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Article

Light Distribution and Perceived Spaciousness: Light Patterns in Scale Models

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Abstract: Previous research showed that light distribution can affect the perception of spatial size and shape. However, most studies are limited to quantitative assessment of a few scenarios without explaining possible causes behind peoples' experiences. This exploratory study aimed to reveal complex relationships between light patterns and perceived size, and to investigate how light patterns affect perceived spaciousness. A qualitative approach was used with pair-wise comparisons between systematic visual observations of scale models. The observations confirmed that illuminated walls increase spaciousness. Yet, darkness impacts the perception of spaciousness as well. Both compound and separated light zones can expand depth, height, or width, depending on the interpretation of these patterns of light seen in relation to the whole spatial context. Furthermore, the position of illuminated areas, with placements on edge or in the center, may additionally influence perceived size.

Keywords: spatial perception; spatial enclosure; spaciousness; light pattern; light distribution; architecture; lighting design

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1. Introduction

Sustainability can be divided into social, ecological, and economic components. Social sustainability relates to how buildings and exterior environments fit human needs and support interaction between people. A well-suited space will probably be used more than a space in which people feel less comfortable. The continuously increasing world population may reduce the physical space available per person. Compared to that of moving physical walls, light is an effective, simple, and economical way to visually enlarge or diminish spaces. However, from an economic and ecological point of view, the intention is not to install more light but to optimize the spatial light distribution. Variations in light distribution affect the visual experience more than the amount of light. The distribution of light is very important to our spatial experience, as it provides shadows, which enhance three-dimensionality, and room perspective is beneficial for a quicker spatial judgement. When a space has visible walls, it is clearly defined and enables orientation, in addition to providing a feeling of safety and comfort [1]. "Spatial anxiety", a term first mentioned by Lynch, occurs when there is a lack of visual guidance [2,3]. Spaciousness is especially important when we are anxious [4]. People, as well as animals, do not like being surrounded by cramped spaces, as it raises their fear of being threatened and not having the same flight possibilities that more spacious surroundings offer.

Light distribution was not the main focus of lighting research; instead, visibility and visual performance received the most attention in the field [5]. Therefore, there is a need to study the basics of spaciousness and room dimensions in the interior as well as in exterior spaces [5–7]. According to architectural practices, shown in the well-known Neufert and Neufert handbook, a horizontal striped pattern on a wall will make a space appear wider, while a vertical pattern emphasizes the height of a room [8]. Color research by Küller and others supports this, but it was not fully investigated [9,10]. The gap between praxis and research is shown by Oberfeldt and Hecht, who could not find evidence for Neuferts' statement that a brighter ceiling raises a perceived room [11]. However, in this article, it is assumed that a pattern created by fields of light on a wall will affect the perception of spatial dimensions. This assumption is supported by Matusiak, who shows relationships between a wide rectangular window and a wide spatial impression as well as between a tall rectangular window and a higher spatial impression [12]. In addition to striped patterns and rectangular window shapes, clusters of light zones can form patterns that stretch in horizontal and vertical directions.

The purpose of this explorative study is to generate hypotheses about the spatial interpretation of lit rooms to reveal the complexity of these relationships. Thus, the study is designed to give practitioners more tools for consciously designing spaces. The study aims to find explanations for, and to describe, how light patterns can increase or diminish perceived spatial size. This leads to the research question: how can light patterns affect perceived spaciousness? The idea of the experiment, the rationale and the main results of this study were originally published in a PhD dissertation in 2012 [13].

