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Light as a Form of Visual Language Supporting Daily Schedules in Educational Spaces: A Design Framework

Stavroula Angelaki [1,*] and Georgios A. Triantafyllidis [2]

[1] Division of Lighting Design, Department of Architecture, KTH Royal Institute of Technology, 100 44 Stockholm, Sweden
[2] Lighting Design Lab, Aalborg University, 2450 Copenhagen, Denmark; gt@create.aau.dk
* Correspondence: angelaki@kth.se

Abstract: This study explores how lighting can be employed as a visual language to enhance communication between the space and its users and develop a design framework for educational spaces. A primary school is used as a case study to apply the proposed design framework. The study focuses on lighting interventions in existing educational spaces to support daily schedules and transitions between activities. In this context, electric light is used as an indicator, highlighting the daily schedule and activities in the space. A theoretical approach is used as a foundation for establishing the design framework that leads to lighting proposals based on the specific spatial characteristics of each study. The outcome is a design solution based on the dominant spatial elements that define the space's identity and function. The study focuses on educational spaces and lighting for peripheral vision while considering pupils' visual and spatial development. The proposal has the role of an additional light layer that signals transitions in terms of activities or spatial mobility.

Keywords: lighting; educational spaces; peripheral vision; pupils' perception; semiotics; primary school

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1. Introduction

Natural light is a fundamental factor in human development; however, people nowadays spend most of their time in interior spaces due to the nature of their daily activities. The modern pace of life and most activities are primarily linked to the built environment and indoor spaces (work, leisure and rest) compared to earlier times [1]. Such spaces include educational buildings, where pupils and students spend much of their day. The need for a holistic design of interior spaces to create a spatial dialogue is more imperative than ever. According to Lockley, light is an essential environmental time signal, and based on Descottes, the presence of light and shadows is related to time orientation [2]. The changes in natural light throughout the day indicate time, but on a greater scale, underline the passage of months and seasons [3,4]. In this context, this study aims to implement light principles related to daylight's dynamic component and time orientation in interior spaces to enhance how time is perceived and underline the connection between exterior and interior space. The variety of activities each space hosts can set the basis for the lighting design, making light a dynamic component that signifies changes and transitions between spaces. This study aims to develop a design framework that analyses existing spaces to create a basis for lighting proposals based on peripheral vision. It specifically targets educational spaces and children to showcase how lighting can be used as a visual language. Considering lighting as a symbolic language in educational spaces, emphasis should also be given to understanding children's vision and perception of scale and space [5]. Therefore, the following study focuses on children's scale and spatial perception, exploring lighting applications for peripheral vision [6]. The way the school classroom is used, and the activities that take place in it set the foundation for defining the lighting schemes [7,8].

Furthermore, the outline of the present study consists of an analysis of the literature to relate the notions of semiotics, visual language and storytelling to educational activities, a theoretical framework that focuses on vision [6,9,10], human scale [11,12] and lighting, specifically targeting differences between children and adults, and the proposed design framework. This framework is based on spatial elements that can be combined and used to inform lighting interventions that focus on peripheral vision. The lighting components are related to children's scale and perception.

2. Methods and Materials

The present study consists of two parts. The first part focuses on developing a design framework for spatial and lighting analysis of educational spaces. The second part presents how this method can be applied to a case study, resulting in a lighting design proposal. Considering the design elements and spatial characteristics, the design framework is applied to existing educational spaces. The following methods are used throughout this study to establish and propose a design framework applicable to educational spaces:

- A literature analysis of four topics (semiotics, visual language, storytelling and rhythms);
- Design thinking principles;
- A case study that acts as an example for applying the design framework.

The literature analysis leads to the main parameters deriving from the theories presented in the study. Design thinking principles are incorporated to develop a proposal closely aligned with users' needs and requirements. A case study is then used to apply and further explain the proposed design framework. Different software is used to perform daylight analysis and simulations of the proposed lighting design.

2.1. Literature Analysis

The literature analysis sets the study's theoretical foundation and creates a basis for further investigation within Section 3 (Theoretical framework). The theoretical background consists of two parts. The first one relates to the design's definition of time, leading to the research question. The research question defines the subsections focusing on children's vision, perception and development. The literature analysis presents the themes of semiotics and visual language to apply their principles to lighting design. The exploration of lighting as a form of symbol or indicator in space was the core around which the theory evolved. The theoretical framework presents theories about the human scale and how it affects children's perception and central and peripheral vision. The main points from theories of visual development and spatial cognition were extracted to be further used as success criteria and guidelines during the design process. Existing design, perception and visual development theories are combined to produce a theory-based design investigation model. The model incorporates spatial and lighting elements to create a proposal that co-exists with the existing elements of space and the functional light layer.

The literature analysis includes the following topics: semiotics, visual language, storytelling and rhythms and routines. Sections 2.1.1–2.1.3 define the different terms and their link to the current study and Section 2.1.4 focuses on children's need for daily routines.

2.1.1. Semiotics

Semiotics is the science that analyses the relations between signs, meanings and behaviours. The use of symbols and signs is analysed through the science of semiotics. This knowledge can be a tool for establishing relations and meanings between signs and users. Semiotics is widely used in design as it establishes a link between the user and the proposed design [13]. Ferdinand de Saussure, the founder of this study, points out the elements of the concept, which are labelled as signified, and the sound image, labelled as the signifier. The combination of the concept and the sound image defines the sign [14]. Apart from de Saussure's approach, another significant theory belongs to the American philosopher Charles Sanders Pierce. He categorised the signs into icons, symbols and indexes, and developed his theory of semiotics through the prism of philosophy. He supported the idea that people communicate by using signs and assigning meanings to anything surrounding them. The common ground for these theories is that using signs and symbols is fundamental for communication. Signs and symbols are also part of the built environment and are essential communication elements of spatial perception.

2.1.2. Visual Language

Visual communication can be performed through various mediums and related to education and recreation [15]. The link between semiotics and visual language rests in using signs with specific definitions that are collectively recognised. Examples of those signs are using specific icons in mobile phones and applications, such as the "save" button. Even though the symbol represents an outdated product, everyone is aware of the meaning it bears [16].

In his "Philosophical Investigations", Wittgenstein supports that facial expressions and gestures are also a form of visual language and forms of communication [17]. One could support the idea that many examples are a form of visual language, which is why, according to this study, a slightly different approach is followed based on the definition given by John Malcolm. According to Malcolm, visual language is a multi-dimensional phenomenon primarily based on semiotics [18]. The multi-dimensionality of a visual language lies in the fact that a visual image can be experienced through the viewer's senses and, therefore, can be subjected to various interpretations. Previous experience, stored as memory, allows such a decoding level. Visual signs can be interpreted as messages through the perceptual process in the same way speech can result in a visual component through one's imagination. Light can be used to create a visual sign. The required time to decode a visual sign that does not contain text is less, and the process is more immediate [19]. Traffic lights and lighthouses are examples of light used as visual symbols to signal certain responses. The changes in traffic lights indicate specific types of movement, while the light's movement in the lighthouses signals the proximity to the shore. Moving on to the way visual language is handled in this study, it should be highlighted that in learning processes, a combination of visual and verbal strategies have been used for the past two decades; therefore, visual language is already part of the educational process [20]. In this case, though, visual language focuses on enhancing existing spatial signs by using light, which indicates the change of activities during the daily schedule. The light can act as a signal, communicating the different activities taking place in the classroom to the users.

2.1.3. Storytelling

Storytelling is the art of narration and is widely known in literature and the movie industry. Storytelling has become a fundamental part of the design process, as it is considered one of the most efficient communication tools. The principles of storytelling are content, execution and interaction. The term content refers to the story's logical progression based on clear transition periods (execution), while interaction underlines the importance of communication between the creator and the user [21]. Storytelling holds a significant role in education, especially since it has been proved that narration supports memory development and enhances abilities such as linking events, providing information and elaborating [22,23]. Since storytelling already exists in one form in educational spaces, lighting can enhance a different parameter of storytelling, one that is linked to daily activities. In this case, there will be a parallelism between the traditional way of narrating through speech and visual narration, described in Figure 1.

The left part of Figure 1 depicts how a story is narrated. Storytelling is a verbal process in which speech and hearing are primarily used. A story is a set of chapters that are tied together through the peaks they contain. These peaks are the elements tying the story together. The story's coherence depends on its core and the rhythm of narration. The terms story, chapter, and peaks are mapped to different concepts during this study. The narration process is not verbal but visual and is based on the principles of visual language. The story being narrated is the school's daily schedule. This schedule consists of different activities (chapters) throughout the day. These activities are interconnected through the transition periods (peaks) that signify the alteration between actions. This study aims to interpret and convey messages from verbal narration into visual language through light patterns.

