval walls and breakout areas in the classrooms would probably call for troublesome adjustments if anyone wanted to break up a *tvennd* or classroom with new walls.

Ties to familiar procedures and surroundings, in coherence with yet another theme laid out by French and associates [12], were also detected, such as the library or the number of shelves in classrooms, presumably designed for folders and books. A somewhat debatable uniformity of the *tvenndir* or classrooms resembling, to some extent, symmetric classrooms from other recent building projects, was, perhaps, yet another example of such ties to older times.

The fourth theme from French et al. [12], however, calling for accountability to ensure that the new space is used as expected and that a new culture is consolidated, were not detected in our formal data nor seemed to be applicable within the scope of our study. Notions from the school leader and the teachers indicated, however, that taking up older ways of teaching would not be an option for the staff members. The school leader also maintained, in one of our short conversations, that the teachers were held accountable for collaboration and teamwork in and beyond their classrooms.

Students valued the level of freedom in their new school, as they were not only allowed but rather expected to regulate, to some degree, the conditions and subject matter of their learning. This is coherent with the results of Kariippanon and associates (2018), who recommended student self-regulation to support the transfer from traditional classrooms to flexible learning spaces. This freedom of choice is also clearly innovative in comparison with results from recent studies at the primary, lower secondary [31], and secondary school levels [24].

4.3. Conceived Innovative Features

Innovative features of significance in the new building in the eyes of stakeholders who participated in our study were numerous. They were generally pleased with their new school, and fascinated, even, with the spaciousness, natural light, bright colors, transparency, and dynamic flow among staff and students alike. They appreciated how well different functions and spaces had been intertwined to create a heart-like core in and around the assembly hall and were able to articulate opportunities that would come with the whole building complex fully built. They proudly pointed out many details or more substantial features of design, such as small indoor windows between spaces, windows and gaps bringing in natural light through the roof or upper floor, grand views through extensive windows or transparent indoor walls, an exceptionally furnished playground, restrooms within classrooms, excellent acoustics in crowded spaces, a shared classroom for art and crafts, giant steps in the assembly hall, and indoor balconies along corridors, as well as small spaces designated for individual assistance, learning how to play musical instruments, studying in quiet, team work, or technical tasks, such as recording and editing media. Mobile podium stands and large displays on wheels were commended as practical novelties, as were the oval cores, oval benches, and round tables and desks placed throughout the whole building. Original details, such as having a living tree and a wall for climbing on the lower floor of an abundance of seats in windows, were also celebrated.

What struck us in this study was how well the design of the school building, both in broad and more specific terms, appeared to fit open and varied pedagogical approaches based on teamwork and collaboration. Such alignment among the physical environment, pedagogic practice, and school culture is the deciding and most profound factor in school building design, as has been so frequently reflected in the literature (e.g., [5,12,15–17]).

4.4. Intentions and Reality

Political and pedagogical intentions behind the construction of Stapaskoli were ambitious from the outset but relatively vaguely defined. Adaption and occupancy are also in their early stages, which makes it difficult to determine whether the new building is a success. Architects brought experience and valuable insights into the building project, while municipal authorities seemed to have maintained venues of consultation and collaboration between key stakeholders and the design team throughout the project up to date, in line with recent recommendations of Duthilleul and associates [1]. One indicator in this respect was the agency of school leadership when it came to decisions on furniture and technology, presumably two important and successful elements of design in the building. The empowerment involved in this kind of collaboration has been recommended by not only Duthilleul and associates [1] but also several other researchers [7,8,17].

Also noteworthy is the freedom that was handed to the architects for this project and how the design drew on their previous experiences from over two or three decades. This serves to show how school building design in Iceland has evolved over time [6] and how it has deviated from the previously accepted grammar of schooling [7]. We might even raise the question of how long new design forms deviating from tradition can be classified as innovative or unconventional. Are open, diverse, and flexible learning spaces that are supported by digital technologies conceivably the new norm in school building design allowing for a more progressive grammar of schooling to override older traditions?

5. Conclusive Remarks

The novelty of the school building under review in our study could be debated, and some of its features could potentially be called the new norm. The results serve, at least, to show considerable strengths and some noted weaknesses of a learning environment deemed as innovative by teachers and teaching assistants, as well as students attending the school under review. The building represents current trends in school design at the national level and resonates with similar trends in many parts of the world. It appears to be a success in terms of supporting teamwork and flexible teaching practices, allowing students to affect their own conditions and subject matter of learning, while proving to be potentially difficult regarding the level of noise and disturbances experienced by some students.

Teachers, teaching assistants, and students alike seemed to commend the new building as a school and community center, as well as appreciate its bright and spacious design. The number of attending students, however, will grow in the coming years, making a comparative study in a few years an interesting prospect. We may also—without going into any technical details at this point—want to look further into some of the faults and potential amendments suggested by staff and students in this study and consider their impact on school practices. A richly furnished playground, which was not included in our study but which flashes a variety of facilities, would furthermore be worth a particular study. Stadler-Altman [32] related how the school ground should provide opportunities for both playing and learning, and it would be of interest to examine to what extent this sophisticated playground meets such requirements.

The data collection method of pedagogical walk-throughs [26] has certain limitations, related in Section 2, but proved to be fruitful and appeared to provide valuable insights with regard to our research questions. It may also make an interesting comparison should we choose to try out other methods that are presented within the framework of a European project on the collaborative redesign of educational spaces [27]. Diamond ranking, to name one, might help us to find out which innovative learning spaces in this ambitious school building work best for teachers, assistants, and students. That is, after all, what innovative learning spaces are supposed to do—work well for the students and the teaching staff.

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buildings

Article

The Influence of Learning Styles on Perception and Preference of Learning Spaces in the University Campus

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Abstract: Good academic performance will occur when learning spaces match or support individual preference and needs. This effect depends on environmental characteristics and individual attributes. Learning styles (LSs) have been used as a tool to capture the behavioral and psychological characteristics of learners in the process of learning activities, which provide instructions to address their learning needs. However, few have focused on the perceptual characteristics of learning space from the view of distinct learning styles. The research aims to identify which kinds of learning spaces in university campus have been preferred by students with different learning styles respectively and the spatial characteristics which have significant influence on the distinct evaluation results; the research consists of 178 college students' LSs measurement conducted by the Index of Learning Styles questionnaire and their subjective assessment to five typical learning spaces obtained by 5-point Likert-type scale. Then, the key spatial influencing factors were identified by the focus group interviews; the results firstly ranked the learning spaces according to their satisfaction evaluation and restorative potential. The self-study rooms are rated highest, followed by professional classroom, traditional classroom, and multimedia classroom. Then, two dimensions of learning styles were proved as having considerable effects on perception. Specifically, there are significant differences between visual and verbal learners' evaluations of multimedia classrooms and traditional classrooms, and between global and sequential learners' evaluations of multimedia classrooms, informal learning spaces, and learning buildings. The other two dimensions including perceiving and remembering have no obvious impacts on learners' perception of any learning spaces. At last, the important influence factors of perceptions of five typical learning spaces were identified, respectively, and their different effects on various groups were discussed. For example, the serious atmosphere in traditional classrooms was regarded as a motivation for sensing learners but a stress for intuitive learners. The studies emphasize the perceptual difference on learning space in terms of students' unique learning styles and key points for each kind of learning space with regard to satisfaction of personalized needs. However, before it can be used by designers as tools, more research is needed.

Keywords: built environment of education; learning space; innovative learning environments; restorative perception; learning style

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1. Introduction

For the past decade, much attention has been paid on the influence of building spaces on people's cognitive activities [1–4]. Some special spatial characteristics will stimulate the operations of the undirected attention and make it rest, which results in positive changes of mind and body, including mental restoration, stress recovery, efficient cognitive process, good emotions, and so on [5–7]. This has become a hotspot especially on the research of official or learning spaces, where people engage in plentiful brain work and suffer from mental fatigue more easily [8–10]. In a transitional stage of physical and mental growth, undergraduates have weaker abilities to identify and process the environmental information, which leads to more mind confusion and exhaustion than adults [11–13]. In developing countries, like China, college students are suffering from emotional problems and peer pressure [14]. Therefore, there is a pressing need to identify the effect of learning space on college students' psychology and behaviors in order to provide building design strategies at the aim of health promoting and efficient cognitive activities.

The relationship between learning spaces and students' self-development and well-being has been studied for a long time [15–17]. Many spatial elements have been proved to effect students' learning behaviors, learning outcomes, self-reported life quality and well-being, including physical conditions (lighting, airflow, temperature, etc.), facilities or furniture, accessibility, spatial scales, and so on [18–23]. Moreover, it has been demonstrated that the greenness (such as potted plant, flowers, natural window view, green wall paintings, etc.) in the learning space offers high restorative quality, which is beneficial for efficient cognitive tasks and innovations [24–27]. However individual perception and understanding of the surrounding environment may differ considerably among persons with distinct characters, such as gender, age, education level, life experience, thinking ways, cultural background, or some other personal attributes [28–32].

The LS describes individual features closely related to learning activities, which supplies a potential variable affecting the perception of learning spaces. However, it will be involved in a confused and expanding area, because how the learning styles would be measured accurately and utilized and how much it could affect learning outcomes is controversial [33]. Although the inconsistent opinions result in its limitation in Educational Science research, the LS have indeed been proved as reflecting the personality including the preferred information and preferred decision-making ways [34], which could supply a perspective or method of understanding the preference for the learning spaces. We focus more on individual difference represented by it and the resulting impacts on spatial perception, rather than the learning style itself.

Thus, the model based on personality rather than fixed trait was selected in the present study, according to which the learning style is conceptualized as a kind of comprehensive personal characteristic related to learning activities, cognitive traits, and psychological behaviors, remains stable within a certain period of time, and will be affected or changed gradually and slowly by the environment [35]. According to Felder-Silverman learning style model (FSLSM), there were four dimensions to describe the learning styles covering processing, perceiving, remembering, and understanding information [36,37]. Each dimension contains two opposing categories (Table 1). Compared with other measuring methods, this model provides more detailed definition of how students prefer and conduct their learning activities, according to which, 16 learning styles are deduced by the Index of Learning Styles (ILS) questionnaire consisting of 44 items [38]. It has been widely used in related studies in China. For example, it has been proved that the learning styles preferences would affect students' academic performance, choices, and mood [39,40]. In addition, more advanced teaching methods and more efficient courses were explored with its assistance [41].

To sum up, through literature reviewing it is suggested that the learning space has a significant influence on students' behavior and mind, which varies because of individual perception. As an important variable, the LS provides more definite and explicit identification of students' characters which should be used for exploring the effects of individual attributes on the spatial perception more deeply. Then, from this perspective rather than other ordinary demographic variables, specialized and well-targeted directions will be put forward to guide the design of campus space with the aim of optimizing academic outcome and promoting psychological health. In spite of increasing research and focus, it is still absent from related analysis [42–44].

Table 1. The description of four learning styles.

Dimension	Classification	Description
Process	Active (A)	Prefer trying things out and putting ideas into practice directly, like to discuss with others and learn new knowledge by working in group.
	Reflective (R)	Prefer thinking things through alone and be good at organizing the material and summarizing the information.
Perceive	Sensing (Sen)	Prefer concrete learning materials, often deal with problems with standard approaches and show more patience with details.
	Intuitive (I)	Do well in facing abstract knowledge and like to try new things, tend to be more innovative and creative.
Remember	Visual (Vis)	Easier to remember what they have seen, including pictures, charts, and flow-diagrams.
	Verbal (Ver)	Specialize in obtaining information from text contents whether they are spoken or written.
Understand	Sequential (Seq)	Like to follow an established logic and grasp knowledge step by step, they often focus more on details and could explain how they understand it clearly.
	Global (G)	Prefer to start with holistic framework of knowledge, they usually learn material randomly without thinking about connection among each part and get a clear understanding after absorbing enough materials.

Therefore, our study draws on the effects of LS on the perception of five typical learning spaces in university colleges, which have been centered on frequently in previous studies [45–49], including (1) traditional classroom (hold 100–200 students, support face-to-face teaching and learning, characterized by rows of fixed desks, tables and chairs all facing the instructor at one end of a rectangular room, usually used for a large and public class); (2) multimedia classroom (hold 20–30 students, equipped with advanced electrical facilities supporting visualization and data retrieval, like computers or projectors, which students are free to utilize, usually for small special teaching, discussions or meetings); (3) professional classroom (places where students can use professional instruments to conduct academic experiments or professional exercises, usually for students who major in science and engineering, arts or design and be utilized by a fixed group, such as laboratory, painting room, and model making room, students usually have exclusive positions there); (4) self-study room (usually existing in specialized learning buildings, like a library and a learning center, support self-directed learning activities without teachers' involvement, such as searching for paper or electronic materials and discussion in groups); (5) informal learning spaces (places where student self-directed learning activities happened out of class, usually do not specifically target learning and have other functions, characterized by social support, such as social hubs, internal student streets, atrium spaces, or reimaging corridors). The examples of learning spaces are shown in Figure 1.

Traditional classroom | Multimedia classroom | Professional classroom | Self-study room | Informal learning space

Figure 1. The examples of five typical learning spaces.

Our hypotheses can be summarized in the following two statements: (1) students with distinct learning styles have different evaluations about five typical learning spaces when considering the suitability for learning activities; (2) some spatial qualities have more significant effects on perception of learning spaces for different learning style owners.

The aim of the study is to identify: (1) how students characterized by different learning styles evaluate learning spaces when taking efficient learning and preference into account;

(2) which spatial characters affect the perception of learning spaces with regard to diverse learning styles.

2. Materials and Methods

2.1. Survey of Students' Learning Styles and Their Preference

For the first aim, an online survey was conducted to collect students' data about learning styles and preference for spaces. The questionnaire consists of three parts. The first part is to obtain demographic information including gender, age, major, and the contact information if they desire to participate in further experiment. The second part is the Chinese version of ILS to definite participants' learning patterns containing 44 items. The last part is to acquire their evaluations of 5 typical types of learning spaces with regard to their preference and spatial restorative potential, which was obtained by 2 questions, including: (1) "I could pay attention to my task easily and there is no distraction here". (2) "I like here and feel comfortable and pleasure here". Additionally, a 5-point Likert-type scale was utilized to show answers (1 = totally disagree, 5 = totally agree). The questionnaire was pre-tested by 10 college students to ensure its clearness and logicality.

2.2. Identifying Spatial Characteristics Affecting the Perception

Considering the lack of related studies, the method of focus group interviews (FGIs) was selected to find out the influence factors of spatial characteristics. This method is good at identifying meaningful factors from people's subjective feelings and life experiences and is suitable for the initial stage of study [50]. The interview focused on 2 core questions: (1) negative spatial characteristics causing distraction, boredom, or confusion; (2) positive ones encouraging mental restoration, calm thinking, or preference. Each interview consisted of 2 stages: (1) participants were encouraged to write their thoughts freely and alone to avoid similar answers caused by other interference; (2) group discussions were performed, and participants were allowed to add new ideas to their answers. Researchers were responsible for recording the discussion and breaking the ice in conversations.

2.3. Sampling

Electronic questionnaires were firstly distributed in the range of researchers' social circles by e-mail or media platform (such as Wechat or Microblog). Then, respondents were asked to spread questionnaires in their social circles after completion which brought about a snowball effect to expand the scope of investigation. Finally, 200 college students majoring in 3 kinds of disciplines were recruited to accomplish the questionnaires. They came from 6 universities located in various regions of China. In total, 178 valid questionnaires were taken into account with exclusion of obviously thoughtless answers with too short answer time. Table 2 shows the distribution of respondents' individual features.

Table 2. The distribution of respondents' individual features.

Individual Features	Classification	Numbers	Proportion
Gender	Male	82	46%
	Female	96	54%
Grade	First year undergraduate	37	21%
	Second year undergraduate	43	24%
	Third year undergraduate	32	18%
	Last year undergraduate	43	24%
	Postgraduate students	23	13%
Major	Natural sciences	69	39%
	Engineering and technology	75	42%
	Arts and social sciences	34	19%

The participants who expressed intentions of further experiment were invited to FGIs considering the uniform distribution of the gender, grade, discipline, and learning styles.

Five students with distinct LSs were assigned to the same group. Each learning space became the discussion object, respectively. Therefore, five groups were identified. For very few responds with unusual learning styles, advanced interviews were conducted to recognize their favorite or least favorite learning space. Their choices determined which group they were assigned to so that more detailed descriptions would be obtained. The time of each interview was limited between half an hour and 40 min and comfortable meeting spaces were ensured.

2.4. Analysis

SPSS 22.0 software was used for data analysis. Firstly, the reliability of questionnaire was checked by Cronbach's alphas. Secondly, descriptive statistics were conducted to show the distribution of respondents' demographic characteristics and LS. Subsequently, for each dimension, means and standard deviations were calculated, respectively, which provided an initial description of students' preferences. Thirdly the one-way ANOVA analysis was used to identify the significant differences in preference evaluation of the same space of different groups.

Finally, the Nvivo 11 software was used to deal with the data of FGIs. The answers from interviews were firstly translated into English and input into the software. The keywords related to research focus were picked up and converted into professional terms, which formed a list of coded words. Then, words with the same meaning were deleted. At last, the occurrence frequency of each keyword was recorded to identify its importance and universality.

3. Results

3.1. Overall Description of Learning Styles

The Cronbach's alphas of spatial scores and the questionnaire were 0.862 and 0.895, respectively, which indicated a good internal reliability. Figure 2 shows the total feature of respondents' learning styles. For the dimension of processing information, 49.4% of students were found to have an active preference, 50.6% had a reflective preference. Regarding perceiving information, 63% were classified as sensing and others tended to be intuitive. Additionally, 83.1% preferred to remember visual information, while 16.9% obtained verbal information more easily. Moreover, there were 67.4% students evaluated as sequential and 32.6% showed global features when considering the progress of understanding information. Some LSs had significantly more owners than others, such as A-Sen-Vis-Seg (23.5%), R-Sen-Vis-Seg (18%), A-I-Vis-Seg (9%), and R-I-Vis-Seg (6.8%). Some LSs such as R-Sen-Ver-G (1%), R-Sen-Ver-Seg (1%), A-I-Ver-Seg(1%), A-Sen-Ver-G (1%), and R-I-Ver-Seg (1%) belonged to very few respondents.

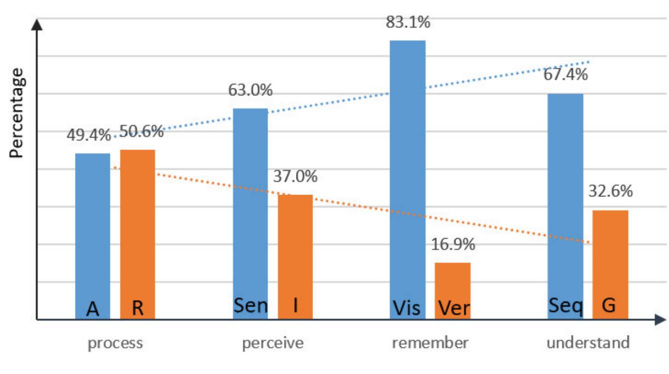

Figure 2. The percentage of responds' preferred manners for each dimension.

3.2. Perception and Preference of Learning Spaces

According to Table 3, the self-study room was rated as the most popular and restorative place followed by the professional classroom, the traditional classroom, the multimedia classroom, and the informal learning space. The results from one-way ANOVA analysis indicated the significant differences between visual learners' scores and verbal learners' scores of multimedia classrooms and traditional classrooms (multimedia classroom: F = 5.980, p = 0.016; traditional classroom: F = 7.583, p = 0.006). Moreover, between sequential participants and global ones, the preference scores of self-study rooms (F = 5.876, p = 0.017), informal learning spaces (F = 4.317, p = 0.041), and multimedia classrooms (F = 4.836, p = 0.031) all differed significantly. Specifically, verbal learners regarded traditional classrooms as places beneficial for focusing attention while visual learners prefer multimedia classrooms. Global learners' preferences for multimedia classrooms and informal learning spaces are higher than sequential learners. However, sequential learners' preferences for self-study rooms are higher than global learners.

Table 3. Average scores for learning spaces by students with different learning styles.

	Traditional Classroom		Multimedia Classroom		Professional Classroom		Self-Study Room		Informal Learning Space	
	Pre	**Res**	**Pre**	**Res**	**Pre**	**Res**	**Pre**	**Res**	**Pre**	**Res**
Active (n = 88)	3.46	3.60	3.71	3.84	4.00	3.96	4.14	4.14	3.46	3.27
Reflective (n = 90)	3.56	3.63	3.57	3.40	3.84	3.76	3.96	4.04	3.42	3.20
Sensing (n = 112)	3.68	3.66	3.45	3.48	4.00	3.89	4.18	4.23	3.46	3.20
Intuitive (n = 66)	3.21	3.58	3.46	3.24	3.79	3.79	3.82	3.85	3.39	3.30
Visual (n = 148)	3.47	3.58	3.80	3.55	3.65	3.68	4.12	4.15	3.45	3.22
Verbal (n = 30)	3.67	3.87	3.33	3.33	3.80	3.73	3.67	3.80	3.40	3.33
Sequential (n = 58)	3.68	3.72	3.40	3.58	4.03	4.00	4.22	4.27	3.33	3.20
Global (n = 120)	3.14	3.45	3.52	3.67	3.69	3.55	3.69	3.72	3.76	3.31

3.3. The Influence of Spatial Characteristics on Preference and Restorative Perception

3.3.1. Group 1: The Traditional Classroom

The common requirements about positive perception are as follows (numbers indicate the frequency of mention): learning atmosphere (5), positive psychological hint (4), silence (5). While, the negative spatial characteristics which have the possibility to interfere with learning and reduce the visiting desire are nervous atmosphere (5), uncomfortable sitting (3), absence of space division (2), fixed seat (2), narrow personal space (3), poor air quality (4), limited supply hubs (2), chaotic people flow (3), smell of food (1). Examples of sentences are shown below:

A1 (male, second year undergraduate, engineering major, R-I-Vis-Seg): I feel the place has overly serious atmosphere which brings back memories of hard lessons. It is hard for me to decide where to sit here because chairs are not suitable for sitting for a long time and there is no sense of being surrounded.

A2 (female, first year of master, engineering major, A-Sen-Vis-Seg): I have narrow personal space although when it is a large room. I can't use my laptop here because of the limited supply hubs. Students may even argue about taking seats. But the nervous learning atmosphere will drive me devote myself to work. So I visit here when facing urgent tests.

A3 (male, fourth year undergraduate, science major, A-I-Vis-G): There are many students working hard here. This makes me feel stressful and motivated. And I will come across new friends here, which is regarded as a novel experience to aspire to.

A4 (male, first year undergraduate, arts major, R-Sen-Ver-Seg): I think it is a pure learning space without other additions and decorations. The electronic devices often distract me so their absence is a good thing for my learning.

3.3.2. Group 2: The Multimedia Classroom

The key themes related to positive experience contain visualization equipment (5), flexible furniture (5), decoration (2), clear vision of screen (3). The distractions are including electronic devices (4), disordered furniture (2), narrow space (2), bad ventilation (3). Examples of sentences are shown below:

B1 (female, first year of master, engineering major, A-Sen-Vis-G): I like here because the smaller space increases sense of security. I can see the screen clearly even when sitting back. My works could be presented more conveniently here with the help of equipment. B2 (male, second year undergraduate, science major, R-Sen-Ver-Seq): I seldom take it as an ideal learning space because the laptop, projector or other advanced electrical equipment often distract me and are unnecessary for my learning.

B3 (male, third year undergraduate, social science major, A-I-Vis-Seq): I don't like the space. The tables wrapped around in a circle are more suitable for extracurricular social activities rather than formal learning activities in my opinions. And the room is so small that I can't take a fresh breath.

B4 (female, second year undergraduate, engineering major, A-Sen-Vis-Seq): This place is occupied by electronic equipment and seems cold and emotionless. I don't think I belong to this place. I often feel tight in my chest when surrounded by computers or screens.

3.3.3. Group 3: The Professional Classroom

The positive factors are familiarity (6), access to facilities (5), bright light (3), teacher guidance (2), practical activity (2). The distractive or boring factors are excessive communication with acquaintance (3), disorderly furnishings (4), teachers visiting (1), bad hygienic conditions (2). Examples of sentences are shown below:

C1 (female, second year undergraduate, natural science major, R-Sen-Ver-G): I am familiar with the environment. Moreover I can keep some personal things here and set the desktop or chairs according to my habits or preferences. These all make me feel comfortable and safe.

C2 (male, second year of master, medicine major, A-I-Vis-Seq): I could conduct experiments to consolidate knowledge. Most of my innovative works are also done here. I could concentrate on myself more easily because there is nothing unrelated to learning around me.

C3 (female, third year undergraduate, engineering major, R-Sen-Vis-G): I seldom come here to study because I often indulge in chatting with classmates and waste much time there. Sometimes teachers will come here which makes me nervous.

C4 (male, fourth year undergraduate, engineering major, R-Sen-Vis-Seq): My professional classroom is furnished disorderly and optionally and every corner is crammed with personal belongings, which make me feel whiny.

3.3.4. Group 4: The Self-Study Room

Participants paid more attention to these spatial features with regard to preference or restorative experience, including: comfortable temperature (3), learning atmosphere (4), rest areas (2), silent environment (5), digital resources (5), WIFI support (3), good facilities (6), spacious (2), green plants (3), colorful chairs (2), beautiful view from window (2). Additionally, negative factors are noise (5), peer pressure (6), low accessibility (2), worry about having a seat (3), close interpersonal distance (2), other people's movements (4) when considering distraction or aversion. Some descriptions of the self-study rooms from participants are presented below as examples:

D1 (male, second year master, engineering major, R-I-Vis-Seq): I like to study here because it is spacious and I have a higher field of vision. I feel this place well designed and equipped because of pot plants, orderly arranged chairs and desks, which allow me think intently and deeply.

D2 (female, third year undergraduate, natural science major, R-Sen-Vis-G): The place brings me learning atmosphere without seriousness. Compared with familiar classmates, there are less acquaintances around me which makes me more relaxed.

D3 (female, first year undergraduate, engineering major, R-I-Ver-Seq): There are too much people concentrating on their studies which forms the peer pressure and makes me feel nervous and worried. And too quiet environment makes me sleepy and agitated especially when I am trying to remember something.

D4 (male, fourth year undergraduate, liberal art major, A-I-Ver-G): Too quiet environment makes me overcautious and I am always worried about making noise or disturbing others. If I tend to visit there, I have to bring plenty of study materials like books or laptop. I think it is very inconvenient.

3.3.5. Group 5: The Informal Learning Space

The positive factors reflect in relaxed atmosphere (3), free to talk (3), high accessibility (1), food support (2) and the distractive elements include flow of people (3), noise (2), pets (3), absence of furniture (1), dim light (3), money cost (2), and children at play (2). Partial views are below as an example:

E1 (male, second year undergraduate, engineering major, A-I-Ver-G): I prefer to learn here because of its more relaxed atmosphere. I will not worry about disturbing others even if I discuss with companions or recite texts in a whisper. I usually listen to light music with headphones on, under the circumstance, the white noise around me has become helpful for my learning.

E2 (female, second year undergraduate, liberal art major, A-I-Ver-Seq): I often visit there to review my lessons because it is close to my dormitory and I can buy cakes, coffee or lunch there. So I would do studies immediately after eating.

E3 (female, second year undergraduate, natural science major, R-Sen-Vis-G): I seldom do my learning here because it contains many uncertain elements, such as noisy parties, lovers' meeting or the sudden appearance of cats. So I can't engaging in learning here. and there are not tables big enough to put my books or laptop on.

E4 (male, first year master, natural science major, R-Sen-Vis- Seq): I think there are too many elements distracting me here, like playing children, background music, food temptation, crowed people. Moreover the dim light makes me sleepy and the daily table is not suitable for writing.

4. Discussion

4.1. The Whole Feature of Learning Styles

According to results, there are more active, sensing, visual, and sequential participants in our sample, which reflects the features of Chinese campus students. It may be explained by the education system in China and the aim of good examination scores. The knowledge is input into students directly, which results in the weak abilities of thinking things through alone and organizing the materials. Thus, more active learners occur, who like to discuss with and learn from others. In addition, students usually understand knowledge by practicing and memorizing repeatedly. Therefore, most choose to learn things step by step, which explains the high frequency of sequential learners. Additionally, Felder and Spurlin (2005) stated that there is a moderate correlation between the dimensions of perceive and understand. The sequential learners organize information gradually and tend to be sensing. This finding supports the combination of sequential and sensing. At last, more visual learners may be due to more legibility and vividness of picture information than words, especially for complicated knowledge in university courses. Understanding the proportion of distinct learning styles helps to know the preference of most people, which is useful for designing the suitable learning spaces for different groups.

4.2. The Influence of Learning Styles on Perception and Preference

The present study tells us that two dimensions of LS have an influence on perception of learning spaces (Table 4). The dimension of understanding has a relationship with the evaluation of self-study rooms, informal learning spaces, and multimedia classrooms. Specifically, when it comes to self-study rooms, sequential learners have given a higher rating than global learners. This may be due to the fact that the environment supplies particular information which they prefer and understand easily. It is generally agreed that sequential learners usually follow a linear and successive thinking path and are guided more easily in similar ways [51]. Therefore, the standard and specialized facilities or settings, like neatly arranged tables and settled chairs, fit with their logical habitat better. Secondly, the informal learning spaces seem more suitable for global learners. According to Pasheler et al. (2009), global learners seldom undertake the rote learning manners so that they have lower requirements for silence or facilities [52]. Moreover, the relaxed and informal environment give them more freedom to think. Thirdly, sequential students encode the information successively and continuously and global ones tend to synthesize the separate parts into a whole [52]. Therefore, the electrical equipment in multimedia classroom supporting clear visualization of knowledge becomes a positive factor for the global learners.

Table 4. The relationship between dimensions of learning styles and perceptions of learning spaces.

The Dimension of Learning Styles	The Type of Learning Spaces				
	Traditional Classroom	Multimedia Classroom	Professional Classroom	Self-Study Room	Informal Learning Space
Processing	✓ Verbal > Visual	✓ Verbal < Visual	/	/	/
Perceiving	/	/	/	/	/
Remembering	/	/	/	/	/
Understanding	/	✓ Sequential < Global	/	✓ Sequential > Global	✓ Sequential < Global

Note: "✓" shows the dimension has significant effects on the perception of this learning space, listed below is the comparison of preference of distinct styles.

The dimension of processing proved to be related with participants' perceptions of multimedia classrooms and the traditional classroom. Verbal learners reported a lower degree of focus in the multimedia classrooms because of too much unacceptable graphic information [53]. Additionally, according to Silberman (2002), the multimedia classroom achieves visual presentation of most learning materials to satisfy the need of visual learners [54].

4.3. Influence Factors of Restorative Perception and Preference

Participants with distinct LS attach importance to various aspects of space. Some spatial features are regarded as positive for one group while negative for others. In line with previous research, some characteristics of traditional classrooms are widely recognized as negative for learning activities, such as the poor facilities, absent support for mobile learning, narrow personal space [55,56]. However, it is controversial if the serious learning atmosphere and silence here are positive for learning activities or not. In our studies, sensing learners seem to regard it as positive encouragement while intuitive learners think it brings too much stress or displeasure. This can be explained in terms of intuitive learners' need or preference for abstract and innovative environmental stimulation which traditional classrooms cannot supply [51]. While, sensing learners focus more on perception than intuition which will be innovated better by normative and classical environments. It further emphasized the importance of a combination of traditional classrooms and new learning spaces, which is consistent with Park and Choi [57].

The advocates of multimedia classrooms obtained satisfaction from characteristics including flexible furniture, visualization of learning material, and smaller spatial scales. The dissenters regarded the electronic equipment and removable desks as distraction more than effective tools. As mentioned earlier, the visualization of learning materials is not beneficial for all students, especially for verbal learners, who obtain more information from words than pictures [38]. Moreover, active learners have more possibilities to give a positive evaluation because they like communicating with companions and improve themselves by cooperating with others, which will be supported better in multimedia classrooms [57].

The positive aspects of professional classrooms in terms of restoration and preference are mainly focused on the familiarity with environment settings and freedom to use facilities, which bring better control over the environment. This phenomenon has been obviously reflected on reflective learners who like studying alone, because the small familiar environment will offer them more personal space and feelings of safety. Moreover, for intuitive learners, the professional classrooms are equipped with professional facilities which meet their needs of practicing and doing experiments. Otherwise, visual learners consider classmates, teachers, and disorderly furnishings as distractions for them. This may be explained by their perceptive features in terms of sensibility to graphic information [38].

Research on self-study rooms obtain consistent results with previous studies. On the whole, the space revealed a wide satisfaction depending on its comfortable and silent environment, digital resources, good facilities, nice decorations, and so on. Then, more details were presented. Reflective learners usually focus on theories in books and are in no hurry to practice, so lots of references stored in the libraries may attract them. On the contrary, the silent environment and standardizing system in most learning buildings will be a kind of barrier or rigid control for active learners who remain outgoing in the process of learning and always try to discuss with others.

In informal learning spaces, there are some distractive environmental characteristics adding the cognitive loads such as noise, playing children. However, it seems that some people are able to adapt to these and enjoy the benefits from this space, like delicious food and easy visiting. It may be explained by Felder and Spurlin's conclusions (2005) that active learners like group discussion and verbal learners are less sensitive to graphic information. Therefore, they could ignore the disadvantages of informal learning space. However, it is easier for sensing learners to pay attention to the irrelevant elements, so they suffer much interference here.

4.4. Implications for Designers, Planners, and Stakeholders

The present findings prove that the preference for learning spaces in campus and the perception of spatial elements differ from LS, which identifies the key points of designing or optimizing the learning spaces. Personalized spatial settings should be considered to satisfy the needs of different groups in order to enhance their preference and visiting desire. Meanwhile, the studies supply instructions for campus administrators to plan and allocate learning spaces.

4.5. Limitations of the Study

The relatively small number of participants presents limitations with regards to generalizing the findings to a larger group. Additionally, the regional culture, learning environment, and majors all have effects on learning styles. Therefore, results may differ when samples change. Some demographic characteristics may affect the perception of the space and the assessment of individual LS, such as gender, age, major, familiarity of environment, environmental value orientation, which will be explored in further research. In addition, the related spatial elements could be identified preliminarily by the method of focus group interviews. More investigations and assessment should be conducted to explore the degree of its effect. At last, considering the inconsistence in the measurement of LS, another evaluation method instead of Felder-Silverman learning style model may result in distinct results. One's LS may change as he or she interacts with the environment, so the results could only reflect individual preferences in the current period of time. As a whole, we tried to explore the effects of personality on spatial perception from the view of LS. Although this is an alterable and debatable attribute, it can to some extent represent the characteristics of one person within some specified period. Additionally, the findings provided preliminary indicators describing the relationship between LS and learning space perception, which need further studies with larger and detailed samples and more comprehensive measurements before they could be used to guide the design.

5. Conclusions

The effects of built environment on individual behaviors have been widely concerned in architecture design. In addition to spatial features, the demographic characteristics have also been proved to affect the perception of learning spaces, such as gender, grade, and major. However, unlike recreational experiences, the individual factors have more impacts on learning activities, especially for students. For example, people could stop visiting a park if its landscape is not beautiful. However, students still have to visit a learning space even if they do not like it. Therefore, the ordinary demographic characteristics are not enough to express the individual differences in the process of learning. Due to the differences in intelligence, talents, habits, and ways of thinking, people will make distinct responses to the learning spaces, even if they belong to the same gender or grade. Studies on LS supply a tool to evaluate them. The learning spaces in line with students' LSs would motivate better task performance, more efficient learning actions, and higher desires to visit. Therefore, the deep understanding of the relationship between LS and the perception of learning spaces is of great importance to develop design strategies.

Our results firstly ranked the preference degree for five typical learning spaces. Then, we compared the preference of different style owners for each learning space, respectively. The significant differences were identified. Specifically, the preference of verbal learners and visual learners for traditional classrooms and multimedia classrooms are distinct. The same goes for the preference of sequential learners and global learners for multimedia classrooms, self-study rooms, and informal learning spaces. This indicates that two dimensions of LS have significant a influence on perception and preference for some typical learning spaces in the university campus, including processing and understanding. At last, certain spatial elements were discussed and their impacts on preference perception were evaluated qualitatively. Although there was no statistical difference in the perception of learning space among individuals with style differences in the other two dimensions, some special spatial elements caused dissension from participants of each learning style. For example, the serious learning atmosphere and silent sound environment in traditional classrooms are positive for sensing learners, but negative for intuitive ones. This result puts emphasis on detailed consideration about satisfaction of personalized needs and calls for larger and wider samples to explore the correlativity further. Additionally, there is no such person as a pure style in nature. The measurement result of LS just indicates the frequency of which they behave in the specific style. Therefore, more comprehensive and deeper studies are required to explore how students with distinct features perceive and cognize the learning spaces.

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Article

Survey on Student School Spaces: An Inclusive Design Tool for a Better School

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Abstract: This paper presents interdisciplinary research focused on the collaborative redesign in schools, in which an inclusive design tool was created for assessing student feedback on their school spaces and considering it as input for creating a better learning environment. It was developed by a research team using a participatory approach in schools drawn from architecture, geography, and educational sciences, to provide a comprehensive and intertwined approach to school spaces, communities and learning activities. The "Survey on Student School Spaces" (S3S) tool and its methodology are described here, which is a combination of two procedures: a questionnaire and a walkthrough. The first engages a far-reaching sample of participants and makes use of an online platform, while the latter details and justifies those outputs and involves visiting the school with the participants. The S3S pilot study was implemented in two partner schools, which act as the first project case studies. The data provided by this tool acted as the basis for the design proposal for one of the case studies, which included the students' feedback and involved all the community in the school's refurbishment. Finally, a discussion was held on the outputs achieved that may contribute towards a participatory design approach in other schools, the validation of the tool per se, and its potential future development and application.

Keywords: school space; students; survey; participative design; inclusive research tool

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1. Introduction

This paper investigates how students evaluate their school spaces and how they propose the refurbishment of those spaces toward the creation of more suitable learning environments for the diverse activities within these schools. This, ultimately, aims at the co-creation and co-rehabilitation of the existing school building stock by considering student feedback as an effective input to both the research into and design of school spaces. For such purposes, it presents a tool which has been implemented in two basic schools with contrasting social and urban contexts in the Portuguese city of Coimbra.

There is wide acceptance in the literature that comfort and well-being in the physical space are paramount for promoting learning and student achievement [1–5] (p. 16) ("School facilities affect learning. Spatial configurations, noise, heat, cold, light, and air quality obviously bear on students' and teachers' ability to perform." [5] (p. 16)), as well as for affecting "teacher mind frames" [6] (p. 19). ("The review sought to establish the existence of any evidence concerning the impact of learning environments on teacher mind frames." [6] (p. 19)). Innovative learning environments have also been shown to impact learning outcomes [6–8] (p. 40). ("It finds a trend is becoming evident that suggests ILEs have a positive impact on student learning outcomes. While this is optimistic, it cautions over-stating of this trend at this time." [7] (p. 40)) (. In addition, not only are classrooms in the traditional sense known to be relevant enablers and enhancers for teaching and learning and considered, therefore, to be "learning tools" [9,10], but informal activities and peer interaction also have pedagogical significance in all school spaces, such as the interaction that takes place in outdoor playgrounds and schoolyards [11,12]. In addition, the uncertainty on the teaching practices, places, and dynamics brought by the pandemic context we live in today, along with the constantly changing circumstances of curricula, teachers and staff, student profiles, teaching practices, and relentless technological advancements have created an environment in Portugal that is highly changeable and uncertain.

This implies a need to rethink the school space, to perceive it as an adaptable environment for current and future learning activities and teaching processes, and to consider school buildings as changeable and adaptable to current and upcoming constraints and requirements [13–15].

The research here presented makes the case for a more participatory school design process for both new projects and the refurbishment of existing ones, in order to cater for present and future needs—a process in which students are included in the decision-making about the environments in which they carry out their daily social and learning activities, creating spaces that are sufficiently flexible and resilient over a longer period of time [14,16].