This article is structured as follows: after the introduction (Section 1), some spatial concepts (Section 1.1) essential for the study are described. After introducing the concept *light zone/light spaces*, a review of research in the area of perception of spatial dimensions is presented (Section 1.2). A description of the present methodology follows (Section 2), specifically targeting the tradition of visual observations (Section 2.1). Further on, the experimental setup and procedure are described (Sections 2.2 and 2.3). This is followed by the results (Section 3) with the themes: contrasts, light patterns, and changes of spatial size (Sections 3.1–3.6). After this, the result section also present examples of the difference between a pattern of light or a pattern of luminaires (Section 3.7). Another example shows how shadows can affect a room to appear deformed (Section 3.8). The article continues with a discussion in which the scale model scenarios are compared with references to architectural sites (Section 4). The article ends with a method discussion (Section 4.2) and a conclusion (Section 5).

1.1. Important Concepts of Light and Space

The spatial enclosure is not only where the limits of the space are located but how distinctly these limits are experienced. Enclosedness is often seen as the opposite of spaciousness [6,14]. Still, these concepts contradict in that some researchers use spaciousness to refer to floor area, and others to volume, while enclosedness mostly relates to walls [15]. Even though spaciousness is often used to refer to a large space, enclosed is not an antonym of small. Seamon discusses Merleau–Ponty's phenomenology with Thiis–Evensen's famous architectural theory about the architectural archetypes: floor, wall, and roof. By these elements', shapes, and positions, depth is created. Depth can be perceived as envelopment, overlap, and enclosure related to insideness and outsideness, contraction, and expansion [16–18]. These theories are relevant not only for physical buildings but also for lit environments. Light beams can together form a space within a space when illuminated areas connect in a three-dimensional relationship to define different planes, or *boundary surfaces* (see Figure 1). A light zone may compete with the enclosure of the *physical space*. Light zones within a space can be experienced as enclosing even though the physical space as a whole is not experienced as enclosed [13,19,20]. In this study, the concept *dark zone* is similarly used in opposition to light zone to describe an especially tangible shadow that creates a spatial unit.

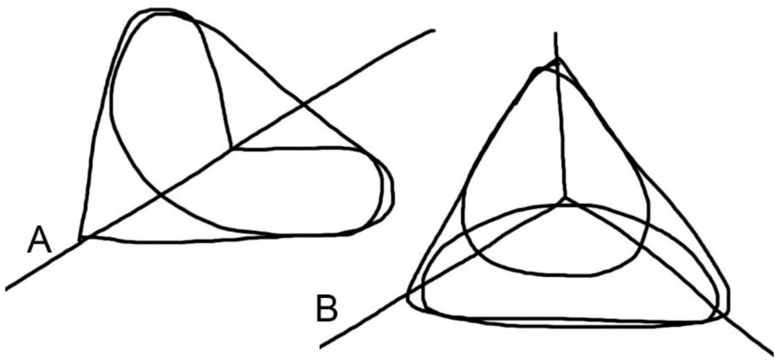

Figure 1. (**A**) An imaginary tangible space, a light zone created by illuminated areas in a transition where wall meets the floor. (**B**) Shape of a light zone in a corner. Sketch by the author [13].

Madsen, used a phenomenological approach and developed the term *light zones (light spaces)* to describe these spatial units constructed of daylight spots within the space [21,22]. Inspired by Madsen, her model with three light-space categories (A, B, C), is here developed to show the light zones mutual position to each other. Madsen uses the categories for describing light zones in relation to walls, a model more suited for daylight analysis. In this analysis, three categories are used for describing if the light zones are *separated* (A), *connected* (B), or *overlapping* (C). Circular symbols show this graphically (see Figure 2). Therefore, the A-B-C model corresponds well with the findings by Hecht et al., implying that people experience their personal space as circular [23,24]. However, in this article, categories B and C are both referred to as compound light zones. Nevertheless, these categories helped observe the light zones relationship, leading to the discussion of compound light zones and directionality.