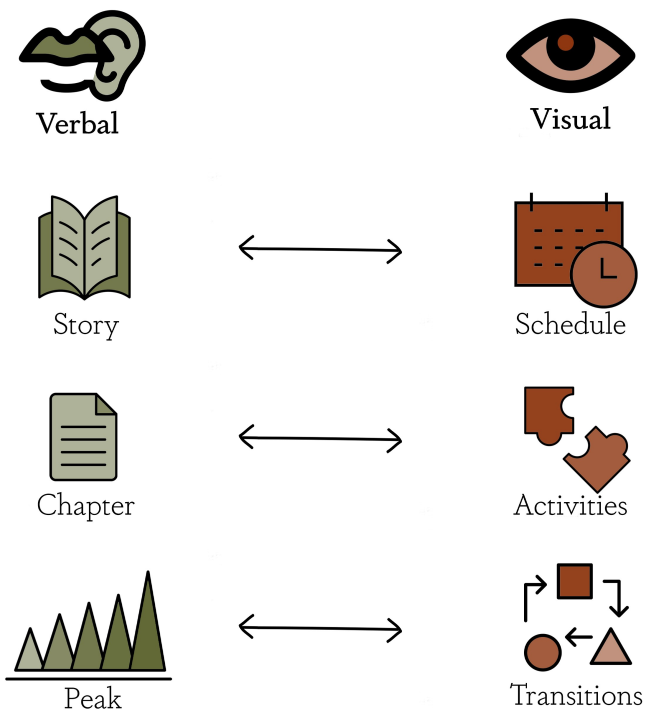


Figure 1. Illustration revealing the use of narration as a visual process.

2.1.4. Importance of Routines in Children's Development

Routines are defined as activities that follow a repetitive pattern during the day. People are familiar with natural patterns and tend to create routines based on them. The sequence of light and darkness is the most important cycle of the day. Almost every human activity develops following these light cycles. Education, mobility and work primarily take place during light hours, and in the past few decades, the use of electric light has allowed the extension of light hours. The link between human evolution, development and light cycles results from light's regulation of the internal biological clocks of all creatures [24]. Natural rhythms are essential; their consistency is valuable since they regulate humans' biological clocks. Humans' internal rhythms are entrained in the patterns of light and darkness; in the same way, everyday activities are developed according to the same patterns. If the natural rhythms are thought to be of a broader scale, then the daily routines are a scaled-down version of them. Similarly, schedules of daily activities are repeated in classrooms precisely. A schedule is essential in children's development, especially for preschool kids. Routines in kindergartens are described as simple steps and tasks that take place during the day. They provide consistency, confidence, security and trust [25]. The first indicator of daily patterns for children is nap routines. Bedtime routines are associated with children's wellbeing and development. Bedtime quality affects daytime activities and has an impact on the learning process. High sleep quality enhances a healthy attitude towards learning and is vital for dental health, especially for toddlers [26].

Routines enhance time perception and support learning by creating a framework within which children can perform and interact [27]. The necessity of patterns in everyday life is apparent and exists throughout all educational stages. Schedules are consistent in activities throughout primary, secondary, and high school. The regulators of those schedules are the educators who ensure adherence to the schedule. The following proposal introduces an additional parameter focusing on how dynamic elements such as light support daily routines.

2.2. Problem Statement

In this context, the research question aims to explore an additional aspect of lighting, focusing primarily on the interaction between light, space and users. The formation of the research question is set as follows:

How can light act as a form of dialogue between educational spaces and children?

The objective is to add a light layer to the existing ceiling lighting. This light layer does not target task and visual performance. It aims to trigger a response related to activity or movement on behalf of the children. It is hypothesised that it can create shorter transition periods between daily activities. The lighting can act as a tool for signifying the transition between the activities based on one of the leading biological needs that light holds, which is time orientation in space. Time orientation is used as a design principle, and the electric light can cover this particular need following the daily schedule. The light layer's placement in space is based on the children's scale. Therefore, the height at which the lights are placed should vary according to the age group. Both spatial perception and visual development during childhood are essential parameters for the lighting proposal.

2.3. Design Thinking

Design thinking is a research-based process of working with data based on users' needs and set requirements [28]. It is a human-centred approach based on interdisciplinarity used in various areas of design, such as product and service design. The cornerstone of this process is the combination of knowledge deriving from various scientific fields, such as behavioural and social sciences. Through design thinking, new alternatives emerge, leading to designs that embody stories with which users can empathise [29]. It is a process that focuses on the human aspect and point of view while at the same time incorporating groundbreaking thinking. The role of design thinking in the present study relates to combining various theoretical disciplines (design, perception, cognition) to set the foundation for the suggested design framework.

2.4. Case Study

A case study of a Greek school was used as an example for applying the proposed design framework. The case study of a primary school in Athens, Greece, allowed the examination of spatial and lighting characteristics, leading to various design proposals for each space. The chosen school has characteristics that are common among most public schools in the region of Athens. The pupils' scale and spatial perception were the core of this study; therefore, a space primarily used by children was necessary for applying the design framework. Different software were used during the study to illustrate and evaluate the lighting. SketchUp 2018 Pro was used to work with natural light since it allows the geolocation of the 3D model, and, therefore, the exact orientation, shadows and daylight intake can be illustrated. DIAlux evo 8.1 was used to simulate the existing electric light. SketchUp and V-ray 3.6 were used for the proposal's final visualisation.

3. Theoretical Framework

The topics presented in this section result in the theoretical foundation of the proposed design framework. These topics are lighting and its relation to time, human scale, spatial perception and vision. The analysis focuses on the children's point of view and the different developmental changes.

3.1. Lighting as a Time Indicator

Natural light undergoes vast variations in intensity, which are not always perceivable by the human eye. These changes follow the cycle of the day, revealing patterns of light and darkness. Light intensity, elevation, and directionality changes are natural time indicators.

Orange and pink light visible close to the horizon is a sign of either sunrise or sunset [30]. This study focuses on the link between light and time orientation. Light changes throughout the day indicate the passage of time. The present study aims to apply the principle of time orientation through light in interior spaces. Contact with natural light throughout the day is essential, and currently, the design of openings providing view and contact with the exterior environment while acting as a medium for the daylight to enter the space has been of great interest [31].

Time orientation in exterior environments is linked to changes and variations in daylight, while time orientation in interior spaces consists of multiple parameters. The first relates to daylight availability in indoor spaces, linking it with the exterior environment. The second parameter is related to electric lighting, which can act as an indicator of time following the changes and rhythm of activities taking place in interior space by changing one or more of its principles (luminance, illuminance, colour, temperature, direction or distribution) [2]. The third parameter is a combination of the above-mentioned aspects. To provide time orientation, the essence of time in the interior must be consistent with the exterior environment. This aspect is linked to the user's expectations regarding the contrast between the interior and exterior spaces. For instance, during the daytime, it is expected that the exterior area needs to be brighter due to daylight, while after sunset, the interior spaces are expected to be brighter than the exterior but not equally bright compared to daytime [30].

3.2. Human Scale and Perception

Human perception is a complex process of recognising one's surroundings. According to Abbasov's book Psychology of Visual Perception, it is a form of knowledge of reality. He describes perception as the process of interpreting information coming from the senses [32]. As described by Abbasov, perception is also related to time and space, bearing the aspects of constancy, structure and selectivity. Even though perception is usually linked to vision, it is the outcome of the coexistence and cooperation of all five senses. Additionally, based on William Lam, it consists of three stages, highlighting the importance of memories as a form of existing knowledge [30]. The three stages are combined, and previous perceptual data is applied as expectations when experiencing space for the first time. Perception is a multisensory process that evolves throughout one's life. Research reveals that perception develops since childhood, constantly evolving and advancing [12]. It is a fundamental process that assists in apprehending, combining and storing knowledge and experience.

Human scale is an essential element for describing the perceptual process. The primary and most important reference for apprehending and "decoding" one's surroundings is their scale. Humans tend to use their scale (size) in relation to the scale of their surroundings. People experiencing space for the first time subconsciously use two essential elements: their scale and previous knowledge or memory regarding spaces and areas looking similar to the one they are assessing. The human scale has been a reference point in design, specifically regarding user-centered design and ergonomics [11].

From a practical point of view, the human scale defines the amount of available information within the viewer's visual field. An example of the differences based on the viewers' scale is presented in Figure 2. In the first row of sketches, the room's dimensions are the same in all three sketches, and the variable is the viewer's height. The first sketch depicts an adult of 1.70 m in height, while a child of 0.70 m in height is depicted in the second sketch. The green and red colours correspond to the visual field of each viewer. The scale difference affects the information within the viewer's field of view. An adult's visual field is split almost equally between information placed closer to the ceiling and the floor, while a child's visual field includes more details placed closer to the floor rather than the ceiling. The room's overall height is greater than 3.00 m in the second row of sketches. The sketches on the right part of the Figure show the differences in the visual fields, comparing an adult to a child. The visual fields differ because of the person's height and, therefore, each person's eye height. Similarly to the first row of sketches, the child's visual field includes more information closer to the floor.