Furthermore, it is proposed that the community be provided with the ability to perceive and to comment on space by means of user-friendly tools, leading to outputs that can be acted upon by designers, politicians, school leaders, and decision-makers, as a complement towards a more comprehensive and inclusive process.

This perspective is supported by the Organisation for Economic Cooperation and Development (OECD), in its recent guidance on *What makes a school a learning organisation?*, where "developing and sharing a vision centred on the learning of all students" and "establishing a culture of inquiry, innovation and exploration" are paramount guidelines to achieve it. This is specifically detailed on the following five actions, which are particularly in tune with the methodology of inclusiveness proposed in the research:

> "A shared and inclusive vision aims to enhance the learning experiences and outcomes of all students;
>
> The vision focuses on a broad range of learning outcomes, encompasses both the present and the future, and is inspiring and motivating;
>
> Learning and teaching are oriented towards realising the vision;
>
> Vision is the outcome of a process involving all staff;
>
> Students, parents, the external community and other partners are invited to contribute to the school's vision". [17] (p. 2)

To this end, this paper describes an interdisciplinary research project which considers that different areas of knowledge can converge to form a more complete investigation, and offers potential guidelines on this subject, as well as the idea that diverse geographical and academic contexts can provide further information for a more holistic and wide-ranging approach to a wide array of site, community, and pedagogical contexts.

In view of the above, this paper presents a study that is currently happening in Portugal within a European Union co-funded Erasmus+ research project. The project, named "CoReD Collaborative Redesign with Schools", includes six international partners from broad geographical contexts. (e.g., University of Newcastle Upon Tyne (United Kingdom), Hogskolan I Gavle (Sweden), Libera Universita di Bolzano (Italy), University of Iceland (Iceland), Aarhus Universitet (Denmark) and University of Coimbra (Portugal).) Starting in October 2019, this project aims to develop user-friendly tools for school practitioners to observe school spaces according to their learning potential. Each partner proposes and implements their own tool, as well as testing some of the other tools in their local case studies. This research project argues for a more comprehensive outlook on schools, drawn from each country's cultural, social, and educational contextual specificities, as well as from the potential common denominators for qualified and effective contemporary learning spaces.

Within this project, the Portuguese researchers have developed the "Survey on Student School Spaces" (S3S) tool that is being used in national case studies and is simultaneously being applied internationally by other partners and schools. (e.g., the United Kingdom and Italy, but due to the reach of the CoReD website, it has also attracted the interest of external practitioners and is being implemented in other settings such as Australia.) The widespread testing of S3S acts as a means to perceive the use of space by students, and it also provides information on whether different spatial, social, and pedagogical contexts are relevant to student spatial dynamics in school and spatial appropriation.

2. Research Methodology

Being supported by knowledge development from previous research focused on school buildings and specifically spatial adaptability in schools [14,16,18], as well as from research on educational planning [19] and educational policies, the research team was created based on a shared academic vision that goes far beyond the reductive disciplinary perspectives that can be characterized (and are still accepted by many) as the science of exclusion, in which the compartmentalization of knowledge is seen as being both firm and fixed [20,21]. Within this context, the Portuguese team included academics from areas as diverse as architecture, education science, and geography, with the intention of creating a tool built and developed to ensure that a holistic vision was employed from the outset. The tool was constructed so that the different types of knowledge with their different practices can work together [22] (p. 162), incorporating developments that have occurred over the last few decades in which the old ways of stricter specialization have given way to newer ideas that embrace interdisciplinarity study [23,24]. This is our understanding of what António Pedro Pita meant when he said that the present is heterogeneous, although the roots that give it form have their own individual stories, which are different from each other and sometimes even cannot be shared [25].

It is within this context that the project, which is transversal in nature and based on the sharing of knowledge, has the principal objective of applying a tool to a municipal territory that consists of a mosaic of heterogeneous entities, to enable the transformation of educational spaces (and their surrounding environments) with the participation of the students who use those environments. This objective is linked to the understanding that the phenomena and habits associated with the educational environment can only be understood when analyzed from an interdisciplinary viewpoint, in which the different areas of social and human sciences and architecture come together as one, complementing each other in an attempt to answer the complex questions posed in the post-modern era, by means of the promotion of an inclusive and critical reflection by the students about the modifications that can be made to the educational space, based on their experience and empirical knowledge.

This research also took place at a particularly significant time in the lifecycle of the Portuguese schools. On the one hand, they are living through a period in which the central state is transferring political competencies and responsibilities in the field of education to the municipalities while announcing the strengthening of the autonomy of schools. On the other hand, schools have been asked to take on truly inclusive spaces, diversifying educational experiences, and also creating conditions for students to stay longer, engaging them in different activities. As Reboul [26] recalled, the School will be inclusive, not because it teaches inclusion, but when it organizes itself as a community that continuously exercises practices that constitute relationships, where everyone can build their identity without discrimination, exercise initiatives and talents, act for the common good and feel challenged to have their own opinion, consensual within the different networks of belonging, on the important issues of the School. The recognition of these rights and the duty to find strategies for their implementation is at the basis of this research, giving students the opportunity to comment on the educational spaces they would like to have, being able to see the results of their ideas and proposals materialized.

The S3S tool integrates a diverse set of data collection tools, designed to help describe and understand a specific situation, as suggested by Tuckman [27] on the *Manual of Research in Education*. In the present study, as can be confirmed in Table 1, the methodology is organized in six stages, ranging from analyses to an effective design proposal, which means going from understanding the context to a proposal for refurbishing school spaces, supported by a participatory process.

Table 1. Sequential methodological development of the S3S tool.

Stages	Objectives	Methods/Techniques	Participants
1.	Socio-geographic analysis of the schools and the city	Analysis	research team
2.	Identify the school spaces most used by the students	Interviews	school community
3.	Feature the activities and feelings that students experience in the most used school spaces	**Questionnaire** Development and provision of the online questionnaire and collection of answers	students
4.	Process the collected data	Synthesis Synthesis of the of the outcomes from the questionnaire	research team
5.	Seek consensus on concrete proposals for transformation of the physical spaces of the school	**Walkthrough**	students, from different groups/classes
6.	Design the refurbishment proposal of these spaces	**Design proposal**	design team

So first, after the selection of schools, based on socio-geographic criteria of representativeness of different features of the school within the municipality; preceding interviews were conducted with the school community, to identify the most used spaces by the students and to fine-tune the questions for the questionnaire. Then, the questionnaire was made available to be answered by the students. This was considered S3S's first milestone.

Subsequently, the results of the questionnaires were analyzed to support the following stage. Here, walkthroughs were organized with students from each class/group who had previously answered the questionnaire, with the purpose of clarifying and deepening the use and feelings experienced in different spaces of schools, simultaneously collecting proposals for the transformation of the space that could improve the quality of its attendance. This was, thus, S3S's second milestone.

Finally, with the data collected, the last stage was activated by a design team that was able to elaborate possible proposals for refurbishing the school spaces. These were then debated with all the school community so that a co-creative solution could be developed and implemented.

We will now specifically address the first milestone of this sequential procedure, which was the questionnaires. Questionnaires are widely used in descriptive studies as a data-collection tool, especially when the general opinion of a determined population needs to be gathered on a specific subject.

In this case, the questionnaire is developed to address all the school spaces classified by their type as outdoor spaces; formal learning spaces; study spaces; eating spaces and passageways and halls. Hence, from the wide array of spaces, the school community overall was asked to identify the spaces that were most used by the students on a daily basis, and which need to be analyzed the most by using this tool. Hence, it was the schools' decision on which spaces to focus on, in each case study. The chosen spaces were then photographed, and a photo of each space was used in the questionnaire. Participants were asked to give their opinion on type and frequency of usage, feelings experienced, and existing conditions, by responding to the following questions using the Likert scale (Table 2). (Likert scales and the semantic differential scale allow the participants of this study to express their level of agreement in relation to self-descriptive statements, characterising their level of frequency in the different school spaces, the use they make of them and the feelings they experience within them).

Since the S3S tool was developed during a worldwide pandemic context due to COVID-19, the choice of using questionnaires brought an added advantage to this research, because it provided us with feedback on school spaces from the students, without physically accessing the schools. This enabled the project to overcome that increased difficulty that the pandemic brought to research on schools. Even during the lockdowns, students were able to reply to this questionnaire from their homes, either on their phones, tablets, or computers. For that purpose, an online and easy-to-use template was developed, as the basis for every questionnaire, which each school could copy and edit, according to their specificities and spatial needs (Figure 1).

Once the information from the questionnaires was processed, a selection was made of the information considered to be most pertinent, and this was used as the main topic of debate in the walkthroughs during visits to the spaces in the following phase of the research, also referred to in the literature as *site-specific focus groups* [28] or *walkthroughs*. Focus groups in general, are a special case among collective interviews and have increasingly come to be used in the practice of qualitative research as well as a methodology for the analysis, understanding, construction, and development of knowledge in socio-educational settings [29,30]. This is because they provide access to information that is the result of a collective assumption of convergent opinions, or of a generalized disagreement, manifested in situations of discussion which are created and recreated, for the group and within the group, as individual and collective reflections arise, in an intersubjective construction of meanings and feelings.

Subsequently, and as the second milestone of the methodology, the walkthroughs were here considered a technique to complement the questionnaire. The groups consisted of ten students each, and the walkthroughs were held throughout the different school spaces that were chosen for the creation of the questionnaires. The debates were led by teachers—class tutors—with researchers accompanying the route through the school and all the debates, as non-participant observers.

As explained, the main objective of this study is to involve students with the physical spaces of their schools, by assessing the types of usage and feelings experienced, as well as their expectations and desires for proposing transformations and changes at different scales on these buildings and surrounding spaces. The tool created for this purpose implied two milestones for gathering student feedback: the first, the questionnaire regarding general patterns of spatial usage, and the latter, the walkthrough, as a more thorough approach to the previous data, and also as a means to justify and detail specific issues previously expressed by students. Hence, by including these two moments of student engagement with their schools, by listening to them and listing their perceptions of school space as possibilities of future spatial refurbishment, this tool enables a sense of ownership and empowerment and, ultimately, it intends to improve schools through a participatory design approach by the students attending it.

Table 2. List of questions for the questionnaire.

Students Online Survey	
1. I am usually here	• Several times a day • Once a day • A few times a week • Rarely • Never
2. I usually pass through here	• Always • Many times • Sometimes • Rarely • Never
3. When I am here	*(always | many times | sometimes | rarely | never)* • I use my mobile phone • I talk about the courses • I talk about everyday things • I have fun with my classmates • I read • I study or do my homework • I interact with teachers • I like to be alone with my thoughts
4. How I enjoy this place	*(I like it very much | I like it | I don't like it very much | I don't like it)* • Size • Comfort • Light • Equipment • Location
5. How I usually feel in this place	*Select the option closest to the mood that best translates your feelings when you are here.* • Happy/sad • Excited/discouraged • Relaxed/nervous • Inspired/uninspired • Active/indifferent
6. In this place, I mostly enjoy:	*Open answer*
7. In this place, I would notably change:	*Open answer*

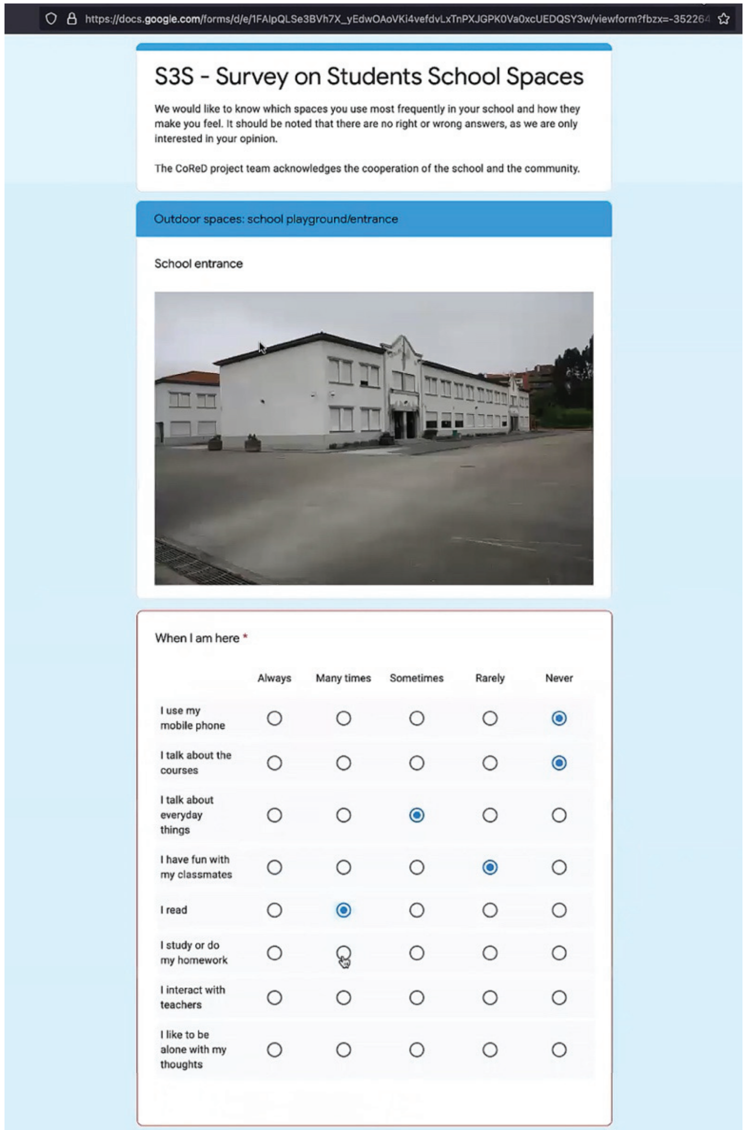

Figure 1. Questionnaire sample.

3. Context and Objectives

The municipality of Coimbra, located near Portugal's central coastline, was chosen as the Portuguese case study. Its population in 2021 was 140,796 inhabitants (including more than 21,000 pre-university students of all levels), distributed over a territory of 319.4 km^2. Morphological characteristics are heterogeneous, with a low mountain range to the east, low hills, and a vast alluvial plain to the west and center, with the Mondego River acting as a strong natural barrier to intra-municipal mobility (Figure 2).

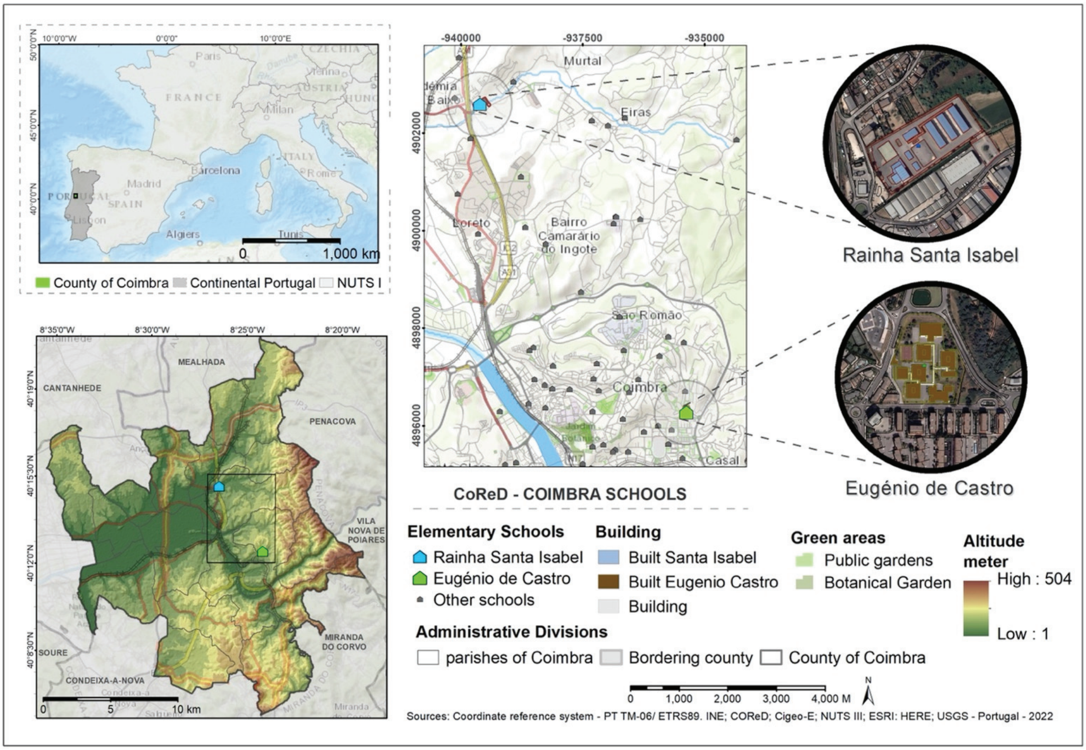

Figure 2. Coimbra Municipality and CoReD schools—Location and main characterization.

The choice of the municipality of Coimbra as the territory to be studied, as well as of two of its schools for the implementation of the tool, was essentially related to the following: the annual academic results achieved in this municipality; present development of a strategic plan of municipal education built on bottom-up logic; a higher school performance than the country average; the geographical proximity of the project team to these schools; the propound knowledge of this territory (socio-economic, demographic, and educational, among others), and the varied architecture offered.

We sought to work with partner schools in different sectors of the municipality, in which the socio-economic and cultural environments were very different from each other [31–34]. Even though this tool may be used by schools with different levels, for the pilot study two basic schools were chosen–from grade 5 to grade 9 (10–15 years old), which corresponds to a full study cycle in Portugal.

The choice, therefore, fell on the "Escola Básica Eugénio de Castro" (EBEC), located in one of the newer centers of the city which is predominantly inhabited by the upper and upper-middle social classes, and the "Escola Básica Rainha Santa Isabel" (EBRS), situated in a peri-urban area encompassing a large rural area to the north of the municipality. This fact caused the EBRS to be included in the *"Territórios Educativos de Intervenção Prioritária"* (TEIP) program in 2009/2010, a priority educational intervention program for schools located in socially and economically deprived areas, ones in which poverty and social exclusion are common, and in which violence, behavioral problems, neglect, and academic underachievement are rife. It seems to be clear that school buildings cannot be understood, interpreted, and further developed without the surrounding society and geopolitical context [8].

The two partner schools involved at this stage of the study present two differing school populations. This is largely due to their size and location, although both schools teach grades 5 to 9. EBEC, which has 938 students and EBRS, which has 533 students, are both at their maximum capacity relative to student intake, in accordance with the rules laid out in the *Carta Educativa de 2ª Geração do Município de Coimbra* [35]—the Municipal Education Charter for Coimbra. School capacity is decided in accordance with the type of buildings in which the school is housed, which is also a result of the demographic make-up of the area in question. EBEC is located in the most populous parish of the municipality, with statistics showing that its population figures come in at over 45 inhabitants per statistical territorial sector, whereas at EBRS, the statistical territorial sectors only rarely achieve those figures (Figure 3).

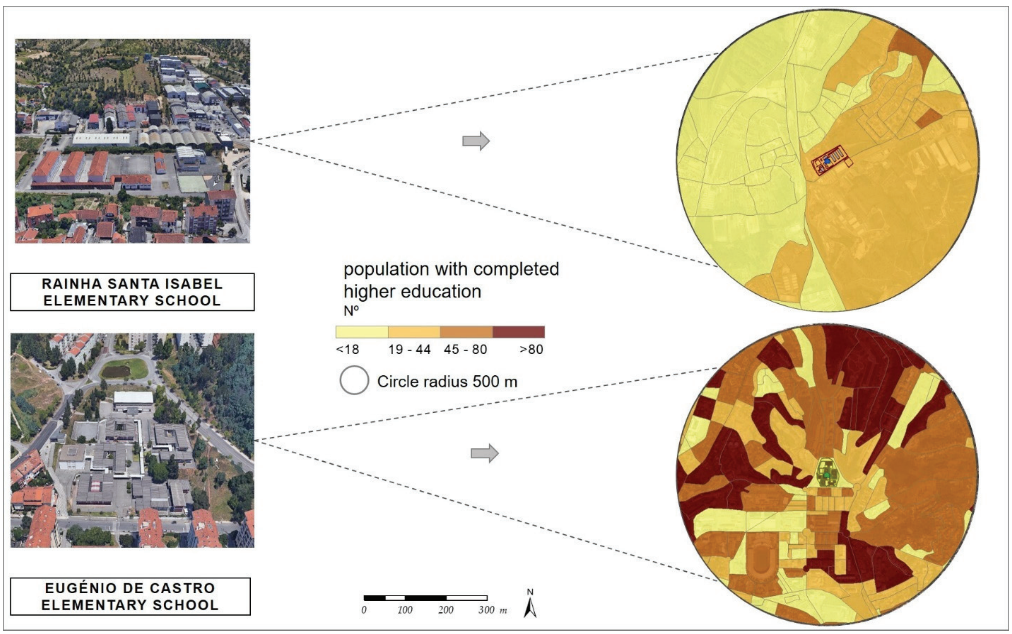

Figure 3. Demographic context of the territories surrounding the partner schools.

The choice of the partner schools was, however, mainly down to the social, cultural, and economic environment in which the schools are located, as the intention was for the same tool to be used by students from different economic backgrounds and family situations. (For this purpose, and making use of a methodology used in previous work [32,36], a multivariate analysis was carried out using "Principal Component Analysis" (PCA) methodology, as well as "Hierarchical Cluster Analysis" (HCA). By using the results of PCA, HCA methodology permits the aggregation of territorial units that have similar characteristics. This aggregation used the Euclidian distances between the individuals, and the Ward method [37,38]. Five territorial clusters were then defined from the resulting dendrogram, with only the relative position of each of the factors considered in the PCA analysis being taken into consideration [36]).

The municipality was then divided into five levels of territorial dynamics, based on 34 variables (in accordance with four socio-economic dimensions: education and qualifications; demographics; economic activity and employment; and standard of living). These five levels are—Highly dynamic territories; Moderately dynamic territories; Low dynamic territories; Stagnant territories; Regressing territories [36]. As can be seen, the two schools are located in sectors with very differentiated territorial dynamics: ESEC is located in a Highly dynamic territory (in the above-mentioned urban center—Solum), whereas EBRS is located in a rural, peri-urban center which consists predominantly of Stagnant territories and Regressing territories (Figure 4).

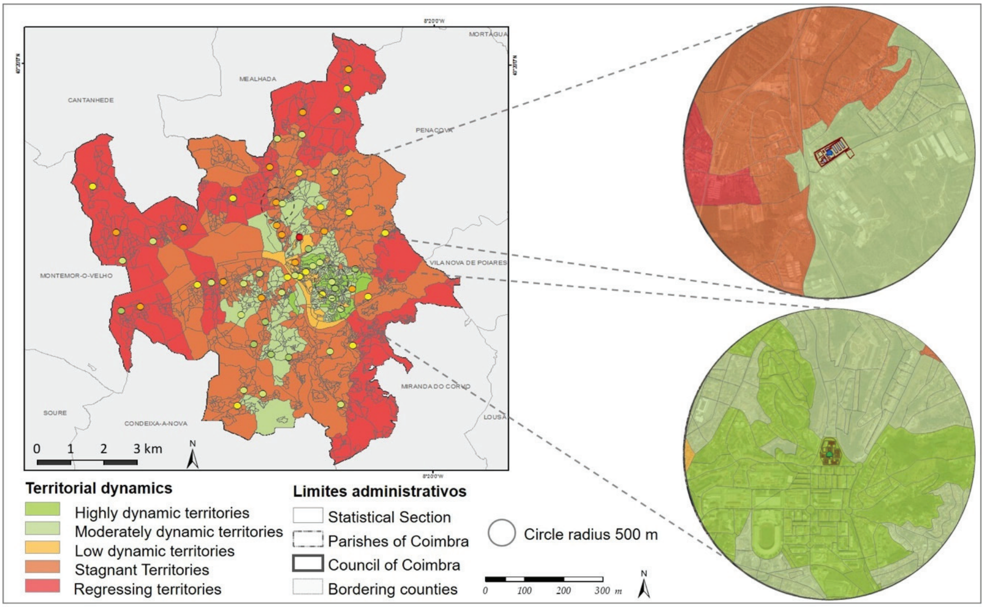

Figure 4. Socio-economic framework (based on the PCA and HCA) of the territorial environment of partner schools.

Given the very differentiated territories in which these two schools are located in both demographic and socio-economic terms, the academic qualifications of the parents in both schools were looked at and considered. In final-year students (grade 9–aged 15) the levels of academic qualifications between the two sets of parents were found to be diametrically opposed. Whereas in EBEC, 42.4% of the mothers had qualifications that are equal to or higher than degree level (for fathers the figure is 37.2%), at EBRS this percentage fell to 23% for mothers (and in the case of fathers, 20.5%). Relative to parents who are qualified to the Ph.D. level, no parent or guardian in EBRS had achieved this level, whereas, at EBEC, the inner-city school, 2.2 % of parents or guardians were educated to this level. As can be seen, the territorial realities for students of the same ages and levels are very different despite both schools being located in the same municipality, thereby providing a very interesting field of study.

From an architectural viewpoint, both schools are set out in pavilions, with the various functions each taking place in a different pavilion–teaching, administration, sport, common areas (library, canteen, bar, etc.)—with a large open space for informal recreation. This model is the result of a set of innovative educational policies that emerged in the late 1960s, in a country subjugated to a dictatorship (1926–1974) that assumed top-down logics, and which led to an equal architecture whatever the place of the country. Moreover, this same vision continued even after the advent of democracy brought by the Portuguese revolution of 1974, with projects still being defined centrally. Schools, although emerging from different political and institutional contexts and dating from different times—one prior and another after the democratic revolution—still maintain a centralizing perspective for their definition and construction, even if they present themselves as physically diverse [18].

“Escola Básica Eugénio de Castro” (EBEC) (Figure 5—left) was one of the first projects, built in 1972, and featured two main innovations: the polyvalent room in the center of the school, acting as its core, and the classroom blocks for general classes and also with a separate block for specialist technical and manual teaching, all of which are deployed on the plot and connected by vertical and horizontal exterior circulations. Each block consists of one floor with eight classrooms around a central patio. The classrooms pursue a modern language, with windows on two sides, and a capacity for 25 students. They are square in shape, allowing for different classroom layouts. This typology continued to be adopted after the democratic revolution in 1974, but the architectural choices that were then made lost their innovative pedagogical and design features due to the need of building schools for large numbers of students, as a result of the extension of compulsory schooling to grade 9.

Figure 5. Drone images from CoReD partner schools—Escola Básica Eugénio de Castro (EBEC) (**left**), Escola Básica Rainha Santa Isabel (EBRS) (**right**).

"Escola Básica Rainha Santa Isabel" (EBRS) (Figure 5—right) was built in 1999 and consists of three classroom blocks in parallel and one block for a canteen, all connected by a covered pathway and with a much expansive scale than the previous ones. In addition, opposite to the previous school, these blocks consist of two floors, with a single-loaded central corridor. The classrooms have a traditional layout, with 4 windows to the east or west, and hold 25 students, with desks set out in rows.

Hence, in a comparative analysis, these schools clearly differ in their site, layout, configuration, internal partitioning, accessibility between blocks, and exterior and communal spaces. The first has a pavilion layout scattered on a multi-level plot and with single-story blocks, each one with a central courtyard; and the latter is defined by three large-scale and two-story blocks, in parallel and deployed on a very wide and bland paved floor, extensively lacking green spaces or trees, and connected by a narrow covered horizontal circulation.

These also reflect the architectural context from which they date, being twenty-seven years apart, respectively, from the 1970s prominence of the pavilion layout, spread all over Portugal, and the end of the 1990s larger scale building blocks. The choice of these two schools as case studies was thus justified by the aim of this research, which is to analyze distinctive spatial layouts and how appropriate they are for contemporary teaching and learning.

4. Data Collected and Analysis

Given the proposed methodology, this double case study research involved these two schools with very different architectural and socio-economic characteristics. It sought first to describe and understand them, by means of the creation of a questionnaire that was answered by two classes per school, one from younger students and another from the older ones. After testing the suitability of the questions on eight students from both schools (who were not included in the sample), seventy-five students responded to the questionnaire, from a total of four classes, two from each of the participant schools. The selection of participants took into consideration the importance of the opinion of the students in their final year, as well as of younger colleagues who had been at the school for lesser time. Each school was therefore asked to nominate one class from grade 9 (the final year of basic education, and the final year offered at both schools) and one class from grade 7 (the first year of the Portuguese '*terceiro ciclo*', with students already having been at the school for two years and in theory with a further two years at school before leaving).

The results of the questionnaires and walkthroughs will now be presented, those belonging to the EBEC classes presented first, followed by those of the EBRS classes. At this moment, and for ethical purposes, this paper states that the participation of the students resulted from their agreement and complete involvement in the different phases of the study, after written authorization of the respective families.

The indicators considered to be the most significant, providing possible explanations of the relationship of the students with the physical spaces of their schools, are flagged. Each school study focused on five types of space defined by the questionnaire: outdoor spaces; formal learning spaces; study spaces; eating spaces, and passageways and halls.

In the case of EBEC, analysis of the 43 replies to the questionnaire showed that 67% of the students stated that they used most of the outdoor spaces several times a day, largely for the use of digital equipment and for being with their classmates, sometimes talking about topics related to subjects that they were learning about in the curriculum. Generally speaking, students associated the use of those spaces with feelings of joy and happiness, rating them highly, and implying their satisfaction with the size and location of the space. The evaluations made by students were more moderate in relation to the comfort provided and the equipment that was available in those spaces. (In line with the definition proposed by the Office of the United Nations High Commissioner for Human Rights on *The Right to Adequate Housing* [39], comfort is here considered the perception of (the students) of the suitability/adequacy of the spaces within the school for the development of specific activities. This is naturally related to physical comfort, e.g.,: heating, colour, size, light, ventilation, . . . , but it can also report to the perception of oneself in space by a more sensitive and cognitive perception. This can ultimately enable or constrain a person or a group to use or decline using a space for a specific activity.)

In relation to formal learning spaces, results indicated that the students liked their sizes and locations, but were not so positive relative to comfort and the amount of light in the rooms. Student evaluation of the quantity and quality of the equipment in the classrooms was even less positive. Despite these statements, almost half of the respondents chose to state that they experienced a general feeling of pleasantness for the duration of their stay in the classrooms.

When it came to study spaces, and the library, in particular, the replies indicated a very moderate usage despite the fact that the vast majority stated that they really liked these spaces and their characteristics, in which they experienced feelings that were predominantly happy ones.

Finally, in eating spaces and passageways and halls: as can be predicted, these were very much used and were generally pleasant, and it can be seen that the location and amount of light were given a high rating. Relative to size, particularly of the canteen, and relative to comfort, the ratings appeared to be much less positive.

The information that emerged from carrying out the walkthroughs can now be analyzed, with the aim of achieving a greater understanding of the main ideas that arose from processing the questionnaires. From this qualitative information it was understood that in relation to outdoor spaces, the students desired greater access to drinking water stations, a general upgrading of the green spaces next to the classroom blocks, and a substantial increase to the space given over to more informal sporting activities. Relative to spaces set aside for the consumption of food, the impression given by the students on the small size of these spaces was clarified, as well as on the problems involved in the use of these spaces at certain times of day when they can become very overcrowded. For this reason, a complete reorganization of these spaces and their layouts in relation to each other appears to be highly desirable.

At the time of the walkthroughs carried out in the classrooms, the level of critical analysis and reflection tended to multiply. All the situations that according to the students needed to be dealt with urgently were identified in a very precise manner. This detailed identification of needed interventions included problems such as the type of curtains, the type and layout of the furniture, the audio-visual equipment and the conditions for heating and cooling of the rooms. Supporting equipment for the labs was also lacking, and the halls for sports and PE were deemed to be in need of refurbishment. In more general terms, and as part of an extremely lively debate, with opinions given and discussions made that were of very high quality, the students agreed that there was a lack of IT equipment and poor Internet access, and suggested that their school, despite being located in a middle to upper-middle-class residential area, had physical conditions that were a lot worse than the schools that they had attended in previous years.

Looking now at the results obtained from the 32 replies at EBRS (Figure 6), it was found that 81% of the students stated that they visited the outdoor spaces several times a day, giving a very high rating to the characteristics of these locations (size, comfort-level, light, equipment, and location), with only half indicating that they felt a general sense of happiness during the various times that they made use of those spaces. In this school, the responses made by the students indicated that they liked the size, the level of light, and the location of the classrooms, but that they liked the quality and quantity of the equipment that was available a lot less. More than half of the students had feelings that were less pleasant during the periods of formal learning that they underwent in these rooms.

Figure 6. Escola Básica Rainha Santa Isabel (EBRS)—photographs of the school spaces used in the questionnaire (from left to right and from top to bottom: outdoor spaces; formal learning spaces; study spaces; eating spaces, and passageways and halls).

Although the library was not referred to as a space where students went very frequently or stayed for very long, it was also clear that the rating they gave the library was frankly positive, even though the feelings that they experienced in the library tend somewhat towards the neutral. In relation to eating spaces, on the other hand, the frequency of use was high, especially the bar and the recreation room. This was also explained by the feelings of great satisfaction that they experienced there, although students suggested that the equipment and comfort level of those spaces needed to be greatly improved.

In this school, the walkthroughs—the guided tours taken by the focus groups, which included moments of reflection and debate—were extremely rich in contributions from the students (Figure 7). The outdoor spaces and passageways and halls were both the favorite locations of the students as well as being the most spontaneously frequented, and were also the locations in which the most changes were desired and suggested: in the opinion of the students involved, these spaces needed to be redesigned in order to be furnished with more equipment as well as more covered/sheltered areas. This would greatly increase the opportunities for recreation and interaction with other students, as well as allowing a wider range of activities to be carried out, such as eating snacks or packed lunches. It would be desirable to increase the amount of green space, reduce the danger that was inherent to paved areas, and to rethink the painting of the building, giving it a "happier" appearance. Furthermore, in this case, the students regretted the lack of possibilities for carrying out a wider range of physical activities—activities chosen by the students themselves.

Figure 7. Escola Básica Rainha Santa Isabel (EBRS)—walkthrough.

It is interesting to note the importance that the participants attached to the need to find different painting solutions for different spaces within the school, such as the exterior façade of the building, the library, and the classrooms. In the case of the classrooms, the suggestions relative to changes to the layouts and the immediate need to improve the quality of the equipment led to a very detailed analysis by the students, which showed very clearly the huge capacity that the students have to observe and to think about their school.

By means of a brief, comparative exercise paralleling the questionnaire responses given by students from the two different schools, the liking that the students showed in using the classrooms became clear, even though the evaluation of the outdoor spaces and the passageways and halls, as well as the feelings experienced there, were, in general much more positive in comparison with the other spaces (Figure 8). In both cases, there was clearly less satisfaction registered with the equipment and comfort level in the different areas. In relation to the walkthroughs, it is important to highlight the strength of involvement of the participants and the quality of the interventions and debates that they initiated. Although the schools are located in very distinct educational territories, with socio-economic/cultural levels within the families also being very distinct, those differences were not observed in any way relative to the capacity for critical analysis and levels of articulacy between the two different groups. The students gave a clear and strong impression of having very well-defined ideas about what they wanted from and for their school, as well as on how the school could and should improve in the service it provides to the students themselves.

Figure 8. Sample of the comparison of questionnaire results on outdoor spaces between the two schools: EBEC (**left**) and EBRS (**right**).

5. Discussion of the Results

The data provided by S3S enabled further developments by engaging a wider school community and co-designing a refurbishment proposal based on the changes expressed by the students through their feelings and needs. Specifically, this last stage of the S3S methodology was promptly activated in Escola Básica Rainha Santa Isabel (EBRS), due to an immediate openness and interest from the school leaders and the municipality to act upon these outputs.

According to the data gathered from this methodology, it was possible to identify a list of three situations that needed to be rethought and redesigned in EBRS, namely: the outdoor spaces, a new entrance to the school near the bus stop, and a new recreation room for the students, very much following what has also been stated in other latitudes (11, 12). This was justified because: the main building blocks are deployed in a very bland, grey, and almost 'barren' ground, with a paved floor that gets very hot in the summer, is lacking trees and shadows and does not have any exterior leisure spaces defined in its extensive area. All these areas needed to be redesigned, in order to cater to those needs and to define dedicated areas to eat, play, and seat with respective furniture and resorting to nature-based solutions [40].

Students also stated that the current school entrance did not cope with the existing network of public transport and mobility dynamics, since most of the bus stops, they used were on the public transport interface located on the opposite end of the actual school gate. In addition, the students that reached the school by car reported a similar situation, because the main road is adjacent to the public transport interface and, therefore, dislocated from the school's entrance as well. In both situations, the students had to bypass the school's perimeter from the bus stop or the main road to reach the school gate.

Lastly, as this school is in the outskirts of the city, it is still lacking an urban definition as a neighbourhood and as an urban core. Students also perceived that weakness, considering that a new entrance would bestow a visual and urban identity to a blurred and emergent area, often seen as underprivileged regarding the city center.

Hence, a protocol was established with the Department of Architecture of the University of Coimbra, for composing a team of architects to design it, which resulted in design proposals that spatialized the needs reported by S3S's previous milestones (Figure 9).

This design proposal also filled the needs expressed by the students regarding a covered entrance that shelters them from the elements, such as rain or extreme heat, but that is still an outdoor space. It is composed of a space to park the bikes, which some use to get to school, a dedicated area for the teachers to park their cars, and a covered seating space for the children to wait for the bus or their caretakers. All these arguments justified the relevance of redesigning the entrance, as both a transitional space and a place to stay, as a reflection of the schools' urban presence, a benchmark towards the neighbourhoods of Eiras and Santa Apolónia nearby, and as a crucial interface to the current mobility dynamics.

Similarly, this also justified the need to paint the three building blocks with identarian colors that were cohesive in the overall layout, but that provided character to each of them, as well as a sense of belonging to the students who attended them.

Afterward, the outcomes were presented at a School Assembly with a wide array of participants, such as the students' representatives, teachers, staff, school leaders, the Municipality, architects, and the team of researchers. This was the moment to collectively discuss among all the stakeholders the school's spatial weaknesses perceived throughout this process, as well as the opportunities for improvement, actively involving the students by encouraging them to pose questions and express their feedback. Visual renderings were produced as visual aids for a better understanding of the proposal. In addition, plans were printed in large formats, so the students could design over them, expressing their opinions in a more immediate and concrete manner (Figure 10).

This enlarged the stakeholders engaged in this process and aimed at empowering all the community towards an active and participatory action in this school. It also demonstrated that it is possible to approach the academia and the community and, similarly, that scientific expertise can be effective and impactful towards the common good.

At the moment, the design proposal informed by this tool and by the students overall, has been generally accepted by the Municipality for its construction in stages in the near future.

Conclusively, based on Table 1 at the beginning of this paper, which presented the sequential development of the methodology, Table 3 has been composed to synthesize the stages developed for the implementation of the tool in the pilot study in the two Portuguese partner schools, specifying the stakeholders in each one and adding the School Assembly as an added milestone towards the co-creation of school spaces and the participation of all the community in the final decision.

Figure 9. Design proposal for the new entrance and refurbishment of the outdoor spaces of Escola Básica Rainha Santa Isabel (EBRS)—edited from the original panel presented at the School Assembly.

Figure 10. School Assembly in Escola Básica Rainha Santa Isabel (EBRS).

Table 3. Sequential development of the implementation of S3S in the pilot study.

	Stages	Methods/Techniques	Participants
1.	March and April 2020	Analysis	research team
2.	May 2020	Interviews	school community
3.	June 2020	Questionnaire	75 students
4.	September and October 2020	Synthesis	research team
5.	April and May 2021	Walkthrough	40 students, from 4 different groups
6.	May and June 2021	Design proposal	4 architects from the University of Coimbra
7.	30 June 2021	School Assembly	60 students 4 teachers 4 representatives of the Municipality 2 school leaders 4 architects 6 members of research team

6. Conclusions

In summary, this tool provides information on the actual usage made by students of the school spaces: those that effectively act as learning environments and their architectural characterization, and the spaces that are in need of spatial improvements, the refurbishment of which would benefit learning acquisition. This could be taken into consideration in future building renovation work and may even enable the school to intervene after receiving the outputs created by means of participation by the school community.