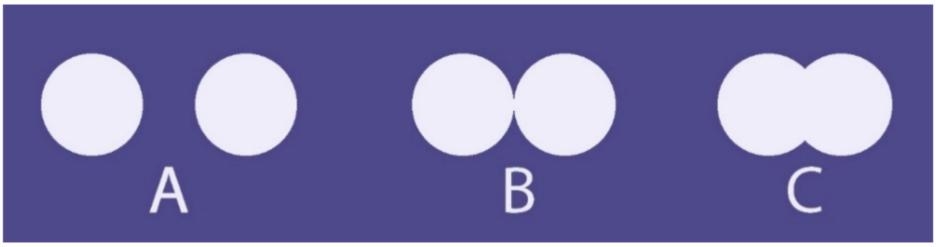

Figure 2. Three categories of light zones: (**A**) separated, (**B**) connected, and (**C**) overlapping. Sketch by the author.

Quantification supports the verification of results, yet it also reduces the focus to a few variables. In our daily life, there are lots of factors that interact and together form our spatial experience. The architect and philosopher Juhani Pallasmaa writes: "In our time, light has turned into a mere quantitative matter and the window has lost its significance as a mediator between two worlds, between enclosed and open, interiority and exteriority, private and public, shadow and light" [25]. If we think beyond windows as a physical apparatus, it is possible to draw parallels to artificial light, further to the experience of being inside or outside a light zone, and to the relation of public and private light zones. Within contemporary light art, we can find several examples of phenomenological observations of light and space, James Turell and Olafur Eliasson's installations are just a few examples. Turell develops phenomenological experiments for the public to observe and explore, often in an empty room, filled with color, light, and shadows [26]. In the installations, observers need to take time to see the phenomena themselves. In the installations *Out of Corners*, *Single Wall-Projections*, and *Shallow-Space Constructions*, Turell studied how the placements of light openings and their shape "corrected" the shape, but also how the architecture can "hold" the light [26].

Light zones/light spaces comprise the whole spatial context within a relationship with many variables. The following section presents previous studies in which most researchers focused on just a few variables at a time.

1.2. Related Research

Brightness is a subjective response, opposite to the measurable *luminance* [27]. Most of the previous research discusses brightness as a factor in spaciousness. Darkness can also play a role in spaciousness; however, this is usually not discussed. There were disagreements between some research studies in this regard [28]. One reason for such conflict could be that researchers are not looking at the same thing, nor are the studies performed in similar contexts. Also, in cases in which informants are used, the experimental setups have a major impact on the results. We can question to what extent a single variable can be generalized. However, despite studies of single variables having the potential to be very informative and important, we also need to see the relationships between phenomena within spaces in a holistic way.