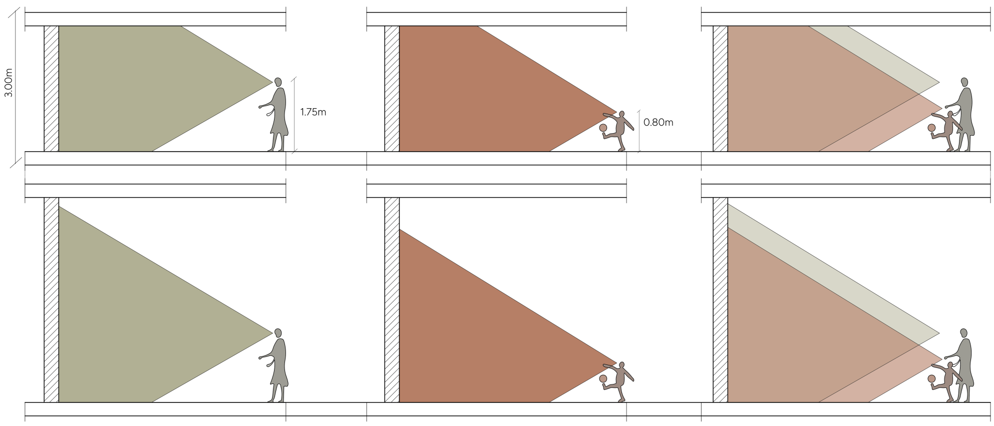


Figure 2. Sketches illustrate how the difference in scale affects the perceived details of scale found in the visual field (*sketch is based on the illustration found in p. 25 of the book "Architect's data" by Ernst and Peter Neufert* [33]).

3.2.1. Perception and Spatial Cognition

Perception and cognition are thought to be two indistinguishable actions, even though they both take part in deciphering the surrounding environment and the activities that take place in it. Perception is characterised as an automated and unconscious process, compared to cognition, which is considered a controlled and intentional process [34]. Cognition involves reasoning, problem-solving and memory. In terms of knowledge, cognition is related to the learning process. The amount of information stored in the conscious part of our brain is gained knowledge and is used during the perceptual process [35,36]. Both perception and cognition develop with age, and depending on the developmental stage, one of them is guiding the learning process. This development also acts as a tool for understanding the philosophical advancement of the human species [37]. In terms of perception, the visual element is the most dominant one, and researchers divide its development into three stages: early, intermediate and late vision. During the early vision stage, the senses are responsible for perceiving and decoding the surrounding elements. In the intermediate stage, object identification and representation are based on memories and stored in long-term memory. In the late stage, perception is mainly based on acquired knowledge, concluding in the importance of cognition [38].

Space can be defined as the enclosure of dimensional elements brought together in an attempt to create an element that will inhabit human activity. Space is produced based, among other parameters, on human needs, mobility, and potential hosted activities. Spatial cognition is a multisensory process that requires the cooperation of all senses. Spatial intelligence evolves through the years and is adaptive based on the surroundings in which each person develops. Spatial thinking contributes to understanding daily relations between social and organisational systems. Spatial cognition is a milestone of intellectual growth, since it relates to various everyday performances [39]. The notion and importance of space are debated due to its objective and subjective definitions. The "objective" space is related to its physical aspect, while the "subjective" space is more intuitive and linked to an empirical and intimate investigation [40]. Spatial cognition is fundamental for navigation and orientation for both children and adults. The notions of navigation and orientation are not strictly linked to a large-scale area like a neighbourhood or a city. During the early stages of development, these notions are related to line and angle appreciation, size recognition and the relative size of objects [41]. The process of spatial development is repeated throughout one's life. Most sensory and cognitive functions undergo extensive developmental changes from childhood to adulthood. Maturity and prior experience are essential elements of cognitive growth. Previous experience is essential both for spatial navigation and orientation. Even though spatial information is primarily gathered through vision, various research studies have revealed that haptic perception is the dominant perceptual sense for children, since it is fully developed at an early age [41,42].

Children primarily perceive and process shapes, lines, distances between objects and directions in terms of spatial cognition. As a result, shapes and lines are the main elements in children's drawings. Children's illustrations enhance their cognition. They are a way of expressing how they perceive their surroundings, and they can indicate developmental difficulties during early age [43]. Children have an egocentric (viewer-dependent) way of analysing spatial information [40]. The egocentric perspective of spatial analysis is linked to the element of scale, both in terms of the human and spatial scales [5]. Piaget describes this process as part of the cognitive stages of development. The first stage (sensorimotor stage) lasts two years and is based on haptic perception. The second stage (preoperational stage) is egocentric and lasts five years. During the third stage (Concrete operational), the child starts considering others' thoughts and feelings, meaning that the perceived space is no longer their immediate surrounding environment but includes others [42]. Throughout spatial cognition, children mainly rely on landmarks for wayfinding and navigation. Research has revealed that in terms of navigation and memory, young children relate more easily to landmarks and junction points. It is stated, though, that it is easier for ten-year-old children to mentally relate certain elements to landmarks compared to six and eight-year-old children [44]. Cognitive development is essential for children, especially since it is a progressive process not fully formed during childhood. In this process, apart from vision, haptic perception is predominant during the first years of age. Moreover, shape, line and angle appreciation are among the primary elements forming children's notion of spatial perception.

Communication through Space

Space is a composition of different elements bearing various functional qualities. The spatial elements can be highlighted using design factors such as colour, material, texture, or lighting. Dominant elements in terms of size or placement, in space, bear a specific functionality or convey a specific message [45]. When certain spatial characteristics contribute to a space's identity, they are prioritised. Therefore, these elements are essential, and emphasising them creates a mental image that becomes the viewer's memory of this space.

Spatial elements are treated in terms of significance due to visual management in space [46]. Openings in buildings, such as doors or windows, symbolise the connection between interior and exterior spaces. Windows lead natural light into the space while providing a view towards the exterior. The door can lead a person to enter or leave a space, symbolising movement in space. Managing a single communication element through space can lead to various conclusions about the message it conveys [47]. For instance, using a particular colour around the doors of a building may indicate that these doors lead to spaces with similar functions. Another aspect of spatial elements is their use in space navigation by creating landmarks, which are fundamentally used as navigational spots. The element of contrast, in this case, can enhance way-finding. There are various examples, and the solutions depend on the building, room or area of interest and its function.

3.3. Central and Peripheral Vision

Foveal and peripheral vision have many differences, yet, at the same time, are co-dependent and complementary. Having only central vision can be described as seeing through a narrow hole in a dark room. Peripheral vision can be described as a blurred image of one's surroundings without the ability to discriminate by colour. It is essential to highlight that due to binocular vision, each eye sees a slightly different image, and due to certain brain functions, the two images are perceived as one. The central field of view is no more than $2°$ and is focused on a small area of the retina called the fovea centralis [4].

These 2° correspond to high visual acuity and the ability to detect small details. It is only 5° from the centre that the clarity of vision is decreased by half, and moving further away from the centre, vision blurs even more.

Peripheral vision is a relic of survival needs; therefore, it is primarily sensitive to movement and changes in brightness. Peripheral vision allows the constant monitoring of the ground. Peripheral sensitivity increases towards the edges of the visual field. Sudden changes in brightness are noticed faster when they occur closer to the edges of the visual field [48]. The forward-facing horizontal field of view is slightly over 210°, while the vertical field of vision is approximately 135° (Figure 3). Symbol recognition is possible in the forward-facing visual field within 30°, while the comfort area is defined as being within a 60° area. Peripheral vision is between 60° to 110°. Within this range, an area of 35° on each side corresponds to the monocular peripheral field of view. That part corresponds to each eye's peripheral visual field. The area from 95° to 110° has the highest sensitivity to brightness changes.

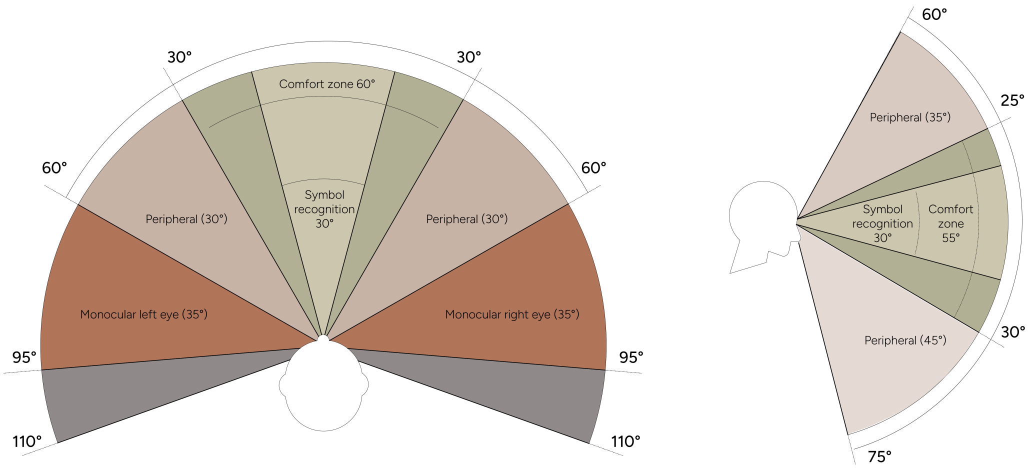


Figure 3. Central and peripheral visual fields. The degree areas correspond to different visual characteristics.