S3S is therefore proposed as a new way of perceiving school spaces as places of gathering and inclusiveness, reflecting a participatory process that includes feedback from the students attending the school. It also leads to an improved sense of belonging, respect, and comfort in space, all of which have a proven impact on education. To quote Cardellino and Woolner "The design of a school building can be understood to play a central role in the creation of learning environments and can therefore support educational change. However, non-architectural elements also need to be considered which can determine the success of a learning environment, particularly when change is attempted." [41] (p. 383).

The networks included in this research are many and diverse in nature: academic–within the project; national–in each project partner's team; scientific–from the interdisciplinary aspects; social and political–with the engagement of the stakeholder community, students, teachers, leaders, and politicians. All these networks come together to support an informed and participatory outcome and, ultimately, an inclusive design practice. So, even if the tool is a product of academic research, its principal purpose is the knowledge transfer of comprehensive social, political, and architectural outputs. It can inform political and management decision-making, as well as provide guidance in urban and architectural design. Generally, it allows participation to happen within the design process which is then able to provide more suitable spaces for each context and overall, to bring the tools of spatial awareness and accountability to each community.

The combination of the two methods (questionnaire and walkthrough) contributed to the success of the S3S tool. The quantitative data collected by means of the first method was confirmed by the results of the second one, which facilitated a profound discussion on the transformation of space, and the identification of ideas and suggestions for renovations. In this sense, while the questionnaire is more focused on diagnostics, the walkthrough is the first step in the participatory design process and has the active participation of students. A good example is the information about the use of the exterior spaces and the discussion about their transformation that took place during the walkthroughs.

It is in the context of the development of municipal strategic plans, associated with the decentralization of education, currently under development in Portugal, that this research operates, within a new logic of governance for the requalification of an aged school building stock. Hence, the relevance of the preparatory analysis of the socio-economic and architectural context, for the understanding of the results, and for fostering the inclusiveness of a wide community of stakeholders in the school.

Although this context is very different from one school to the other, as analyzed in the topic "Context and Objectives", student answers in both methods were not so very different. In fact, both schools are experiencing some level of decay (degradation level), leading to similar types of answers and suggestions, such as green areas, adequate places for outdoor activities, better equipment/furniture, and general maintenance, in line with other references [11,12]. There was also a general appreciation for the library and the outdoor spaces, which students agreed as being important to a shared well-being. This led to another common denominator, which was the desire for better equipped and more comfortable outdoor spaces in which to play, eat, and study, with suitable amounts of shade and greenery, furniture, and sports facilities, for improving this preferred area. The study also showed that students valued formal and informal learning spaces equally in their schools for knowledge exchange and acquisition, and as relevant parts of the overall equipment.

The design proposal was developed under a context of nature-based solutions, but it is also a contribution towards the landscape qualification of the overall territory/neighborhood in which the school is integrated. We are, thus, testing a tool whose objective is the co-creation between the different actors of the community, whose buildings originally had no concern with the outdoor and convivial spaces, focusing on the built-in and formal spaces. This justifies its current condition, which at present, does not meet the needs and demands that the 21st century desires.

The transformation carried out through the co-creation between the different actors of a school, whose constructive genesis showed no major concerns for the outdoor and convivial spaces, focusing only on the continuous and formal spaces, made it possible to reformulate the outdoor spaces. The transformation has also already taken into account the challenge set to the school community regarding the problems of the Sustainable Development Goals (SDGs), namely the educational (SDG 4) and environmental and social issues (SDG 11 and 13), e.g., thermal comfort and resilience to climate change—problems that this school's typology and the country overall are enduring, underlining the relevance of nature-based solutions in such contexts [40].

Naturally, this research faced its challenges, the first being the difficulty in accessing both schools and students during the outbreak of the pandemic. Having schools locked down twice in Portugal, and for the remaining time only authorized personnel could enter the schools or engage with students, added doubts on the tool's implementation. Nevertheless, it also created one of its strengths, because it led us to develop an online questionnaire that is widely accessible and free, and that can be edited according to each schools' spatial urges and students' age groups.

We wish, at this point, to present some of the lessons learned from this pilot study: first, that academia can positively input practice and that it has a place in the community, and that interdisciplinary research enables a triangulation of methods both quantitative and qualitative and interdisciplinary knowledge that promotes a more comprehensive outlook and application of otherwise more hermetic contents. Second, that students have a very evident critical sense relative to their schools, and despite their different levels of education, they all hold the same capacity to analyze space and make proposals. Most of all, students are clearly willing to participate in rethinking their schools. Third, by applying S3S we argue that it is important and more enriching to combine more than one research method (quantitative and qualitative) and it is also important to combine diagnostics with design (Table 3). Finally, we argue that participatory tools, such as S3S, create awareness about learning spaces and are drivers in mobilizing the school community toward the creation of a better school environment. All in all, by using S3S and enabling participation, an opportunity is created for the implementation of an inclusive approach to design.

Listening to the students, their feedback and criticism on the school in which they learn, as well as their proposals for possible changes, by means of targeted questions and methodologies that promote the debate and generate consensus, proved to be an option capable of finding better answers to the spatial interventions in schools. Not only because it showed the potential to increase the functionality and aesthetics of the spaces, but also because it demonstrated its capacity to enable participatory dimensions repeatedly referred to as inclusion practices. All of them, as evidenced in the introduction of this paper, constitute fundamental educational experiences, which the school must also provide.

As can be seen in this paper, not only at the beginning but fundamentally at the end of the process, co-creation was assumed and had from the students (and other actors) an acceptance above the expected in a country not accustomed to these processes. The interdisciplinary team is now rethinking and working on the redesign of educational spaces throughout the municipality, and it intends to use this tool in an extensive way in all schools in the territory, both in the design and the rehabilitation of urban spaces, with the inclusion of young people's contributions to the very redefinition of the urban spaces experienced by them, [42,43]. Thus, we aim to use this tool and methodology in the broader framework of the city and the municipality, which implies crossing the borders of the school and building bridges with the surrounding territories and communities.

In conclusion, this pilot study provided validation of the tool per se, as well as of its potential future developments and applications. This can be tested by carrying out other case studies in different geographical contexts or with participants of other age ranges, which as mentioned previously, is already being developed. This will enable us to compare the stock of school buildings in different countries and contexts, to identify the most and the least appreciated design solutions, potential convergent claims for learning spaces, and, most of all, to continue working with all stakeholders and school communities for an inclusive and welcoming learning environment.

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Informal Learning Spaces in Higher Education: Student Preferences and Activities

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Abstract: Informal learning spaces play a significant role in enriching student experiences in learning environments. Such spaces are becoming more common, resulting in a change to the spatial configuration of built environments in higher education. However, previous research lacks methods to evaluate the influence of the spatial design characteristics of informal learning spaces on student preferences and their activities within. This paper aims to tease out the spatial design characteristics of informal learning spaces to examine how they shape students' preferences in terms of their use of the spaces and what they do within them. The two case studies selected for this study, both in the UK, are the Diamond at the University of Sheffield, and the Newton at Nottingham Trent University. A mixed-methods study is applied, including questionnaires, observation, interviews, and focus groups. Six significant design characteristics (comfort, flexibility, functionality, spatial hierarchy, openness, and other support facilities) that influence student use of informal learning environments are identified. These can be used to inform future design strategies for other informal learning spaces in higher education.

Keywords: informal learning space; spatial organisation; student experience; student behaviour; student preference; spatial evaluation

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1. Introduction

Three new trends are emerging in higher education—increases in numbers, funding, and quality control [1]. All these aspects are having an impact on the architecture of higher education—the capability of accommodating student populations, spatial and corporate identity, and satisfaction of the customers (students). Historically, the development of the university campus was shaped by an emphasis on traditional instructional methods in formal learning spaces [2,3]. However, 'informal' learning spaces are emerging as an alternative and are increasingly considered as an essential spatial construct in the university setting. The design of informal learning spaces for students to spend time in between more formal education experiences such as lectures are booming as campuses seek to enhance their student experience offering. Due to the social nature of recreation in higher education, these types of experiences typically occurred in libraries, student cafeterias, and other socially oriented spaces. All these spaces were called informal learning spaces, or sometimes part of the Informal Learning Landscape [4,5].

Researchers gradually attempted to interpret the functional definition and the spatial design of informal learning spaces [6–11]. For example, Brown and Lippincott [12] indicate that informal learning spaces are any space outside the classroom that can be used for learning. However, the boundary between 'inside', 'outside', and 'between' formal learning spaces became blurred. This increased the emphasis on informal learning spaces, resulting in the creation of atrium spaces, reimaging corridors, and other circulation spaces, and the finding of ways to layer learning activities on to spaces previously used for social activities, such as dining or playing [2]. More and more institutions made endeavours to create highly adaptable and integrated informal learning spaces instead of specialised learning spaces. To respond to this demand, social 'hubs', internal student 'streets', and other designated spaces that promote both social and learning-related activities outside the classroom are being built [13]. The spaces of the campus landscapes can be described as *'socially catalytic'* because they catalyse socialising and are key to fostering a sense of community and engagement [14]. How to design such a social catalyst becomes an important issue in the future of higher education environments. Existing research has demonstrated the significance and impact of the spatial design characteristics of learning environments upon student achievement [15–17] and student experiences [18–21] based on environmental behaviour theory. Different spatial design characteristics were explored to support learning, and numerous authors proposed either lists of design principles or sets of critical characteristics that contemporary learning spaces should exhibit (these are summarised in Table 1). However, the methods of evaluating informal learning spaces remain uncertain. Furthermore, empirical research on examining informal learning spaces is required to better understand student experiences and the activities undertaken within them.

Table 1. Spatial design characteristics of learning spaces that impact students' experiences, as drawn from literature.

Spatial Design Characteristics	Sources
Light; Acoustics; Temperature; Ventilation; Furniture (Colour/Material)	[3,6,10,16,17,22–24]
Mobility; Adaptability; Diversity; Flexibility	[2,6,8–10,13,19,22,25,26]
Socialising; Sense of Community; Informative; Attractiveness; Openness; Enclosure; Safety	[2,3,10,13,19,26,27]
Support group work and collaboration; Supports individual learning	[6,9,10,19]
Location (proximity to formal learning environment); Outside Views	[28]
Circulation; Legibility; Intelligibility; Privacy; Spacious	[9,17,27,29–33]
IT-rich environment; Wi-Fi Coverage; Plugs and Sockets; Food and Beverage	[6,12,21,22,26,34,35]

The aims of this research are to:

(1) conduct a mixed methods study to investigate student activities and preferences in informal learning spaces;
(2) provide an empirical evidence base to understand student activities and their selection and use of informal learning spaces in the higher education setting; and
(3) tease out the significant spatial design characteristics that influence how and why students use informal learning environments.

This exploration of spatial design is undertaken to create more effective informal learning spaces in higher education and to generate evidence to inform future designs.

2. Materials and Methods

This research employs a case study method to achieve these aims. A mixed-methods approach was undertaken, including observations, interviews, questionnaires, and focus groups. These were selected and refined based on a literature review and pilot tests, as shown in Phase 1 (as illustrated in Figure 1). More specifically, the literature review indicated how researchers identify spatial design characteristics that influence learning spaces (as illustrated in Table 1), which informed the generation of the research plan. The pilot allowed for testing and refinement of the methods. In Phase 2 (as illustrated in Figure 1), the mixed-methods approach was employed at the Diamond at the University of Sheffield and the Newton at Nottingham Trent University to gather empirical data, including students' preferences on the spatial design characteristics of informal learning spaces and their activities within. All the students included in the study were informally approached, anonymised, and voluntarily offered to participate. More details are shown in the following sections.

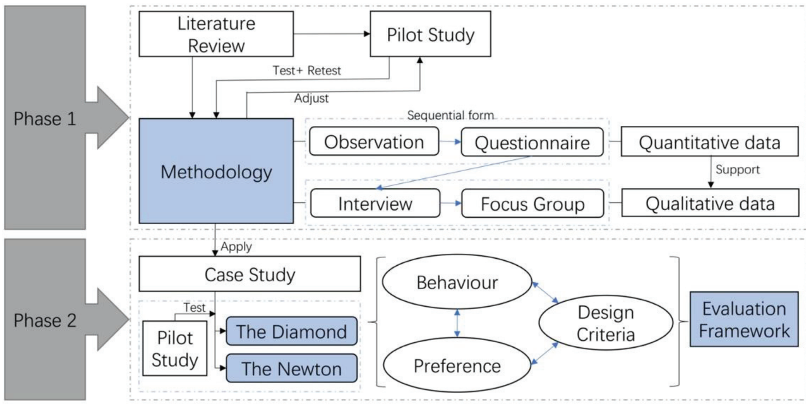


Figure 1. Research Design.

2.1. The Context of the Case Studies

The selection of the case studies was based on four sets of criteria: (1) accessibility for research, and proximity to the research team based in the Midlands, UK; (2) completion in the 21st century; (3) used by students from multiple disciplines (i.e., not only for one program or course); and (4) reputation and award-winning status in terms of the building design. Consequently, two cases, the Diamond at the University of Sheffield and the Newton at Nottingham Trent University, which provide suitable places to investigate the informal learning spaces in higher education, were selected.

Designed by Twelve Architects and completed in 2015, the Diamond offers students the opportunity to move between formal and informal learning situations. The enriched teaching and learning spaces are centralised and vertically organised around a four-floor height atrium and enlarged corridor spaces (as illustrated in Figures 2 and 3).

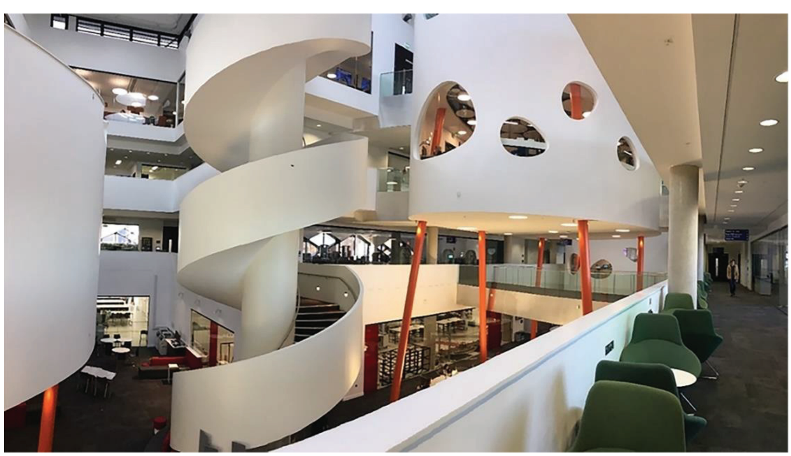


Figure 2. Atrium Space of the Diamond at University of Sheffield.

Figure 3. Floor plan of Diamond with different functional zones (Level B and Level E).

Designed by the Hopkins Architects in 2009, The Newton is a circulatory space, providing an environment for student socialising as well as informal learning activities. The heart of this area is organised beneath a glazed roof with a wooden structure within an atrium known as the Central Court (as illustrated in Figures 4 and 5). With large lecture spaces, computer rooms, and small seminar spaces around, the Central Court is seen as an in-between learning space. With a student service centre, a careers hub, three food outlets, and one main canteen, the Central Court supports student campus life.

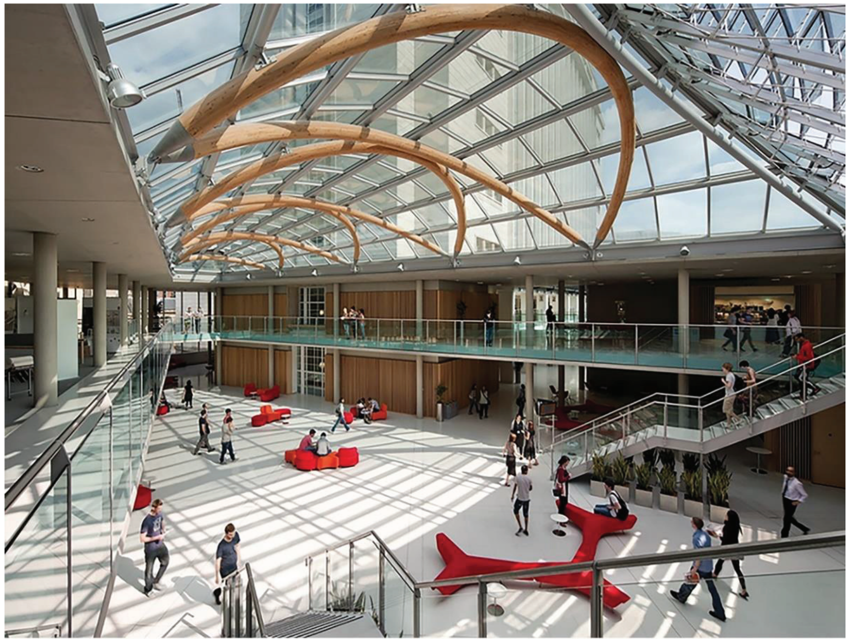


Figure 4. Central Court of Newton at Nottingham Trent University.

2.2. Observations

Fieldwork at the Diamond (as illustrated in Table 2) took place over 20 working days, spread across 4 weeks before the Easter vacation (from 8 March to 31 March 2017). The study at the Newton (as illustrated in Table 2) was carried out on one day as a pilot study and in 12 working days across four weeks from the 19th of April to the 10th of May 2017. Based on the pilot study, one session took place in the evening and three in the day during every weekday observed at the Diamond, while only three sessions took place in the daytime at the Newton due to its closure at night. Each 'session' lasted two hours made up of six 20-min time periods each of which incorporated four 'walk-by' observations once every five minutes [19]. Walk-bys and timed observations were implemented to identify users' location, to count the number of users, and to identify the activities users engaged in. In total, four volunteer postgraduate students were recruited to help carrying out the observations. The informal learning spaces are divided into four functional zones, Entrance Space, Café Area, Corridor Space, and Open Space.

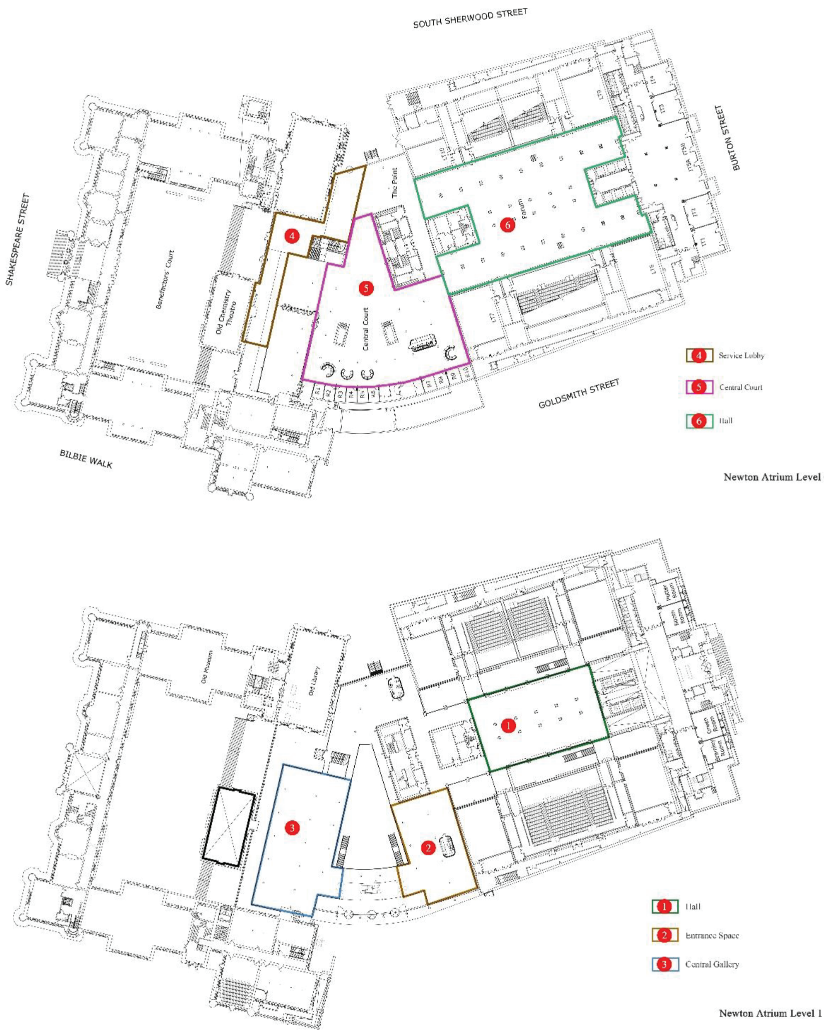


Figure 5. Floor plan of Newton with different functional zones (Level 0 and Level 1).

Table 2. Observation schedule of Diamond at University of Sheffield (8–31 March) and Newton at Nottingham Trent University (19 April–10 May).

	6 March Monday	7 March Tuesday	8 March Wednesday	9 March Thursday	10 March Friday	11 March Saturday	12 March Sunday
8–10 am			Pilot Study	Pilot Study	Entrance Space	N/A	N/A
12–2 pm			Pilot Study	Pilot Study	Café Area	N/A	N/A
5–7 pm			Pilot Study	Pilot Study	Open Level C	N/A	N/A
8–10 pm			Pilot Study	Pilot Study	Corridor Level D	N/A	N/A
	13 March Monday	**14 March Tuesday**	**15 March Wednesday**	**16 March Thursday**	**17 March Friday**	**18 March Saturday**	**19 March Sunday**
8–10 am	Corridor Level D	Open Level C	Café Area	Corridor Level E	Open Level F	N/A	N/A
12–2 pm	Entrance Space	Corridor Level D	Open Level C	Open Level E	Corridor Level E	N/A	N/A
5–7 pm	Café Area	Entrance Space	Corridor Level D	Corridor Level F	Open Level E	N/A	N/A
8–10 pm	Open Level C	Café Area	Entrance Space	Open Level F	Corridor Level F	N/A	N/A
	20 March Monday	**21 March Tuesday**	**22 March Wednesday**	**23 March Thursday**	**24 March Friday**	**25 March Saturday**	**26 March Sunday**
8–10 am	Corridor Level F	Open Level E	Corridor Level D	Entrance Space	Café Area	N/A	N/A
12–2 pm	Open Level F	Corridor Level F	Open Level C	Corridor Level D	Entrance Space	N/A	N/A
5–7 pm	Corridor Level E	Open Level F	Café Area	Open Level C	Corridor Level D	N/A	N/A
8–10 pm	Open Level E	Corridor Level E	Entrance Space	Café Area	Open Level C	N/A	N/A
	27 March Monday	**28 March Tuesday**	**29 March Wednesday**	**30 March Thursday**	**31 March Friday**	**1 April Saturday**	**2 April Sunday**
8–10 am	Open Level C	Open Level F	Corridor Level E	Open Level E	Corridor Level F	N/A	N/A
12–2 pm	Café Area	Corridor Level F	Open Level F	Corridor Level E	Open Level E	N/A	N/A
5–7 pm	Entrance Space	Open Level E	Corridor Level F	Open Level F	Corridor Level E	N/A	N/A
8–10 pm	Corridor Level D	Corridor Level E	Open Level E	Corridor Level F	Open Level F	N/A	N/A
	17 April Monday	**18 April Tuesday**	**19 April Wednesday**	**20 April Thursday**	**21 April Friday**	**22 April Saturday**	**23 April Sunday**
8–10 am			Pilot Study	Service Lobby	Hall in Level 1	N/A	N/A
12–2 pm			Pilot Study	Hall in Level 0	Entrance Space	N/A	N/A
5–7 pm			Pilot Study	Central Court	Central Gallery	N/A	N/A
8–10 pm			Pilot Study	N/A	N/A	N/A	N/A
	24 April Monday	**25 April Tuesday**	**26 April Wednesday**	**27 April Thursday**	**28 April Friday**	**29 April Saturday**	**30 April Sunday**
8–10 am	Hall in Level 0	Hall in Level 1	Mini Open Day	Central Court	Entrance Space	N/A	N/A
12–2 pm	Hall in Level 1	Central Court	Mini Open Day	Hall in Level 1	Central Gallery	N/A	N/A
5–7 pm	Service Lobby	Hall in Level 0	Mini Open Day	Central Gallery	Hall in Level 1	N/A	N/A
8–10 pm	N/A	N/A	N/A	N/A	N/A	N/A	N/A

Table 2. *Cont.*

	1 May Monday	02 May Tuesday	3 May Wednesday	4 May Thursday	5 May Friday	6 May Saturday	7 May Sunday
8–10 am	Bank Holiday	Central Gallery	Service Lobby	Entrance Space	Hall in Level 0	N/A	N/A
12–2 pm	Bank Holiday	Service Lobby	Hall in Level 0	Service Lobby	Central Court	N/A	N/A
5–7 pm	Bank Holiday	Entrance Space	Hall in Level 1	Hall in Level 0	Service Lobby	N/A	N/A
8–10 pm	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	8 May Monday	**9 May Tuesday**	**10 May Wednesday**	**11 May Thursday**	**12 May Friday**	**13 May Saturday**	**14 May Sunday**
8–10 am	Central Gallery		Central Court			N/A	N/A
12–2 pm	Entrance Space		Central Gallery			N/A	N/A
5–7 pm	Central Court		Entrance Space			N/A	N/A
8–10 pm	N/A		N/A			N/A	N/A

2.3. Questionnaires

The questionnaires were structured to examine: (a) student experiences in the informal learning spaces, which included the frequencies of 22 social and informal learning activities, 8 time periods where students use the social and informal learning spaces, and 15 reasons for selecting and using social informal learning spaces; (b) student preferences of the spatial design characteristics of the informal learning spaces, which assessed the design characteristics and performance and student opinions on social informal learning spaces, and (c) personal background information, which inquires about whether they were an international student, gender, department, mode of study, level of study, year in school, and accommodation type.

A 5-point Likert Scale was employed on questions (i.e., 1 = strongly disagree; 2 = disagree; 3 = no comment; 4 = agree; and 5 = strongly agree), which examined the frequencies of student activities and attitudes of the spatial design characteristics numerically (see Appendix A—Questionnaire Form). The questionnaires were delivered and collected in person by providing an incentive (a chocolate bar) in the informal learning spaces. Ethics approval for the study was obtained from the University of Nottingham.

Through communications with the building managers of both buildings, it was estimated that daily use in the Diamond is 1500 people, and in the Newton, 1000 people. Of these populations, 10% were selected as the sample for the questionnaire given the resources and timeframe available to the research team. Consequently, in total 261 questionnaires (157 at the Diamond and 104 at the Newton) were collected. 148 valid questionnaires at the Diamond were collected with 94.3% efficiency, and 97 valid questionnaires at the Newton were collected with 93.3% efficiency (as illustrated in Table 3). The response rate was 98.1%.

Table 3. Personal background information of two case studies by questionnaires.

Category	Diamond	Newton
Total number of questionnaires	157	104
Valid questionnaires	148	97
Male/Female	63/85	40/57
International/Local	71/77	19/78
Undergraduates/Postgraduates	102/46	86/11
Lecture-based/Studio-based/Lab-based	122/6/20	90/3/4

Data analysis of the questionnaires was initially conducted in Microsoft Excel and crosstabulation was employed. SPSS software was used for the statistical analysis of data. Cronbach's alpha was used as an estimate of the reliability of the scales in questionnaires. The value of the Cronbach's Alpha of this questionnaire was 0.845, which indicates good reliability. Kaiser–Meyer–Olkin (KMO) measured sampling adequacy of the validity in three dimensions: the construct of frequencies of student activities (KMO = 0.718, $p < 0.000$), the construct of preferences of the spatial design characteristics (KMO = 0.660, $p < 0.000$), and the construct of spatial satisfaction (KMO = 0.785, $p < 0.000$), representing that the questionnaire was valid. After testing the reliability and validity of questionnaires, the results were analysed by multiple response analysis and principal component analysis.

2.4. Interviews

Semi-structured interviews were also employed in the Diamond and the Newton. The research found out that interviews with 12 and 7 participants (ID1-12 and IN1-7) in the Diamond and the Newton, respectively, were sufficient to reach the data saturation, which is the point at which no new information is obtained in the data from the completion of additional interviews [36]. Interviewees were the students who used the informal learning spaces and agreed to share their ideas and views on this research. Most of the questions were based on existing research on the users' activities and preferences in the learning environment and public spaces [20,37]. The data from the interviews were collected face-to-face after the process of questionnaire and observation. The interviews were recorded for revisiting and reflection on the information provided. All the records of the interviews were scripted into Microsoft Word and analysed using NVivo 11 software. Open coding was employed to record the preferences and the spatial design characteristics of the informal learning spaces to generate the probes of the focus group.

2.5. Focus Groups

A focus group for each case study was also employed. Recruitment posters were displayed around the spaces, and questionnaire participants were also sent emails to invite them to participate further in the research. Focus group participants were recruited that were familiar with the informal learning spaces and were carefully selected to ensure that they have different personal background information (considering gender, department, mode of study, level of study, year in school, etc.). Nine participants were selected as participants for the focus group at the Diamond, and five participants at the Newton. The participant information of the focus group at the Diamond and the Newton are listed in Table 4.

Table 4. Participant information of focus groups at Diamond (PD1-9) and at Newton (PN1-5).

Participants	Gender	Age	Subject
PD1	Female	24	Architectural Design
PD2	Male	24	Robotics
PD3	Male	28	Architecture
PD4	Female	23	Finance Economics
PD5	Female	23	Financial Economics
PD6	Female	24	Financial Economics
PD7	Female	24	Landscape Architecture
PD8	Male	26	Advanced Software Engineering
PD9	Male	28	Architectural Design
Participants	**Gender**	**Age**	**Subject**
PN1	Female	26	Interior Architecture
PN2	Female	19	Business Management & Marketing
PN3	Female	23	Interior Architecture
PN4	Female	24	Interior Architecture
PN5	Female	21	Business Account & Marketing

3. Results

3.1. Time Period of Regular Use in the Informal Learning Spaces

How long the students can stay in the informal learning spaces and how many students keep staying there can indicate their efficiency and the attraction of the environment. The time period of regular use in the informal learning spaces at the Diamond and the Newton are analysed by using a multiple response analysis using SPSS BIM 23 software, and the comparison can be seen in Figure 6.

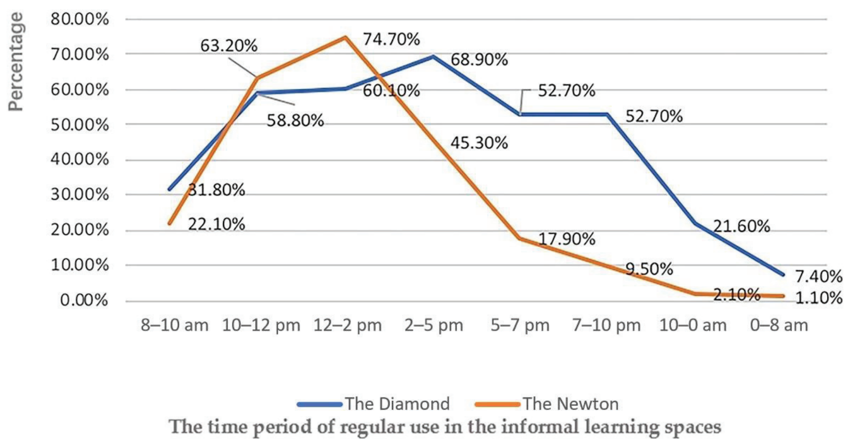


Figure 6. Percentage of students selecting time periods of when they regularly use informal learning spaces of Diamond and Newton, from questionnaire.

The number of students using the Diamond maintains a high percentage for a long time (over 50% from 10 am–10 pm). However, 50% of the respondents use the Newton only from 10 am–2 pm. This result is informed by the functional characterisation and operation of the two informal learning spaces. The Diamond is organised as a learning space where the learning process is well-considered. The informal learning spaces at the Diamond provide more opportunities for all the students who wish to stay longer. At the Diamond, students are free to access with their student cards 24/7 throughout the year. Comparatively, the function of the Newton is to link different departments and support students' transition from lecture to lecture. Moreover, the Newton is a place for students to have a rest at lunchtime. Therefore, the peak time of use at the Newton is lunchtime. The Newton is closed when there is no lecture at night-time. Consequently, it provides a relatively dark environment and less support for the students staying in due to lights being reduced in low occupancy periods.

3.2. Reasons for Student Selecting and Using the Informal Learning Spaces

Students have their own preferences regarding choosing a space. In terms of the spatial design characteristics and spatial organisation of higher educational informal learning spaces, the investigation based on the questionnaires identified reasons that influence these choices. Students were able to choose from 15 reasons in terms of why they use the informal learning spaces (see Appendix A—Questionnaire Form), and the percentages of students selecting these reasons for using the informal learning spaces at the Diamond and the Newton are marked blue and orange, respectively (as illustrated in Figure 7). Consequently, comfortable lighting (81.8%), other support (such as Wi-Fi, etc.) (80.4%), functionality (support individual and group work) (68.2%), spatial hierarchy (67.6%), openness (64.9%), comfortable temperature (62.2%), and flexibility (52.7%), are the top seven influential design characteristics for students selecting and using the informal learning spaces at the Diamond, while spatial hierarchy (80.4%), comfortable lighting (73.2%), other support facilities (such as Wi-Fi, etc.) (67%), openness (62.9%), comfortable temperature (60.8%), flexibility (54.6%), and functionality (53.6%), were the seven most important design characteristics at the Newton.

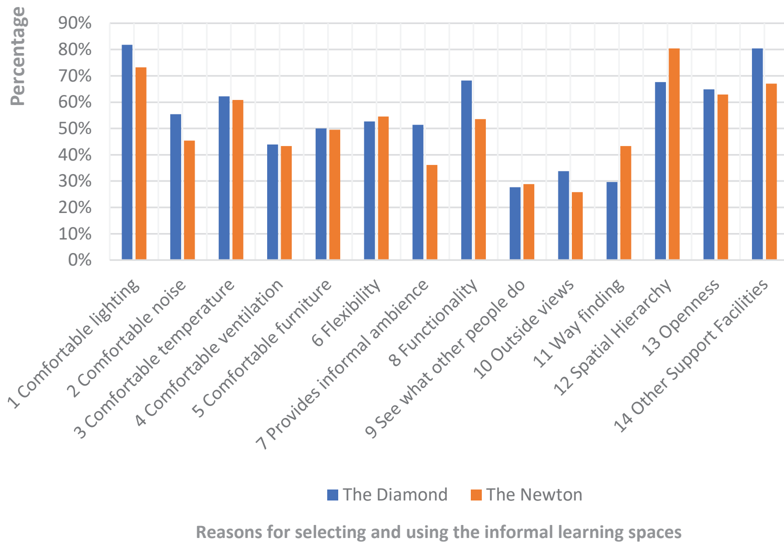


Figure 7. Percentage of 14 reasons for selecting and using informal learning spaces of Diamond and Newton, from questionnaire.

The same seven reasons were mentioned by over 50% of responders in both case studies even though they are in a different order. Based on the questionnaires, these seven design characteristics can be seen as important aspects to evaluate and consider in the design of informal learning spaces. Drawing from this quantitative analysis, along with the interviews, focus groups, and the literature review, six spatial design characteristics of comfort, flexibility, functionality, spatial hierarchy, openness, and other support facilities are highlighted and discussed in the following section.

4. Discussion: Student Preferences in the Informal Learning Space

4.1. Comfort

Comfort is a sense of physical or psychological ease [38]. Comfort in terms of lighting, acoustics, and temperature in educational buildings were widely researched [39–41]. Most research focuses on comfort in formal learning spaces, such as classrooms, while the research on the informal learning spaces is limited.

Slightly more students chose to use the spaces at the Diamond due to the level of lighting comfort than at the Newton—but in both, lighting was one of the most important factors influencing choice of space, with over 70% of students in both buildings identifying this. Compared with that of purely socialising activities, informal learning activities require a brighter environment. Due to a preference for natural light and poor artificial lighting provided at the Newton, students used the informal learning spaces at the Newton more frequently in the daytime than at night. As one of participants (PN 1) noted, she prefers to work in the Newton atrium because: *"there's lots of natural light to work in."* One of participants (PN 5) also noted: *"I like the sunshine. So, no matter what season it is, I like the central court because the central court provides sufficient (natural) light."* A participant in the Diamond (PD2) noted: *"I like the windows as they let in a lot of light"*. However, students tended to do learning activities at the Diamond for a longer period due to the better artificially lit environment at the Diamond, which provides lighting comfort in the day and at night.

The student perception of the acoustics suggests that the acoustic level is a bigger driver to where students work at the Diamond than that at the Newton. Most of the background noise was generated from group discussions or collaboration activities in the open space as well as the corridor space at the Diamond. These were lower than the sounds of students participating in socialising activities and passing through the spaces, which was a more frequent activity at the Newton. As one interviewee in the Newton complained: *"I find the background noise a bit irritating, so I always have my headphones in."* However, students that chose to study in the open space and corridor space of the Diamond were tolerant of the background noise. In the focus group, one participant (PD3) stated that,

> *"Well, besides loud noises made on purpose, sounds from the surroundings have little effect on me. It really doesn't matter if the discussion occurred in the booked private room or simply in the open study place. In fact, I prefer working with some background sounds."*

There are also plenty of silent studying rooms at the Diamond for students who are not comfortable with background noise. However, over half of the students were involved in more socialising activities at the Newton and more people passing through the informal learning spaces at the Newton were recorded during the observations. Consequently, the students who were undertaking learning activities felt impacted by the noise of socialising activities and by the people passing through the space. To stimulate informal learning activities, it is important to create a place where students can realise the place is designed for informal learning activities rather than for just socialising activities. The learning atmosphere therefore requires careful control of acoustic levels, as demonstrated by the findings here.

Temperature is also an important design criterion for informal learning spaces. The respondents at the Diamond and the Newton mentioned the importance of keeping appropriate temperatures in the learning environment. To this point, the glass curtain walls and rooftops contribute to the dilemma. From one side, the transparent walls and rooftops provide natural lighting, which was highlighted by respondents in the focus groups as positive (PN5 and PD7). However, from another perspective, they can also negatively affect the indoor temperature of the building by providing a passage for unwanted thermal gain, which can cause discomfort and overheating.

4.2. Flexibility

Flexibility is a previously identified characteristic of education spaces, allowing students to adapt their physical environments to accommodate individual preferences [8,9]. The two cases, the Diamond and the Newton, provide significant flexibility of their informal learning spaces (as illustrated in Figure 8).

(**left**) (**right**)

Figure 8. Reconfigurable tables and removable chairs allow students to shape their learning spaces individually or by group in open space at Diamond (**left**) and corridor space at Newton (**right**).

The open space and the corridor space of the Diamond and the Newton support different group sizes of student learning and socialising activities, provide ample models of the boundary control, possess the ability to reconfigure their learning space, and enhance diverse ambiences. Respondent (PN3) expressed the significance of the adaptable and removable furniture and how it influenced their activities in the informal learning space at the Newton:

> *' . . . It is quite a flexible area. For example, furniture settings can be changed according to different activities. . . . The functional partition can also be changed by the arrangement of the movable walls. From a functional perspective, this area is very practical.'*

The respondent (PD3) also indicated that the adaptation of social activities and learning activities are also important:

> *'I think the Diamond is like a "Learning Place" compared with a "library". Now, I like this atmosphere after I got used to studying in this environment. In this place, I can find both silent areas and space for group discussion if needed.'*

Based on this research, the impact of the diverse movement flow upon student experiences in the informal learning spaces can be noted. The extended informal learning space at the Newton can hold many students passing through and undertaking socialising activities.

4.3. Functionality

It is inevitable that informal learning spaces possess student socialising spaces and accommodate social activities. Through observation, it was noted that there were different types and degrees of informal learning activities in the Diamond and Newton, which were based on the nature of the work: the intensity of that work (and thus, the need for seclusion), or the extent to which progress resulted from discussions with others. Learning activities, such as individual revision, coursework preparation, and studying alone, demand seclusion and avoiding distraction. This requires a relatively stable and quiet learning environment. However, some of the learning activities, such as group discussion and so on, require communication. The function of the informal learning spaces at the Newton creates a socialising ambience to encourage peer-to-peer learning, group study, and discussions. As one of participants (PN5) noted: *"Even though they also have their own space, the common areas are next to these spaces to support students who are from different department students' learning activities and socialising. The common area is especially designed to encourage interaction."* These results cannot articulate how to better design informal learning spaces, however, through the analysis, there are differences between the cases. Even though they are both informal learning spaces leveraging circulation areas, they play a different role in their educational complexes. Hence, more specific advice on the different types and roles of informal learning spaces should be discussed separately in future studies.