Most prevailing research generally assumes that brightness increases perceived size and spaciousness [29–31]. In a study by Flynn, Spencer, Martyniuk, and Hendrick, it was found that wall-oriented uniform peripheral lighting contributed to an experience of increased spaciousness; additionally, informants preferred spaces with illuminated walls [32]. This finding was supported by Loe, Mansfield, and Rowlands, who investigated whether the luminance of vertical surfaces in a horizontal 40° band in eye height could increase the assessed level of visual interest [33]. Loe proposed that the relationship between uniformity and variation of illuminance and luminance should be studied further [34]. People also seem to prefer light with variation and less uniformity [35]. Varied light is beneficial for comfort and wellbeing [36]. Nonuniform lighting with a repeated pattern of light beams referred to as 'scallops can create a rhythm that divides larger walls into sections [1]. Nasar et al. found that separate placed light zones on the ground can decrease the light uniformity; if the light zones are connected it increase the uniformity [37]. Durak et al. repeated Flynn's study and found that spaciousness was increased by wall-washing with a high light level [28]. Additionally, visual clarity is enhanced by spaciousness [5]. Furthermore, brightness increases clarity [32]. Contrastively, Prozman and Houser found that a diffuse dimmed peripheral light increases spaciousness [35]. This may relate to Hesselgren's findings that the enclosedness level increases with a raised light level, but when the light level goes beyond a certain level the experience of enclosedness disappears [38,39]. Matusiak found that strong luminance contrasts between spatial surfaces assisted an observer to estimate the actual size of the space [31,40]. She also found that when luminance contrasts between the room surfaces are small, a higher luminance of a surface will make it appear farther away so that the space is perceived as larger. Stamps and Krishnan found contradictory results in two similar experiments [41]. Firstly, they found that a darker space was seen as larger than a brighter one, and in the other experiment, they found the opposite in that the brighter room was seen as larger. A possible explanation is a difference in the general light level. A horizontal area (the area one can walk on) is found to have the largest effect on perceived spaciousness, followed by boundary height, while the effect of elongation differed between concave and convex spaces [6,42,43]. Spaciousness can be affected more by one dimension than the others when the choices are depth, height, and width. In particular, depth (length) is important [7]. Oberfeld, Hecht, and Gamer discovered that contrasts of lightness on walls further emphasize the effect of a bright ceiling to make a space appear more spacious, while a light-colored floor is of less importance for increasing perceived height [44]. Furthermore, Oberfeld, et al. point out that the brightness contrast is more important for spatial depth than the level of brightness [44]. If there is a large contrast between an object and the background that it is seen against, it is more likely that the object appears nearer. This relationship seems independent of whether the object or the background is brighter or darker [44]. Oberfeld and Hecht, found ambiguity in that a bright ceiling seen from below surrounded by dark walls, and the reverse situation, do not correspond to the theory of a dark/bright object and background [11]. Illuminated small objects cannot be generalized to three-dimensional spaces. Furthermore, the experienced height interacts with the width. Ceiling and wall lightness together increase the perceived height. Hence, in their study, the experienced height did not relate to the room's physical boundaries [11]. Perceiving room surfaces and objects are not the same. It is more likely for people to notice an object that is closer to them, and for a bright object to be perceived as closer [45,46]. Greater brightness contrasts between an object and its background imply that the object is seen more as a figure than as a background [47]. The concept of figure-ground organization, commonly used in Gestalt psychology, describes how two adjoining areas in the visual field shift between being the main object or being the background [48]. Wagemans et al. describe this as 'when the figure-ground reversals occur, the border-ownership switches' [48]. For example, a space with a white rear wall, ceiling, and floor but black sidewalls were perceived as either high and narrow, but also shallower (shorter) than the other spaces in the study: a space with a white ceiling and black walls, or a space with a white floor and black walls and ceiling [11,44,49]. Davoudian has studied the relationship between a building's visual saliency in relation to its background and the whole visual context [2,50]. According to Davoudian, only nonuniformly illuminated surfaces can create a light pattern. With more objects in the background, the impact of the figure becomes reduced. Furthermore, shadows can change the perceived shape of an object, for example from appearing convex to concave [51].

Previous lighting research is primarily, by tradition, performed with quantitative methods [52–54]. Today, qualitative research has started to enter the arena, since architectural lighting and lighting design are increasing in professional fields.

2. Materials and Methods

2.1. Methodological Choice and Approach

Design and architecture are multidisciplinary fields, which is mirrored by the mixed methodology used in the study [55]. Spaces are complex and context dependent. Qualitative methods are better suited than quantitative methods for investigating patterns in complex relationships. For studies in real spaces, all variables cannot be controlled; rather, every spatial factor must be seen holistically in a relationship [56]. This study not only seeks answers to what we perceive and experience but also searches for a wider understanding of how and why we experience what we do.