Figure 3 depicts the horizontal and vertical visual fields. The vertical field of vision is also divided into central and peripheral vision. The central field of view is 55° degrees, and this area includes symbol recognition and the comfort zone. The visual field's central part is the focus area. The upper peripheral visual field is 35° degrees, while the lower part is 45° degrees. The lower part is responsible for monitoring the ground. Even though both central and peripheral vision are essential for perception, this study focuses on the peripheral field of view and, more specifically, on children's peripheral vision.

3.3.1. Peripheral Vision and Cognition

Visual development is a fundamental factor for perception and cognition. Vision is related to cognition and learning, especially regarding children. Even though haptic perception is the dominant sense leading and regulating perception during the first developmental stages, vision is predominant during the transitional stages and is used by children to mimic new skills [49]. Peripheral vision relates to learning activities and reading skills [50]. Nevertheless, peripheral vision in children differs from that in adults since its development continues until the age of twenty-two. The left part of the peripheral field of view tends to be slightly more advanced, following how children learn to write and read, from left to the right [6,51]. The right part is more advanced for written languages that follow the opposite direction.

Reading and writing are two of the most complex skills a child learns. The way a text is read requires the combination of central and peripheral vision since the eyes move in a specific direction. It is supported that, in a similar way as written language is understood, symbols and signals are perceived as related to peripheral vision [52].

3.3.2. Visual Development in Children

Vision differs in infants, children and adults because it undergoes a developmental process until adulthood. Vision changes from the moment the eyes form during the second week of pregnancy until adulthood. Visual differences impact perception and the decoding process of one's surroundings. Peripheral vision evolves and alters from childhood until adulthood. The eyes undergo rapid changes from when a child is born to the age of three. Most babies are hyperoptic when born. Astigmatism is also common in infancy. Iris pigmentation occurs after birth, and the colour of the iris darkens during the first two years before acquiring its final colour [53]. Infants tend to perceive space as a fluid mass since they can only distinguish the details of objects close to them, and their surroundings are perceived as a blurred image [42]. Their attention mainly focuses on the central view, as the expansion of their horizontal and vertical visual field evolves significantly during the first six months, resulting in a visual field closer to the one adults have [9,54]. The focus on central vision is linked to the higher spatial resolution when the presented stimuli are within the central visual field and not in the periphery [55].

Visual development in preschool children is related to the increase of peripheral sensitivity from three to six. At the same time, visual acuity reaches its peak at the age of three [53]. During this time, visual development affects spatial perception, given that it is either perceived as "far space" or "near space". The peripheral field of view continues to expand and evolve until the age of twenty-two, meaning that up to that age, the peripheral field of view is more restricted compared to an adult. The changes are less intense than the first years of age. By age fifteen, peripheral sensitivity is similar to foveal sensitivity for static targets [56].

4. Design Framework

The research question and theoretical framework defined four success criteria for evaluating the proposed lighting designs.

- Use of different lighting to enhance certain **spatial elements.**
- Focus on **changes of brightness** and movement performed in different paces.
- Design a lighting scenario based on **peripheral visual perception**.
- Additional lighting layers are not used as task and/or functional lighting. Therefore, the lighting standards do not correspond to this proposal.

The success criteria are related to the project's design directions, which are based on the human scale, the lights' placement in space and spatial cognition while focusing on children's peripheral view. Furthermore, creating a rhythmic light pattern aims to signify the various daily activities in the classroom. Changes in brightness are of the utmost importance due to the high sensitivity in the peripheral view. The colour temperature remains unchanged since the peripheral field of view is not sensitive to colour discrimination. The following design framework combines spatial elements, site and light analysis. The light-related analysis consists of daylight and existing lighting analysis. The goal is to propose a set of tools and steps that can act as guidelines for working in educational spaces.

This framework constitutes a series of steps, primarily focusing on spatial characteristics, the purpose/use of the space and current lighting. Since architecture and design use elements as signs in the space, their interpretation into principles or design directions is fundamental [57].

- Step 1: Spatial analysis. Focuses on analysing spatial signs to establish a profound understanding of the space.
- Step 2: Analysis of how the space is used and potential problems that need to be resolved. This step is essential since it sets the basis for the semiotic/narration component [58].
- Step 3: Light analysis. Description and illustration of the existing lighting situation. In this step, both electric and natural light are studied and presented.

Furthermore, combining the previous steps results in the proposal of additional light layers. The proposed design framework can be used to analyse different types of educational spaces, providing multiple design alternatives. Moreover, even though the steps are the same, the resulting design proposal is based on each space's unique characteristics. Considering that each space's identity is unique, so are the elements composing it. Respectively, the elements and the approach used for resolving existing problems in space are also unique. Figure 4 illustrates the suggested workflow deriving from applying the design framework in a case study. The recommended steps are to be consistent for every case, and the variables are each case's functionality and spatial characteristics, determining the proposed design. What needs to be highlighted is that there can be more than one design solution for each case study.

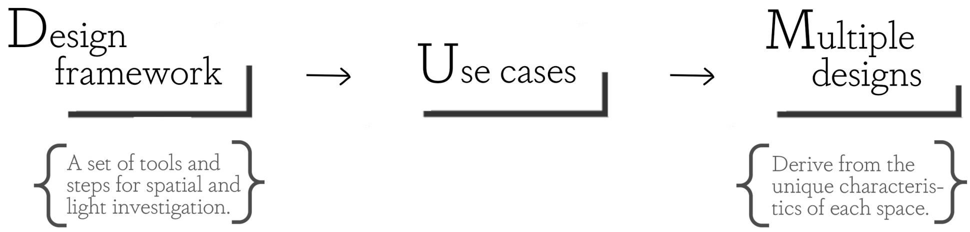


Figure 4. Illustration showing how the framework can be applied, resulting in multiple designs based on a use case.

Spatial and Light Analysis

The first set of steps is related to spatial elements, focusing on their interpretation and understanding in relation to spatial semiotics [59]. Analysing an existing space requires investigating its separate components. These components are presented in Figure 5. Firstly, a study of movement in space is conducted under various scenarios based on spatial function and activities [60]. After investigating space's mobility, the main spots of interest are defined as the areas of higher concentration of human mobility. The points of interest can be passages leading to the exterior space, a different room or areas within the classroom, such as the area close to the board. The third step is to define the dominant shapes and lines within the spots of interest. Those elements can be used as signs or symbols in space to make them stand out. The fourth step incorporates the use of colour in space. The geometry and colour analysis reveal the balance of their composition, which is fundamental for creating a unified environment [61]. In the final step, knowledge from the previous steps is used to create a basis (pattern) for lighting based on the dominant spatial elements [58].

The information gathered from the previous stage is input for the light investigation presented in Figure 6. The first step is to study and evaluate the existing lighting regarding natural light intake and lux levels. The current study aims to create an additional light layer; therefore, the standards are not part of the final proposal's evaluation factors. The second step in the process is the definition of possible light placements based on spatial needs, the spatial scale and the human scale. The element of scale is essential for light placement (topology) decisions since the spatial and human scale influence perception [11]. The third step is analysing how light can enhance or define the different activities in the space. The lighting scenarios should support the space's function and activities. Colour can be a light variable and a factor indicating the change in spatial functionality or activity. The last step of the process is the implementation of rhythm. Rhythm can be used as an indicator of change and movement in space [4]. Rhythm as a light variable can be expressed through brightness variations.

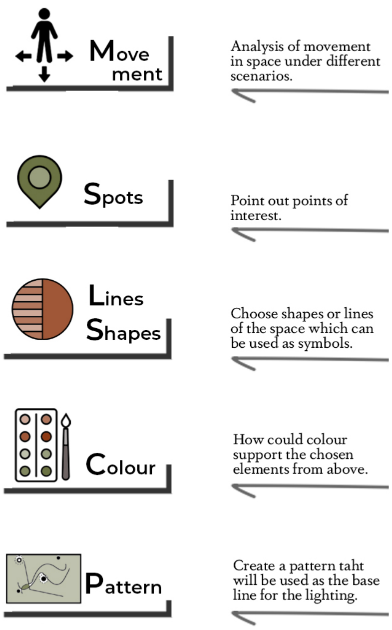


Figure 5. The steps of spatial analysis.