4.4. Spatial Hierarchy

Spatial hierarchy refers to spatial legibility, accessibility, and privacy. From one side, students require a space that is easily understood, and they can easily find where they want to go. The atriums at the Diamond and the Newton are both located in the centre of the educational complex, which provides a hub to link together different destinations. The setting of spatial hierarchy from open space to corridor space to lecture room provides a sense of layering, which contributes to the legibility of the space. Consequently, students could not feel *"too many confusions"* (PN2) in terms of orientating themselves. Furthermore, student services of the university provide inductions regarding understanding the spaces: *" . . . we have induction week when we first come here. The induction week covers all the map information and wayfinding, etc."* (PN2).

From another perspective, the more formal the learning process, the more the students prefer to study in a more silent and private part of the learning space, or in a place where there is less contact with their surroundings. An appropriate spatial configuration can enhance a sense of privacy through the control of the boundary and the reconfiguration of the learning settings. To this point, the diverse learning settings and spatial configuration at the Diamond provide students with private spaces to facilitate more formal learning activities. Based on the observations at the Diamond, the students preferred to do more learning activities in the spatial capsule, a small private learning space in the open area where the arrangement of the furniture shaped a learning unit in the open area. Besides, the flexibility of the informal learning space also contributes to privacy through the student's self-organisation of the spatial configuration.

4.5. Openness

The atrium is often seen as an in-between space. In informal learning environments, it can provide a *'visual antidote'* [42] for students emerging from lecture halls and classrooms. The visual antidote attracts students to decide what they want to do, whether they prefer to remain or to leave and to use the informal learning spaces, and which time period they want to get involved in the atrium. The spatial configuration of the atrium brings people into space and gives them reasons to converse, share ideas, or enjoy lingering in different areas of the environment.

These spontaneously occurring activities are encouraged in the atrium, which provides a socialising ambience for space. The feedback collected from focus groups confirms that the openness provides a space where occupants have good views and a relaxing experience. With this relaxed feeling, students can be "*rejuvenated*" (PN4) from the long periods of studying and undertake activities like group study or collaboration, where they speak to another person or undertake activities that require collaboration.

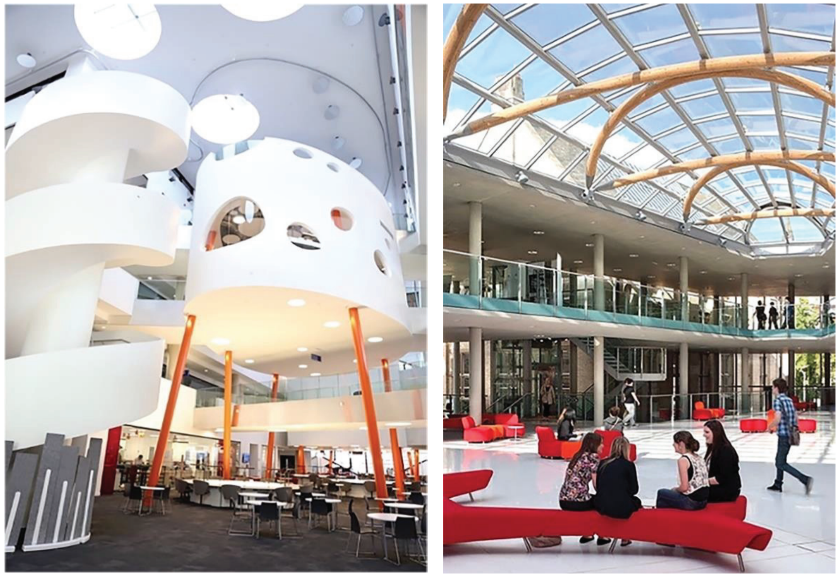
Furthermore, the open ambience at the Diamond provides a sense of learning community. Even though there are discussion activities in the space, the students undertaking individual study are tolerant of the distraction caused by the surrounding discussions to some extent. A respondent (ID3), at the Diamond, gave this explanation:

> *'In a silent study, I find it's harder to concentrate. Whether there's people talking or a bit of background noise, it helps me focus in on my work more.'*

Furthermore, the openness of informal learning spaces supports people watching and movement through the space, and the enjoyment of social life. Spatially, the openness reinforces an image that enriches student experiences in the campuses and an *'increased impression of the university'* (PN1). These enhanced spatial experiences improve the value of the informal learning space. As another participant (PN 3) mentioned:

> *' . . . I think the atrium space is the most important space for students. No matter if you have experiences in studying here or never come here before, it is the first place where people are paying attention to. . . . It is also a place of students' showroom.. I think it is the first impression of the space (Central Court at the Newton). ...'*

The participants also believed that staying in the atrium for a while before or after lecture helped them to relax. Meanwhile, the atrium is not only a place for gathering and multiple activities, but also a place to create memories. The participants were proud of having *'the fantastic learning environment'* at the Diamond (PD2) and the Newton (PN1). Universities therefore also have an opportunity to recruit students by promoting these atria spaces as a visual attraction (as illustrated in Figure 9).



(**left**) (**right**)

Figure 9. Openness of atrium in educational complexes of Diamond (**left**) and Newton (**right**).

The openness of informal learning spaces can support social interactions. Socialising activities, including casual chatting, taking a break from studies with friends, eating, attending events such as exhibitions, open days, coursework shows, finding the space as a route to a lecture room, gathering to go to another place together, people watching, etc., are observed as evidence to prove the existence of socialising activities occurring within the informal learning spaces. Meanwhile, this socialising ambience seems to be a key learning preference expressed by learners who viewed it as, *'designed as a place where students do whatever they want to do' (PN2)* at the Newton. These activities are seen as essential in these environments, with face-to-face social interaction being important to student experience [43]. One respondent (PD3) described this learning style at the Diamond in his own words:

> *' . . . we are in group discussions and, whatever you want to say and to do, you can do it in here . . . It is very convenient.'*

Meanwhile, another respondent (PN4) claimed that the socialising ambience made them feel 'rejuvenated' at the Newton. Furthermore, they provide for intermittent exchange: to study alone, but with occasional interaction with others. This type of student activity refers to learners undertaking their individual coursework but staying near to or next to peers who are known to them. This behaviour was also reported by Harrop and Turpin [21] who termed it *'working alongside'* (p. 16).

This provides a great place to support diverse activities. Meanwhile, the openness of the extended corridor space at the Newton was described as providing, *'sufficient and adequate furniture, provides opportunities for conversations that develop within the group discussion and a quick rush over certain details after lectures'* (PN5). This is also supported by O'Neill [13] as partly the reason why corridor spaces in both cases are used as learning spaces.

The spatial volume of the atrium provides an openness and multilayered quality, but there is a lack of research on how these characteristics impact individual preferences. Researchers evaluated the openness of atria spaces using 3D Isovists, which is a method of using a mathematical way to quantify the spatial openness of the atrium [44–46], but more research to examine this in the context of informal learning spaces is needed.

4.6. Other Support Facilities

Higher education is experiencing a rapid change in the 21st century. Consequently, the potential of new digital technologies is listed as one of the main characteristics of higher education practice [47,48]. The use of technology is perceived to meet not only current but future needs as well [49]. The informal learning spaces, designed to offer a combination of spaces that support individual activity and research as well as social learning activities, should enhance the impact of technology [50]. The quantitative analysis through questionnaires indicated that the IT- 'rich' environment at the Diamond is a bigger driver of use than at the Newton (as illustrated in bar 14 in Figure 7). Even though the usage of IT-rich environment involved a mixed pattern of use that supported research, communication, and other learning-related activities [51], this research cannot articulate how the technology helps students to engage in informal learning activities. However, it does influence students' choice of space and experience: *"I feel the space supports us well. Lots of tables are provided with lots of plugin and sockets. If you have your own computer, you can work here for a long time with sufficient electrical support. If you bring your battery charger for the phone, you can charge when you are waiting for your friends there." (PN2)*

Furthermore, the provision of the food and beverages outlets can contribute to making a space attractive to learners [12,26], especially to those who intended to stay for a longer time. Observations demonstrated that even though the café area supported almost all the dietary related activities at the Diamond, students were allowed to take snacks and even meals, such as sandwiches, into the other spaces in informal learning environment.

5. Conclusions

The design of the 21st-century learning environments in higher education to promote student learning experiences as well as meet the evolutional requirements of pedagogical theory attracted more and more attention, yet still requires further exploration and research. In particular, the design characteristics of informal learning spaces need to be considered from a holistic perspective, considering the spectrum of students' activities and their preferences. Nevertheless, the evaluation of the design characteristics of the informal learning spaces is affected by a dearth of empirical research. This research examined student preferences influencing their use and activities in informal learning spaces. The research suggests the needs and preferences of users to be better considered in the spatial design strategies for the informal learning spaces so that they can effectively contribute to the design of their facilities. The results of this research highlight six key spatial design characteristics, including comfort, flexibility, functionality, spatial hierarchy, openness, and other support facilities, that influence the use and activities of students in informal learning spaces. This exploration of spatial characteristics sheds new light on designing higher education informal learning spaces and how they can be analysed to generate empirical evidence. However, more comprehensive studies are required to enhance our understanding of these spaces and how students use them in different buildings, contexts, and climates.

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Appendix A. Questionnaire Form

You are invited to complete a questionnaire about your experiences of social spaces in the Newton Atrium at the Nottingham Trent University | the Diamond at the University of Sheffield. It should take approximately 10 min and some open questions will also be asked. As part of my PhD research I am exploring the impact of social spaces on students' experiences. The research will contribute to my advanced research study, be written up and submitted as a PhD thesis at the University of Nottingham.

All the data collected will be anonymous. Your name will not be linked to any of the data collected, and you will not be identified in the writing in the research. Your participation is entirely voluntary, and you can choose to stop taking part at any time you wish. The research was approved by UoN Department of Engineering ethics committee through a research ethics application. If you have any further enquiries, please contact me Xianfeng Wu: xianfeng.wu@nottingham.ac.uk

My research supervisors are:

Katharina Borsi: katharina.borsi@nottingham.ac.uk

Tim Heath: tim.heath@nottingham.ac.uk

By completing the questionnaire overleaf, you consent to take part in the research and give permission for me to access, analyse, and report the data that you provide.

Thank you for your time.

(1) Questions about activities.

a. How often have you done these activities in this social space per week? You can tick (✓) at the space given.

Subject	Scale				
	Never	Slightly Frequently	Frequently	More Frequently	Most Frequently
Focused Informal Learning (paper-based or book-based self-study)					
1. Prepared coursework	1	2	3	4	5
2. Discussed ideas from reading books or lectures	1	2	3	4	5
3. Worked with others on coursework	1	2	3	4	5
4. Study alone	1	2	3	4	5
Intermittent Exchange (information interchange)					

Subject		Scale				
		Never	Slightly Frequently	Frequently	More Frequently	Most Frequently
5.	Talked about career plans	1	2	3	4	5
6.	Study alone, but with occasional interaction with others	1	2	3	4	5
7.	Worked with others on activities other than coursework	1	2	3	4	5
8.	Received prompt feedback from the faculty on your academic performance	1	2	3	4	5
9.	Tutored or taught other students	1	2	3	4	5
10.	Had serious conversations with students of a different program or department than your own	1	2	3	4	5
Focused Socialising						
11.	Took a call	1	2	3	4	5
12.	Used of tablet, laptop, or phone	1	2	3	4	5
13.	Casual Chatting	1	2	3	4	5
14.	Took a break from studies with friends	1	2	3	4	5
Dietary Related Activities						
15.	Had a meal	1	2	3	4	5
16.	Had a snack	1	2	3	4	5
Serendipitous Encounter (Seeing, greeting, or short chats with each other because of encounter)						

Subject		Scale				
		Never	Slightly Frequently	Frequently	More Frequently	Most Frequently
17.	Met a friend of someone you know, but neither of you planned to	1	2	3	4	5
Ambient Sociality						
18.	Attended events such as Exhibitions, Open Days, or Coursework Shows	1	2	3	4	5
19.	Found the space as a way to a lecture room or gathering for going to another place together	1	2	3	4	5
20.	Used as a meeting point before or after lectures	1	2	3	4	5
21.	People watching	1	2	3	4	5
22.	Had a rest	1	2	3	4	5

b. During what time do you regularly use this social space? Please tick (✓) the time period when you use social spaces. You can tick (✓) more than one.

Time	Please tick (✓) if yes
8 am to 10 pm	
10 am to 12 pm	
12 pm to 2 pm	
2 pm to 5 pm	
5 pm to 7 pm	
7 pm to 10 pm	
10 pm to 0 am	
0 am to 8 am	

(2) Questions about the spatial experiences and perception of social informal learning spaces in higher education.

a. I select and use this social space because the space … Please tick (✓) the reason(s) of you select and use this social space. You can tick (✓) more than one.

I select and use this social space because the space . . .	Please tick
1. Provides comfortable light environments	
2. Provides comfortable noise environments	
3. Provides comfortable temperature	
4. Provides comfortable ventilation	
5. Provides comfortable colour/material of furniture	
6. Is flexible, adaptable, and diverse	
7. Provides informal ambience	
8. Support individual and group work	
9. Provides good view of seeing what other people are doing	
10. Provides good outside views	
11. Makes people feel easy for way finding	
12. Is easily accessible	
13. feels generous, open, and spacious.	
14. Provides other support (such as Wi-Fi, enough plugs and sockets, IT-rich environment)	
15. Other, please specify: ______	

b. Based on my experience, I think . . . Please rate how agree the following subjects described and tick how the height of the space (its vertical dimension) enhances this perception.

Subject	Scale				
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Physical Comfort (Light)					
The space provides good natural light.	1	2	3	4	5
The space provides sufficient lighting after dark.	1	2	3	4	5
The space provides a good comprehensive light environment.	1	2	3	4	5
Physical Comfort (Acoustic)					
The noise level of the space is good for socialising.	1	2	3	4	5
The noise level of the space is good for informal learning activities.	1	2	3	4	5
Physical Comfort (Temp/Ventilation)					
The temperature of the space is adequate for socialising.	1	2	3	4	5
The temperature of the space is adequate for informal learning activities.	1	2	3	4	5

Subject	Scale				
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Windows and air condition can be controlled by myself.	1	2	3	4	5
Physical Comfort (Colour/Material of Furniture)					
The colours of furniture support a comfortable learning environment.	1	2	3	4	5
The materials of furniture support a comfortable learning environment.	1	2	3	4	5
The furniture is light weight and movable for reconfiguring according to its use by individuals or groups.	1	2	3	4	5
Flexibility (Adaptability)					
The space can be easily reconfigured in a short period of time for group and individual work.	1	2	3	4	5
The space is usable 24/7 and maximises use over time.	1	2	3	4	5
Flexibility (Diversity)					
The space supports a diversity of learning styles.	1	2	3	4	5
The space offers a combination of spaces that supports socialising and informal learning activities.	1	2	3	4	5
The availability of food and drink is important for using this space.	1	2	3	4	5
Ambience					
The space feels welcoming.	1	2	3	4	5
The space provides a good sense of learning community.	1	2	3	4	5
The space is attractive.	1	2	3	4	5
The space is stimulating.	1	2	3	4	5
The space is contemplative.	1	2	3	4	5
Functionality					
The space supports group work and collaboration.	1	2	3	4	5
The space supports individual study and learning.	1	2	3	4	5
The space provides opportunities for socialising.	1	2	3	4	5
The space provides opportunities to meet peers, friends, and acquaintances.	1	2	3	4	5

Subject	Scale				
	Strongly Disagree	**Disagree**	**Neutral**	**Agree**	**Strongly Agree**
The space supports casual learning activities.	1	2	3	4	5
The space appeals to students from different courses and encourages interdisciplinary learning.	1	2	3	4	5
Situation					
The space supports discussions about course content following lectures or seminars.	1	2	3	4	5
The space provides good outside views.	1	2	3	4	5
Adjacency					
The space makes people feel easy for way finding.	1	2	3	4	5
The staircase is accessible and destination reachable.	1	2	3	4	5
The broader, open staircase allows for travel between floors at a more leisure pace.	1	2	3	4	5
Hierarchy					
The circulation is helpful to increase opportunities for socialising (students can easily and accessibly meet up in this area because of sufficient and efficient staircases and lifts.)	1	2	3	4	5
The circulation is helpful to increase opportunities for informal learning (students can easily have discussions after courses or lectures in this area because of the convenient staircases and lifts.)	1	2	3	4	5
The location of the space is easily accessible.	1	2	3	4	5
Openness					
The space feels generous, open, and spacious.	1	2	3	4	5
The space provides good visibility of the activities of other people.	1	2	3	4	5

Subject	Scale				
	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The space is bright.	1	2	3	4	5
Other Support					
The space provides good Wi-Fi coverage.	1	2	3	4	5
There are enough plugs and sockets available.	1	2	3	4	5
The toilet is easily accessible.	1	2	3	4	5
The space provides an IT-rich environment.	1	2	3	4	5
The space provides food and beverage.	1	2	3	4	5
The space provides a sense of safety (provides evacuation marks/stair railing/guardrail/entrance guard/staff support/card only system).	1	2	3	4	5

(3) If you have any additional comments that you would like to make about any aspect of the building and your working environment, please note them here.

If relevant to a particular question, please give the question number.

(4) Questions about personal background information.

- Are you an international student? Please circle: Yes/No
- Gender, please circle: Male/Female/wish not to say
- Which department do you study or work in? Please write down: _______
- Mode of Study, please circle: Full-time/Part-time
- Level of Study, please circle: PhD/Undergraduate/Masters
- Type of Programme, please circle: Lecture-based/Studio-based/Lab-based
- Year (How many years have you studied here), please circle: less than 1/1-2/3-more

Appendix B. Interview Form

(1) Introduction

a. Welcome and introduction of interviewer

b. Objective Informal learning refers to student learning outside of designated class time. The objective of the informal interviews is to gather information for a research project investigating students' perceptions on how social informal learning spaces impact on student experience.

c. Process I will be taking audio record during the interview so I can revisit and reflect on the information provided. We respect your right to privacy. Our Ethical Clearance ensures that any information that is obtained in connection with this study and that could be identified as relating to you will remain confidential. If you decide to participate in the interview, you are free to discontinue participation at any time without prejudice.

(2) Questions

Personal Background Information

1. Could you please introduce yourself?
   (a) What's your occupation?
   (b) Which department are you in? What's your subject? Which year are studying?
   (c) Where is your nearest classroom or workplace?

Frequency, Activity, and Reasons

2. What brings you here?
3. Which types of activities do you normally do there?

If yes, please answer the following questions.
If not, skip questions 3 and proceed to question 4.

4. Which types of activities do your friends normally do there?
5. How often do you use this space as a whole? Why?

Student perceptions of social spaces/role in student experience

6. Who do you (all) think this space was designed for?

Use of space:

7. How do you (all) think this space should be used?
8. How do you (all) use it?
9. How do you think using the social informal learning space impacts on students' academic performance?
10. What are the three most important things about this space that you would not want to change?
11. What are the three most important things that you would like to change or add on these spaces?

Student voice:

12. What is your favourite social informal learning spaces story/memory?

Appendix C. Focus Group Form

Focus Groups Discussion Guide: The Impact of Informal Learning Spaces upon student experiences (1 h)

- Consent forms (xN per set of groups)
- Recorder (smart phone & iPad)
- Focus Group Registration Form

Time	
5 min	**Welcome and Introduction** Provide respondents with: • Consent forms • Pens • Ask respondents to complete permission forms and collect in. • Welcome participants and explain general purpose of the discussion: "Thanks very much for coming. This group is being run to understand your thoughts about the design quality of your learning experience at university/college and your ideas about it for the future. This is one of a series of groups being run with students as part of wider research project. The information will be used to help us improve the quality of students learning experiences and to better support a social informal learning spaces in the future."

Time	
5 min	• Explain confidentiality of opinions shared. • Explain that it is not a test and that we want an honest an open discussion. Explain that the group will: - Start off with a general discussion of university life - Move on to explore your expectations of different aspects of your learning experience in the social informal learning spaces - How things were whilst you were there - How you think things can be improved for students • The group will last about 1 h • Explain the presence and purpose of recording equipment (to help facilitator write up notes later rather than during the focus group) and ask for permission. • Explain that discussion notes will be analysed, and no personal data will be shared. • Set out ground rules (speaking up, one at a time, respect for others' opinions, etc.) • Go through any health and safety procedures for the building, timed fire alarms, etc. • Explain that I am a PhD student in the University of Nottingham and that all work is conducted ethically and in accordance with the UoN code of conduct • Explain that as participants in the research, the respondents are entitled to a copy of the final report if requested • Start recording
5 min	**Icebreaker** • Moderator to introduce themselves • Ask each person to please briefly: - Introduce themselves - Where they come from - which Subject, School & Department they study - which year they are in - If needed to break ice: What's your summer plan? Where is your hometown? What's your favourite food?
20mins	Students' experiences (preferences and activities) Question: a) What do you think of the space? b) How do social informal learning spaces support social & learning activities? Probes: peer learning/collaboration/support/Different degrees of informal learning process
15 min	**Design Quality** Ask respondents to identify key design quality of a successful social informal learning spaces based on their own experiences of learning and socialising activities by themselves and discuss what they wrote. Question: Thinking about the experiences of learning or socialising activities here, describe the characteristics of a successful social informal learning spaces. Prompts—this could include the likes of: The Physical Comfort: Light/Acoustics/Temperature/Ventilation/Furniture (Colour/Material) The Flexibility: Mobility/Adaptability/Diversity/Flexibility The Ambience: Socialising/Sense of Community/Informative /Attractiveness /Openness /Enclosure /Safety The Functionality: Support group work and collaboration/Supports individual learning The Situation: Location (continue classroom discussions immediately following class time)/Outside Views The Spatial Hierarchy: Circulation/ Legibility/Intelligibility/Privacy/Spacious The Other Support: IT-rich environment/Wi-Fi Coverage/Plugs and Sockets/Food and Beverage
15 min	**Space In-Between** Questions: What influence the design of the atrium gives you in the social informal learning spaces?
	Thank and Close • Thank them for all their help in this group.

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Article

Design Framework and Principles for Learning Environment Co-Design: Synthesis from Literature and Three Empirical Studies

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Abstract: The need for environments conducive to learning and wellbeing has been broadly recognised. Considering particularly learner perceptions in the learning environment design is known to improve both their learning and wellbeing. There are no, however, shared theoretical frameworks guiding the learning environment co-design from the learner perspective. As a response to this challenge, a learning environment design (LED) framework was developed based on the literature and co-design involving learners aged 7 to 19 (n = 342) in Finland (n = 266) and Spain (n = 76). The LED framework entails 53 characteristics grouped under seven constructs. It draws attention to the importance of balancing communality with individuality, comfort with health, and novelty with conventionality. Flexibility and functionality are recognised as central enablers for a quality learning environment. The study suggests a design framework and principles for learning environment co-design. They can serve as a research-based introduction to the topic after which priorities can be defined based on the concrete design target and goals, and concrete design solutions can be created in the participatory design involving learners and other key stakeholders.

Keywords: design framework; design principles; educational design research; learning and wellbeing; learning environments; participatory design; co-design

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1. Introduction

In recent years, there has been a growing interest in reconsidering the design of educational spaces and environments. The need to design environments conducive to learning and wellbeing has been broadly recognised. For instance, Learning Environments Evaluation Programme (LEEP) by the Organisation for Economic Co-operation and Development (OECD) was created to support the development of environments leading to "improved education, health, social and well-being outcomes" [1].

There is already a strong body of research representing the field of education (e.g., [2]), health science (e.g., [3]), environmental science (e.g., [4]), and architecture (e.g., [5]) contributing to identifying learning environment characteristics supporting both learning and wellbeing. Earlier research has emphasised the importance of social relations, individualisation [6], pleasantness, physical wellness [7], novel and conventional tools and spaces [8], and flexibility and functionality [9]. Different aspects of learning environments, such as psychosocial, physical, and technological are, however, most commonly studied separately [10–12].

Byers and colleagues [13] argue that it is vital to assure that environments support high quality teacher–student interactions and that pedagogy (e.g., interactive instruction), space (e.g., student-centric space), and use of technologies (e.g., tablet PCs) are aligned. A similar attempt towards more holistic visions can be found in a study by López Costa [14] considering an environmental, pedagogical, and digital-technological dimension in the integration of digital devices in early childhood, primary, and secondary school environments. Studies by Barrett and colleagues [7,15], in turn, have identified a holistic impact of naturalness (light, sound, temperature, air quality, and links to nature), individualisation (ownership, flexibility, and connection), and appropriate level of stimulation (complexity and colour) on learning. Likewise, López-Chao and colleagues [16,17] have identified relationships between learning outcomes and variables such as ventilation, artificial light, noise, Wi-Fi coverage, room size, ergonomics, and connection with nature. Further, López-Chao and López-Pena [18] found that academic results are influenced by the place attachment, the classroom design as a facilitator of social interaction, social interaction in learning, and the satisfaction of indoor environmental quality.

Despite these efforts towards a more holistic understanding of the influence of different learning environment dimensions on learning and wellbeing, research knowledge seems not to transfer well to frameworks and principles that can guide the learning environment design process and designers.

The importance of considering particularly learner (pupil or student) perception in the learning environment design process is supported by the research indicating that the congruence between learners' perception of preferred and experienced environments can impact learning positively [2]. The approach is also supported by learner-centred pedagogies promoting learners' agency in a learning process [19]. However, studies on learners' opinions seem not to provide useful frameworks that designers and architects could use in the school design process [10], nor do they commonly gather learner perceptions on environments fostering both learning and wellbeing. The few studies looking at learners' views from both learning and wellbeing perspectives are small-scale qualitative studies (e.g., [8,20]). They also commonly lack a broader theoretical framework [5] and therefore the results are difficult to apply to different sociocultural contexts. Participatory design (PD) projects may, therefore, remain isolated and experimental and lack both sustainability and scalability [21]. On the other hand, there is research on school architecture that is focusing on the architecture itself, not on the activity taking place in the space. For instance, Gislason ([12], p. 127) has criticised that research on school architecture typically considers "teaching and learning apart from architectural settings" or studies are centred on "the built environment separately from classroom practices".

This study responded to the identified demand to develop theoretically and practically significant, empirically tested learning environment design (LED) framework to support the participatory (re)design of environments conducive to learning and wellbeing. The study merges perspectives from various theories and disciplines and creates a framework to support the participatory co-design of environments fostering learning and wellbeing based on the research literature and empirical studies involving learners representing different age groups (from 7 to 19 years), genders, and cultural contexts, Finland and Spain, in the design process. The aim was to create a framework which supports balancing the use of previous theoretical insights and research-based know-how with learners' voice in co-design initiatives. The following research questions were set:

- Q1: What kind of structure can be identified as optimal for the LED framework?
- Q2: What are the relevant learning environment characteristics of the LED framework based on learners' views?

In this article, we start by defining the theoretical background of this study. We proceed by presenting the research design with methodological approach and data collection. After presenting the empirical results, in discussion, we propose substantive, i.e., content-related, design principles formulated for co-designing learning environments based on the study and also supported by other studies in this field.

The study is a synthesis of three sub-studies [22–24] which were also part of doctoral dissertation in educational science [25]. Unlike the previous publications, this article synthesises and conceptualises the results in order to also contribute to design research and practice. This article focuses on presenting the overview of the framework development based on the literature and shared views amongst the learners representing different sociocultural contexts and educational levels. More detailed description of each sub-study, research instruments, and analysis can be found in the published sub-studies.

Theoretical Background

Guided particularly by Dewey's [26,27] educational philosophy, the study aimed at capturing learning environment characteristics fostering highly interconnected cognitive, emotional, social, and physical dimensions of learning and wellbeing (see also [8,28]). In line with Dewey [26,27], sociocultural and socioconstructivist paradigms inspired by authors such as Vygotsky [29], and the ecological model of Bronfenbrenner [30], individual and social human activities (i.e., psychosocial environments) are seen as highly interconnected with physical environments. Further, Dewey's [27] descriptions of time- or space-wise immediate and remote environments were connected with more recent considerations of technology-enhanced learning and virtual-physical or hybrid environments [31–34].

In this research, learning environments are conceptualised as complex, closely interconnected psychosocial and technology-enhanced physical and virtual environments [25]. Therefore, the object of design in a case of learning environment is not only the physical and virtual spaces and tools, but also individual and social human activities, that is, policies, practices, services, interactions, etc. connected with the spaces and tools (see also [35]). In this research, the attention is particularly at the microsystem level (immediate environment), but mesosystem linking, e.g., home and school environments, and wider societal and cultural environments are also considered (see [30,36]). In line with Dewey [26,27], individuals are viewed to be in dynamic interaction with their social and (technology-enhanced) physical environments; while these environments can promote, permit, or hinder human activities, individuals and groups can also actively influence them.

A literature review [25] was conducted prior to empirical studies towards the construction of a preliminary conceptual framework (Version 1.0, i.e., V1.0). The aim was to identify learning environment characteristics frequently presented in the literature and to construct a conceptual understanding of key characteristics of environments conducive to learning and wellbeing. Various electronic databases (e.g., ERIC, Google Scholar, JSTOR, and ScienceDirect) were used. The most frequent keywords were "physical or psychosocial or technology-enhanced learning environment(s)", "classroom or school or educational environment(s)", "school design or architecture", and "learning spaces". Keywords were used both separately and in various combinations. They were also combined with the keywords "learning" and "wellbeing". The literature studied represented various disciplines, mainly educational and architectural studies but also studies in the field of computer science, environmental psychology, and health sciences. It included theoretical and empirical literature and both qualitative and quantitative studies. There were studies involving learners, and studies involving various stakeholders and studies not involving any stakeholders in the design. Earlier literature reviews were also examined. Initially, around 150 publications were selected based on their relevance in general (e.g., number of citations) and their relevance in relation to the research objectives. Of these publications, 55 were selected for a more in-depth analysis.

The main learning environment characteristics of the conceptual framework V1.0 guiding the study were divided into the following three partially overlapping constructs: (I) overall wellbeing, (II) learning situation, and (III) learning tools and space design (Figure 1). The three constructs identified based on the literature have similarities with Cohen's [28] considerations of school climate consisting of physical and social-emotional safety, relationships (cf., wellbeing), teaching and learning (cf., learning situations), and external environment (cf., learning tools and space).

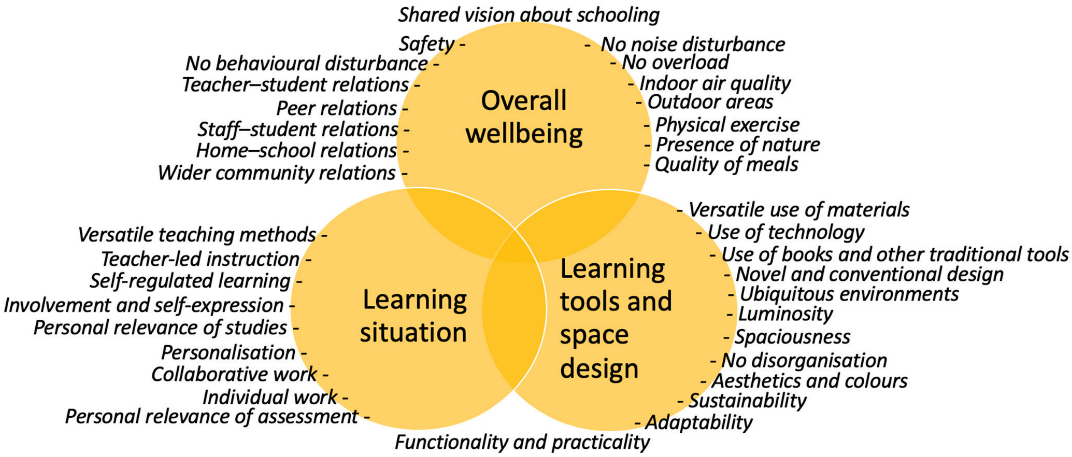

Figure 1. Learning environment design (LED) framework V1.0: Constructs and characteristics selected based on the literature review (Example literature, see [2–12,20,33,34,37–67]).

2. Research Design and Procedure

The methodological approach in this study is one branch of design research (cf. e.g., design research described by Luck [35]) labelled "educational design research" [68]. It focuses on the design in education and intertwines educational planning, practice, and theory development. The approach includes design experiments [69,70], developmental research [71], and design-based research [72]. As typical for such approaches [72], this study aimed at theoretically significant contributions by creating a framework, whose content and construct validity is tested in empirical studies. The study was also guided by the principles of pragmatism and practicality [70,73]: research know-how was employed in the actual learning environment design process during the study and can be used in the future (external validity). In addition to the LED framework development, the aim was to formulate substantive, that is, content-related design principles [68] that can serve as guidelines in the future design.

The aim was that the framework developed and tested in various contexts balances both fixed and emerging elements, thus allowing both contextualisation and generalisation between contexts [69,74,75]. The study consisted of iterations, with each iteration considered a semi-independent research cycle leading to progressive improvement of the design framework [76–78]. A mixed-methods approach was employed [69,79] by embedding statistical methods within predominantly qualitative research. Finally, as typical to educational design research [75,76,80], various stakeholders were involved in the design research. The focus was, however, particularly on gathering learning environment characteristics relevant for learners.

In relation to the learner participation, the present educational design research utilised some aspects of the participatory design (PD) approach. This approach has commonly been employed in the design of physical learning environments [38,81–83]. It has also been employed in instructional design [84] and in the design of educational technology [85]. PD has been used to combine perceptions of designers, teachers, and learners [86] as well as other school staff members, parents, and the wider community [87], including, e.g., policymakers, local authorities, and contractors [88].

PD is in line with learner-centred educational views honouring learners' epistemological agency [19,26,27]. Similar ideas have also been expressed in approaches involving learners as (co)researchers [89] and those focusing on learners' voices [90–92]. Concepts "participatory design" and "co-design" are used in this study in a broad sense to refer to knowledge sharing and creation (in relation to the past, present, and future) between participants representing various backgrounds [93]. Smith and Iversen [21] emphasise the importance of carefully defining the relationships and forms of participation for each stakeholder group. In this study, learner involvement was particularly important so as to see what learning environment characteristics they considered as relevant to their learning and wellbeing. By combining previous research literature with empirical studies focusing on learners' perceptions, the aim was to create a framework whose validity was confirmed by learners.

Figure 2 summarises the research cycles of this study in relation to research aims and sub-studies (see also [25]). Design cycles numbered as 1 to 6 refer to student (learner) involvement.

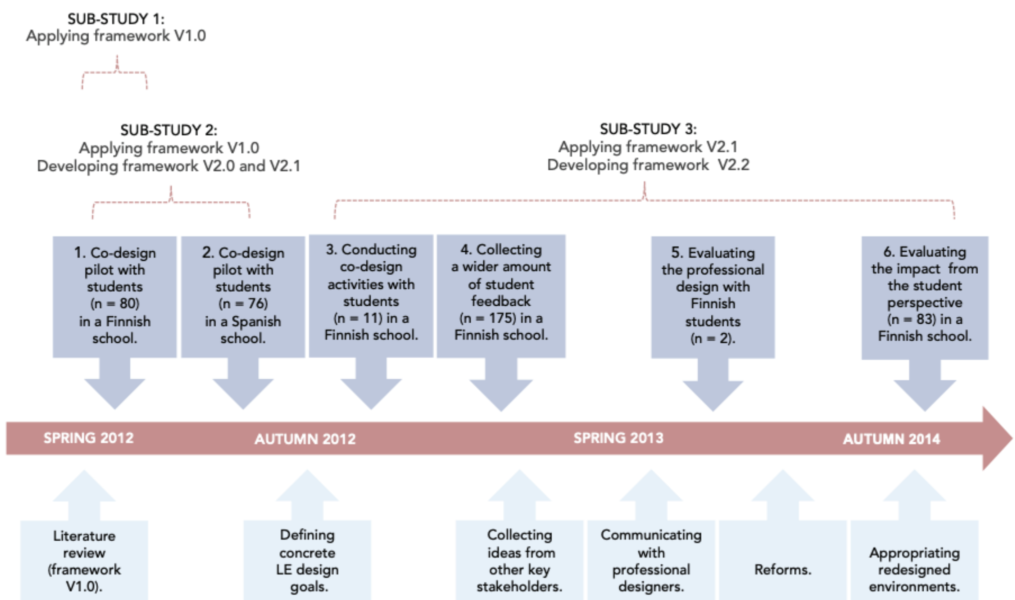

Figure 2. Design cycles in relation to sub-studies (Image by Mona Johansson in [25]).

The study aimed at rich understanding of the learners' perspectives by collecting quantitative, written, oral, and visuospatial data and analysing it with quantitative and qualitative methods (see [21,90,94,95]). The framework V1.0 was created based on the literature review (see Figure 1). Numeric and written data were collected by means of web questionnaires (sub-studies 1–3) and student feedback form (sub-study 3). Surveys contained fixed items but open questions were used for issues not raised previously. In sub-studies 1 and 2, participants elaborated physical scale models or mock-ups and in sub-study 3, virtual 3D models (see Figure 3). Visual or visuospatial methods are, however, often constrained by the participants' skills [96], they do not directly provide answers to why-questions [97] and the data may be easily misinterpreted [20]. This is why visuospatial data were combined with (semi-structured) interviews, giving participants an opportunity for explaining and presenting their work [64,98]). For the purpose of sub-study 3, a type of member checking [99] was employed by inviting learners to evaluate the design proposals to assure that their insights had been interpreted correctly and considered in the design. Table 1 summarises the participants, data, and data analysis of each sub-study. For a more detailed description of the materials, see [25].

Figure 3. Examples of designs by Spanish 3rd graders (**upper left**), Finnish 8th graders (**down left**), and upper secondary school students (**right**).

In sub-study 1 (cycle 1), the framework V1.0 was applied in the co-design pilot sessions with learners (girls: $n = 34$; boys: $n = 46$) aged 7 to 14 years (from 2nd grade of primary school to 2nd grade of lower secondary school) in a Finnish university-affiliated teacher training school in late spring 2012 and early autumn 2012. The web questionnaire (numeric and written data) was used as an introductory pair work activity, followed by a collaborative scale model design and group discussions. In sub-study 2 (cycles 1 and 2), the same research design was employed in co-design pilot sessions with learners aged 7 to 14 years (from 3rd grade of primary school to 3rd grade of lower secondary school) girls: $n = 40$; boys: $n = 36$) in a publicly financed private school in Spain in late autumn 2012, to test for the cross-cultural relevance and consistency of framework V1.0. An exploratory factor analysis was conducted to guide the restructuring of the initial framework with respect to theoretical constructs. Content elements (learning environment characteristics) confirmed by the quantitative and qualitative data were grouped under the renewed constructs, which were further divided into thematic sub-blocks. If the cross-analysis revealed some apparent discrepancies, a more in-depth analysis was conducted to search for their possible origin and explain them in light of the overall data. The data analysis led to the development of framework versions V2.0 and V2.1.

Sub-study 3 (cycles 3–6) was carried out in the same teacher training school in Finland where the first pilot took place. This school achieved funding for reforming some of their learning spaces. The aim was to involve upper secondary school students in the redesign of their natural science classroom and its adjacent hallway. Co-design activities (cycle 3) were part of a visual arts project course conducted during the autumn term of 2012. For their final coursework, the participating students (females: $n = 8$; males: $n = 3$) created learning environment designs consisting of 3D models/sketches and colour, furniture, and technology plan. These designs were displayed in an exhibition (cycle 4), where other students (females: $n = 104$; males: $n = 61$; no information on gender: $n = 10$) had an opportunity to express their views on a structured student feedback form. Student designs and summaries of student suggestions were next presented to teachers and teacher students who first evaluated students' ideas and subsequently gave their own suggestions. Suggestions from all participant groups were finally communicated to the professional designers. Before implementing the changes to the actual redesign, the researchers invited participants of the co-design project course to evaluate the professional design (cycle 5). Two male upper secondary school student co-designers participated in this activity. After some final revisions, the reforms took place in summer 2013. After some months of appropriating the redesigned environments, students were invited to answer an online student satisfaction survey (females: n = 45; males: n = 37). The survey's formulation (cycle 6) was guided by the conceptual framework V2.1 but was based on the learning environment characteristics highlighted by the students in previous design cycles. The V2.2 of the framework was then constructed based on the analysis of the results of research cycles 1–6 (sub-studies 1–3).