A different kind of attention is used when we observe the whole than when we observe parts [57,58]. Like other qualitative studies, the quasiexperimental approach used here, 'a laboratory phenomenology', is explorative, with the aim of generating rich and deep descriptions of spatial complexity [54]. Visual observations of spaces and phenomena with one observer have a tradition within the field of perception of color and light, especially in the Nordic countries. A research community of color and lighting researchers developed a qualitative approach for visual observations in real-life settings, inspired by phenomenology [22,58–66]. However, this kind of approach is still very unusual within lighting research. Nevertheless, Boyce refers to introspective observations as valuable for generating ideas and assumptions, though they can be prone to bias [67,68]. A single observer can be beneficial in revealing relationships, generating extensive observations, and describing them thoroughly. In this case, the rich descriptions of relationships would be harder to collect from several informants, requiring very extensive instruction and experience obtained in visual evaluation. In this case, a single observer study was planned as a pilot study, with the aim to follow up the hypotheses with a larger study, including informants. As Rockcastle and Andersson tested, it is also possible to switch order, and start with a larger quantitative study and afterward verify it with a few trained qualitative observers who search for relationships and patterns [69].

The quasiexperimental approach with scenarios compared to each other in a given order provides the study with structure and focus, more easily revealing relationships between objects for comparison and discussion. Pairwise comparisons are for example used by Haans and de Kort and Stokkerman et al. [70,71]. A paired comparison experiment can be performed without a reference, and it can show smaller differences [70]. Most often scale models are used for daylighting studies in interiors when comparing different scenarios [72,73]. Nowadays, experimental settings are commonly visualized through computer visualizations. This is also a good alternative for simulating full-scale settings. However, experiencing spatial depth in VR or pictures can hardly be the same as a real three-dimensional room, even though it is scaled down, the materiality is so important for the architectonic lived experience. Lau showed that illuminated scale models are assessed in the same way as illuminated real spaces [74]. Holmberg et al. found that a difference between using a scale model compared to full-scaled rooms is that, in a real 1:1 room, you will never grasp the whole space at a glance. Moreover, the distance to the wall is important for volume perception [75,76].

2.2. Experimental Setup

Two identical plain, scale model rooms without daylight and furniture were constructed to observe the effect of just one variable, the luminaire position. Because of the reduction, more focus was directed at the phenomenon being studied. The models stood side by side in a dark space without daylight or any other ambient light, and they were observed through an opening in the models' short side (see Figure 3). In each illumination scenario, the same amount of light was added, with six luminaires in each scenario (see Figure 4). The models were built using a scale of 1:7.5, which corresponds to a full-scale size of 5.4 m × 4.2 m × 2.4 m (see Figure 3). The walls were painted with standard white paint (NCS 0502-Y) with matt gloss 7; the ceiling was painted with NCS 0502-Y matt gloss 3; and the floor was made of unpainted beige MDF boards, judged to be approximately the same color as NCS 3510-Y30R. Six fiber-optic cables directed light from a 50-watt, 12 V low-voltage halogen projector to spots in the ceilings of the models in a manner similar to semirecessed downlight luminaires (color temperature 2700 K). The model of the projector was ETII from SAAS Instruments OY. The glass fiber cables were Schott Spectraflex S8, size 24, diameter 6.0. The fiber ends were used without additional lenses. When the experiment was performed, the choice of fiber optics with halogen was done dictated by the technical solutions available at the market in 2012. Today, LED (Light Emitting Diode) would be a natural choice. The light qualities vary with the light sources. However, the choice of the light source is not crucial for the result—it is more important to use the same light source through all observations.

Figure 3. Scale models standing side by side for pairwise comparison. Photo by the author [13].