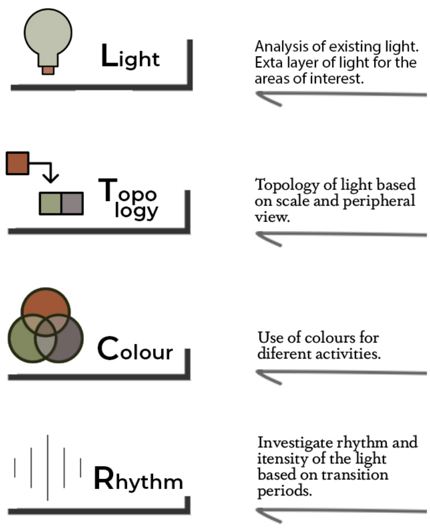


Figure 6. The steps of the light investigation.

5. Case Study

The current case study is an example of the design framework's application. The following case study is a primary school in Athens, Greece. The chosen spaces are located on the first floor of the school. The third- and fourth-grade pupils use the classrooms. The two classrooms were chosen to study two scenarios due to differences in orientation and furniture layout. The following sections will apply and explain the steps composing the design framework. Each step is presented in parallel for both spaces during the analysis process. The analysis of the third-grade classroom is presented first, followed by the analysis of the fourth-grade classroom.

5.1. Spatial Analysis

The first part of the framework is the spatial analysis. The primary spatial elements are pointed out in the following subsections, leading to the composition of a spatial pattern as a final step. Movement in space is explored through the analysis of pupils' mobility. Since on-site data collection was not feasible, the analysis is based on the pupils' hypothetical trajectories. Movement patterns under two different scenarios are presented. The first scenario is the movement pattern during a course presentation, and the second is the movement pattern created during break time when pupils have to leave the classroom. The nature of the course is not significant at this point and is not a variable.

Based on the hypothetical trajectories, a set of heat maps illustrating the different scenarios is produced. The colours in the heat maps represent the motion density in space. Red colours represent the areas with a higher concentration of trajectories, while areas of lower mobility are in blue colours. The left floorplans in Figures 7 and 8 illustrate the heat maps created during a course, while in the right floorplans, the motion density patterns change during the break time scenario. A similar process is followed to illustrate the fourth-grade scenarios. The hypothetical movement is based on the furniture layout and the classroom's elements. The primary difference between the two classrooms is the desks' layout and, therefore, the difference of possible movements under the two scenarios. The right floorplans in Figures 7 and 8 illustrate heat maps that assist in analysing motion density in space. Red areas represent the higher density of movement, and blue areas correspond to lower-density areas. Similarly to the third-grade classroom, higher density is closer to the whiteboard during a course. The break time scenario has a higher concentration closer to the door.

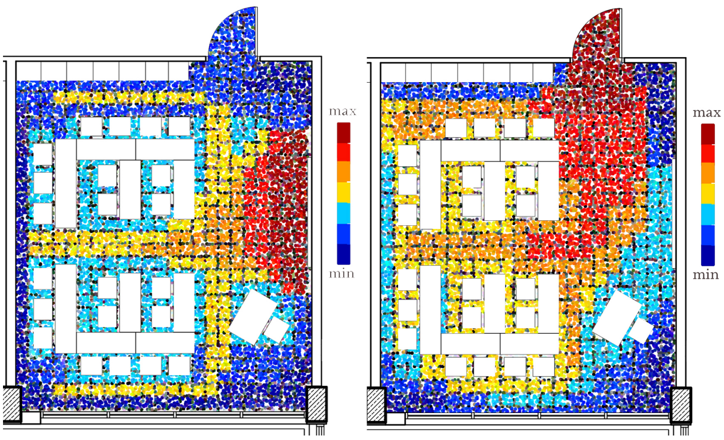


Figure 7. Heat maps illustrating the movement density in space (third-grade classroom). The left floor plan illustrates motion patterns for the course scenario. The right plan illustrates the motion density during break time.

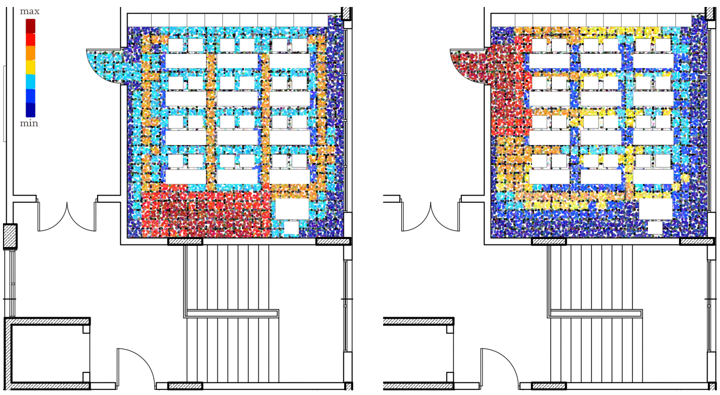


Figure 8. Heat maps illustrating the movement density in space (fourth-grade classroom). The left floor plan illustrates motion patterns for the course scenario. The right plan illustrates the motion density during break time.

5.2. Points of Interest, Lines and Shapes

The first step in spatial analysis indicated two points of interest under the defined activities. These points are defined by the motion density of each activity. Based on the hypothetical movement in space, the points of interest in both classrooms are the same. The areas of interest are close to the board and the door. These areas are the dominant elements in space, symbolising the teaching activity in the classroom and activities outside the classroom, such as break time. The geometry and shapes of these four areas are similar. The dominant shapes are solid rectangles and squares. The geometry of these elements will be fundamental for creating the pattern since they can act as signs in space.

5.3. Colour in Space

The next step in the process is the analysis of the classroom's colour palette. Colour analysis is essential for lighting since colours' properties, such as saturation, hue and reflectance, affect their appearance and reaction to lighting in space. For the third-grade classroom, the most used colours in space are ochre on the wall and the dark colour on the floor, followed by the green hue, which denotes the area around the board. There are also colourful lockers next to the door, the second point of interest (Figure 9).

Figure 9. Colour palette for the third-grade classroom. The size of the rectangle shows which colours are dominant in the classroom over colours used moderately.

The fourth-grade classroom's colour palette is similar to the third-grade classroom in terms of the wall and floor colours. There is also a coloured area around the board, indicating where the information is displayed during the course. The difference between the two classrooms is the colour of the wall on which the board and projection area are situated. The fourth-grade classroom has a darker green tone compared to the third grade. The wall where the door is located has no other elements, making ochre the dominant colour in this area (Figure 10).

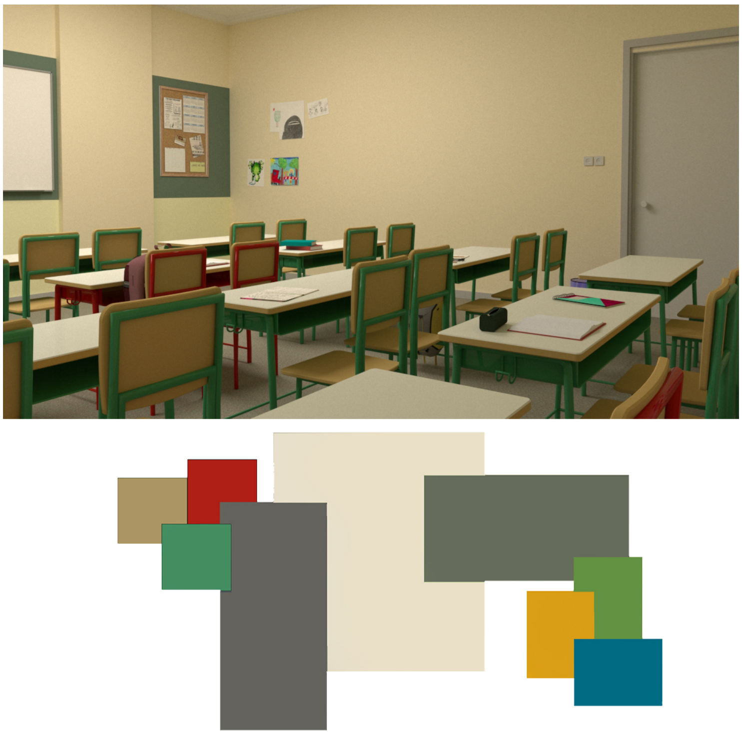


Figure 10. Colour palette in the fourth-grade classroom. The size of the rectangle shows which colours are dominant in the classroom over colours used moderately.