Table 1. Participants, data, and data analysis of each sub-study.

Study	Participants	Data	Data Analysis
1	Learners (n = 80) age 7 to 14 years in a Finnish school	- A web questionnaire (numeric and written data) - Scale models/mock-ups (visuospatial data) - Semi-structured group discussions (oral data)	Cross-analysis of - qualitative data: content analysis, and - quantitative data: descriptives (means and standard deviation) and group differences (Independent-Samples t-test).
2	Learners (n = 156) age 7 to 14 years in a Finnish (n = 80) and Spanish (n = 76) school	- A web questionnaire (numeric and written data) - Scale models/mock-ups (visuospatial data) - Semi-structured group discussions (oral data)	Cross-analysis of - qualitative data: content analysis, and - quantitative data: descriptives (means and standard deviation), exploratory factor analysis (principal axis extraction with direct oblimin rotation).
3	Learners (n = 186) age 16 to 19 years in a Finnish school	- Learners' (n = 11) designs (3D models) - Written student feedback (n = 175) - Professional design evaluation (oral data) with students (n = 2) - Student satisfaction survey (n = 83)	Cross-analysis of - qualitative data: thematic analysis and content analysis, and - quantitative data: descriptive statistics (means, standard deviation, and frequencies).

In the Results section, we summarise the empirical results of the three sub-studies. This is followed by the discussion presenting the design principles formulated based on the sub-studies and supported by the literature.

3. Results

Sub-study 1 [22] employed the preliminary framework (V1.0, see Figure 1) in analysing Finnish 7- to 14-year-old learners' (n = 80) perceptions on environments that foster learning and wellbeing. It tested the consistency of the initial framework (construct validity) and its relevance (content validity). The focus was on participants' shared views. The three main constructs ("overall wellbeing", "learning situation", and "learning tools and space design") of the framework V1.0 were found to be valid with respect to representation of relevant learner perceptions. The three constructs appeared, however, to be highly overlapping and interrelated. In relation to framework content validity, 24 characteristics included into framework V1.0 were corroborated as the most relevant for participant learners based on the data.

In sub-study 2 [23], the consistency and relevance of the initial framework (V1.0, Figure 1) was further explored based on the analysis of data from 7 to 14-year-old participants in both Finland (*n* = 80) and Spain (*n* = 76). Participant learners' views analysed supported cross-cultural relevance (content validity) of all characteristics included into the initial framework V1.0. In relation to framework consistency, factor analysis on the student ratings data supported restructuring of the three constructs of the initial framework into framework V2.0 with five constructs. These constructs were also subdivided in thematic clusters or sub-themes: (I) communality (social relations, teaching-learning interaction, sense of belonging, safety), (II) individuality (privacy and peacefulness, individualisation), (III) comfort (physical ease, pleasantness), (IV) health (physical wellness, no overload), and (V) versatile tools and spaces (novel tools and spaces, conventional tools and spaces, flexibility and functionality). In the data analysis, pairs of concepts of communality–individuality and comfort–health were first identified. The same idea of thematic equilibrium was also identified in two of the main themes of the fifth construct, that is, balancing novel and conventional tools and spaces. Therefore, these two themes were promoted as constructs. This left the last theme in the fifth construct, flexibility and functionality as a meta-construct that can be applied to all other constructs. A cross-analysis with other data types and theoretical, empirical, and practical considerations led to the construction of framework version 2.1. The revised framework consisted of seven constructs each divided with two to four sub-themes, and a total of 41 characteristics.

Sub-study 3 [24] aimed at testing and further developing the constructs and contents of framework V2.1 in an actual co-design project with Finnish upper secondary school students (*n* = 186) between 16 and 19 years of age. Framework V2.1 constructs were found to be feasible for this co-design project. Of the 41 characteristics included in framework V2.1, 26 characteristics were replicated, 15 characteristics were not directly replicated, and 11 characteristics emerged from this data set. The results were generally in line with the earlier sub-studies. The framework V2.2 developed based on this study cycle consisted now of 52 characteristics. In the final analysis, based on the attention participants gave to colours, aesthetics and colours were yet considered as separate characteristics (cf. Figure 1) leading to a total of 53 characteristics in the learning environment framework V3.

On a general level, learners representing different sociocultural contexts, ages, and educational levels had very shared views of environments supporting their learning and wellbeing. These general, more detailed results for each construct are presented in the following subsections.

3.1. Communality Balanced with Individuality

Table 2 presents four sub-themes and 14 characteristics related to communality as well as two individuality-related sub-themes and their 10 characteristics confirmed based on empirical findings of this study involving 7- to 19-year-old learners in Finland and Spain (sub-studies 1–3). In relation to communality, most of these characteristics were confirmed in at least two sub-studies. For instance, in survey responses from Finland and Spain (sub-study 2), social relations-related items received the highest ratings of all (M = 4.3–4.5 of 5). Learners considered particularly *peer relations* and *collaborative work* as important and wished, e.g., for group working spaces and furniture and good areas for socialising and spending time with peers. Further, three new characteristics, namely *teacher visibility*, *homelike environments*, and *transparency* emerged based on sub-study 3 involving upper secondary school students. Participants' concerns related to teacher visibility were particularly related to the plan of removing the tiered classroom floor in the redesign process. Participants also wished to have a transparent glass wall separating the classroom and the hallway. On the other hand, various characteristics were out of the scope of the specific design goals focusing on the redesign of a natural science classroom and thus were not replicated in sub-study 3.

Based on the results of sub-studies 1–3, as a whole, participant learners seemed to consider individuality-related characteristics as somewhat less important than communality-related characteristics (Table 2). Of these characteristics, *only personal relevance of studies* and *individual work* were amongst the most prominent 24 characteristics identified in the sub-study 1. In a survey result of sub-study 2 involving Finnish and Spanish learners, item "individual work" received the lowest ratings (M = 3.4 of 5) of all survey items. In a sub-study 3 involving Finnish upper secondary school students, individual work was wished to be supported, e.g., by choosing desktops allowing individual configurations.

Table 2. Communality- and individuality-related characteristics confirmed or emerged in sub-studies.

I Communality	Sub-Study	II Individuality	Sub-Study
(a) Social relations		(a) Privacy and peacefulness	
Teacher–student relations	1, 2	No noise disturbance	2, 3
Staff–student relations	2	No disorganisation	2, 3
Peer relations	1, 2, 3	No distractions	2, 3
Home–school relations	1, 2	Private spaces	3
Wider community relations	2		
(b) Teaching-learning interaction		(b) Individualisation	
Teacher-led instruction	1, 2, 3	Personalised learning	2, 3
Teacher visibility	3	Personal relevance of studies	1, 2
Collaborative work	1, 2, 3	Personally relevant assessment	2
(c) Sense of belonging		Individual work	1, 2, 3
Shared vision	1, 2	Self-regulated learning	2, 3
Involvement and self-expression	1, 2	Studying during the breaks	3
Homelike environment	3		
(d) Safety			
No behavioural disturbance	1, 2, 3		
Transparency	3		
Physical safety	1, 2, 3		

Furthermore, *personalised learning* or opportunities to make choices related to one's own learning (sub-study 2) and creating various smaller-scale learning stations, enabling the selection of the working space (sub-study 3), were wished by the participants. In sub-study 2, participants considered "reducing noise disturbance" as relevant (M = 4.1 of 5). In sub-study 3, participants wished for concrete solutions such as good soundproofing, acoustic panels, and textiles to reduce noise. In sub-study 2, a characteristic of *no distractions* emerged. In sub-study 2, participants proposed, e.g., that restricting the use of the Internet may be a good way to reduce distractions. In sub-study 3, dimming curtains were wished to separate the classroom from the hallway, when in need of full concentration. Further, in sub-study 3, characteristics *private spaces* and areas for *studying during the breaks* emerged.

3.2. Comfort Balanced with Health

As can be seen in Table 3, the comfort construct was divided into two sub-themes comprising a total of seven characteristics and the health construct included two sub-themes and eight characteristics. Comfort-related characteristics were viewed as highly important by different-aged learners participating in this study in Finland and Spain. Most of these characteristics were confirmed by all sub-studies. For instance, results of sub-study 2 indicate that in both countries, both primary and secondary school learners generally considered "spaciousness" as important (M = 4.3 of 5). In the group discussions, small children explained that they wished for more space to play, whereas adolescents complained about overly cramped spaces for working.

In sub-study 2, a characteristic *comfortable furniture and spaces* (e.g., sofa groups and cushions) emerged. Further, characteristic no overload was divided into rest and leisure time (cf. Figure 1 and Table 3). In sub-study 3 involving Finnish upper secondary school students, a characteristic of *enough seats, seating, and table space* emerged. "Aesthetics" was not rated high (e.g., in sub-study 2, M = 3.6 of 5) in comparison to other items but the importance given to decorative elements of scale models indicated that participants valued these characteristics. Participants in all sub-studies gave lots of importance for *colours*. In sub-study 3, they wished for, e.g., balancing colours that are stimulating, fresh, or not depressing, with calming, not disturbing colours. Participants also proposed colour-changing lamps so as to vary colours. *Presence of nature* was considered as important by participants in all sub-studies (see Figure 4). For instance, gardens, park areas, presence of water (sub-studies 1 and 2), and interior plants (sub-study 3) were wished for.

Table 3. Comfort- and health-related characteristics confirmed or emerged in sub-studies.

III Comfort	Sub-Study	IV Health	Sub-Study
(a) Physical ease		(a) Physical wellness	
Spaciousness	1, 2, 3	Quality of meals	2
Enough seats, tables, and table space	3	Indoor air quality	2, 3
Comfortable furniture and spaces	2, 3	Indoor air temperature	3
(b) Pleasantness		Ergonomics	3
Aesthetics	1, 2, 3	Good outdoor areas	1, 2
Colours	1, 2, 3	Physical exercise	1, 2
Luminosity	1, 2, 3	(b) No overload	
Presence of nature	1, 2, 3	Rest	2, 3
		Leisure time	2, 3

Figure 4. Learning environment design details by Finnish 2nd graders (beach), Spanish 8th graders (park), Finnish 6th graders (ice hockey rink), and Spanish 3rd graders (football stadium).

In relation to characteristics grouped under health construct, 7–14-year-old learners both in Finland and Spain rated health-related survey items as generally high (M < 4). Scale model constructions and group discussions revealed that learners in both countries viewed possibilities for *physical exercise* as important. For instance, Finnish participants paid attention to good ice hockey rinks and Spanish participants to football camps (Figure 4).

Characteristics of *quality of meals*, *good outdoor areas*, and *physical exercise* were not replicated in sub-study 3, possibly because they were out of the scope of the specific redesign project focusing on natural science learning environments. On the other hand, characteristics of optimal *indoor air temperature* and *ergonomics* (e.g., adjustable desks and chairs, science lab furniture) emerged based on participants' wishes.

3.3. Novelty Balanced with Conventionality

As can be seen in Table 4, the five novelty-related and five conventionality-related characteristics are divided into two sub-themes. Most of the characteristics were confirmed as relevant by participant learners in sub-study 2 analysing Finnish and Spanish 7- to 14-year-old learners' perceptions. For instance, in a survey, "use of technology" and "use of books" were rated equally highly (M = 4 of 5). In sub-study 2, ubiquitous learning environment was divided into *informal* (e.g., beach, city), *non-formal* (e.g., libraries, museums, science centres), and *formal* (e.g., classrooms) learning environments (cf. Figure 1 and Table 4). Characteristics of informal, formal, and non-formal learning environments were not replicated in sub-study 3 as its focus was on the formal school design. On the other hand, characteristics of *educational design elements* (e.g., planetarium ceiling, solar system model, or colour-changing lamps for teaching colour theory) and *inspiring and motivating spaces* emerged in sub-study 3.

Table 4. Novelty- and conventionality-related characteristics confirmed or emerged in sub-studies.

V Novelty	**Sub-Study**	**VI Conventionality**	**Sub-Study**
(a) Novel tools		(a) Conventional tools	
Use of technology	1, 2, 3	Use of books and other traditional materials	1, 2, 3
Educational design elements	3		
(b) Novel spaces		(b) Conventional spaces	
Informal learning environments	2	Sustainable design	2
Novel design	1, 2, 3	Non-formal learning environments	2
Inspiring and motivating spaces	3	Formal learning environments	2
		Conventional design	1, 2, 3

3.4. Flexibility and Functionality

Finally, construct flexibility and functionality entailed four characteristics (see Table 5). In the survey results of sub-study 2 involving Finnish and Spanish learners, "versatile materials", "functionality and practicality", and "adaptability" were rated as relatively high (M = 3.8–4 of 5). In sub-study 3, these characteristics were given an important weight by the Finnish upper secondary school students. Moreover, *versatile methods* emerged as a new characteristic. Participant students wished, for instance, varying learning stations both inside and outside the classroom as well as furniture allowing multiple configurations.

Table 5. Characteristics related to flexibility and functionality confirmed or emerged in sub-studies.

VII Flexibility and Functionality	**Sub-Study**
Versatile use of tools and materials	1, 2, 3
Versatile methods	3
Adaptability	2, 3
Functionality and practicality	2, 3

4. Discussion

The aim of this educational design research was to develop a shared design framework for co-designing psychosocial and technology-enhanced physical and virtual environments fostering learning and wellbeing. The framework was developed based on the theoretical, empirical, and practical considerations, focusing particularly on learners' perceptions. The research questions were related to the LED framework's constructs and contents. Results of this study suggest that there are specific structures that can be used to classify and gather characteristics improving learning and wellbeing when practicing co-design of learning environments. Furthermore, findings revealed several characteristics that were found relevant by learners. The framework guides particularly towards identifying the balance between communality and individuality, comfort and health, and novelty and conventionality, while giving flexibility and functionality a centric role in the design. To synthesise the findings from literature and the three empirical studies, it is possible to present a design framework (Figure 5) that can be utilised in design processes.

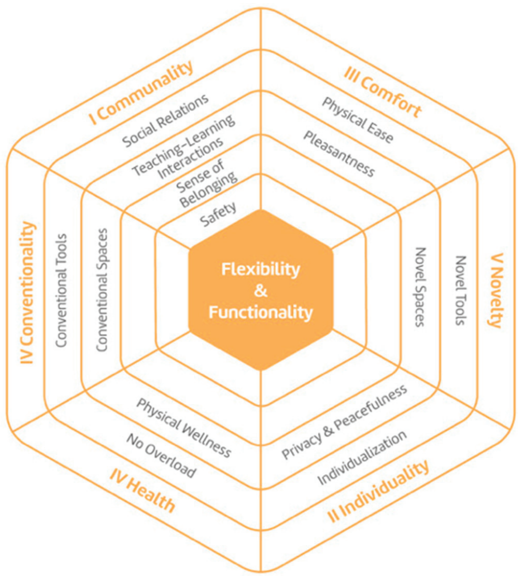

Figure 5. Visualisation of the LED framework V3 by Iconograph [100].

In relation to the LED framework constructs (Q1), to our knowledge, there are no previous frameworks that have consistently been built around the idea of maintaining equilibrium between various learning and wellbeing needs. However, some of the earlier models also consider the notion of "balancing". The pair of constructs "communality" and "individuality" are closely related to the dimensions "relationship" and "personal development" in Moos' (e.g., [101]) human environment model. Gee's [102] "human-centred design guidelines" include dimensions "communality" and "solitude". The model by Barrett and his colleagues [7] balances "open" with "private". Comfort and health, in turn, are notions typically reflected in architectural designs. Comfort, for example, was chosen as one of the main constructs in Sulonen and Sulonen's [103] characteristics, while Gee's [102] guidelines include the construct "healthful". Further, the concept of balancing novelty with conventionality is reminiscent of Moos' model's [101] dimension, "system maintenance and system change", i.e., an equilibrium between stability and responsiveness to change. The construct of "novelty" shares properties with the design principle of "stimulation", which Barrett and his colleagues ([7], p.681) described as an indicator of "the degree to which the school provides appropriate diversity (novelty)". The conventionality-construct shares similarities with the construct "durability" used in other conceptualisations [103,104]. Finally, the conceptual decision to place "flexibility and functionality" as the centric construct of framework is supported by both architectural [7,38,102,103]) and educational [61,104] literature.

In relation to contents of the framework (Q2), in addition to confirming the importance of each characteristic for participant learners in at least one of the three sub-studies, there is a wide body of literature confirming their relevance and transferability to various educational contexts. Example literature has already been presented in the theoretical background (see Figure 1).

In the following, we present each construct with 15 general design principles and their sub-principles that are delivered from the sub-studies 1–3 and the literature. Substantive design principles are formulated for each construct and learning environment characteristic. The generalisability of the design principles in other educational contexts are strengthened by research literature. The assumption is that the simultaneous design of psychosocial environments with physical and virtual environments will lead to improvements: on one hand, the individual and social human activities, practices, and services will be adequate for the designed spaces and tools. On the other hand, the designed spaces and tools will better enable the desired activities, practice, and services.

4.1. Communality

Principle 1: Design environments fostering good social relations.

Principle 1.1: Facilitate staff–student relations. Virtual and physical spaces should allow encounters for developing particularly good teacher–student relations (sub-studies 1 and 2; [18,54]) but also other staff–student relations (sub-study 2; [41]). These entail, e.g., the school direction [105], teaching assistants, and non-teaching staff working in the office, catering, and maintenance [41].

Principle 1.2: Support peer relations. Good peer relations can be supported by physical and virtual areas for socialising and spending time with peers (sub-studies 1–3; [40]). Social activity may be also encouraged by "open space and the school's compact interior" ([12], p.141). Literature (see [18]) indicates that that social interaction, particularly in relatively small groups, may be beneficial for learning.

Principle 1.3: Enable encounters with parents and other stakeholders. It is important to have time and spaces to get together and communication to promote good home–school relations (sub-studies 1 and 2; [6]) as well as to open the school to the wider community (sub-study 2; [3,50]).

Principle 2: Design environments for quality teaching–learning interaction.

Principle 2.1: Promote interaction. Collaborative work may be supported by group working tables and small and large group areas (sub-study 3; [12,65]), as well as by technological tools allowing collaboration [85]. While tiered classroom floors may support teacher-led instruction and teacher visibility (sub-study 3; [12,49,65]), they may not be recommendable as more passive presentation activities and didactic teaching should be limited [32], for instance, for introducing new topics for learners and when gradually guiding them towards more self-regulated forms of learning (see [29]). Teacher scaffolding may also be supported by novel technological tools [85]. Students may perceive both social and physical (instructions, tags, signs, labels, information boards) scaffolding as useful [106,107].

Principle 3: Design environments enhancing sense of belonging.

Principle 3.1: Support creating a shared vision. Efforts need to be made to create a shared vision about schooling (sub-studies 1 and 2; [32]). Shared vision can be fostered in different gatherings, ceremonies, and celebrations both physically and virtually. Presenting school symbols on the walls may also foster shared vision [38].

Principle 3.2: Promote self-expression, involvement, and cosiness. Providing possibilities for self-expression and involvement by means of co-design (sub-studies 1–3; [94]) and creating homelike environments and inviting, welcoming, and cosy areas (sub-study 3; [8,10,65]) may also enhance learners' sense of belonging and overall wellbeing. Presenting student works on the walls may foster a sense of ownership of learning space and equipment, as well as cosiness [38].

Principle 4: Design environments promoting safety.

Principle 4.1: Reduce behavioural disturbance. Behavioural disturbance such as bullying (sub-study 1), troublemaking, or vandalism (sub-study 3) may be reduced by creating pleasant environments increasing sense of ownership, belonging, and school-liking (sub-study 1–3; [38]). As argued in other studies [54], democratising classrooms, allowing for greater choice, and including the use of ICT may increase particularly adolescent students' engagement levels and positive attitudes towards schooling and school rules.

Principle 4.2: Promote transparency of activities. Transparency and openness [7,9] can be supported by transparent surfaces, e.g., glass walls or doors (sub-study 3) and good communication design. They also augment feelings of safety [38].

Principle 4.3: Ensure safe environments for all. Physical safety (sub-study 1–3) may be promoted by increasing security (sub-studies 1 and 2; [6,81] and by designing safety working areas for experiments (sub-study 3). Social and physical scaffolding may also increase students' feelings of safety [106]. Safety can also be increased by assuring that it is easy to find one's way around at school [11].

4.2. Individuality

Principle 5: Design environments for privacy and peacefulness.

Principle 5.1: Ensure good acoustics and noise control. Noise disturbance (sub-studies 2 and 3; [42]) may be reduced by good soundproofing, acoustic panels, and textiles (sub-study 3). Noise disturbance may also be related to a specific type of learner behaviour [16]. For instance, while learners participating in this study representing two sociocultural contexts generally seemed to value environments free of noise disturbance, more intensive conversational style in Spain in comparison to Finland may require particularly good acoustic design.

Principle 5.2: Promote good organisation. Disorganisation (sub-studies 2 and 3; [46]) may be avoided by providing good storage spaces (sub-study 3; [108]).

Principle 5.3: Support managing possible distractions. Both pleasant and unpleasant distractions (sub-study 2; [12,34,109]) may be reduced, e.g., by restricting the use of the Internet (sub-study 2) or providing dimming curtains (sub-study 3) to prevent getting distracted by too much transparency. Study by López-Chao and colleagues [16] also suggest that views from the windows may cause distractions.

Principle 5.4: Provide privacy for all. The right for privacy may be supported by designing private spaces (sub-study 3; [32,65]) and time to be and work alone. Moreover, possible age, individual, and sociocultural differences in the need for privacy should be taken into account.

Principle 6: Design environments supporting individualisation.

Principles 6.1: Create possibilities for choosing personal preferences of studying. Personalisation of learning (sub-studies 2 and 3) may be supported by creating opportunities to make choices related to one's own learning (sub-study 2; [94]) and creating various smaller-scale learning stations enabling the selection of the working space based on personal preferences (sub-study 3).

Principle 6.2: Promote personal meaningfulness of studies and assessment. Personal relevance of studies (sub-study 1 and 2) and assessment (sub-study 2) can be promoted by increasing connectedness with students' real-life aspirations [54], e.g., by means of real-life projects. Learners should be able to connect their studies also with personally relevant environments, and there should be both physical and virtual spaces where to receive personal feedback from teachers of one's progress.

Principle 6.3: Enable individual work and configuration. Individual work (sub-studies 1–3; [46]) requires desktops allowing individual configurations (sub-study 3). It is important to provide areas for reading, reflection, and quiet time for individual work [3,65].

Principle 6.4: Support self-regulation and studying during the breaks. Self-regulated learning (sub-studies 1–3; [37]) may be fostered by providing spaces for studying during the breaks (sub-study 3) entailing spaces for informal learning outside the scheduled classes [63]. In addition, physically mediated guidance such as clear, well-structured spaces, and technological devices proving guidance to one's work may support students' self-regulation and sense of autonomy [107].

4.3. Comfort

Principle 7: Design environments to nurture feelings of physical ease.

Principle 7.1: Design enough comfortable spaces and furniture for all. It is important to ensure environmental spaciousness (sub-studies 1–3; [65]) and that there are enough seats, seating, and table space for different purposes (sub-study 3; [110]). Likewise, possible age, individual, or sociocultural differences should be considered in the need for space. Providing comfortable furniture and spaces, e.g., sofa groups and cushions (sub-studies 2 and 3; [8,65] is likely to foster physical ease in learning environments. Excessive comfort may, however, be unergonomic and even detrimental to learning [16,17]. This calls for the design carefully balancing comfort with health.

Principle 8: Design pleasant environments.

Principle 8.1: Design aesthetically pleasant spaces. It is important to pay attention to aesthetic interior design and colours (sub-studies 1–3; [7,10,46]), e.g., by balancing colours that are stimulating, fresh, or not depressing, with calming, not disturbing colours or by colour-changing lamps so as to vary colours (sub-study 3).

Principle 8.2: Design for control of light. It is important to ensure that spaces are luminous (sub-studies 1–3, [8]), e.g., by designing wide windows, glass surfaces, and good lighting (sub-study 3). Good artificial light control and quantity have been associated to better learning outcomes [16]. Further, the need for good artificial light design is likely to be more important in geographical areas such as Finland with shorter periods of daylight during the winter.

Principle 8.3: Design spaces entailing elements of nature. Learning environments should include elements of nature (sub-studies 1–3; [11,16]), e.g., gardens, park areas (sub-studies 1 and 2) and interior plants (sub-study 3). Natural environment can also be seen to entail daylight, connection of the classroom with the outside, and natural ventilation [17]. There may also be more need to focus on the presence of nature in highly urban areas in comparison to areas that are exposed to nature.

4.4. Health

Principle 9: Design environments promoting physical wellness.

Principle 9.1: Provide high quality meals. Physical wellness may be nurtured by the healthy and tasty school meal (sub-study 2; [46]). Literature [11,104] supports the importance of paying attention to the type and quality of school canteen and catering, having sufficient time for eating, and access to water.

Principle 9.2: Design for good indoor air quality and temperature. It is important to pay attention to optimal indoor air quality (sub-studies 2 and 3; [20]) and temperature (sub-study 3; [42,111]). In countries such as Finland with long winters and low temperatures, good insulation and heating is an important requirement. In warmer countries such as Spain, in turn, there may be a need to focus on preventing overheating but also extreme cold, e.g., due to manual window-airing in the cold season [16].

Principle 9.3: Provide opportunities for exercise, play, and hanging out with peers. Good outdoor environments (sub-study 2; [63]) and opportunities and spaces for physical exercise (sub-studies 1 and 2; [44]) are known to support physical wellness.

Principle 9.3: Design for good ergonomics. There is a need to consider good ergonomics and provide ergonomic furniture, e.g., adjustable desks and chairs (sub-study 3; [34,110]). It is important to consider not only body measurements but also the adequacy of furniture ergonomics for different learning situations [16] such as teacher-led instruction and practical work.

Principle 10: Design environments that help to avoid overload.

Principle 10.1: Provide possibilities for rest and leisure time. Provide time and spaces for rest (sub-studies 1–3; [43,65]) and for more active recreation and leisure time (sub-studies 1–3; [3,20,104]). Separate leisure zones as well as loft beds, niches for quiet reflection, "caves" or shallower places under the stairs (see [81]) may be employed during the breaks.

4.5. Novelty

Principle 11: Design environments with novel tools.

Principle 11.1: Design use of technological tools so that there is easy access to them and support needed for their use. It seems recommendable to use technology (sub-studies 1–3; [9]) together with support for teachers for their use (sub-study 3; [31]). Tanner [65] recommended that technological equipment be placed so that its use is easy to integrate with curriculum, teaching, and learning. Likewise, it is important to design and select technological tools based on the specific requirements of each educational level [14]. The layout of hardware and technical support materials should also be designed so that they do not limit the flexible use of spaces [16,112,113]. Attention should also be paid to issues such as the Wi-Fi coverage and the placement of sockets, power strips, and wires [14,16]. There may also be local differences in the quality of ICT infrastructure that need to be considered in the design and use of technology

Principle 11.2: Design educational elements to the spaces, indoor and outdoor. Educational design elements, e.g., planetarium ceiling, solar system model, or colour-changing lamps for teaching colour theory (sub-study 3) may be used so as to consider the whole school building as a tool for learning (see also [63,104]). Spaces with visible infrastructure provide a possibility to use the building structure as a learning tool [104] and walls may be used as display areas for subject material or products of research activity [63].

Principle 12: Design environments entailing novel spaces.

Principle 12.1: Promote informal learning. It is good to take advantage of informal, outside school environments and create connections between formal and informal learning (sub-studies 1 and 2; [9]). Novel mobile technology may also be used to augment physical spaces and expand activities outside the classroom [85].

Principle 12.2: Foster inspiration and motivation. It seems beneficial to design spaces with novel, inspiring, and motivating interior design (sub-study 3; [7]) with exciting and surprising elements such as different textures, shapes, or untraditional furniture. There should be "an atmosphere of excitement for learning" ([65], p. 453). The importance of novel, inspiring, and motivating environments is also supported by studies highlighting the importance of satisfaction, joy, and happiness for student learning and wellbeing [6,8,109].

4.6. Conventionality

Principle 13: Design environments allowing the use of conventional tools.

Principle 13.1: Design by building on tradition. Instead of abandoning books and other traditional materials (sub-studies 1–3; [8]), it is recommended to balance novel tools and, e.g., computer access with adequate space for books and other non-digital learning materials [34].

Principle 13.1: Design for sustainability as a model for others. It is important to consider sustainability in the design (sub-study 2; [46]). As recommended by Nuikkinen [38], the school building can serve as a physical model of ecologically, economically, socially, and culturally sustainable design.

Principle 14: Design environments including conventional spaces.

Principle 14.1: Provide opportunities to integrate non-formal and formal learning. Attention should be paid to creating connections between non-formal learning environments, e.g., libraries, museums, science centres, and formal learning environments, e.g., classrooms (sub-studies 1 and 2; [8]).

Principle 14.2: Respect conventions. Conventional design, but also spaces that retain reversibility or convertibility to the traditional classroom may satisfy both learner-centred and traditional, teacher-led instruction (sub-studies 1–3; [32]). As Frelin and Grannas [81] remind us, chance does not necessarily mean improvement: well-functioning arrangements should not be abandoned only for the sake of change.

4.7. Flexibility and Functionality

Principle 15: Design flexible environments with high functionality.

Principle 15.1: Design versatile environments. It is important to employ versatile tools and materials and versatile methods (sub-studies 1–3), supported e.g., by varying learning stations both inside and outside the classroom (sub-study 3). Learner-centred activities such as presentations; large, medium, or small interactive activities; creative work (e.g., art, laboratory); and reflection (reading, writing, research) require a wide range of different spaces: classrooms, commons, meeting areas, fixed areas, spaces for outdoor learning, and so on [32].

Principle 15.2: Ensure that environments are adaptable, functional, and practical. There is a need for adaptable, functional, and practical tools, spaces, and ways of working that can be easily modified, e.g., furniture allowing multiple configurations (sub-study 3) and adapting the learning environment design in accordance with context-specific requirements (sub-studies 1–3). There is also a need for fluidity or adaptability, i.e., the space capacity or agility for flow and change between activities [32]. It is important also to support adaptation to, e.g., open and flexible learning environments [112]. All members of the learning community need to be supported in the transition to innovative learning environments [81] in order to assure their functionality and practicality.

5. Limitations and Future Directions

This study focused on shared perceptions of learners representing different socio-cultural contexts, ages, and educational levels with the aim of constructing a generic design framework and principles which considers learners' perceptions and is also supported by the literature. There are, however, differences between contexts as well as purposes of spaces (e.g., classroom, art class, laboratory) that need to be considered when applying these principles in the learning environment design (see also [14,16,17]). As stated by Veloso and Marques ([113], p. 246), it is important to consider "the specific needs of the schools, such as its organisational, social environment, space uses, and learning aims". As proposed by Woolner and Cardellino ([114], p. 14), PD can be seen as a way to avoid excessive generalisation or "uncritical transfer of practices, curricula, and school buildings between differing contexts". We encourage, however, to also use the LED framework to reflect if there are some challenges in the context that should be tackled. In this way, the co-design can lead to changes in the existing context, instead of only adapting the design into the context.

While this study focused on shared views, some differences were also identified. Particularly in sub-study 3 focusing on the co-design of natural science learning spaces with upper secondary school students, various new characteristics emerged. In addition to focusing on a specific type of space, it is also likely that older learners were more aware and able to express particularly more abstract ideas related to their learning environment preferences. It is, indeed, important to adapt co-design goals and methods to participants' age and educational context. In future studies, more attention could be given to identify the contextual differences that need to be considered in the design in order to respond to specific needs of each learning community.

It is also good to bear in mind that the LED framework synthesising a wide range of characteristics conducive to learning and wellbeing is limited in its capacity to consider each characteristic individually. For example, within the subtheme "teaching–learning interaction" or "individualisation", there could be a long list of activities that could be employed in learning situations. We think that the role of the LED framework is to provide general directions, which can then be specified in each co-design process.

This study did not focus on interrelations or dependencies between different learning environment characteristics, nor did it measure the impact of these characteristics on learning outcomes (cf. [7,15–18]). In addition to focusing on interrelations between various characteristics or their effects on learning outcomes, in the future, it would be interesting to collect wellbeing data, e.g., by means of wearable sensors (see [115]) in order to evaluate the impact of learning environments on wellbeing, for instance, balance between stress and recovery during the day.

Furthermore, the framework presented in this article focuses particularly on the learner perceptions. In future research, the aim is to employ and further develop the framework in a learning environment co-design with teachers. There is also need to facilitate collaboration between teachers contributing pedagogical ideas and, e.g., interior architects contributing to comfort, work stations, furniture, and so on [81]. Views of other internal stakeholders such as non-teaching staff should also be considered [114].

The aim is also to adapt the framework to early childhood and higher education. Furthermore, the COVID-19 pandemic has brought to light various challenges that need to be addressed in the learning environment design, particularly related to remote learning in home environments but also to needs such as enabling a safe distance in face-to-face learning situations. In the future studies, the aim is also to ensure that the LED framework responds to the design of hybrid or blended learning environments.

6. Conclusions

This study responded to the need to create both theoretically and practically significant design framework and principles gathering psychosocial and technology-enhanced physical and virtual learning environment characteristics fostering learning and wellbeing. The focus was particularly on ensuring that characteristics relevant for learners are considered in the framework. As a new, both theoretical and practical contribution, in comparison to earlier models, particularly the need for balancing and reaching the equilibrium between varying needs and preferences is now more strongly emphasised.

The empirically and theoretically grounded LED framework and principles developed in this study can be used for planning, gathering information, classifying data, and structuring the evaluation of individual co-design initiatives. The framework can be used as a check-list guiding design research and in organizing co-design workshops with stakeholders. The seven constructs of the framework are interlinked and should all be discussed and dealt concurrently in relation to each other. The design framework and principles may help designers in the design process to recognise design opportunities, challenges, and constraints. They can serve as a research-based introduction to the topic after which priorities can be defined based on the concrete design target and goals and concrete design solutions can be created in the co-design sessions.

In addition to individual co-design initiatives, the LED framework and principles can be used to compare and generalise findings between different learning environment co-design projects. In each co-design case, depending on the target, some characteristics are expected to be confirmed as relevant while some may not. It is also possible that some new characteristics, that could be added to the framework, emerge. We view, however, that the LED framework and principles can serve as a research-based starting point creating awareness of the issues identified as important in international body of literature. After that, PD efforts are made to concretise the contextual needs and design decisions.

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Institutional Review Board Statement: The study was conducted according to the guidelines of the Declaration of Helsinki and Finnish Advisory Board on Research Integrity, and instructed by the University of Jyväskylä Ethical Commitee. Only information on participants' gender, age, nationality, and school was asked without linking any other personal data to responses. For this reason, there was no need for an additional Institutional Review Board Statement.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. Also parental consent was obtained from participants under 18 years old.

Data Availability Statement: The datasets used and analysed during in the study are available in original languages from the corresponding author on reasonable request.

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Designing and Building Robust Innovative Learning Environments

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Abstract: Prior research shows that creating innovative learning spaces that work well for pupils and teachers is a challenge which implicates different stakeholders. The aim of this article is to inquire into how educational visions evolve and are expressed through the different phases of two school design processes as well as visualize how stakeholders' roles in the processes result in innovative learning environments and practices that work well. The data consists of photographs from school visits, briefs, and interviews. The material is analyzed with a particular focus on educational vision, organization, and working methods. An analytical model showing the stakeholders' levels of participation at each stage is revised and developed. The results indicate four common themes: Continuity (several stakeholders involved in more than one phase); Preparation (processes were long-term, continuous, and iterative, with future users testing and evaluating prototypes and other innovative interior design elements to be used in the new spaces); Alignment (early and extensive considerations of the school's organization and working methods); and Participation (multi-professional teams with representation of a pedagogical perspective at the higher levels of participation). From this, it can be concluded that achieving robust, innovative learning environments involves stakeholders' regard to the aspects of knowledge, education, organization, and economy.

Keywords: built pedagogy; educational vision; innovation; interior design; learning environment; participatory design; school building; school design; school architecture

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1. Introduction

Across the globe, newly built schools are increasingly featuring non-traditional learning environments, where classrooms and corridors are replaced by more flexible, complex, and multi-use learning spaces. In order to create functional schools that serve their intended purposes and users, attention has been directed toward the involvement of different stakeholders in the design and building process. In a comparative case study, the design and building process is examined in two schools with innovative learning environments in order to further the understanding of how alignment can be created between the school building, its users, and its educational practices. The aim of this article is to visualize how and by which stakeholders pedagogical visions are generated, developed, translated, negotiated, and embedded into learning spaces. In addition, an analytical model is suggested for analysis of when and how stakeholders can be involved in the different phases of school design and building. The model can benefit those involved in the planning, designing, building, ownership, and use of school buildings by providing an improved understanding of the complexities of creating innovative learning environments that serve their intended purposes and users.

1.1. Innovative Learning Environments

In the learning environment research field, the notion of an innovative learning environment (ILE) has become a common way of describing schools and school spaces that in various ways break away from traditional configurations (i.e., those typically represented by a square classroom with desks in rows and the teacher at the front of the room, delivering a teacher-centered education). In contrast, innovative learning environments have been connected to student-centered and activity-based pedagogy [1], flexibility [2,3], multiple zones [4], open spaces [5,6], and new technologies [7,8]. Mahat et al. [9] defined ILEs as products of innovative design and innovative teaching and learning practices. The notion of innovation has to do with calls for change expressed, for example, by the Organisation for Economic Co-operation and Development (OECD), which stresses the need to prepare pupils for a new future requiring twenty-first century competences such as communication, creativity, and collaboration [10–12]. Although the ILE concept is also used to denote a combination of space, pedagogy, and organization, considerable attention has been given to physical learning environments as drivers for educational change [12–14]. It should be noted that the discourse on the need for new practices and spaces has been criticized, because change does not necessarily mean improvement, and there is, therefore, a risk of abandoning well-functioning arrangements for the sake of change [15].

1.2. Challenges of Alignment

Learning environments can be viewed holistically as ecosystems consisting of intertwined times, places, people, relationships, and activities and being connected to particular educational purposes [16–19]. However, they are only successful when they fulfill the purposes for which they are built. ILE design thus needs to connect to educational theory [1,20,21]. Gislason [22,23] described the notion of a good fit between what he called a school's educational programs and the design of its learning spaces, and he stressed the importance of school design, see also [1,24] Teachers who are mainly responsible for aligning space and pedagogy often experience challenges in this respect [13,25,26]. Indeed, some building projects have failed to deliver such an alignment, which has led to expensive and time-consuming rebuilds [27–29].

1.3. Preparations for Sustainable Transitions to ILEs

Several studies highlight the challenges of organizing time, people, and space differently and call for adequate preparation in order to achieve sustainable change [6,20,30] when transitioning to teaching and learning in ILEs. Many studies have shown that successful transition processes take time for investment both in real time and over time, often lasting several years [14,31–33] and involving multiple stakeholders. They also stress the role of leadership in managing such changes using preparations [31,32,34]. For example, head teachers can introduce change gradually in the existing environment in a way that nudges teachers toward organizing their teaching and learning differently, establishing and communicating structures that help teachers to adopt new practices [26,31], and helping teachers to manage perceptions of risk [35].

Creating and promoting a shared vision in a school is a long-term process [33]. The same goes for building relationships and culture among teachers that sustain the vision and translate it into everyday practice [31]. Moreover, teacher support for creating alignments is necessary for successful transitions to ILEs [36]. Teachers need time and support to prototype and experiment with new spatial arrangements and to understand the new plans [25,26,37]. The learning space design process may also include an activation phase led by the designer for translating the designed intentions for the spaces into action [38,39].

Financial robustness is an important aspect addressed, for example, by Leiringer and Cardellino [3]. School designs that cannot accommodate an increase of the pupil-to-teacher ratio due to classroom size may result in a financial loss. They also point to large and noisy spaces that cannot be used in the way they were intended, e.g., [40].

1.4. Participatory School Design

One way of enhancing the fit or alignment between learning spaces and educational practices is to use a participatory design process [41–44] in which teachers and pupils are included as important stakeholders [20,28,44–47]. Although in larger schemes their participation is often lacking [48], in participatory design processes, the extent to which stakeholders have influence and the phases during which participation occurs vary.

In a research project on the UK Building Schools for the Future program, analysis by Daniels, Tse, Stables, and Cox [28] of the accounts of multiple stakeholders highlighted the challenges of multi-agency work and the importance of continuity throughout the process for translating visions into buildings [49]. Tse, Learoyd-Smith, Stables, and Daniels [50] stated the following: "Maintaining continuity between different design stages and different stakeholders and preserving leadership is essential to delivering the educational vision of the project throughout the design and construction of a school" (p. 79). They argue that different professional groups have different knowledge and motives and that tensions and trade-offs made in and between the phases could jeopardize the delivery of an effective environment for teaching and learning.

1.5. Main Aim and Conclusions

To summarize, the design process is important for alignment between the place and practice, especially in innovative learning environments, and there is a need for more research on how these design processes can be improved. In this article, we examine the design and building processes adopted by two schools to successfully introduce innovative learning environments in order to show how educational visions are translated and negotiated into spaces and practices that work for the users.

2. Materials and Method

The school design and building process is a complex endeavor. In order to visualize it, we used a case study approach [51]. Each school building was studied as a case in itself, and the same kind of data was collected in the two cases. The collected empirical material was first subjected to a within-case analysis and then a cross-case analysis.

2.1. The Swedish Context

Most Swedish children attend preschool, and in Sweden, the comprehensive school system spans from the ages of 6 to 16. From the age of 16, upper secondary schools offer 3-year vocational and academic programs. The school system is regulated by a national school law [52], and national curricula are issued by the Swedish National Agency for Education [53] along with a course syllabus for each subject. Around 85% of comprehensive schools are managed by municipalities, and the rest are publicly financed but privately run so-called independent schools or "free schools" (similar to charter schools). (Including upper secondary school, 25% of students attend independent schools. For more information, see https://www.skolverket.se/andra-sprak-other-languages/english-engelska, accessed on 8 June 2021) The subjects and the number of guaranteed teaching hours per subject during each school year are nationally determined by the Ministry of Education and passed by the Swedish Parliament. Regular inspections of schools are carried out by the Swedish Schools Inspectorate, which also reviews and approves the establishment of independent schools.

2.2. The Case Schools

The two case schools were selected at the outset of the project by the funding agency due to their innovative learning environments, architectural qualities (both had been nominated for or awarded prizes), and participatory design processes. As such, they were considered exemplary cases of a new type of learning environment that is trending in school buildings. Moreover, a survey that was conducted in both schools indicated that the teachers perceived a high degree of alignment between the school building, its users, and its educational practices [54]. In this article, the names of the two schools have been changed for ethical reasons, and their aliases are Hill School and Valley School. (The choice to change the names and omit photos and blueprints has been deemed necessary for ethical reasons, in accordance with ethical guidelines for Swedish research.)

Both opened their new school buildings in 2019. Located in the greater Stockholm area with a population of 1.5 million, both schools accommodate pupils from above average socioeconomic groups in comparatively affluent areas. Hill School's uptake area is mainly local, whereas the pupils attending Valley School also travel from other areas. Additional data is provided in Table 1.

Table 1. Description of Hill School and Valley School.

School	Hill School	Valley School
Ownership	Municipality	Independent
Pupils' ages	6–12	6–15
Number of pupils in full operation	900	520
Square meters	8850 m^2	5000 m^2

Hill School is a municipality-run school built on sloping ground in an industrial cultural heritage area. The school is located near a park area, which is within walking distance. One of the school's older buildings has been integrated into the new design. The surrounding residential area mainly consists of newly built flats and is still largely under development. The entire complex was designed in a way that took the challenges of the location and slope (over 10 meters and resulting in 6 different levels) into account. The design solution consisted of two buildings connected by a partly submerged area containing the dining hall and other common functions. A separate building for physical education is located across the street. In full operation, Hill School serves 900 pupils from preschool to year 6 (ages 6–12), although it is also able to take pupils up to year 9 (aged 15) due to its special facilities for science and other school subjects. Each year has its own team learning environment (TeLE) that can house up to 90 pupils and includes 1 large open area, 2 classroom-sized, and 4 breakout rooms, all of which are furnished and have other affordances (see Figure 1).

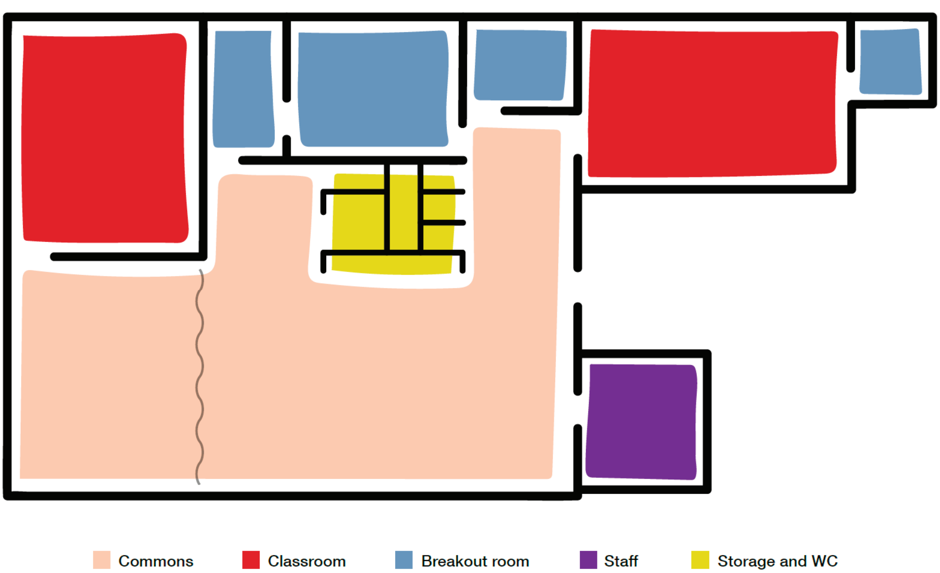

Figure 1. Team learning environment in Hill School.

Valley School is an independent school that is privately operated and tax funded. It first opened in 2013 in temporary modular buildings and moved into the new three-story school building in 2019. The school is located in a hilly residential area, and the school building is located adjacent to a small forest. It consists of one large rectangular building. At the heart of the building, there is a large open area with stairs and a dining hall, and the three floors include open areas for communication and study outside the learning spaces. The school is built to accommodate 520 pupils from preschool to year 9 (aged 6–15), with each year housed in a team learning environment for up to 56 pupils. The TeLE contains a large open area, one large breakout room, and two small breakout rooms, all with different kinds of furniture and other affordances (Figure 2).

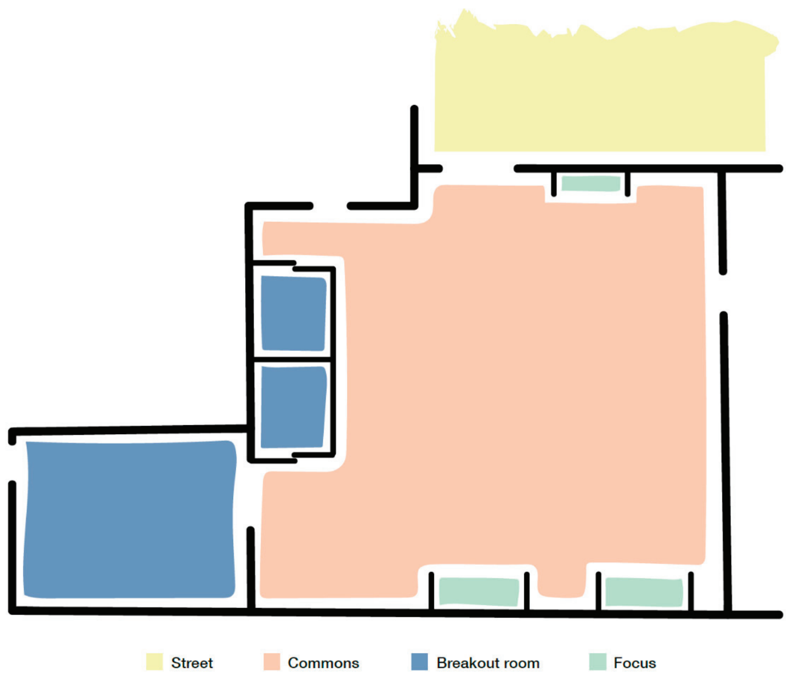

Figure 2. TeLE in Valley School.

2.3. Data Collection

The newly built case schools were visited early on in the research project in order to familiarize the researchers with the buildings and their learning environments. During guided tours of the premises, photographs were taken to support the analysis process, and the researchers asked clarifying questions in preparation for the data collection. Documentation such as building briefs and programs, blueprints, school website addresses, and mission statements were collected. The data that were used for the analyses in this article were collected during the spring of 2020 and consisted of 10 semi-structured interviews with stakeholders involved in the school design processes, which are shown in Table 2.

Table 2. Overview of interviews.

Hill School	Valley School
Architect	
Interior architect	Architect
Head teacher	Interior design agency
Municipality's educational property coordinator	Operations manager
Municipality's educational planning officer	Learning environment consultant
Municipality's building company project manager	

2.4. Interviews

Most of the interviews were conducted at a location chosen by the informant. However, due to restrictions during the COVID-19 pandemic, the interviews with four of the informants were conducted using a video conferencing system. Both researchers participated in all the interviews, during which the informants were initially informed about the study and consent obtained in accordance with the prevailing ethical guidelines. Each informant was asked about their role during the design and building process and their knowledge and influence regarding the school's educational vision, organization, and approach. An interview guide was used, and the questions included the following examples: "What can you tell me about the vision of the school? How is it negotiated throughout the process? How is it expressed in the building? In the furniture? In the technological solutions?" A large sheet of paper and pens were provided during the on-site interviews, with prompts to make notes about important events, people, and other aspects of the design and building processes in chronological order. The informants were also occasionally asked to make sketches of space layouts, furniture, and other features, as exemplified in Figure 3.

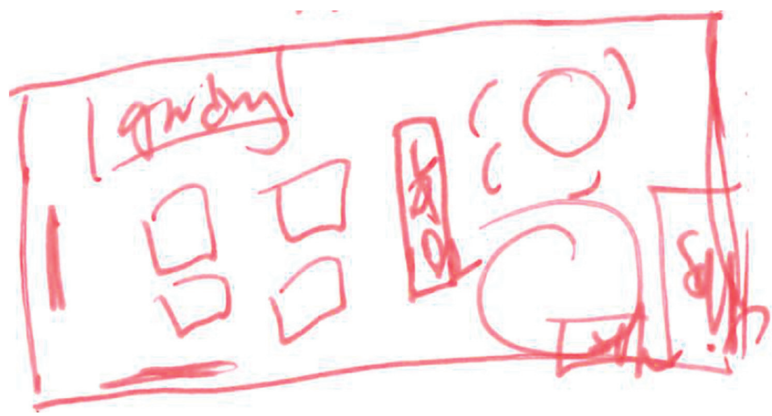

Figure 3. Detail of space layout sketch during interview.

The informants whose interviews were conducted online e-mailed their notes to the researchers afterward. The duration of the interviews ranged from 50 to 130 min, and all were audio recorded. All the data were stored on a password-protected server [55].

2.5. Data Analyses

The within-case data analyses followed a three-stage process, after which comparative cross-case analysis was conducted. *Initially*, the data from the interviews in each school were compiled into one common document and sorted under the three categories of *educational vision*, *organization and approach*, and *physical environment*, as stated in the purpose of the project. The data from each informant were color coded in the text. To support the process, the informants' timelines were used to clarify and complement the interview accounts. *Secondly*, this document was used to construct a common process timeline on a large sheet of paper, with the three categories displayed in rows and the years written from left to right. Keywords from the informants' accounts were color coded and written against the approximate year and category they referred to. This process timeline was intended to aid the discernment of phases in the process. In fact, it revealed instances where there were an absence of distinct beginnings and endings in the process and showed ways in which different phases in the design and building processes overlapped and interacted, such as through the actions and interactions of the stakeholders, and other factors such as policy and concrete obstacles. At this point, and drawing on the research literature, an analytical model was developed to capture the stakeholders' roles in the different parts of the process (see the details below).

Finally, themed common process timelines were used to construct a common narrative of the design and building processes in each school. In this narrative, the different voices were merged to add chronology and thickness to the description [56]. It also laid the foundation for the cross-case analysis. The common narratives were read by both researchers in conjunction with the corresponding document from stage one and accordingly corrected and complemented with details and quotations. This version was checked by the head teacher and the operations manager at the respective schools.

2.6. Constructing an Analytical Model

In order to make sense of the design and building process, during the analysis, previous models were examined for this purpose. Of particular use were a stage model by Daniels et al. [28] and Singer and Woolner's [57] climbing frame of participation using Arnstein's [58] ladder of participation. Daniels, Tse, Stables, and Cox's [28] model illustrates the different stages of a school building project: vision, concept design, design development, technical design, construction, and occupation, and highlights how stakeholders with different motives and knowledge act and interact in multi-agency work, resulting in trade-offs and tensions in and between the various phases.

Singer and Woolner [57] used a typology developed by Arnstein [58] to describe stakeholders' roles. Arnstein's ladder of participation features eight rungs of (non)participation in matters of citizen participation from manipulation to citizen control, of which they used four:

- *Control*: the final word in decisions and negotiating the conditions for others to have influence over them;
- *Partnership*: planning and decision making is shared in negotiations throughout the process;
- *Consultation*: the involved actors are informed and their views solicited so that they may be taken into account;
- *Inform*: the involved actors are informed, but information flows one way with little possibility for feedback.

Based on indications in the data material, a modified analytical model was developed containing elements from all three of the models mentioned above, as shown in Figure 4. Although important actors' roles during various phases were being visualized in the previous models, the role of interior design was not made visible. Other changes were made to enhance the visibility of stakeholders during the phases. In addition, the period of occupancy was omitted in order to refine the focus on the design and building process.

School name	Educational Vision	Concept Design	Space Design	Interior Design	Technical Design/ Construction
Control					
Partnership					
Consult					
Inform					

Figure 4. The ECSIT model, consisting of educational vision, concept design, space design, interior design, and technical design and construction.

In the model, the left-hand column indicates the different stakeholders' levels of influence in the design process.

The other columns each represent a phase, and these may overlap:

- Educational vision: the pedagogical ideas and values are formulated;
- Concept design: a design brief is produced, transforming ideas and values into functional demands;
- Space design: a building program with spaces and their relations is developed, and drawings of floor plans are produced;
- Interior design: furniture and other artifacts are chosen and ordered;
- Technical Design and Construction: technical drawings are produced, and the building is erected.

The model introduced below shares some features with the one above, but it has distinctive differences. The stakeholders are indicated in each column according to their level of representation in that phase, rather than having a column of their own as in Singer and Woolner's model. We did not distinguish between technical design and construction like in Daniels et al.'s model. Moreover, as an important theme in our interviews was the interior design, we distinguished between space design and interior design. In this article, and based on the interviews and documents, stakeholder involvement was traced for each school and phase and presented in the results. In a school design and building process, one stakeholder could be present on a high level throughout all phases and another only in one or two phases and on a lower level. One process could have many stakeholders with little continuity, whereas another process could have fewer involved with strong continuity through all phases, please see Figure 4.

It should be noted that even though the pupils were not included in the data here and were not formally part of the process, their indirect influence was present in their verbal and non-verbal feedback to the teachers during the everyday teaching in both schools and, in the case of Hill School, through extensive interviews, which also fed into the building briefs and programs.

The ECSIT model could be used in building projects in order to design participant design processes, to facilitate multi-agency discussions during the process in terms of the definition of and agreement on roles and involvement, and for evaluation purposes after the participant design processes. The model may prove valuable in terms of planning the school design and building processes with adequate actor competence and user representation in the different phases, as well as preventing a loss of knowledge due to a lack of continuity between the phases. Moreover, in research, it could be used as an analytical tool for examination of singular processes or for comparative purposes.

2.7. Cross-Case Analysis

Finally, cross-case analysis was conducted to compare the two case schools. The focus for the comparison was how and by what the stakeholders' pedagogical visions were generated, developed, translated, negotiated, and embedded into the spaces and practices during the design and building processes. The cross-case analysis was based on comparisons of the results from the within-case analysis. The comparisons highlighted the similarities, the patterns that emerged between the cases, as well as the specifics in each case.

3. Results

The design and building processes of both schools are presented, analyzed, and compared in this section.

- First, the processes for both schools are presented in narrative form. As the processes in the two schools were somewhat different, the headings are not identical in these narratives.
- Secondly, the ECSIT model is used to plot stakeholder involvement in different parts of the process in each school.
- Lastly, the two cases are compared in terms of the various features of the process from vision to building.

3.1. Hill School

3.1.1. Background: School Buildings Program

The process of designing and building Hill School's learning environments can be traced back to the development of a common school buildings program initiated by the municipality to support the building of more schools in the city. The municipality's educational property coordinator led this project from 2012–14, which included site visits, workshops with stakeholders, and interviews with a number of teachers and 300 pupils, all of which provided input and helped to shape the program.

The program expresses educational ideas about thematic practices, culture, the use of technology, and approaches to pupil diversity. The organization that the program's schools are expected to support includes team teaching and the provision of learning environments accommodating the equivalent of three to four classes per year group (max. 90–120 pupils). The intention is for the TeLEs to function as smaller units in a larger organization, rather like schools within a school, where teachers have a common work room and are expected to work collaboratively in teams. These areas, in which pupils have all their classes that do not require special spaces (such as science and physical education), reflect the educational ideas from the school buildings program and include the following features:

- Areas where pupils' work can be displayed;
- Screens and projectors;
- Large open and common areas;
- Variations in the sizes of the different areas;
- Sound-absorbing materials for floors, such as carpets.

Another aspect of the school buildings program, and one that is not based on pedagogic ideas, is that of the size of the school. The creation of larger schools is seen as a way of creating economically sound units. Space efficiency is also important and is expressed in terms of reducing areas that are not directly related to teaching and learning, such as corridors or multifunctional areas. An example of this at Hill School is the integration of the cloakroom into the large open space in the TeLE. The overall ambition is that each space can be used as a potential learning environment, which is why the windows are at floor level and the windowsills are wide; this is so that they can be used as study spaces.

3.1.2. The Design of the New School

Important factors when drawing up the plans for Hill School were the differences in height in the building plot and also that the existing buildings in the industrial heritage area should form part of the new school. These aspects made the project differ from many others. The architect's vision for the design included comfort, safety, and security, and already in the initial stages, an interior architect was commissioned to produce design sketches for the different areas that included furniture. One design example was finding a solution that gathered 60 pupils in one place in order to free teachers for other work.

A head teacher for Hill School was appointed during the design phase in 2016, when most of the architecture was in place. Following this appointment, the municipality's educational property coordinator, who had had a prominent role in the design and building processes, and the head teacher worked side by side until the latter became more familiar with the project. The head teacher wanted the learning environments to accommodate the needs of as many pupils as possible and had pedagogical ideas about the looks and layouts of these environments. Other ideas included shared leadership and delegating control to the staff. These ideas aligned with those expressed in the municipality's school buildings program.

At the time of the head teacher's appointment, the floor plans were more or less complete, although there was still ample opportunity to influence the interior spaces. The same interior architect who produced the design sketches was recommissioned, as that person was already familiar with the building. A 2-year collaboration process began, during which the interior architect, the head teacher, and sometimes the architect gradually shaped the learning environments. The head teacher explained this as follows:

She helped me with the procurement documents for the furniture and interior decorating because these aspects were very time consuming. She made suggestions for everything from boxes, desks and drawers/ . . . /so that I did not have to search for them./ . . . /My goal has been that all the spaces in this school should benefit the pupils, so that they always have access to a learning environment, no matter what. Our conference room is also a classroom. [The interior architect] drew these kite-shaped tables, we talked a lot about what I wanted and developed them together].

The collaboration included negotiations about transparent or non-transparent walls, the choice of materials, and what kind of furniture should be included. The interior architect contributed ideas about the importance of comfort, pupils being able to choose where to work, how to furnish the various areas, and the creation of an environment that supported teaching and learning based on democratic values. The head teacher in turn contributed pedagogical ideas and visions about the organization, the working methods, and the need for furnishings that supported these aspects. During this process, a furniture collection was designed and produced. This included a combined seating group and locker area and kite-shaped tables that could easily be arranged into different groupings.

3.1.3. Preparations in the Existing School

In 2016, the academic staff and pupils who were to inhabit the new school building had their classrooms in a nearby school with temporary module buildings. At that time, the number of pupils was 90, a number that increased with each new year's intake of pupils. New teachers were appointed as the student body grew. The head teachers had several pedagogical ideas: to introduce a subject teacher system for each year's grouping, create a flatter organization, and put more emphasis on pupil welfare. (A Swedish class teacher is a teacher who mostly teaches a primary school class in many school subjects. A subject teacher usually teaches several school classes in one or more school subjects. Subject teachers are most common in secondary and upper secondary schools.) Each work team was also expected to be more self-sufficient and make its own decisions, including how to group the pupils taught in the TeLEs. This organization was gradually implemented.

The head teacher also started the process of identifying core values for the new school and included the teachers in this development work. This led to so-called expectation cards for teachers, pupils, and parents. In 2017, the head teacher introduced new year organizational units and, in parallel with this, created a pilot learning environment in a large classroom in the present premises, with a focus on accessible learning. Here, the more traditional furniture was replaced, and the teachers and pupils were instead asked to test and evaluate new alternatives, such as prototypes of the kite-shaped tables. Some of the furniture that was to be used in the new school was tested in the old school. The head teacher introduced blueprints so that the teachers would be able to visualize the new learning environments and taught them about how they were designed to function.

3.1.4. Applying the ECSIT Model

The ECSIT model is applied here (Figure 5) with information from the various data sources to visualize the levels of stakeholder influence.

The model shows the shifting levels of participation throughout the process. For example, the highly influential role of the municipality's school buildings coordinator (MBC) was gradually phased out, and the partnership between the head teacher and the architect (and the property manager later) increased. The school buildings program and the MBC influenced the design of the space, and the head teacher and the interior designer influenced the interior design. Movements in the various positionings can be discerned in the process flow of the stakeholders. A downward move is exemplified by the MBC, from control of the program to a partnership with the architect. The architect, on the other hand, was involved in the various partnerships throughout the process in what can be characterized as horizontal positioning.

Hill School	Educational Vision	Concept Design	Space Design	Interior Design	Technical Design/ Construction
Control	MBC (program) HET (from 2016 on)				
Partnership		ARC MBC	ARC MBC (decreasingly) HET (from 2016 onward)	INT HET	ARC PRM
Consult	TEA (other, via program)	INT	INT PRM	ARC TEA (via use)	
Inform	TEA (at the school)	PRM			

Figure 5. The ECSIT model plotting stakeholder influence in different phases of the design and building process at Hill School. ARC: architect; HET: head teacher; INT: interior designer; MBC: municipality's school building coordinator; PRM: property manager; and TEA: teachers.

3.2. Valley School

3.2.1. An Educational Vision for a School

The pedagogical ideas for Valley School were formulated early on by the founder of the school who later became operations manager. This person's experience was mainly outside the world of school, and the idea was that the school should differ from mainstream schools to increase motivation and that the pupils should do things "for real" and display them. The ideas were based on thoughts about the role of the school for the pupils' own personal development, motivation, and learning and that they should be regarded as subjects. The aim was for Valley School to foster creativity. As a consequence, the learning environments differed from traditional classrooms and offered a variety of different spaces that also promoted the teachers' own learning and development. The school was organized around ideas about goal-oriented management, shared leadership, and collaboration. Already from the start, the school introduced co-teaching, with ideas about interdisciplinary theme work and cooperative and value-creating learning. This kind of approach aimed at promoting individual motivation. A development of self-knowledge meant accommodating pupils' different learning styles regarding work, movement, and learning. Digital tablets were important components in the learning environments, which in turn meant the provision of Wi-Fi and furniture that supported this way of working.

3.2.2. Prototype School with Pilot Learning Spaces

The school started in 2013 with 57 pupils in so-called modular buildings. This was a temporary solution prior to the building of more permanent school premises. Early on, the teachers were encouraged to test ideas for new learning environments that improved the quality of teaching, and a prototype mode of thinking was applied. A learning environment consultant was included in the process and held workshops with the teachers once every 6 months for several years. An interior design agency known to the founder was also involved in this work.

Ideas about how to reduce stress, ensure safety and security, and create different areas that best met the pupils' motivation and needs were behind the formation of the learning environments and the different zones. The latter were to be defined spaces that were easy for the pupils to interpret and use. The learning environment consultant worked with the teachers on how best to use the zones, both in their own teaching and for the pupils' work. One idea was to reduce the amount of furniture. Another was to create corners, safe zones, and leisure zones. It was also important to improve the flow through the various zones (i.e., the "space choreography") so that the teachers could easily move around and help each pupil and so that pupils did not disturb others with their movements.

The first prototype for the TeLEs, or so-called learning studios, was designed to accommodate two classes of pupils (i.e., a total of up to 56 pupils and 2 teachers). After iterations, this was later changed to one larger and one smaller space, both of which were tested and evaluated to ensure that they reflected the school's working methods. Prototypes were also used for the furniture with the involvement of the design agency. A stairs prototype was also tested, and after feedback, new versions were designed iteratively. Another prototype involved so-called niches for quiet reflection and overview. Loft beds were also bought and tested in the modular building, and new versions for the different age groups were designed. Other places for reflection were so-called caves, developed from a first prototype that was found to be too deep toward a finished, shallower place under the stairs. At first, the stairs were placed in the center of the large space as a divider, but in the new building, they were against a wall and facing movable screens and whiteboards, which gave the teachers more of an overview and better sight lines.

3.2.3. The Design of the New School

The learning environment consultant who was involved in the development of a brief for the new school building was inspired, for example, by Hertzberger's L-shaped classrooms. The idea behind the new building was that it should be a welcoming environment with a clear pattern language, natural and sustainable materials, and a uniformity throughout the year groups, with defined zones and varied spaces. The founder recalled the following:

We discussed these things early on: activity, variation, collaboration, safety and security. We also thought about displaying and exhibiting, but they are connected to the idea of value-creating learning, being able to exhibit and display things in the different environments.

The design agency also worked on the design of the new school's learning environments by doing research, leading workshops, and interviewing the teachers.

The TeLEs, one for each year group, consisted of a larger space than a regular classroom and a smaller space that was bigger than a regular breakout room. Each learning studio was designed to cater for each year group and was equipped with high-backed chairs, tables, and armchairs with high backs and sides. In addition, they had the same custom-built features of stairs, two smaller breakout rooms with glass frontages, a loft (for younger children), seating areas in the windowed areas, and an enclosed space. New kinds of sound-absorbent panels were installed in different places in the school, where the acoustics were designed to fit the collaborative working methods that generated more noise than individual work. In line with this, no outdoor shoes were allowed in the TeLEs.

The architect's designs were discussed with the founder, the learning environment consultant, a furniture company representative, the design agency, and the teachers, and changes were made in the placement of the functions in the common areas. Discussions about the design of the TeLEs also included which wall parts were to be transparent or not. It was also considered important for the teachers to be able to see the different study areas, including the adjacent areas outside the studios. During the testing and prototype work, the teachers became highly aware of the teaching and learning space, which enabled them to ask questions and contribute to the formation of the different learning areas. As it turned out, the building project was delayed for technical reasons, which gave more time for testing and prototyping. According to the founder, this delay proved advantageous in terms of the design and development of the learning environments.

3.2.4. Applying the ECSIT Model

In the same way as for the Hill School, the information from the various data sources were applied to the ECSIT model in Figure 6.

Valley School	Educational Vision	Concept Design	Space Design	Interior Design	Technical Design/ Constructio n
Control	OPM	OPM			
Partnership		LEC INT TEA ARC 1	OPM ARC 2 LEC INT TEA	OPM LEC INT TEA FUR	ARC 2 PRM
Consult					
Inform	TEA				

Figure 6. The ECSIT model plotting stakeholder influence in different phases of the design and building process at Valley school. ARC: architect; FUR: furniture company representative; INT: interior designer; LEC: learning environment consultant; PRM: property manager; and TEA: teachers. OPM: Operations Manager.

In the case of Valley School, the operations manager was responsible for the design process from beginning to end. The second architectural firm entered at a later stage, and the process was characterized by partnership with many different stakeholders. The property manager was involved to a limited degree. The design and building process at Valley School was influenced by the learning environment consultant and the interior design agency. Here, it can be noted that the teachers and other stakeholders were involved in a partnership collaboration with other stakeholders throughout the design process.

3.3. Comparative Analysis

The visions for the two case schools were *generated* from two different directions. At Hill School, the vision came from inside the school sphere, initiated by the municipality's administration and carried out by the municipality's educational property coordinator, who had worked for many years as a head teacher, and supported by many voices from interviews with a large number of pupils and teachers. At Valley School on the other hand, the vision came from the outside and was derived very much from the thoughts of the school's founder. Here, the vision was, from the outset, more directly aimed at the development of a particular kind of individual, whereas at Hill School, the vision was directed toward creating an environment that would ensure the pupils' well-being and allow for meaningful educational activities.

The visions for the new schools were *developed* in two separate documents. At Hill School, the vision reflected the municipality's school buildings program, which was to be applied in many schools, and a design brief was created specifically for the vision of Valley School. During the design and building phases, these visions were tested and revised. An existing learning environment and modular building were gradually shaped to match the visions of the new head teacher at Hill School and at Valley School to reflect the environments in the modular buildings. In both cases, larger spaces than classrooms were created and equipped with furniture and other artifacts to be tested for use in the new school. The testing process at Valley School was longer, more systematic, and involved workshops with consultants and an iterative way of working, although in both cases, the teachers were supported in the change process both internally and externally.

The *translation* of the vision became more distinct at Hill School when the new head teacher was appointed and gradually took the design process over from the municipality's school buildings coordinator. The head teacher brought to an almost finished space design clear visions and ideas for the organization and working methods and collaborated with the interior architect for 2 years in order to translate these visions into learning environments in the new school. The process resulted in new designs of furniture that would support her vision, and she also instructed and consulted teachers on the use of the new team learning environments. At Valley School, the transition of vision to practice was more extensive in several phases, and the translations were more gradual and in partnership with the teachers. At Hill School, when the building program was generated, the processes to translate the vision were already set in motion based on the teachers' and pupils' feedback. Here, the translation of the vision for the design of the furniture and interiors was largely in the hands of the head teacher. At Valley School, the iterative process of translating the vision was closely linked to the existing teaching and learning practices and carried out prior to moving into the new school building.

Both schools encountered opportunities and challenges during the design and building process and had to *negotiate* and adapt their visions in the different phases according to circumstances. For example, due to need for space efficiency, at Hill School, the cloakrooms were integrated into the team learning environment, which resulted in the development of new types of furniture being used that integrated group seating with the pupils' need for storage. It also had to cut out some of the technological features due to budgetary constraints. Delays in the building process meant that Valley School had to stay in the modular buildings for longer than originally planned, but this also allowed more time for the iterative development process.

The above results indicate the processes through which the visions became *embedded* in the learning spaces in both schools. For example, at both schools, the vision of team teaching and the vision of learning spaces that allowed flexibility and variation were embedded in the configuration of the TeLEs in the school buildings. Although the sizes of the TeLEs and the working methods varied, both made use of customized interior design features.

4. Discussion

One of the challenges during the design and building process was the translation between the professions involved, particularly how to create and sustain a multi-professional language [49]. Another challenge was to create and maintain a clear pedagogical vision. Gislason [23] stressed the importance of achieving a fit between educational programs and the design of the teaching and learning spaces in a materialized vision, also [59]. In the two cases studied here, such a fit was largely achieved in relation to the school buildings and the ILEs [54]. In the results, the analyses of the design and building processes were presented with the aim of investigating how the educational visions were translated and negotiated into spaces that supported the visions and practices. Although the processes differed in terms of vision, stakeholder involvement, work methods, and finished learning environments, they had some common features. Below, the important themes are discussed in relation to previous research and the contributions of the present study indicated in relation to the themes. Questions and suggestions for future design and building processes are also formulated.

4.1. Continuity: Creating Knowledge Robustness

Common for both processes is the participation of several stakeholders in more than one phase and the representation of a pedagogical perspective at the higher levels of participation. In one case, the operations manager was involved throughout the process, and in the other, the MBC, a former head teacher, gradually handed over responsibility to the appointed head teacher. Working closely together, those involved in the space and interior designs and the end users participated in the design process, albeit at a higher level in one school. The engagement of many of the stakeholders stretched over several years, during which trusting relations were formed that seemed to facilitate the collaboration and development of a multi-professional language, also [50]. In some cases, the stakeholders were familiar with one of the parties involved. The successful use of continuity and long-term investment for stakeholders in the design and building processes is consistent with previous research [28,32–34,50,60], and we suggest that the ECSIT model contributes to making stakeholders' levels of participation visible in the different phases of the planning, design, and construction processes.

4.2. Preparation: Creating Educational Robustness

Several studies draw attention to the need for adequate preparation when transitioning to teaching and learning in ILEs [20,29,30]. Previous research shows that the more an ILE deviates from traditional design, the more important preparing habitants becomes [6,25,28]. If this process is not achieved to a sufficient extent, it can cause severe problems during the initial period, as well as attrition among head teachers and teachers at the new school. Thus, when planning a design and building process, particular attention needs to be paid to the preparation factors that facilitate the transition and thus support the creation of an educationally robust ILE. This preparation involves supporting a new pedagogy or changes in the pedagogy, which has also been highlighted in the research literature, such as [9,59].

In both cases, the preparation practices were continuous and took several years. Onsite workshops were connected to the practices, which allowed for the iterative process of testing and evaluating the prototypes and other innovative elements to be present in the space and interior design in the new learning environments' everyday practice. Some testing could be seen in terms of a participatory activation phase in which spatial awareness and competence were developed, see also [38]. Preparation also involved recurring external and internal professional development, although the level of teacher participation was higher in one of the schools, and the development of experiential spatial competence was more systematic. The spatial competence that teachers developed during the preparation process and the long-term relationships that developed with external participants facilitated the evolving of a multi-professional language and understanding that then became expressed in the design of the spaces and interiors [38]. Based on the results, we suggest that developing teachers' spatial awareness and competence [38,61,62] is important and can motivate more participation in the design and building processes [14,28,50].

4.3. Alignment: Creating Organizational Robustness

As has been pointed out elsewhere in the article, one of the challenges of a well-functioning ILE is to align space and practice. In previous research studies, it was argued that teachers carry the main responsibility for aligning space and pedagogy [13,25]. This is certainly true from a narrow teaching and learning perspective, but it ignores other basic factors such as management, organization, and various support functions. Our results have highlighted that making ILEs robust involves early and extensive consideration of the school's organization and working methods. Previous research indicates the importance of creating relationships and culture among teacher, for example [31]. This article also highlights the organization of practices, such as co-teaching and subject teaching, in the preparation work. As organizational components are in need of further attention in research on ILEs [4], they are factors to consider in the alignment of vision and practices in new school buildings.

4.4. Participation: Creating Economical Robustness

A vital component of the design and building process is the creation of economically robust ILEs. This was part of the municipality's school buildings program at Hill School and something that was raised by Leiringer and Cardellino [3]. An efficient use of learning environments involves making sure that all the available spaces are used but that none are crowded. Making cutbacks in the wrong places during the design and building processes could easily hamper the attainment of the envisioned practices as argued, for example, by Tse et al. [50]. This is an argument for involving multi-professional teams with pedagogical competence throughout the process and the continuous engagement of users in the various phases. We suggest that even if participatory design processes are costly, they may still contribute to economic robustness by ensuring an alignment between space and practice. However, as user participation may produce challenges like idiosyncratic buildings and ill-fitting solutions [50,60], making room for the development of the users' spatial awareness and competence in everyday practice among future habitants could be a sound investment. Moreover, attention needs to be paid to carrying the vision across phases, because breaks in continuity can create weaker alignments and affect the function of the finished spaces so that they become less effective.

4.5. Concluding Remarks

In conclusion, this article has drawn attention to considerations regarding the involvement of different stakeholders when planning for schools characterized as ILEs. For example, the role and content of the visions and the carriers of these visions throughout the process as challenges and opportunities are discovered and negotiated. The ECSIT model can be used to discuss the need for and recruitment of competencies in multi-professional teams and when and on what level stakeholders should be employed. It can also help to clarify the windows for opportunities and points of no return for the stakeholders.

Spaces can change practices, but this is not a causal process, as has previously been demonstrated for example by [13,14]. Every new building brings opportunities for pedagogical development. However, change takes time, and pedagogical developments perhaps need as much time as the building project itself in order to be both economically and educationally robust. Being prepared includes being familiar with space and interior design before moving in. Additional things to consider are the testing of new organizational solutions with co-teaching and larger pupil groups and alternative ways of scheduling the teaching and learning activities. The challenges of changing established ways of working, organization, and alignments when transitioning to an ILE need further attention [4].

The challenges of creating economically robust ILEs need to be included in the planning process, and the economic viability of the visions needs to be negotiated in the early phases. For example, will the new building, organization, and pedagogy survive future cutbacks in funding or conversion into teaching other student year groups? The design process itself also needs to be economically sustainable, and the ECSIT model can help to plan for a cost-efficient participatory design process and identify breaks or weak points that may lead to additional costs. Making sure that there is sufficient competency in the different phases can help to guarantee economically robust projects.

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Article

Analyzing the Time-Varying Thermal Perception of Students in Classrooms and Its Influencing Factors from a Case Study in Xi'an, China

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Abstract: Owing to movement in the spatial environment and changes in activity levels, students' thermal perception is time varying in classrooms throughout different periods of the day. However, previous studies have rarely considered the time-varying thermal perception in different periods of the day, which may cause discomfort for students and lead to energy wastage. Therefore, a study was conducted to investigate the time-varying thermal perception of students and its influencing factors in different classes of the day. In addition, the differences in students' adaptive behaviors in different periods were also explored. A total of 578 university students were surveyed using questionnaire surveys during the heating season in Xi'an, China. The following results can be obtained: (1) The thermal sensation vote and thermal preference vote values in the afternoon were significantly higher than those in the morning. At the start of the first class in the morning/afternoon, the thermal sensation of the students had the highest sensitivity to outdoor temperature changes. (2) The students' thermal perception was greatly affected by the preclass activity state at the start of the first class in the morning/afternoon. However, in other periods, the above phenomenon was not obvious. (3) In the afternoon, the frequency of clothing adjustment was greater than that in the morning, and this behavior would significantly affect the students' thermal sensation. (4) Compared with the current classroom heating strategy, the heating strategy of dynamically adjusting the indoor set temperature according to the time-varying characteristics of the students can theoretically achieve energy savings of 25.6%.

Keywords: university classroom; thermal perception; building energy efficiency; influence factor; adaptive behaviors

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1. Introduction

Several studies have indicated that the thermal environment of the classroom has an important impact on the health and productivity of students [1]. Moreover, appropriate thermal environment design parameters can help to reduce building energy consumption [2,3]. Therefore, it is important to create a comfortable classroom thermal environment. University students frequently move between different spaces in teaching buildings to attend different classes, and usually spend less than 2 to 3 hours a day in a classroom [4]; thus, the thermal environment experienced by university students is constantly changing [5]. Therefore, the thermal perception (i.e., thermal sensation, thermal preference, and thermal comfort) of students at different periods of the day may have time-varying characteristics. Although existing standards, such as ISO 7730 [6], EN15251 [7], and ASHRAE

Standard 55 [8], provide indoor thermal comfort guidelines, the different thermal comfort requirements of university students at different times of the day are ignored [5,9,10]. Thus, students' thermal perceptions in the classroom cannot be accurately reflected in the relevant standards. Therefore, it is necessary to explore the characteristics of students' thermal sensation changes in different periods of the day.