5.4. Pattern

Creating a pattern in space is the outcome of combining all previous stages and focusing on the children's peripheral view. The initial concept is linked to the children's scale in relation to the overall scale of their classroom. This re-scaling process aims to create a frame closer to children's scale in terms of dimensions. The first set of sketches in Figure 11 addresses the pattern creation in the third-grade classroom. A set of rectangles is added to the wall through the rhythmic repetition of the door's shape. Since there are lockers on that wall, only a part of the pattern is visible. The symmetrical mirroring of the same pattern on the upper part of the wall acts as an extension of the hidden part. The green colour on the wall around the information area makes it stand out in the classroom. Extending the same colour on the sidewalls highlights the pupils' peripheral view while sitting at their desks. The board and projection area are parts of the pupils' central view and act as a focus area during the courses since, according to the layout, the teachers use the area closer to the board. The geometries from the repetition and the combination of dominant elements lead to a linear light configuration visible in the last row of sketches.

For the fourth-grade classroom, a similar process resulted in the rhythmic repetition of the door's shape, as seen in Figure 12. In this case, choosing different sides of the repeating rectangles to place the lights resulted in three different linear compositions. The reason for choosing specific sides instead of whole shapes is that children primarily perceive lines and shapes related to spatial cognition. In addition, the pattern should not distract the users by occupying a large wall area, creating unnecessary contrast in space. At the same time, it is important to mention that parts of the walls are used to showcase children's paintings, texts, and other activities; therefore, using the whole wall surface was not practical according to the current needs.

The second point of interest is incorporated by extending the green area, which surrounds and highlights students' focus. The second matrix of sketches (Figure 13) illustrates how the created pattern can be combined with the horizontal extension of the board. For the fourth-grade classroom, the last light configuration will be further analysed for the lighting proposal.

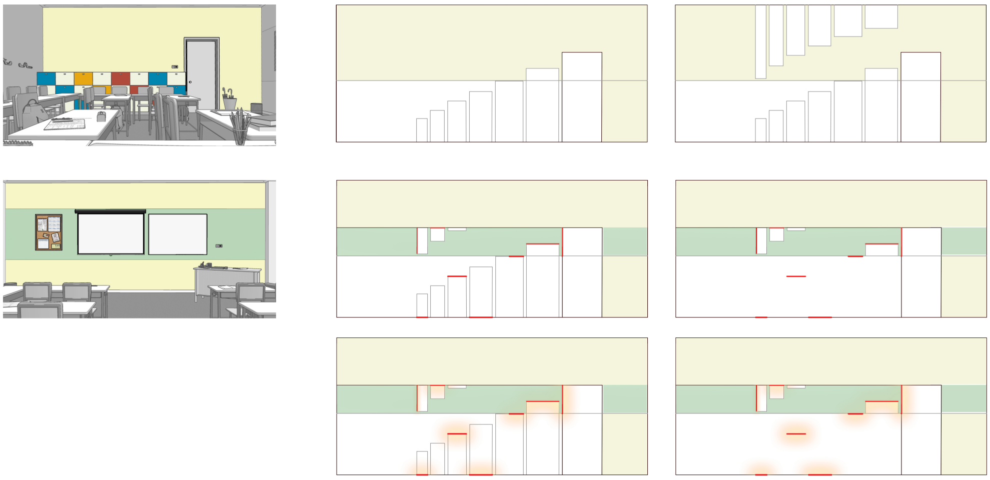


Figure 11. Concept sketches for lighting placement layouts in the third-grade classroom.

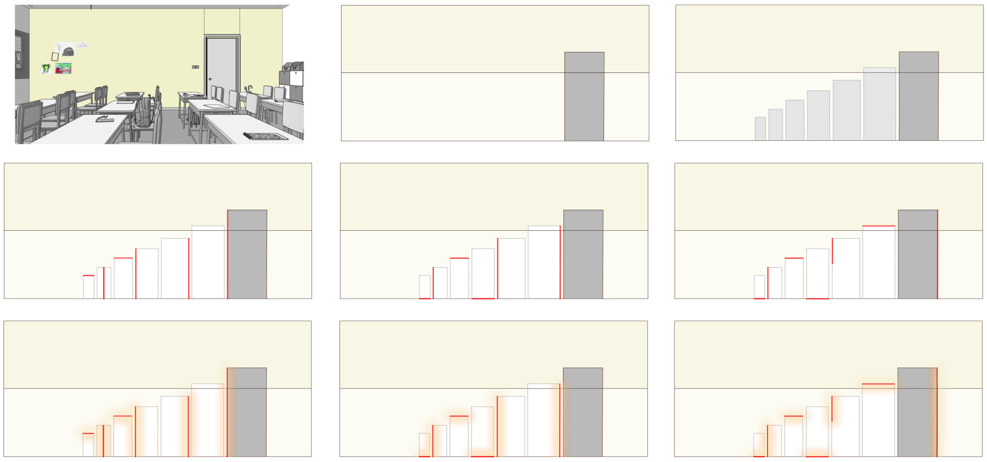


Figure 12. Concept sketches for lighting placement in the fourth-grade classroom.

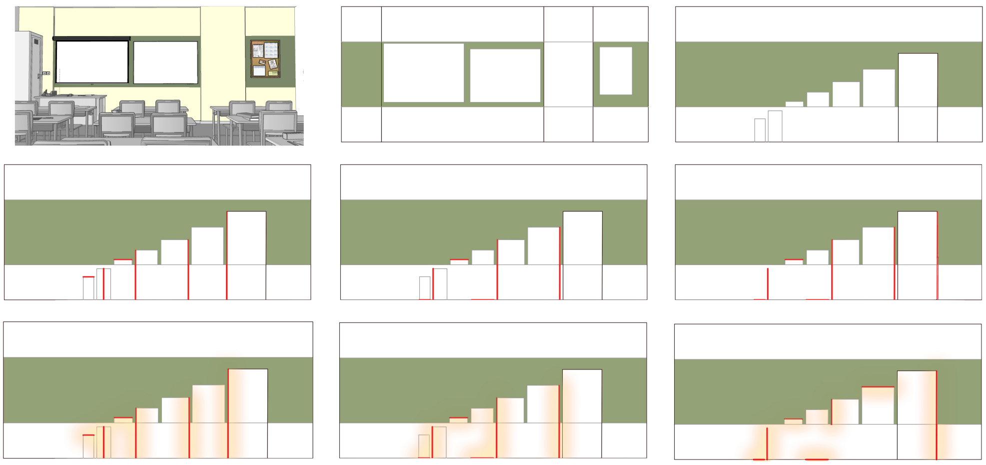


Figure 13. Concept sketches for the fourth-grade classroom.

5.5. School Schedule

The school's daily schedule is presented and analysed, following the definition of the primary spatial elements. The case study is an educational space; therefore, the space's use is defined by its daily schedule. Primary education in Greece lasts six years (grades

1 to 6) and starts at the age of six [62]. Based on the educational system's structure for primary schools, each grade has a main classroom where most courses occur. The primary classroom's role is to create a familiar and stable environment for the children.

Based on the chosen grades, their daily schedule is analysed according to the information provided by the official website of the Hellenic Ministry of Education [63,64]. This investigation aims to gain insight regarding the frequency with which the classrooms are used daily [65]. The third and fourth grades have an equal number of courses per week. There are eleven courses in total. Five occur in different classrooms, and two can be performed in another classroom throughout the year [63,64]. Each school has different building facilities. Therefore, changes in classroom spaces can vary. In the present case study, there are dedicated spaces for specific courses. According to the schedule, daily activities are divided into three types, as shown in Figure 14. Firstly, some courses are always taught in the main classroom while others are taught in a different classroom from the main one. Therefore, there are transition periods between the courses for the pupils to move from one space to another. The last type relates to courses that can occasionally be taught in another classroom, leading to a possible transition between spaces. Lastly, break time can be the most extended transition since the pupils can leave the classroom at their own pace.

Types of activities	Transitions
Courses taught in the main classroom.	No transition
Courses taught in **different classrooms**.	Transitions between courses.
Courses which can be taught **both** in the main and other classrooms.	Possible transition between courses.
Break time	Transition for break time. (longest)

Figure 14. Summary of the activities and the corresponding transitions according to the third and fourth-grade schedules.

The definition of various types of activities suggests three different lighting scenarios that correspond to each transition. Every scenario indicates the type of transition, and the goal is for the light to act as an indicator of change in the classroom. The change in lighting aims to inform the children that the current activity is over and that it is time for either a break or a different course. The specific light characteristics that indicate this change are presented in the following section.

5.5.1. Light Analysis—Existing Lighting

The last part of the design framework focuses on light. A study of the existing lighting is necessary to propose a new lighting scenario. Natural light, especially for educational spaces, is a fundamental environmental factor in design and a key element contributing to pupils' performance [66–68]. The proposed lighting does not target task or visual performance. The first step of the analysis focuses on understanding the existing lighting situation. Natural and electric light are presented separately to provide an overview of the current situation and inform the lighting proposal. A 3D model was designed in SketchUp 2018 Pro to analyse natural light. The model was geolocated to orient and visualise the daylight intake accurately. Four rendered images corresponding to the solstices and equinoxes of the year were created using SketchUp. The time was set at 10.30 a.m. for all renders.