Identifying the factors that affect the thermal perception of students will help us to better understand the response of students to the classroom's thermal environment. When university students enter a new classroom, their thermal perception is affected not only by the current thermal environment but also by the thermal environment they experienced last time [4,5]. Owing to the influence of course timetable, students experience different thermal environments and activity levels before class at different times of the day. Therefore, the factors that affect the thermal perception of students may change at different periods of the day. At a certain period, students will feel uncomfortable when there are more negative factors. In order to achieve a good comfort level in different periods, students often adopt adaptive behaviors. However, during class, students' thermal adaptive behaviors are restricted to a certain extent. Previous studies have shown that personal behavior (e.g., adjusting clothing) is the most common adaptive action among students in both uncomfortably warm and cold conditions [11]. Owing to the fact that students' thermal perception changes in different classes of the day, the probability of students' thermal adaptive behaviors may change. Exploring the differences in the influencing factors of the thermal perception and thermal adaptation behavior of students in different periods will help to develop strategies for improving the thermal comfort level.

Owing to the extreme climate conditions and large indoor and outdoor temperature differences, the challenge of achieving thermal comfort in the classroom is intensified during the heating season in cold regions [12]. The heating season usually lasts from late autumn to early spring in northern China. The majority of heating systems in cold regions of China use coal as fuel, resulting in high building energy consumption and severe air pollution [13–16]. Because inappropriate heating temperatures will reduce occupant comfort and even increase carbon dioxide emissions [17–20], investigating the time-varying thermal perception of university students during the heating season and identifying the factors that affect the thermal perception of students may also help to reduce building energy consumption and environmental pollution.

1.1. Literature Review

In recent years, a large amount of research has been published that deals with the thermal comfort of students in classrooms based on field surveys [21–23]. The functional requirements of the classroom vary with student density in the classroom, indoor environment control, clothing choices, activity, and use of the Internet and communication technology [24]. Therefore, separate guidelines or standards for students of different age groups at different stages of their education are necessary [24]. Although thermal comfort field studies in university classrooms were conducted later than in primary and secondary schools, there has been an increase in studies in university classrooms in the past two decades [4]. Singh et al. [24] summarized research articles on thermal comfort in classrooms over the last 50 years. It was observed that university students were in a transient condition for about 20–30% of the class time (if a class has a duration of 1 h), and the memory of the previous environment significantly affected their thermal perception in classrooms. In the heating season, especially in cold regions, the temperature difference between indoors and outdoors is large. When students experience an outdoor–indoor transition, the thermal perception will change significantly, especially when entering a classroom with heating on from the outdoors [25,26]. Because setting a proper indoor temperature based on students' actual thermal perception will help to save energy, Jing et al. [2] investigated the thermal comfort state of students in university classrooms during the heating season in Taiyuan, China, and found that the indoor temperature lower limit for 80% acceptability is 19 °C. If the indoor design temperature decreases from 21.85 °C (determined by the heating load duration curve) to 19 °C, 3.46% of the annual heating load can be saved. Therefore, it is important to study students' actual thermal perception in a university classroom during the heating season.

There are many factors that affect students' thermal perception in the classroom, including the outdoor environment, indoor environment, and personal characteristics. The existing literature primarily focuses on the thermal perception of students and their influencing factors in different climate zones and room operating modes. Zomorodian et al. [4] observed that most studies were conducted in temperate/mesothermal climates (e.g., the UK, USA, and China). Differences in students' thermal comfort levels have been evaluated in classrooms with different heating systems [27–29] and ventilation strategies [30–33]. In most studies, it was proven that indoor temperature, relative humidity, air velocity, outdoor temperature, and solar radiation have significant effects on the thermal perception of students. Moreover, gender, height, weight, activity level, clothing level, and so forth also affected the thermal perception of students. For example, Song et al. [34] suggested that an increase in air velocity is an essential phenomenon in obtaining a thermal comfort environment. Song et al. [35] observed that heated clothing could serve as an effective method to improve both the local and whole-body thermal comfort of university students while sitting in cold classrooms. In addition, Jowkar et al. [11] observed significant differences in the comfort temperature of students in various classroom types in the UK. Moreover, they explored how climatic background or long-term thermal history influences individuals' in-the-moment thermal comfort experiences [36]. Mishra et al. [5] observed that mode of travel, point of departure, prior food/beverage consumption, and medical aid are likely to have an effect on occupant thermal sensation.

The above studies mostly focused on the thermal perception of students in university classrooms in different regions. However, the thermal perception of students at different time periods has not been studied in depth. Moreover, there are few studies on the differences in thermal perception influencing factors at different times. Ning et al. [37] conducted a field survey on students' thermal comfort from late autumn to early spring, covering the entire space heating period in Harbin, China. Cao et al. [38] conducted a field survey on students' thermal comfort and thermal adaptability during summer and winter in Beijing. However, there are few studies on the changes in students' thermal perception during class in a day. In universities, it is common for students to enter and leave different classrooms for different classes [39]. When entering the classroom, the memory of the previous environment will significantly affect the thermal comfort and preferences of the students [24], and student thermal perceptions change significantly as the class progresses [5]. Therefore, it is necessary to study the thermal comfort of students in university classrooms and the factors that influence it during class hours in the heating season.

1.2. Research Objectives

The thermal perception of students in the steady-state environment of university classrooms in different geographic regions has been extensively studied. However, there are few studies on the time-varying characteristics of students' thermal perception and its influencing factors in university classrooms in the heating season. At different periods of the day, students often move in and out of different spaces, and the thermal environment they experience constantly changes. In addition, due to the influence of the course timetable, the intensity of students' activities in a day varies from time to time. In this case, how does a student's thermal perception change? Are there significant differences in the factors that affect students' thermal perceptions? These questions remain to be answered.

This study aims to explore the changes in the thermal perception of students in different classes over the course of a day to provide evidence for design strategies so as to improve the indoor thermal environment. In Xi'an University of Architecture and Technology, objective measurements and subjective surveys were conducted to obtain indoor and outdoor environmental parameters, students' personal characteristics, and thermal perception votes. The thermal perception of students in the classroom during class time and its influencing factors were analyzed based on the acquired data. The three objectives of this study are as follows:

- Clarifying the changes in the indoor thermal environment of university classrooms and the thermal perception of students in different classes over the course of a day during the heating period;
- Exploring the differences in the factors affecting the thermal perception of students in different classes over the course of a day;
- Analyzing the differences in students' adaptive behaviors to maintain a comfortable thermal state in different classes over the course of a day.

The remainder of this paper is organized as follows. Section 2 describes the related research methods. Section 3 provides the survey results with regard to demographic conditions, indoor and outdoor thermal environment conditions, students' thermal perception development, factors influencing thermal perception, and students' adaptive behaviors. Finally, the conclusions are presented in Section 4.

2. Methods

2.1. Location and Climate

Xi'an City is located in the western region of China, between 33°42′ and 34°45′ N and 107°40′ and 109°49′ E. According to the "Code for Thermal Design of Civil Buildings" (GB50176-2016), there are five climate zones in China, and Xi'an belongs to the cold climate zone [40]. The outdoor temperature in Xi'an varies from −3.0 to 33.5 °C throughout the year, with the highest monthly average temperature in July (28.1 °C) and the lowest monthly average temperature in January (0.6 °C) (Figure 1). The monthly average outdoor relative humidity ranges between 51% and 74%. The heating season of Xi'an begins in mid-November and continues until mid-March of the following year. Our survey was conducted on the Caotang campus of Xi'an University of Architecture and Technology, where the outdoor temperature in the heating season is lower than that in the urban area of Xi'an.

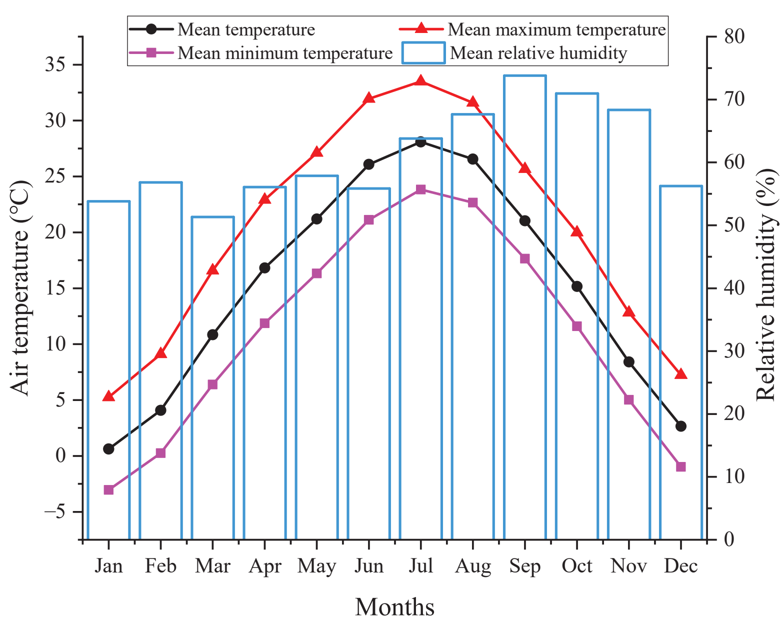

Figure 1. The monthly variation of temperature and relative humidity in Xi'an (2010–2019) [41].

2.2. Classroom Information

In this study, one typical classroom was selected. The design and layout of the classroom in this study are similar to those of classrooms in most universities in China. The classroom (14.4 × 9.6 × 4.5 m, l × w × h) (Figure 2a) is located on the first floor of the teaching building, and the adjacent classroom has the same geometric structure as the classroom. The building thermal properties of the classroom comply with the design standard for the energy efficiency of public buildings in China, GB50189-2015 [42]. The classroom has a construction area of 138.24 m^2 and can accommodate 140 students. There are six windows of the same size (2.1 × 2.6 m, l × h) in the classroom, each with a blinding curtain that students can control. Six radiators are located under the window (Figure 2b). The heating period is from mid-November to mid-March of the following year.

(**a**) (**b**)

Figure 2. The studied classroom: (**a**) interior view of the classroom, (**b**) heating radiator.

2.3. Physical Measurement

To measure the indoor thermal environment, temperature and humidity sensors, anemometers, black-ball thermometers, and carbon dioxide (CO_2) analyzers were placed in the middle of the classroom (Figure 3) at a height of 1.1 m from the floor. The indoor environmental parameters measured in this study included air temperature (Ta, °C), relative humidity (RH, %), air velocity (Va, m/s), black bulb temperature (Tg, °C), and carbon dioxide concentration (CO_2, ppm). Detailed information on the measuring equipment is shown in Table 1. Because the classroom is located on the first floor and the windows are often blocked by curtains in the heating season, it is difficult for sunlight to enter the classroom. Therefore, solar radiation was not measured in this study. Referring to Jiang et al. [1], this study used the black bulb temperature and indoor air velocity data to calculate the average radiant temperature. The parameters of the measuring equipment met the accuracy range required by the ISO 7726 standard [43]. The indoor thermal environment was measured on the day the questionnaire was issued. The measurement time was from 08:30 to 17:20 h, and the data were automatically recorded every 10 min.

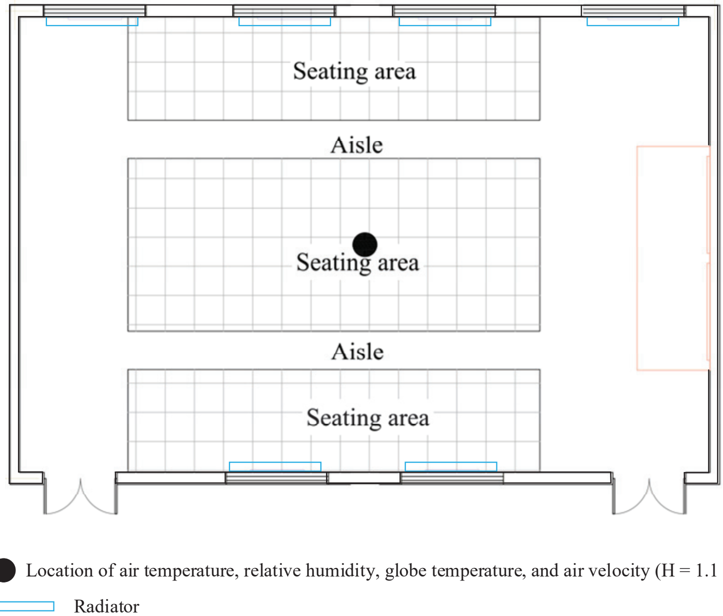

Figure 3. The classroom layout with sensor locations marked.

Table 1. Information of the measuring equipment and parameters.

Parameters	Equipment	Model	Range	Accuracy
Air temperature and relative humidity	Temperature and humidity sensor	TR-72ui	T_a: −20–60 °C; RH: 0–95%	T_a: ±0.5 °C; RH: ±3%
Air velocity	Anemometer	ZRQF-F30	0.05–60 m/s	±(0.04 U ± 0.05)
Globe temperature	Black-ball thermometer	TR102S	−100–400 °C	±0.3 °C
CO_2 concentration	CO_2 analyzer	TES-1370	0–2000 ppm	±1 ppm

The outdoor environmental parameters measured in this study included the outdoor air temperature (Tout, °C) and relative humidity (RHout, %). Referring to the study of Mishra et al. [5] and Jiang et al. [12], the temperature and humidity sensors (Table 1) were installed on the roof of the teaching building. The measurement time was from 00:00 to 23:00 h every day, and the data were automatically recorded every 10 min.

2.4. Questionnaire Survey

The duration of each class was 2 × 45 min, with a 5 min break in the middle. A classroom can have a maximum of four classes per day: 08:30–10:05 h (period A), 10:25–12:00 h (period B), 14:00–15:35 h (period C), and 15:45–17:20 h (period D). To understand the time-varying thermal perception of the students in each class of the day, two subjective questionnaires were provided at the beginning and middle of the class, namely, questionnaires I and II (Figure 4). Questionnaire I was distributed before each class, questionnaire II was distributed during the break, and all questionnaires were collected at the end of each class (Figure 5). Participants were asked to complete the questionnaire within 5 min, and the specific time of filling in the questionnaire was marked. Questionnaire I contained the following information: (1) basic information about the students, such as gender, age, height, weight, and clothing; (2) the students' activity status before class, consumption of food and beverages, and whether he/she had a class in the previous period; (3) TSV, thermal preference voting (TPV), and thermal comfort voting (TCV), which are listed in Table 2; and

(4) the adaptation behavior of the students, including thermal adaptation behavior and cold adaptation behavior. Questionnaire II contained the following information: (1) the students' TSV, TPV, and TCV and (2) clothing adjustments. Before the questionnaire was issued, the surveyor presented a brief explanation of the questionnaire content and professional terms to the students. Student participation in the survey was completely voluntary.

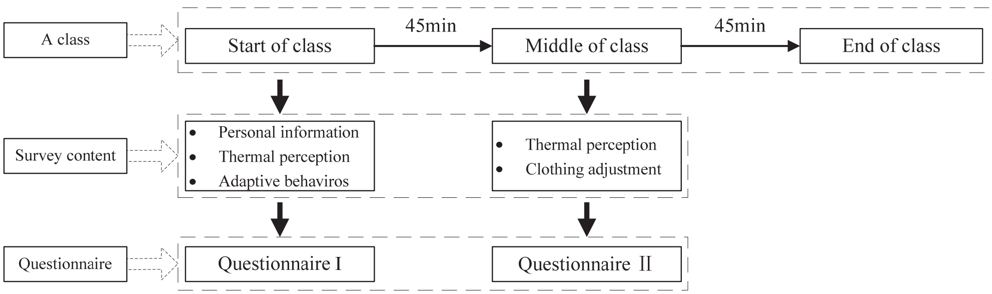

Figure 4. Subjective survey design.

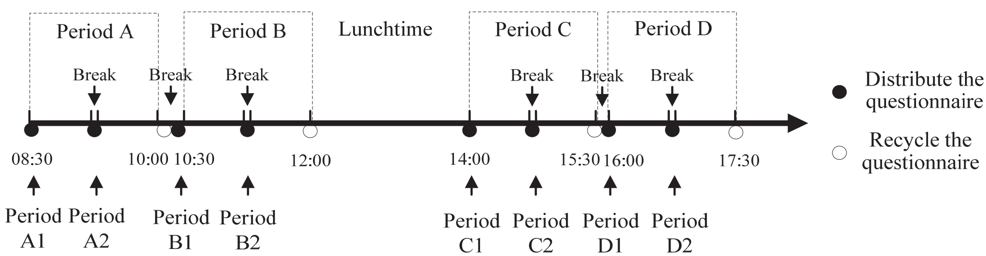

Figure 5. Timeline of the questionnaire survey.

Table 2. Thermal perception responses.

Scale	TSV	TPV	TCV
3	Hot		Very uncomfortable
2	Warm	Much Cooler	Uncomfortable
1	Slightly warm	Slightly Cooler	Slightly uncomfortable
0	Neutral	No change	Comfortable
−1	Slightly cool	Slightly warmer	
−2	Cool	Much warmer	
−3	Cold		

Owing to the winter vocation, the heating period of university classrooms is mainly in mid-November and mid-December. Therefore, this study randomly selected 4 days for investigation in mid-November and mid-December, namely, November 14 (Day 1), November 28 (Day 2), December 4 (Day 3), and December 18 (Day 4). The sample size obtained in 4 days met the minimum required sample size [2]. On Day 1 and Day 2, period B was not scheduled for classes. On Day 3 and Day 4, all four periods were scheduled for classes. To ensure the accuracy of the analysis, returned questionnaires were screened to eliminate samples with contradictory phenomena [44], for example, students who perceived an extremely hot environment but wished for a warmer environment.

2.5. Data Analysis

In this study, IBM SPSS Statistics 26 [45] was used for statistical analysis. The sample values of TSV, TPV, and TCV in this study did not conform to the normal distribution. Therefore, the nonparametric test method was used. The purpose of this study was to determine whether there were significant differences in the distribution of different sample data. This involved the difference test of two independent sample data (e.g., thermal perception samples from any two periods or from different genders) and multiple independent sample data (e.g., thermal perception samples from different food consumptions or preclass activities). In order to achieve the study's purpose, the Wilcoxon rank sum test was used to detect the difference between two independent samples. The Kruskal–Wallis test was used to detect the difference between multiple samples. According to the types of variables, different correlation analysis methods were selected. In this study, the mean thermal sensation vote, operating temperature, and outdoor temperature were all continuous variables. Therefore, the Pearson method was chosen to calculate the correlation coefficient between TSV and operating temperature and between TSV and outdoor temperature. The significance α level was set at 0.05. The operating temperature (Top, °C) was selected as the indoor thermal index. This was used to analyze the relationship between the indoor thermal environment and the students' thermal perception. The calculation method of Top was based on that of Jiang et al. [1]. The parameters that needed to be considered in the Top calculation were the indoor air temperature, black bulb temperature, and air velocity. Referring to ASHRAE Standard 55-2017 [8], the clothing insulation is calculated by Equation (1).

$$I_{cl} = \sum_{i}^{n} I_{cl,i} + I_{cl,chair} \tag{1}$$

where I_{cl} represents the total clothing insulation; $I_{cl,i}$ represents the insulation of the i-th piece of clothing, and the specific value refers to ASHRAE Standard 55-2017 [8]; n represents the number of clothes worn by the students; and $I_{cl,chair}$ represents the insulation of the chair. The classroom in this study has wooden chairs, so this value is 0.01.

3. Results and Discussion

3.1. Demographic Condition

In this study, one typical classroom was selected for the investigation. A total of 578 students participated in the survey. Table 3 presents the mean demographics and clothing insulation of the questionnaire respondents. Of the respondents, 323 were male and 255 were female. The ages of the respondents fell within the range of 16 to 21 years old. BMI was within the normal range. At the start of the classes during periods A, B, C, and D, the average clothing insulation values were 1.44, 1.48, 1.41, and 1.44 clo, respectively. This showed that the clothing insulation values of the students during the afternoon class were lower than those during the morning class. The clothing insulation value of females was generally 0.02–0.13 clo higher than that of males.

Table 3. Mean demographics and clothing insulation of questionnaire respondents.

	Sample	Male	Female	Age (Year)	Weight (kg)	Height (m)	BMI (kg/m^2)	Clothing Insulation (clo)	
								Male	Female
Period A	156	112	44	19 (0.89)	63.02 (12.04)	1.73 (0.07)	21.05 (3.33)	1.40 (0.14)	1.53 (0.15)
Period B	81	33	48	19 (0.56)	58.60 (11.60)	1.70 (0.09)	20.10 (2.48)	1.47 (0.12)	1.49 (0.12)
Period C	174	99	75	19 (0.75)	61.35 (11.92)	1.71 (0.09)	20.99 (3.27)	1.38 (0.14)	1.46 (0.16)
Period D	167	79	88	19 (0.81)	60.55 (10.89)	1.70 (0.09)	20.84 (2.87)	1.39 (0.13)	1.48 (0.15)

Note: Values in brackets denote one standard deviation around the mean.

3.2. Thermal Environment Condition

3.2.1. Outdoor Thermal Environment

During Day 1, Day 2, Day 3, and Day 4 of classes (08:30–12:00 and 14:00–17:20), the average outdoor temperature was 12.8 (SD = 1.8 °C), 4.0 (SD = 1.2 °C), 1.5 (SD = 0.8 °C), and 1.9 °C (SD = 2.1 °C), respectively, and the average relative humidity was 61.1% (SD = 6.7%), 68.5% (SD = 6.7%), 72.7% (SD = 4.9%), and 52.7% (SD = 8.6%), respectively (Figure 6). During the heating season, the average outdoor temperature gradually decreased. The average outdoor temperature on Day 1 (initial heating period) was significantly higher than that on Day 2, Day 3, and Day 4. During classes, both the lowest average outdoor temperature and the highest average outdoor relative humidity occurred in period A, and the highest average outdoor temperature and the lowest average outdoor relative humidity occurred in period C (Table 4). The average outdoor temperature in the afternoon was significantly higher than that in the morning.

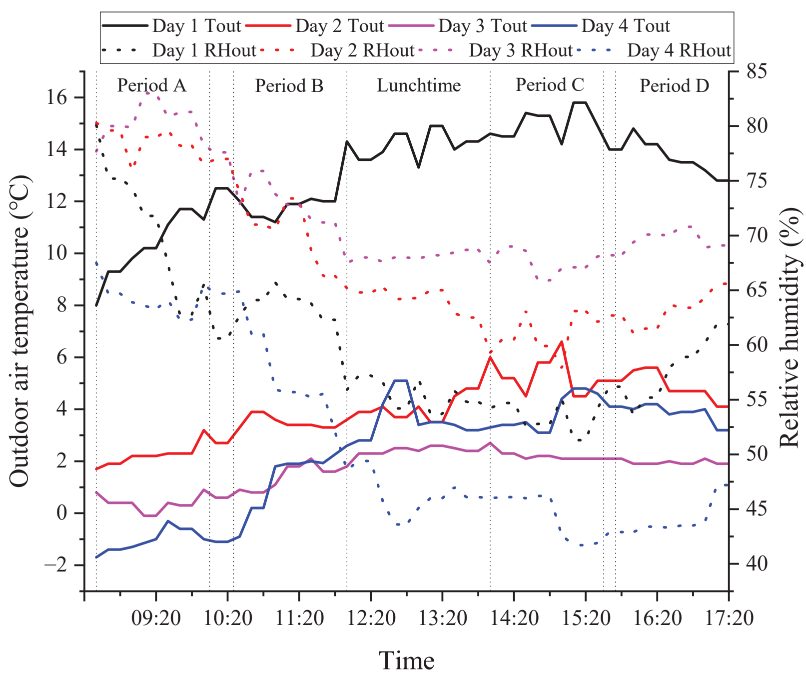

Figure 6. Outdoor air temperature and relative humidity.

3.2.2. Indoor Thermal Environment

The indoor thermal environment of the investigated classroom during different periods was analyzed as follows. On Day 1, Day 2, Day 3, and Day 4, the indoor air temperature was significantly higher than the outdoor air temperature (temperature difference ranged from 5.9 to 23.3 °C), and the indoor relative humidity was significantly lower than the outdoor relative humidity, especially during class (Table 4). On Day 2, Day 3, and Day 4, the temperature difference between indoors and outdoors (ΔT) was above 15 °C. In addition, the temperature difference between indoors and outdoors in the morning was greater than in the afternoon. The main reasons for this were radiator heating and human heat release. At the beginning of the first class in the morning (period A1), the indoor temperature was the lowest, but Day 4 was an exception. This is because there was a class meeting in the classroom before class on Day 4. There was no significant difference between the indoor temperatures during periods B, C, and D (Figure 7). During Day 1, Day 2, Day 3, and Day 4 of classes (08:30–12:00 and 14:00–17:20), the average indoor air temperature was 20.2 (SD = 4.5 °C), 19.9 (SD = 4.3 °C), 18.9 (SD = 4.1 °C), and 21.2 °C (SD = 4.5 °C), respectively, and the average relative humidity was 36.4% (SD = 7.9%), 33.0% (SD = 7.2%), 29.0% (SD = 6.4%), and 30.9% (SD = 7.2%), respectively. The survey found that when the classroom was occupied, the windows and doors were often closed, the air velocity was kept below 0.2 m/s, and the CO_2 concentration was high, in the range of 578–947 ppm (Table 4).

Table 4. Mean values of climatic parameters.

		T_{out} (°C)	RH_{out} (%)	T_a (°C)	T_g (°C)	T_{op} (°C)	ΔT (°C)	RH (%)	CO_2 (ppm)
Day 1	Period A	10.3 (1.1)	70.7 (5.6)	17.7 (1.3)	18.8 (0.9)	18.7 (0.9)	8.4	38.9 (1.8)	778 (142)
	Period B	12.0 (0.8)	62.9 (2.5)	20.5 (0.3)	20.4 (0.2)	20.4 (0.2)	8.4	34.9 (0.7)	736 (87)
	Period C	15.0 (0.5)	53.4 (1.3)	21.0 (0.3)	21.4 (0.2)	21.4 (0.5)	6.0	35.6 (0.7)	880 (87)
	Period D	13.7 (0.6)	58.0 (2.7)	21.7 (0.2)	21.7 (0.5)	21.7 (0.5)	8.0	35.8 (1.8)	947 (246)
Day 2	Period A	2.2 (0.4)	78.6 (1.4)	18.9 (0.7)	19.8 (0.2)	19.8 (0.2)	17.6	33.9 (1.5)	738 (68)
	Period B	3.5 (0.2)	70.0 (3.1)	19.6 (0.3)	19.9 (0.4)	19.9 (0.4)	16.4	31.6 (0.5)	697 (73)
	Period C	5.3 (0.7)	60.9 (1.7)	20.1 (0.3)	20.8 (0.4)	20.8 (1.3)	15.5	34.5 (0.5)	944 (73)
	Period D	4.9 (0.5)	63.3 (1.5)	20.9 (0.2)	20.6 (0.2)	20.7 (0.2)	15.8	32.2 (0.3)	725 (52)
Day 3	Period A	0.4 (0.3)	80.5 (1.7)	17.3 (0.8)	17.8 (0.5)	17.7 (0.5)	17.3	33.2 (1.2)	661 (54)
	Period B	1.4 (0.5)	72.5 (2.3)	19.7 (0.2)	19.8 (0.5)	19.8 (0.4)	18.4	28.3 (2.5)	643 (34)
	Period C	2.2 (0.2)	67.5 (1.1)	19.4 (0.2)	20.0 (0.5)	20.0 (0.4)	17.8	27.4 (2.5)	596 (34)
	Period D	2.0 (0.1)	69.7 (0.8)	19.2 (0.3)	19.6 (0.2)	19.6 (0.2)	17.6	26.5 (0.6)	717 (55)
Day 4	Period A	−1.1 (0.4)	64.2 (1.5)	22.3 (0.1)	23.6 (0.2)	23.6 (0.2)	24.7	34.4 (1.0)	543 (60)
	Period B	1.4 (1.1)	56.6 (4.4)	20.8 (2.0)	21.9 (2.2)	21.9 (2.2)	20.5	32.7 (1.3)	693 (150)
	Period C	3.8 (0.7)	44.5 (2.0)	21.2 (2.0)	22.3 (2.2)	22.3 (0.5)	18.5	30.4 (1.3)	723 (150)
	Period D	3.9 (0.4)	44.4 (1.6)	20.4 (0.4)	21.4 (0.5)	21.4 (0.5)	17.5	25.9 (1.0)	978 (56)

Note: Values in brackets denote one standard deviation around the mean.

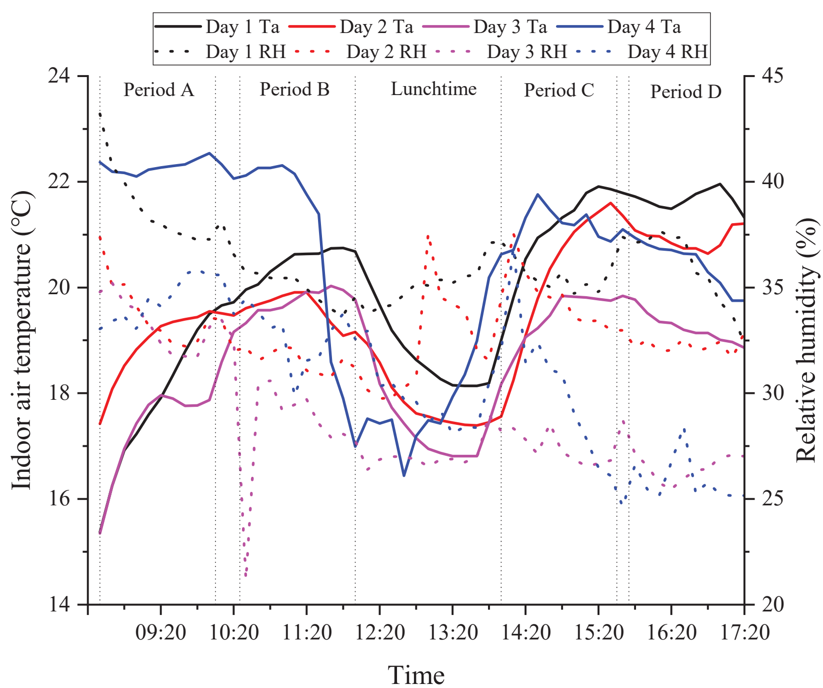

Figure 7. Indoor air temperature and relative humidity.

3.3. Student Thermal Perception Development

3.3.1. Thermal Sensation Votes

According to the survey results, the TSV showed significant differences at the beginning and in middle of the class (TSVA1, B1, C1, D1 vs. TSVA2, B2, C2, D2: $p < 0.001$). Table 5 shows that in the morning and afternoon, the TSV differed significantly. No significant differences were found in the TSV values between periods A and B in the morning. The TSV did not differ significantly between periods C and D in the afternoon either.

Table 5. Differences of TSV in different periods.

	p		p
TSV_{A1} vs. TSV_{A2}	0.001	TSV_{B1} vs. TSV_{D1}	0.158
TSV_{B1} vs. TSV_{B2}	0.047	TSV_{C1} vs. TSV_{D1}	0.174
TSV_{C1} vs. TSV_{C2}	0.170	TSV_{A2} vs. TSV_{B2}	0.555
TSV_{D1} vs. TSV_{D2}	0.041	TSV_{A2} vs. TSV_{C2}	<0.001
TSV_{A1} vs. TSV_{B1}	0.965	TSV_{A2} vs. TSV_{D2}	0.002
TSV_{A1} vs. TSV_{C1}	0.001	TSV_{B2} vs. TSV_{C2}	<0.001
TSV_{A1} vs. TSV_{D1}	0.032	TSV_{B2} vs. TSV_{D2}	0.020
TSV_{B1} vs. TSV_{C1}	0.018	TSV_{C2} vs. TSV_{D2}	0.261

The mean values of the TSV of periods A1, A2, B1, B2, C1, C2, D1, and D2 were 0.47 (SD = 0.89), 0.03 (SD = 1.15), 0.65 (SD = 1.08), 0.15 (SD = 0.75), 0.89 (SD = 1.07), 0.66 (SD = 0.92), 0.66 (SD = 0.98), and 0.52 (SD = 0.98), respectively. In each period, the students' thermal sensation tended to be between neutral and slightly warm. The TSV value at the start of the class was significantly higher than that during the middle period of the class. As the class progressed, the students' thermal sensations gradually changed from slightly warm to neutral (except for period A2, during which the students' thermal sensations became slightly cool) (Figure 8). The TSV value in the morning class (periods A and B) was significantly lower than that in the afternoon class (periods C and D); that is, in the afternoon, the students' thermal sensations were closer to slightly warm. Compared with periods A1, B1, C1, and D1, the TSV value showed a trend of rising first and falling later. The TSV value of period C1 was the highest, and that of period A1 was the lowest. Compared with periods A2, B2, C2, and D2, the TSV value showed a "decline–up–decline" trend. The TSV value was the highest during the first class in the afternoon. This phenomenon was observed on Day 1, Day 2, Day 3, and Day 4 (Table 6).

3.3.2. Thermal Preference Votes

Table 7 presents the test results of the difference in the TPV values in different periods. Table 7 shows that in the morning and afternoon, the TPV values differed significantly. No significant differences were found in the TPV values between periods A and B in the morning. The TPV also did not differ significantly between periods C and D in the afternoon. No significant differences were found in the TPV values between the beginning and the middle of the class.

The mean value of the TPV of periods A1, A2, B1, B2, C1, C2, D1, and D2 were −0.23 (SD = 0.62), −0.33 (SD = 0.77), −0.10 (SD = 0.68), −0.27 (SD = 0.59), 0.08 (SD = 0.69), 0.07 (SD = 0.65), −0.04 (SD = 0.73), and −0.01 (SD = 0.63), respectively. Except for periods C1 and C2, the students preferred a higher indoor temperature. The TPV value in the morning class (periods A and B) was significantly lower than that in the afternoon class (periods C and D); that is, the students' willingness to prefer a higher indoor temperature during the morning class was stronger. This phenomenon was observed on Day 1, Day 3, and Day 4 (Table 6).

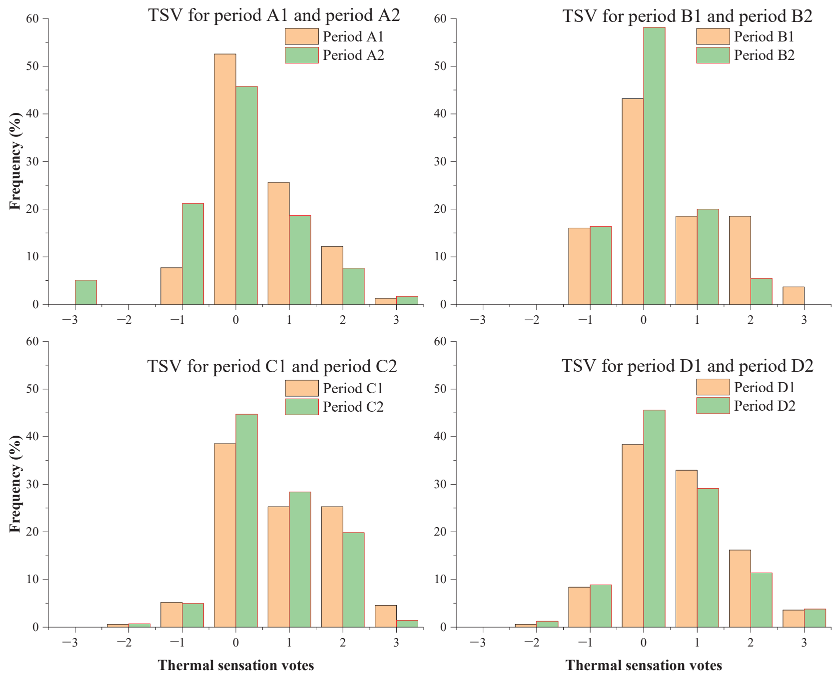

Figure 8. Thermal sensation votes.

Table 6. Mean values of subjective votes.

	Day 1			**Day 2**			**Day 3**			**Day 4**		
	TSV	TPV	TCV	TSV	TPV	TCV	TSV	TPV	TCV	TSV	TPV	TCV
Period A1	0.75 (0.75)	−0.46 (0.64)	0.20 (0.40)	0.48 (0.93)	0.03 (0.52)	0.12 (0.33)	0.47 (0.96)	−0.15 (0.68)	0.22 (0.41)	0.62 (0.93)	−0.25 (0.43)	0.22 (0.48)
Period A2	−0.38 (1.22)	−0.65 (0.83)	0.31 (0.62)	0.33 (1.21)	0.04 (0.68)	0.29 (0.45)	0.30 (1.01)	−0.18 (0.66)	0.36 (0.55)	0.33 (0.57)	−0.22 (0.53)	0.22 (0.42)
Period B1	-	-	-	-	-	-	0.70 (1.15)	−0.21 (0.66)	0.15 (0.41)	0.45 (0.93)	0.10 (0.66)	0.24 (0.43)
Period B2	-	-	-	-	-	-	0.08 (0.79)	−0.33 (0.61)	0.18 (0.44)	0.11 (0.60)	−0.13 (0.50)	0.20 (0.54)
Period C1	1.13 (0.92)	0.02 (0.61)	0.26 (0.48)	0.95 (1.17)	0.08 (0.79)	0.20 (0.40)	0.87 (1.01)	0.09 (0.75)	0.35 (0.63)	0.94 (1.11)	0.19 (0.59)	0.39 (0.55)
Period C2	0.49 (0.71)	0.15 (0.62)	0.32 (0.59)	0.90 (0.80)	0.00 (0.45)	0.34 (0.54)	0.45 (0.98)	−0.07 (0.74)	0.31 (0.60)	1.09 (1.10)	0.30 (0.69)	0.35 (0.63)
Period D1	0.75 (0.89)	−0.13 (0.77)	0.37 (0.62)	0.71 (0.97)	−0.02 (0.52)	0.29 (0.51)	0.62 (1.07)	−0.11 (0.80)	0.54 (0.83)	0.81 (0.97)	0.36 (0.64)	0.22 (0.71)
Period D2	0.42 (1.04)	−0.03 (0.65)	0.58 (0.75)	0.52 (0.90)	−0.12 (0.43)	0.24 (0.51)	0.64 (1.04)	0.21 (0.77)	0.57 (0.90)	0.67 (0.82)	0.00 (0.67)	0.36 (0.42)

Note: Values in brackets denote one standard deviation around the mean.

Table 7. Differences in the TPV in different periods.

	p		p
TPV_{A1} vs. TPV_{A2}	0.157	TPV_{B1} vs. TPV_{D1}	0.448
TPV_{B1} vs. TPV_{B2}	0.164	TPV_{C1} vs. TPV_{D1}	0.106
TPV_{C1} vs. TPV_{C2}	0.899	TPV_{A2} vs. TPV_{B2}	0.435
TPV_{D1} vs. TPV_{D2}	0.785	TPV_{A2} vs. TPV_{C2}	<0.001
TPV_{A1} vs. TPV_{B1}	0.163	TPV_{A2} vs. TPV_{D2}	0.002
TPV_{A1} vs. TPV_{C1}	<0.001	TPV_{B2} vs. TPV_{C2}	0.001
TPV_{A1} vs. TPV_{D1}	0.012	TPV_{B2} vs. TPV_{D2}	0.024
TPV_{B1} vs. TPV_{C1}	0.025	TPV_{C2} vs. TPV_{D2}	0.329

Figure 9 presents a cross-tabulated summary of the TSV compared with the TPV. Figure 9 shows that at any time, when the TSV values were −1 and −2, the ratio of the TPV as "Slightly warmer" was significantly higher than that of "No change". When the TSV values were 1 and 2, the ratio of the TPV as "No change" was significantly higher than that of "Slightly cooler". The above results indicate that the students were sensitive to the cooler environment and had a greater tolerance of the warmer environment. Therefore, because the indoor and outdoor temperatures were lower in the morning compared with those in the afternoon, the students had a stronger desire for higher indoor temperatures in the morning.

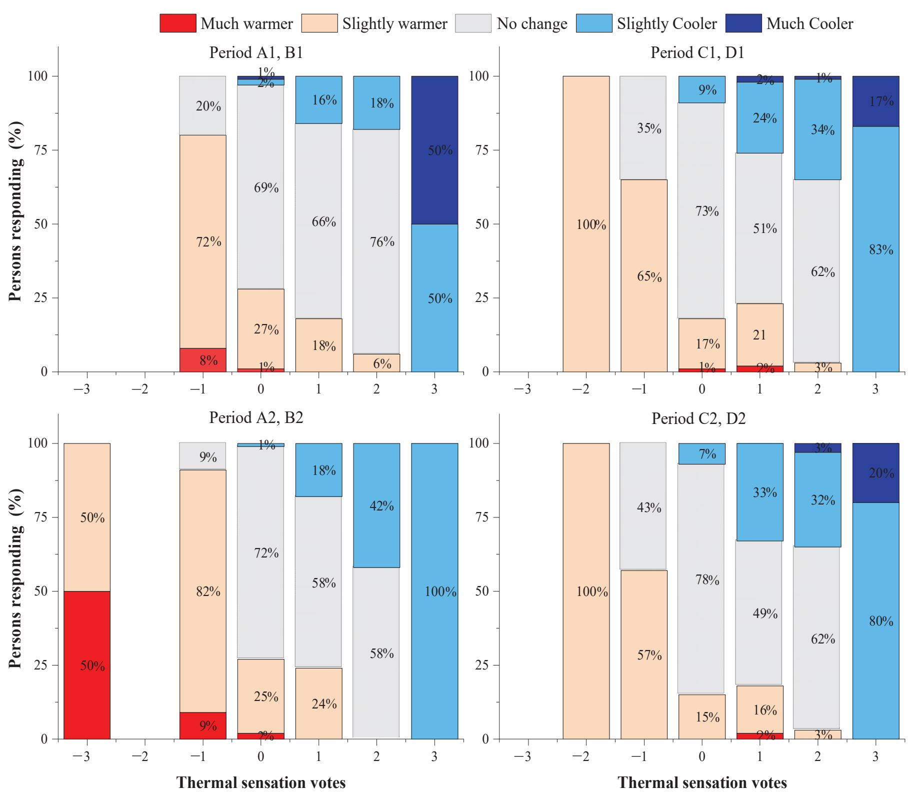

Figure 9. Cross tabulation of thermal preference votes on thermal sensation scale. Note: Since there was no significant difference in the TPV values of the two classes in the morning/afternoon, the data of the two classes in the morning/afternoon were combined.

3.3.3. Thermal Comfort Votes

Table 8 presents the test results of the differences in the TCV values in different periods. Table 8 shows that the differences in TCV values were significant in periods B and D. No significant differences were found in the TCV values between periods A and B in the morning. The TCV also did not differ significantly between periods C and D in the afternoon. No significant differences were found in the TCV values between the start and the middle of the class.

Table 8. Differences of TCV in different periods.

	p		p
TCV_{A1} vs. TCV_{A2}	0.083	TCV_{B1} vs. TCV_{D1}	0.023
TCV_{B1} vs. TCV_{B2}	0.723	TCV_{C1} vs. TCV_{D1}	0.324
TCV_{C1} vs. TCV_{C2}	0.761	TCV_{A2} vs. TCV_{B2}	0.084
TCV_{D1} vs. TCV_{D2}	0.724	TCV_{A2} vs. TCV_{C2}	0.886
TCV_{A1} vs. TCV_{B1}	0.823	TCV_{A2} vs. TCV_{D2}	0.336
TCV_{A1} vs. TCV_{C1}	0.080	TCV_{B2} vs. TCV_{C2}	0.064
TCV_{A1} vs. TCV_{D1}	0.009	TCV_{B2} vs. TCV_{D2}	0.023
TCV_{B1} vs. TCV_{C1}	0.107	TCV_{C2} vs. TCV_{D2}	0.389

The mean values of the TCV of periods A1, A2, B1, B2, C1, C2, D1, and D2 were 0.19 (SD = 0.41), 0.31 (SD = 0.54), 0.18 (SD = 0.42), 0.19 (SD = 0.47), 0.29 (SD = 0.53), 0.33 (SD = 0.59), 0.39 (SD = 0.66), and 0.43 (SD = 0.71), respectively. At any time, the comfort level of the students decreased slightly as the class progressed. Compared with periods A1, B1, C1, and D1, the TCV value showed an upward trend. Compared with periods A2, B2, C2, and D2, the TCV value showed a trend of falling first and rising later. The comfort level of the students in periods D1 and D2 was lower than that in periods B1 and B2. Although in periods D1 and D2, the indoor temperature reached the expected range of the students, the indoor RH was low, and the indoor CO_2 concentration reached the highest level during the day (Table 4), the students felt that the indoor air was increasingly stuffy. Therefore, administrators must not only create a good indoor thermal environment, but also ensure good air quality [46].

Figure 10 presents a cross-tabulated summary of the TSV compared with the TCV in periods B1, B2, D1, and D2. It can also be seen from Figure 10 that in periods B1 and B2, the students generally felt comfortable or slightly uncomfortable, while in periods D1 and D2, the proportion of the students who felt uncomfortable was high. Therefore, the thermal environment during period D must be improved. In addition, as seen in the figure, when the TSV values were 0, 1, and 2 during periods B1, B2, D1, and D2, most students felt comfortable. However, when the TSV values were −2, −1, and 3 during periods B1, D1, and D2, most students felt uncomfortable. It can be concluded that the comfort level of the students in a warm environment was higher than that in a cold environment. As the students were used to warm rooms with space heating in the heating season, their adaptability to the cold indoor environment weakened; thus, they were sensitive to the cold indoor environment in the heating season [38]. When a respondent entered a cold room, he/she could not easily adapt to the low indoor temperature and therefore felt uncomfortable. Therefore, to improve the comfort level of the students, a neutral or warm indoor environment should be created during class.

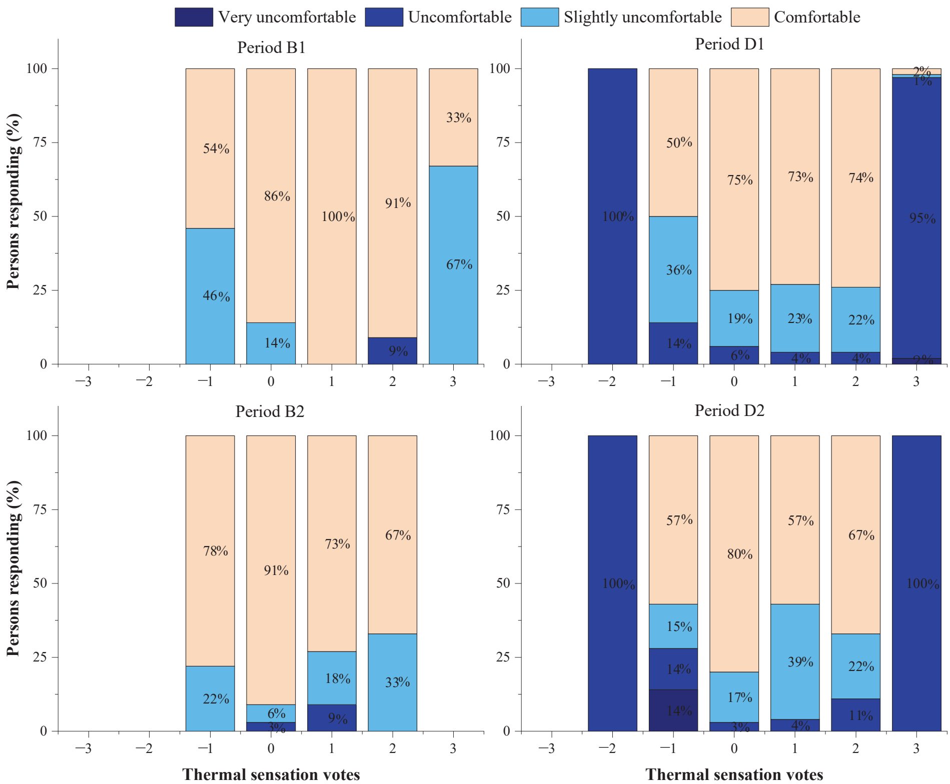

Figure 10. Cross tabulation of thermal comfort votes on the thermal sensation scale.

3.4. Factors Influencing Thermal Perception

3.4.1. Outdoor Temperature and Indoor Operating Temperature

At the start of the class, there was a significant positive correlation between TSV and Tout (Table 9). In the middle of the class, the correlation between TSV and Tout became weak. Figure 11 presents the relationship between TSV and Tout during periods A1, C1, and D1. Figure 11 shows that the slope of the regression curve is very small—that is, although there was a positive correlation between TSV and Tout, the sensitivity of the students' thermal sensation to outdoor temperature was poor. Compared with period D1, the students were more sensitive to changes in outdoor temperature in periods A1 and C1. In period D1, most students moved between different rooms in the same building, but in periods A1 and C1, most students transitioned from outdoors to indoors. Therefore, in periods A1 and C1, the thermal sensation of the students was more sensitive to outdoor temperature changes. In addition, the large temperature difference between indoors and outdoors in the morning also significantly affected the students' thermal sensation. Studies have shown that a temperature difference of more than 12 °C can cause thermal shock to the human body. On Day 2, Day 3, and Day 4, the temperature difference between indoors and outdoors was above 15 °C. Therefore, the transition from outdoors to indoors had a strong impact on the thermal sensation of the students.

Table 9. Correlation between outdoor temperature, operating temperature, and TSV.

	Period A1	Period A2	Period B1	Period B2	Period C1	Period C2	Period D1	Period D2
Outdoor temperature vs. TSV	r = 0.964 p = 0.036	r = −0.854 p = 0.146	-	-	r = 0.975 p = 0.025	r = −0.399 p = 0.601	r = 0.951 p = 0.049	r = −0.880 p = 0.120
Operating temperature vs. TSV	r = −0.463 p = 0.537	r = 0.891 p = 0.109	-	-	r = 0.156 p = 0.844	r = 0.909 p = 0.041	r = 0.628 p = 0.372	r = −0.988 p = 0.012

Note: Owing to the insufficient sample size of periods B1 and B2, the data of the two periods were not analyzed.

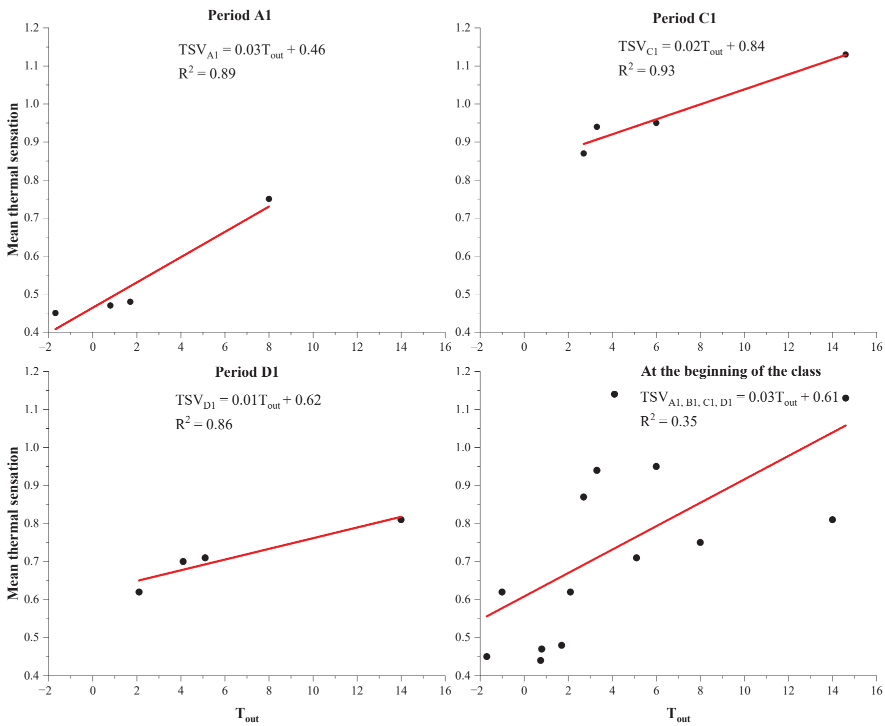

Figure 11. Relationship between TSV and outdoor temperature. Note: Owing to the insufficient sample size of periods B1 and B2, the data of the two periods were not analyzed.

At the beginning of the class, there was no significant correlation between TSV and Top. As the class progressed, the correlation between TSV and Top gradually became apparent (Table 9). Figure 12 presents the relationship between TSV and Top during periods A2, C2, and D2. During periods A2, C2, and D2, the student's thermal neutral temperatures were 18.7, 19.2, and 18.1 °C, respectively. The student's mean thermal neutral temperature during class was 18.74 °C. In general, at any time of the day, when the students entered the classroom, the outdoor temperature affected the students' thermal sensation. If the students had been in the classroom for a while, the influence of outdoor temperature on the students' thermal sensation weakened. At the same time, the indoor operating temperature gradually affected the students' thermal sensation.

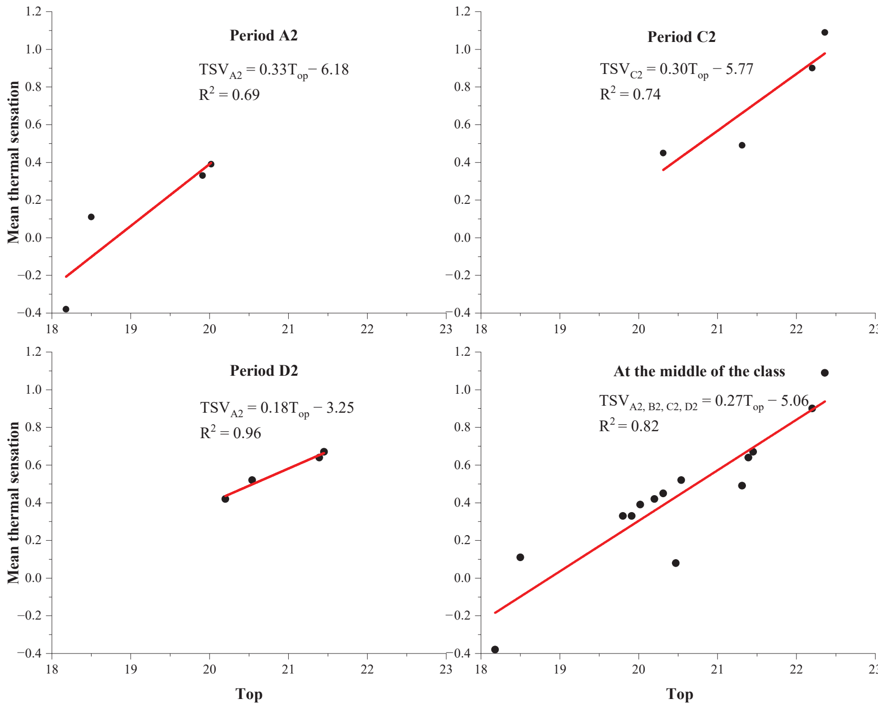

Figure 12. Relationship between TSV and operative temperature. Note: Owing to the insufficient sample size of periods B1 and B2, the data of the two periods were not analyzed.

In order to improve the thermal comfort of the students, the thermal environment of the classroom should be dynamically adjusted. For example, the indoor temperature should be increased gradually as the class progresses. In addition, the flow of indoor air should be strengthened to make the temperature of each area in the room more uniform. At the beginning of the class, in order to enable the students to adapt to the indoor thermal environment more quickly, a few minutes should be reserved for the students to adopt adaptive behaviors.

3.4.2. The Gender Influence

Owing to the physiological differences between males and females, gender may have an impact on individual thermal sensation [47–49]. At the beginning of the class, there was no significant difference in the thermal sensation between males and females (TSVA1: $p = 0.20$, TSVB1: $p = 0.81$, TSVC1: $p = 0.51$, TSVD1: $p = 0.05$). At the beginning of the class, the mean TSVs of males and females were 0.69 (SD = 1.04) and 0.56 (SD = 0.97), respectively. In periods A2, B2, C2, and D2, there was a significant difference between the thermal sensation of males and females (TSVA2: $p = 0.04$, TSVB2: $p = 0.05$, TSVC2: $p = 0.05$, TSVD2: $p < 0.01$,), and the mean TSV value of females was lower than that of males. In the afternoon class, the difference in TSV between males and females was more obvious.

These results indicate that the influence of gender on the students' thermal sensation gradually appeared as the class progressed. This was likely because of the influence of preclass activities, as there was no significant difference in the metabolic rate between males and females at the start of the class. Thus, the effect of gender on TSV was not obvious. In the middle of the class, the students could be regarded as being in a steady-state environment. Therefore, as the class progressed, owing to the physiological differences between males and females, gender differences had a significant impact on the respondents' TSV.

3.4.3. Food Consumption

In periods A1 and C1, the proportion of the students who had eaten food within 20 min before class was higher; in periods B1 and D1, more than 50% of the students had not eaten food within 20 min before class (Table 10). Food consumption did not significantly affect the students' thermal sensation (Table 11). However, at the beginning of the class, food consumption significantly affected the students' thermal preferences ($p = 0.01$). The students who did not consume food expected a greater degree of indoor warming than those who consumed food. As the class progressed, food consumption did not significantly affect the students' thermal preferences. In order to ensure the robustness of the results, this study retested the influencing factors of food consumption in the same dataset of preclass activities, and the results obtained do not show any difference from the above results.

Table 10. Student information before class.

	Period A1 (%)	Period B1 (%)	Period C1 (%)	Period D1 (%)
Food consumption				
Hot	66.67	38.27	67.82	36.75
Cold	4.49	11.11	32.18	7.23
Hot and cold	5.77	0	0	2.41
Nothing	23.08	50.62	0	53.61
There is a class				
Yes	-	75.64	-	78.92
No	-	24.36	-	21.08
Active status				
Resting	24.18	2.47	38.51	3.60
Working	49.67	90.12	39.08	89.82
Sporting	26.14	7.41	22.41	6.59

Note: Period A was the first class of the day. There was a long interval between periods B and C. Therefore, in periods A1 and C1, the participants were not surveyed as to whether there was a class in the previous period.

Table 11. Difference of TSV based on food consumption.

	Period A1	Period A2	Period B1	Period B2	Period C1	Period C2	Period D1	Period D2
Hot/cold/nothing	$p = 0.12$	$p = 0.64$	$p = 0.24$	$p = 0.88$	$p = 0.39$	$p = 0.91$	$p = 0.73$	$p = 0.91$
Something/nothing	$p = 0.48$	$p = 0.90$	$p = 0.37$	$p = 0.90$	—	—	$p = 0.43$	$p = 0.79$

Note: (1) "Something" includes the following situations: consumption of cold food, consumption of hot food, and consumption of cold and hot food. (2) Before the classes in periods C1 and C2, all the participants consumed food, so the *p*-value of "Something/nothing" in periods C1 and C2 could not be calculated.

In periods A1, B1, and D1, food consumption significantly affected the students' thermal preferences (TPVA1: $p = 0.01$, TPVB1: $p = 0.04$, TPVD1: $p = 0.04$). Compared with periods B1 and D1, in period A1, there was a greater difference between the TSV values of the students who did not consume food and those of the students who consumed food. However, this phenomenon was not observed in period C1 (TPVC1: $p = 0.43$), because in period C1, all the students had eaten. Before the classes in periods A1 and C1, it was breakfast and lunchtime, respectively. However, in period A1, more than 20% of the students did not eat before class because of waking up late. Therefore, in period A1, most students reflected that the comfort level was low and had a stronger desire for higher indoor temperatures. In order to improve the thermal comfort level of the students in period A1, incentive measures should be taken to urge the students to get up early.

3.4.4. Preclass Activities

To investigate whether there was a significant difference in TSV between the group of students with and without a class in the previous period, during periods B1 and D1, the students were asked to answer whether they had a class in the previous period. In periods B1 and D1, 75.64% and 78.92% of the participants answered “Yes”, respectively (Table 10). In period B1, there was a significant difference in the TSV values between the student groups with and without a class in the previous period ($p = 0.01$). This may be due to the difference in the degree of thermal environmental change caused by the outdoor–indoor and indoor–indoor transitions; therefore, the thermal sensations of the students may be different. The TSV value of the student group without a class from the previous period was significantly higher than that of the student group with a class from the previous period. The above phenomenon could also be observed in period D1; however, the difference was small. The possible reason for this was that compared with period B1, the temperature difference between indoor and outdoor was smaller in period D1.

To understand the impact of the students’ activities in the 20 min before the class on the students’ thermal sensation, the students were asked to answer whether their main activity status in the 20 min before class was rest, work, or sports during periods A1, B1, C1, and D1. For the students who had a class in the previous period, their activity status was considered as work. At any time, the main activity state before class had no significant effect on the students’ thermal sensation (TSVA1: $p = 0.98$, TSVB1: $p = 0.82$, TSVC1: $p = 0.77$, TSVD1: $p = 0.81$). Combining the data of periods A1, B1, C1, and D1, it was observed that the main activity state before class had a significant impact on the students’ thermal preferences ($p = 0.04$, TPVresting vs. TPVworking: $p = 0.02$, TPVresting vs. TPVsporting: $p = 0.03$, TPVworking vs. TPVsporting: $p = 0.88$). At the start of the class, the students whose preclass activity status was resting had a stronger desire to increase the indoor temperature than those whose status was work or sports. In periods A1 and C1, the main activity state before class had a significant impact on the students’ thermal comfort level ($p = 0.04$, TCVresting vs. TCVworking: $p = 0.20$, TCVresting vs. TCVsporting: $p = 0.02$, TCVworking vs. TCVsporting: $p = 0.59$). The students whose preclass activity status was resting had a lower level of comfort than those whose activity status was sports. This phenomenon was not observed in periods B1 and D1. This may be because in periods B1 and D1, the number of people whose preclass activity status was rest and sports were small.

In summary, preclass activity levels have a significant impact on students’ thermal preference and thermal comfort in the classroom. Activity levels that are too high or too low can cause discomfort for students. For example, before the first class in the morning, some students’ activity state was rest, and they did not eat breakfast, which can cause a low metabolic rate. Therefore, at the beginning of the first class in the morning, some students felt that the room was cold. However, when students have strenuous activities before class (e.g., running, playing basketball), they can feel that the room is hot. Because each student has a different preclass activity level, it is difficult to create a thermal environment that everyone is satisfied with. Therefore, managers should guide students to carry out appropriate preclass activities.

Research by Mishra et al. showed that air temperature decreases as one gets farther from the radiator [5]. Therefore, it is possible to meet the thermal preferences of different students by arranging the seats of the students reasonably. For example, it is recommended that students whose preclass activity state is resting sit close to the radiator. In addition, considering the activity status of students before class, the room temperature should dynamically be adjusted at the start of the class. If most students were in a resting state in the previous period (e.g., lunch break), the indoor temperature of the classroom that the students move to in the next period should be increased in advance.

3.5. Adaptive Behaviors

Extensive research has shown that adaptive behavior can significantly affect the thermal comfort of occupants [50–52]. The thermal adaptive behaviors of university students are less restricted than those of primary and secondary school students [53,54]. In this study, the participants were asked to answer which adaptation behaviors they would take when they felt uncomfortable. The results show that during class, fewer students used energy-consuming equipment (e.g., radiators and fans) to obtain greater comfort, and most of them adopted non-energy-consuming behaviors (e.g., opening/closing windows or doors and adding/reducing clothing) to improve the surrounding thermal environment (Table 12). This can be partly attributed to the fact that the adjusted buttons of the radiators and fans were close to the window, and therefore, they were generally controlled by the students in the seat near the window, and the chances of the other students being able to control the adjusted buttons were lower. Therefore, to attain a good indoor thermal environment during class, there is an urgent requirement for equipment managers to manage indoor energy-consuming equipment uniformly and intelligently.

Table 12. Adaptive behaviors.

Thermal Adaptation Behavior	Frequency (%)	Cold Adaptation Behavior	Frequency (%)
Use an electric fan	2.26	Turn up the heating	9.50
Use a fan	1.97	Close the door	18.01
Open the door	18.19	Close the window	20.57
Open the window	35.68	Add clothes	26.38
Draw the curtains	2.26	Drink cold beverage	17.16
Reduce clothes	33.85	Use hand warmer	8.37
Drink hot beverage	5.78		

In the classroom, students can improve their comfort level by adopting thermal adaptive behaviors. However, taking actions (e.g., using fans, increasing the temperature of the radiator) to improve the surrounding thermal environment can also increase the energy consumption of the building. In the survey, it was also found that students sometimes have inappropriate thermal adaptive behaviors. For example, some students often take off their thick coats while increasing the temperature of the radiator. In addition, owing to the differences in the thermal perception of each occupant, in public places (e.g., classroom), occupants changing the indoor environment may cause thermal discomfort for others. Therefore, classroom managers should uniformly set the temperature of the radiator in the classroom based on the thermal comfort range of most students. At the same time, students should be guided to adopt appropriate thermal adaptation behaviors.

In the heating season, the students' clothing insulation value was high (above 1.30 clo), and the clothing insulation value in the morning was slightly higher than that in the afternoon (except on Day 2) (Figure 13). At the start of the class, TSV did not significantly correlate with the clothing value (TSVA1: $p = 0.19$, TSVB1: $p = 0.23$, TSVC1: $p = 0.71$, TSVD1: $p = 0.09$). The possible reason for this phenomenon is that students have almost the same level of insulation value. Table 12 shows that adding or reducing clothes was one of the main adaptive behaviors of university students. In questionnaire II, the participants were asked to answer whether they adjusted their clothes to improve their thermal comfort. The results show that the proportion of unadjusted clothes (84.26%) was relatively large, while the proportion of added clothes (13.77%) or reduced clothes (1.97%) was relatively small. The main reason for this was that the students usually wore thick cotton jackets in the heating season, and taking off their jacket would significantly reduce their comfort. Therefore, when the students felt hot, most chose to unbutton or unzip their clothes. During class, the students usually did not bring more clothes, so when they felt cold, the behavior of adding clothes did not appear obvious. In periods A2, B2, C2, and D2, the total frequency of adding and reducing clothes gradually increased (Figure 14). In the morning class, TSV did not differ significantly between the students who did and did not adjust (namely, add or reduce) their clothing (TSVA2: $p = 0.23$, TSVB2: $p = 0.23$). However, in the afternoon class, the behavior of adjusting clothes significantly affected the students' thermal sensation (TSVC2: $p = 0.03$, TSVD2: $p = 0.04$). Moreover, in the middle of the class, the thermal comfort of the students who adjusted their clothes was significantly improved compared with that at the start of the class. The students who did not adjust their clothes had lower comfort levels (TCVA2, B2, C2, and D2 = 0.30), and the main reason for discomfort was cold hands and feet. Therefore, in order to encourage students to improve their comfort by adjusting clothes, hangers should be added in the classroom to facilitate the placement of students' surplus clothes. In addition, in order to improve local thermal comfort, students should be given the ability to control the local thermal environment, such as by installing electric heating equipment at each seat.

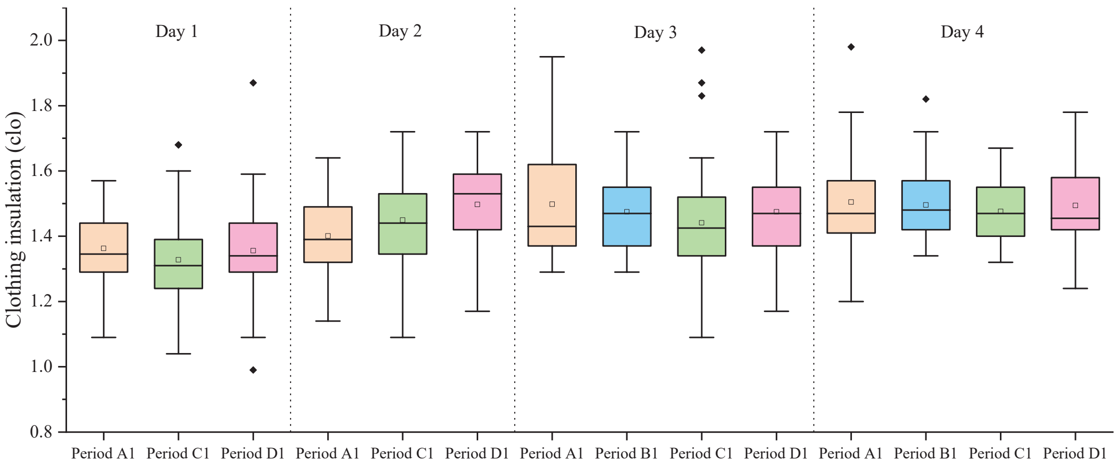

Figure 13. Clothing insulation value in different periods.

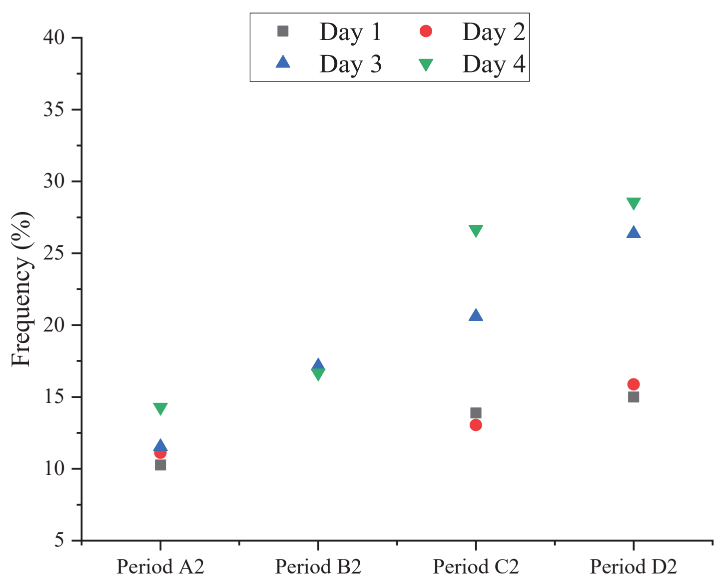

Figure 14. Total frequency of adding and reducing in different periods.

3.6. Energy-Saving Potential

The time-varying characteristics of students' thermal sensation should be carefully considered to determine the energy-saving potential of teaching buildings. To analyze the energy-saving potential of the classroom in this case, the following four strategies were generated.

Strategy A: an actual average indoor temperature of 20.1 °C in the classroom in the heating season was used as the indoor design temperature during class. Strategy B: The lower limit of the indoor comfortable temperature (i.e., 18 °C) in the heating season in cold areas specified in the Design Code for Heating Ventilation and Air Conditioning of Civil Buildings in China was used as the indoor design temperature during class. Strategy C: The upper limit of the indoor comfortable temperature (i.e., 24 °C) in the heating season in cold areas specified in the Design Code for Heating Ventilation and Air Conditioning of Civil Buildings in China was used as the indoor temperature during class. Strategy D: The thermal neutral temperatures of periods A, C, and D (i.e., 18.7, 19.2, and 18.1 °C) were used as the indoor design temperature during class.

It was assumed that the classroom was only heated in periods A, B, C, and D. EnergyPlus [55] was used to calculate the total heating load for the four strategies in November and December. According to Figure 12, the actual thermal sensation of students under different strategies can be calculated. The results are shown in Figure 15. Compared with strategies A and C, strategy D achieved 25.6% and 64.1% energy savings, respectively. In strategy D, the students' real thermal sensation was neutral, while in strategies A and C, the students' real thermal sensation was slimly warm. Although strategy B had the lowest heating load, it was found that the actual thermal sensation of the students in strategy B was slightly cool—that is, strategy B cannot guarantee the thermal comfort of the students.

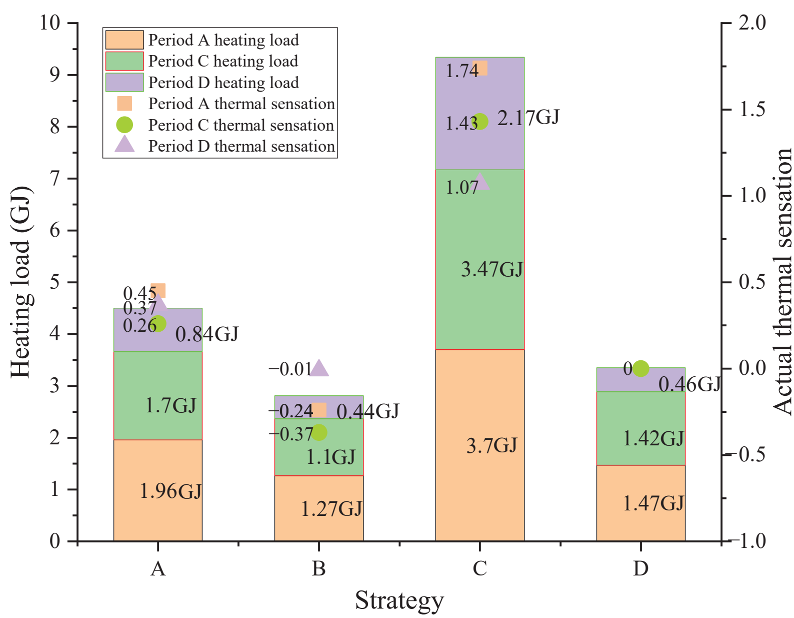

Figure 15. Heating load of sample building in November and December and students' actual thermal sensation under different strategies.

In addition, referring to the previously published study conducted by the authors [56], the energy savings of teaching buildings can be further achieved by course timetable optimization. The implementation process was divided into the following four steps: Step A: according to the time-varying characteristics of students' thermal sensation, the thermal neutral temperature of students in different classes over the course of a day is calculated. Step B: the energy consumption calculation model is established in EnergyPlus [55], in which the thermal neutral temperature of students in different classes over the course of a day is used as the set temperature of the classroom to calculate the heating load of the teaching building. Step C: the course timetable optimization model is established in Matlab [57] and solved by a genetic algorithm. Step D: the cosimulation model is established and the building controls' virtual test bed platform [58] is used to couple EnergyPlus and Matlab. An energy consumption calculation model, course timetable optimization model, and cosimulation model can be found in the authors' previous study [56]. If the time-varying characteristics of students' thermal sensations can be taken into account when optimizing the course timetable, the courses would be intensively arranged in periods when students' thermal neutral temperature is low. Thus, the total heating load of the teaching building can be reduced.

3.7. Comparison with Previous Study

A large number of studies [5,24,59] demonstrated that students' thermal perception changed significantly throughout the duration of a class. The same conclusion was also obtained in this study. In addition, this study found that the students' thermal perception also had significant differences in different classes over the course of the day. The spatial transition from outdoor to indoor is one of the reasons for the changes in the students' thermal perception [5]. Previous studies [5,24,60] have shown that at the beginning of the class, perception varies primarily depending on the outdoor environment (such as outdoor temperature). This study demonstrated that at the start of the first class in the morning and afternoon, the thermal sensation of the students had the highest sensitivity to outdoor temperature changes. As the class progressed, the students gradually adapted to their classroom environment, and thus, their thermal perception changed [5].

Differences in previous activities (e.g., food consumption and activity status) also have an important impact on changes in students' thermal perception [24]. A study by Jowkar et al. [11] showed that food consumption significantly affected students' thermal sensation. However, Mishra et al. [5] obtained the opposite conclusion. This study found that, at the beginning of the class, food consumption significantly affected the students' thermal preferences rather than thermal sensation. A study by Aparicio-Ruiz et al. [61] showed that, owing to the influence of outdoor temperature, there would be significant differences in the activity levels of students in the morning and afternoon. This study found that there were significant differences in the activity levels of students before different classes. This may be caused by the schedule of the course. The correlation between preclass activity status and TSV was not found in this study. A study by Mishra et al. [5] supported this view. In addition, this study confirmed that the main activity state before class had a significant impact on the students' thermal preferences and comfort level.

In order to achieve a good comfort level in different periods, students often adopt adaptive behaviors. Studies [11,38,59] showed that individual adaptive behaviors, such as adjusting clothes, were common adaptive behaviors among university students in classrooms. However, this study found that owing to the inconvenience of adjusting clothes, the proportion of students who adjusted their clothes during the class was relatively low. Studies by Talukdar et al. [30] and Gou et al. [62] showed that the value of the student's clothes decreases as the operating temperature rises. In this study, the temperature in the afternoon was higher than that in the morning, the clothing value of the students in the afternoon was slightly lower, and the probability of reducing clothes in the afternoon was greater than that in the morning. In addition, the behavior of adjusting clothes in the afternoon had a more significant impact on the students' thermal sensation.

The adaptability of students to the local climate contributes to building energy conservation [2,59,60]. The relevant standards in China consider the adaptability of the occupant and provide the range of design temperatures in the classroom during the heating season. However, they do not explain how one should choose the optimal design temperature under different environmental conditions. This study obtained the optimal design temperature of classrooms in the Xi'an area located at the foot of the Qinling Mountains through a field survey. In addition, this study confirmed that the optimal design temperature of classrooms is different in different periods. Compared with the current classroom heating strategy, the heating strategy that takes into account the optimal indoor design temperature in different periods can achieve energy savings of 25.6%.

4. Conclusions

The purpose of this study was to explore the time-varying thermal perceptions of university students in the heating season and their influencing factors. A 4-day on-site monitoring and subjective questionnaire survey was conducted at Xi'an University of Architecture and Technology. A total of 578 students participated in the survey. The following conclusions can be drawn from the statistical and data analysis.

- The TSV value at the start of the class was significantly higher than that in the middle period of the class (the students' thermal sensation gradually changed from slightly warm to neutral). The TSV and TPV values in the morning class were significantly lower than those in the afternoon class. The comfort level of the students decreased slightly as the class progressed. Moreover, the comfort level of the students in a warm environment was higher than that in a cool environment.
- At the start of the first class in the morning and afternoon, the thermal sensation of the students had the highest sensitivity to outdoor temperature changes. As the class progressed, the correlation between TSV and Top gradually became apparent. During periods A2, C2, and D2, the students' thermal neutral temperatures were 18.7, 19.2, and 18.1 °C, respectively.
- At the start of the first class in the morning, food consumption had the greatest impact on the students' thermal preference. At the start of the first class in the morning and afternoon, the students whose preclass activity status was resting had a lower level of comfort than those whose activity status was sports. This phenomenon was not observed in other periods.
- The frequency of adjusting clothes in the afternoon was greater than that in the morning. At the start of each class of the day, TSV did not significantly correlate with clothing value. In the morning class, TSV did not differ significantly between the students who did and did not adjust their clothing. However, in the afternoon class, the behavior of adjusting clothes significantly affected the students' thermal sensation.
- Compared with the current classroom heating strategy, the heating strategy of dynamically adjusting the indoor set temperature according to the time-varying characteristics of the students can theoretically achieve energy savings of 25.6%.

The results of this study have a reference value for the design of classroom heating systems. First, the indoor temperature should be raised in advance before the classroom is occupied for the first time in a day. The indoor temperature should increase gradually as the class progresses. Second, considering the activity status of students before class, the room temperature should be adjusted at the start of the class. If most students were resting in the previous period (e.g., lunch break), the indoor temperature of the classroom that the students move to in the next period should be increased in advance. In addition, according to the thermal comfort temperature range of most students in different class periods, the temperature of the radiator should be set uniformly and dynamically adjusted.

A study on how to optimize the course timetable to achieve both the energy conservation of teaching buildings and the thermal comfort of university students should be carried out in the future. The limitation of this study is that the number of indoor environmental monitoring points was limited, and the parameters (temperature, flow rate) of the radiator were not monitored, which may cause the monitored value to be lower than the actual value. In addition, the potential energy savings of 25.6% obtained by the simulation in this study are only informative, and were not confirmed by measurement. In a future work, more sensors will be added to monitor the thermal environment in different areas of the classroom. In addition, the findings of this study will be applied to the design of the classroom heating strategy, and the actual energy savings of the teaching building will be obtained through monitoring.

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