Figure 15 depicts the third-grade classroom. The illustrations corresponding to the March and September equinoxes and the summer solstice show minimum daylight. During the winter solstice, daylight reaches the back wall of the classroom. A Dialux study focused on electric lighting in the classroom. According to the EN 12464-1:2011 lighting standards for indoor workplaces [69], the minimum lux level on the working surface for educational spaces in Greece should be 300 lux. In this classroom, the average lux level is 300 lux, and the lux level on the desks is approximately 700 lux (Figure 16).

Figure 15. Natural light intake, third-grade classroom.

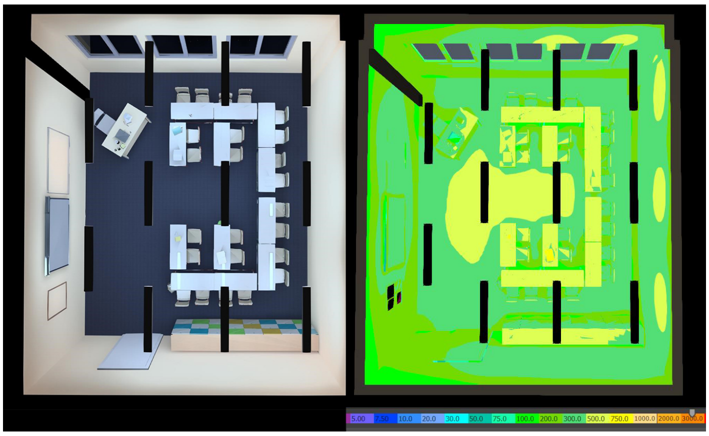


Figure 16. False colour representation of the light levels in the third-grade classroom.

A similar process is followed for fourth grade. Figure 17 depicts a matrix illustrating the solstices. Due to its orientation, there is more daylight in this classroom. During the summer solstice, sunlight enters a small part of the classroom. In winter solstice, the sun's elevation is lower, resulting in increased daylight intake at an earlier time. The fourth-grade classroom model is also recreated in Dialux to showcase the existing light levels. The ceiling lights represent the functional light layer. The light levels are similar to those in the previous classroom. The average light level is above 300 lux, and on the desk surface, it is 700 lux (Figure 18). The lighting layout has a linear configuration of rows of lights following the furniture layout. The proposed lighting does not have a functional character in terms of on-desk tasks. Hence, a profound understanding of the current lighting is necessary. The conclusion drawn from this step is that the two classrooms have differences regarding daylight intake related to their orientation.

The ceiling light follows the set standards for educational spaces in Greece. Consequently, the result creates a static lighting situation without changes throughout the day. The existing lighting remains the same in intensity and colour temperature throughout the year. The current lighting is supposed to have the same intensity and colour temperature regardless of the exterior situation. The current electric light levels create functional but non-adjustable and dynamic lighting. The additional light layer aims to signal transitions between activities through changes in rhythm and intensity. The proposed lighting aims to momentarily create contrast in space, resulting in a dynamic and active environment. The additional layer will be used during the transition periods and not throughout the courses.

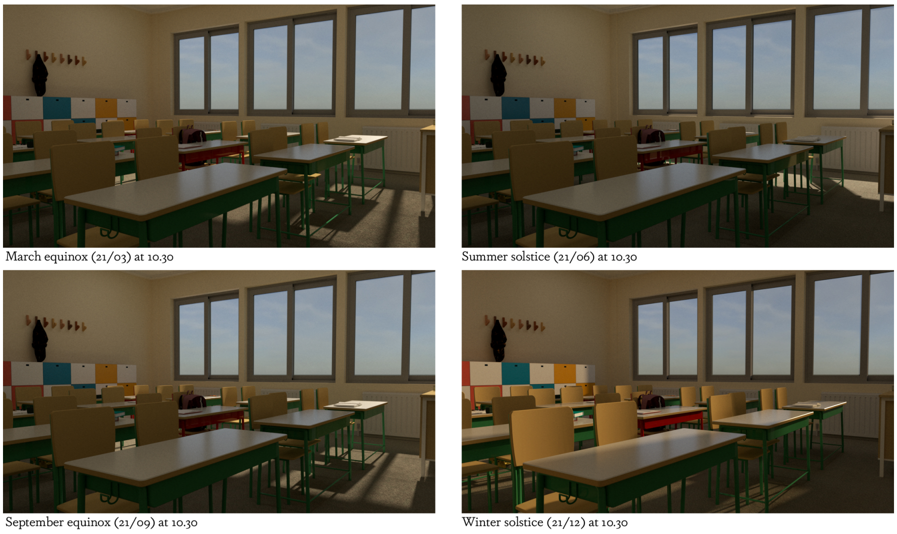


Figure 17. Natural light intake, fourth-grade classroom.

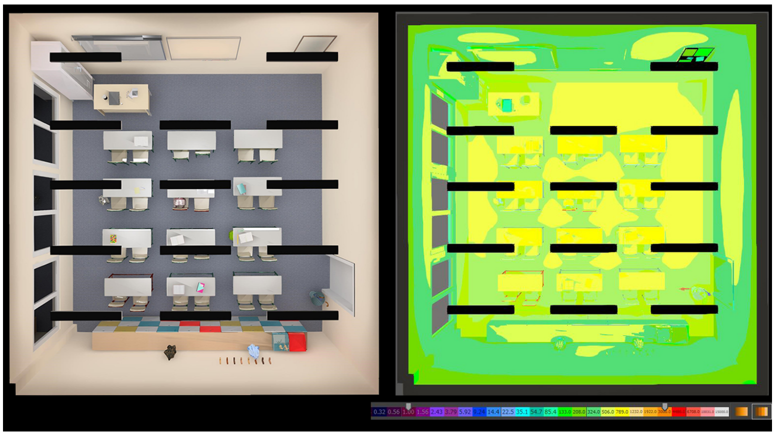
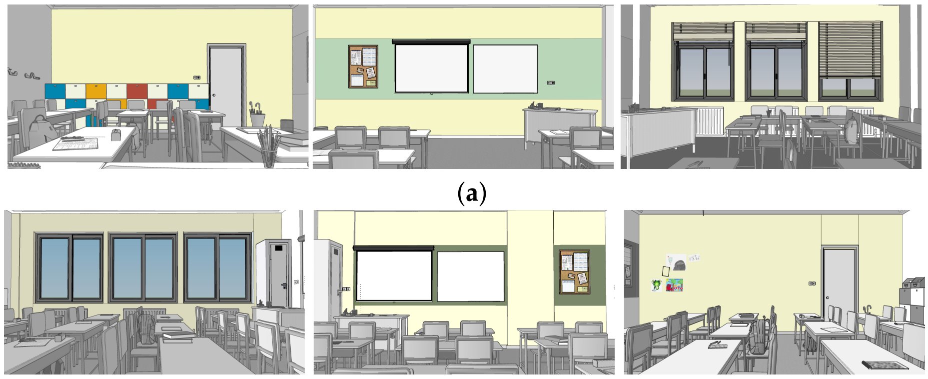


Figure 18. False colour representation of the light levels in the third-grade classroom.

5.5.2. Placement of Light

The lights' placement is essential for the perceptual process and is related to the peripheral view, since peripheral vision is highly sensitive to changes in brightness and motion. The colour in the sketches defines the limits of the peripheral view. The coloured line acts as an extension of the central area within which the board is placed. Therefore, the proposed configurations in both classrooms consist of lights placed within the peripheral view area. The first two scenarios correspond to course transitions, while the third indicates break time. The proposed lighting is placed on the wall where the door is located. Since the study focuses on the peripheral view, there are two options related to the peripheral view. A trifold of sketches illustrates the wall with the board in the middle and the sidewalls on each side. The lighting can only be placed on the wall with the door. The second option is the wall where the windows are located; therefore, there is no open area for placing lights on the height of the peripheral view.

The first row of illustrations in Figure 19 depicts the third-grade classroom. The door is on the left wall, while the windows are on the right side of the room. Hence, the proposal is placed on the left wall. The second-row sketches illustrate the fourth-grade classroom in Figure 19. In this case, the difference is the placement of the windows on the left wall compared to the previous classroom. The proposal is placed on the right wall. The middle area of the wall highlights the area of information on which students' attention is focused. The middle part of the wall is the pupils' peripheral view during a course, corresponding to the board's height. The lights placed at the central part of the wall are used for transitions between courses. When all lights are turned on, they signify break time.

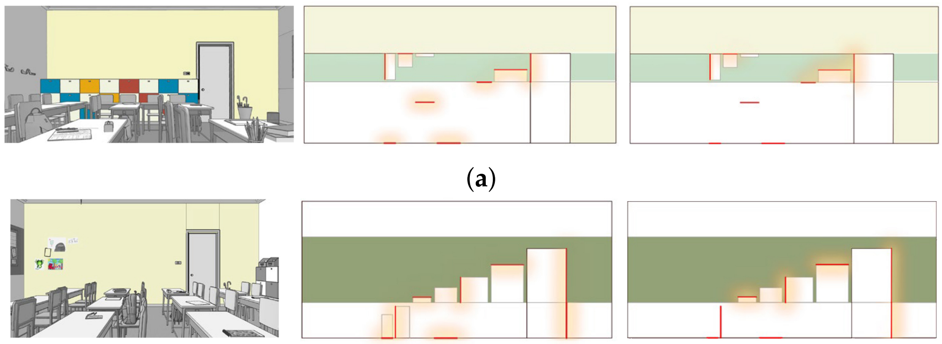


(**a**)

(**b**)

Figure 19. Trifolds for the two classrooms. (**a**) Third-grade classroom trifold. (**b**) Fourth-grade classroom trifold.

Figure 20 depicts two lighting scenarios for each grade. The left sketch shows the area where the lights are placed, and the central sketch shows the lights that indicate break time. In the right sketch, only the lights placed in the middle of the wall are turned on for course transitions. The choice of different lights for each scenario is linked to the proposed transition time for each case. The transition period between the two courses is shorter than the transition, signalling break time. Transitions between courses need to be quicker so that teaching time is not affected. The same principle is followed for the fourth-grade classroom. The left sketch depicts the area of application in space. The middle sketch depicts the break time scenario, while the right sketch illustrates the course transition. Only four of seven lights are used for the scenario addressing course transitions.

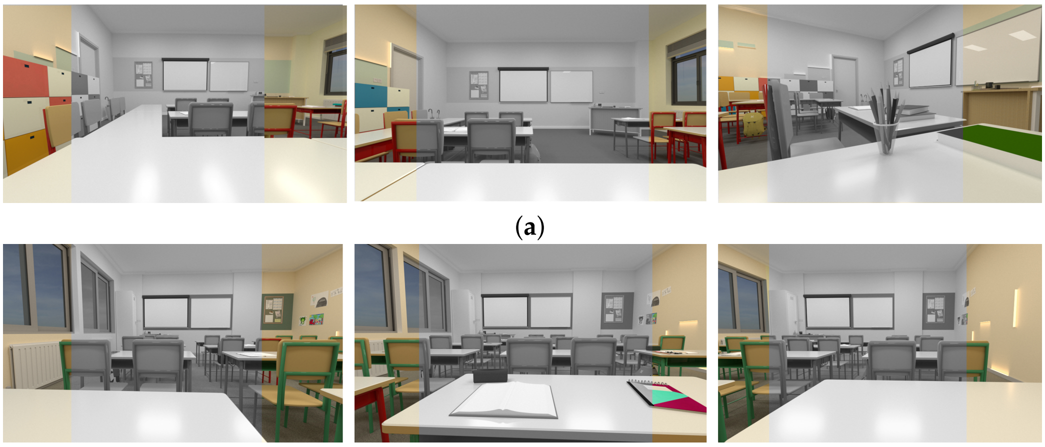


(**a**)

(**b**)

Figure 20. Proposed peripheral lighting for the two grades. (**a**) Lighting proposal for the third-grade classroom. (**b**) Lighting proposal for the fourth-grade classroom.

As shown in Figure 21, the following renders show the visual information within the peripheral view in three sitting locations in the classroom. A camera with a field of view similar to the human eye was set to extend the rendered frame. The area in colour indicates the peripheral view. The lights are located in the peripheral visual field in the illustrations.



(a)

(b)

Figure 21. Peripheral vision in two classrooms. (**a**) Render illustrates the third-grade classroom's central and peripheral view. (**b**) Render illustrates the fourth-grade classroom's central and peripheral view.

5.6. Colour and Rhythm

The colour temperature for the lighting proposal is set at 3500K. The lighting-related variables for this study are light intensity and rhythm. Changes in brightness and movement are primarily perceived by peripheral vision, so they are used to signal different activities.

A summary of the proposed lighting scenarios is presented. According to the schedule, three types of transitions are identified:

- Break time.
- Change in space due to course change.
- Occasional change in space due to the course.

These transitions correspond to three different lighting scenarios. Table 1 summarises the differences between the scenarios regarding the rhythm and number of lights used in each case. The rhythm and light intensity differ based on the transition type. The first scenario, which corresponds to break time, has the slowest rhythm. For this scenario, all light fixtures are used. The second scenario signals the transition between courses and requires moving from one classroom to another. The rhythm is moderate, and limited lighting fixtures are used. The last scenario is related to an occasional classroom change for specific courses. This scenario has the fastest rhythm and uses fewer lights. The same number of lights are used for the second and third scenarios. For all three scenarios, the direction of the "light movement" aims at the door. The first light that turns on is located furthest from the door. The remaining lights gradually turn on, following one another. The last fixture to be turned on is the one by the door. In all cases, a different space from the current classroom needs to be used; therefore, the pupils need to use the door to exit the classroom. The light is an indicator of change and a guide simultaneously in space.

Table 1. Table illustrating the parameters corresponding to the three lighting scenarios. Scenario 1: break time; Scenario 2: transition between courses; Scenario 3: possible transition between courses.

Parameters	Scenario 1	Scenario 2	Scenario 3
Rhythm	Slow	Moderate	Fast
Direction	Towards the doors	Towards the doors	Towards the doors
N. of lights	All	4/5 (based on classroom)	4/5 (based on classroom)

The matrix in Figure 22 illustrates how lights turn on, following a direction leading to the door. The lights symbolise movement towards a different space. This series of rendered images illustrates the first lighting scenario (break time). Hence, all the lights eventually turn on in the last image.

Figure 22. Used lights under the break scenario, for third-grade classroom.

The second series of renders in Figure 23 can correspond to the second and third scenarios. The difference between the scenarios is the lights' rhythm (slow, moderate). The lights placed at the same height as the board area are used for these cases. As stated above, the rhythm is faster in the third scenario, meaning the lights turn on one by one within a shorter period of time.

Figure 23. Used lights under the course scenario, for third-grade classroom.

6. Discussion and Future Work

This study focuses on investigating and implementing lighting as an indicator of change in space. Following one of the essential biological needs for light related to time orientation, electric light can be designed to support this need [2,3]. In this study, light becomes a visual component that creates a dialogue between space and its users [70]. Previous research revealed that visual elements are extensively used in education since they are immediate to understand, and the conveyed information is engraved in children's memory [19]. Human scale, spatial cognition and peripheral vision are design elements. Developing a design framework results in spatial and light analysis steps. The framework is applied in a case study of a primary school. Physical tests and observations were not possible during this study due to COVID-19 restrictions and limitations on school visits.

The additional light layer aims to signal transition periods between course activities based on the daily schedule; the lights are turned on during the transition periods. The height and topology of the proposed light configurations follow children's peripheral view and scale. The lights' intensity creates momentarily contrasts, suggesting activity changes in space. Colour temperature and direction are the same in all three proposed cases.

Certain limitations regarding physical tests and direct observations are in place, which require further exploration and evaluation. The set CCT was 3500 K, though it needs to be further investigated whether the colour temperature should change based on the time of day or season. Furthermore, additional testing is required to evaluate if this change is perceivable since the lights are placed in the peripheral visual field, where colour discrimination is not dominant. Another aspect that needs to be tested is the exact time frame of each transition period. An on-site experiment should be designed to test this variable. The experiment needs to focus on the appropriate interval for each lighting scenario and collect pupils' feedback on their functionality. Additionally, the intensity of the proposed light should be further analysed in terms of contrast under different weather conditions and in relation to electric lighting. For instance, in the case of sunny weather, the sunlight is more intense, and the light transitions might not be visible. Therefore, the overall impression of the space is brighter, and the light configuration should also have a higher intensity. The contrast will not be the same on a cloudy or rainy day compared to sunny conditions. Finally, future research could involve conducting user-centric studies to evaluate the effectiveness of the proposed lighting design framework on non-verbal communication and supporting daily activities. Specifically, we plan to engage students in real-world settings where they will utilise the proposed lighting setup and provide feedback on its functionality and overall impact. Such evaluation will help validate the effectiveness of the proposed design and inform potential refinements for optimised performance in educational environments.

Overall, this study aims to explore lighting as a form of visual language used to support transitions between daily activities in educational spaces. The proposal does not focus on visual tasks or lighting standards. However, it does include a preliminary analysis of the spatial and lighting qualities. The design process should implement children's scale and visual development to inform and guide the suggested lighting proposal. The outcome of this study is that both central and peripheral vision need to be considered when designing a space, since both visual information are located in different spots of the visual field.

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