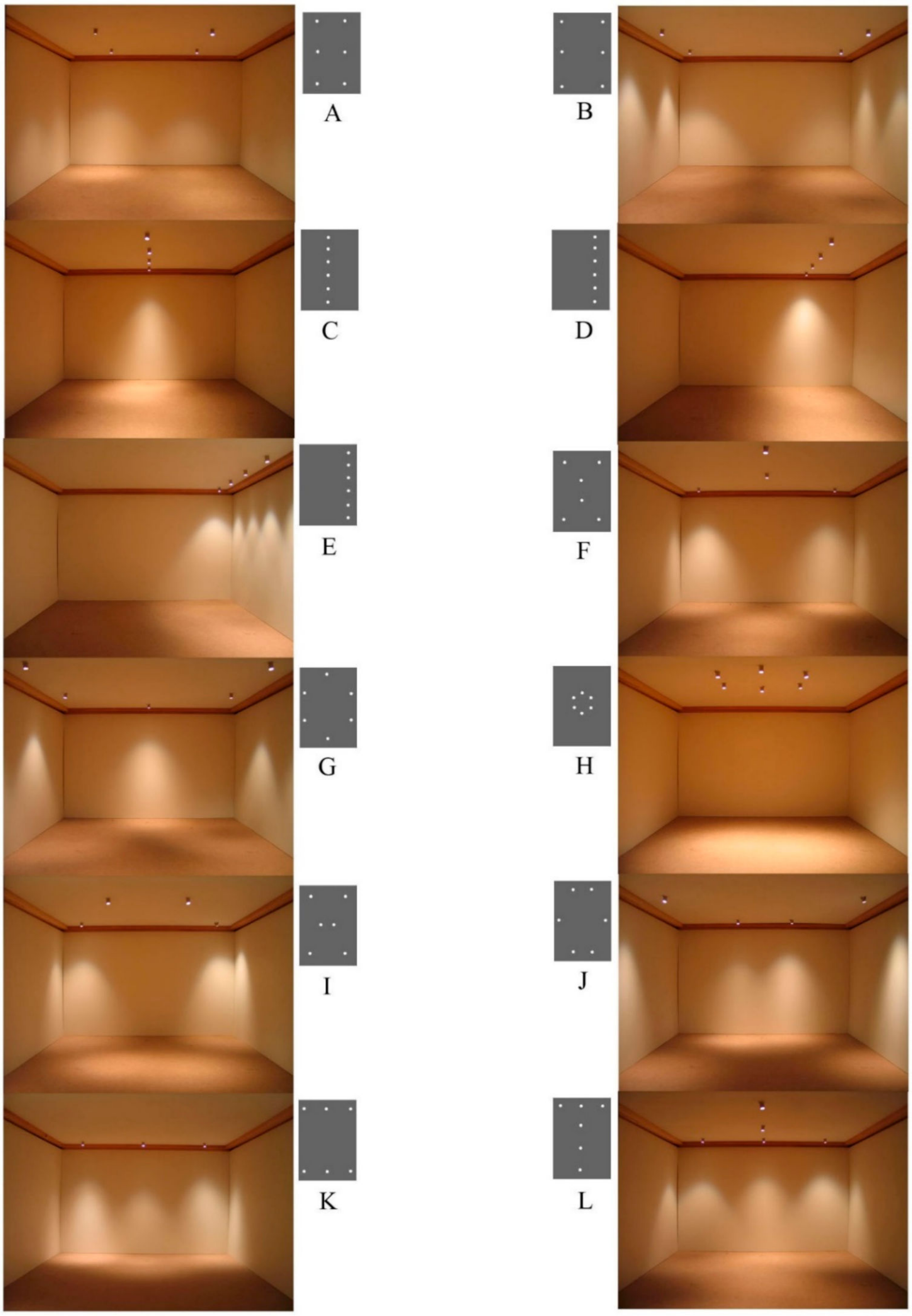

Figure 4. All luminaire placements. Luminaire plans are placed next to each scenario photo. Each scenario has same amount of added light. Photos by the author [13].

Using light from only the scale model ceiling was the easiest way of solving the model construction, although this still shows the variety of experience a ceiling illumination can create by simply changing the luminaire positions. The 12 luminaire placement plans were chosen to represent common solutions where a sideway position was the variable (see all luminaire placements, Figure 4). Scenario A was chosen as a typical principle to illuminate an average Swedish room of this size, with two rows of luminaires oriented parallel to the long sides. In scenario B, these luminaire rows are placed closer to the walls, so an increased amount of light falls on these. The double rows were compared to single rows, as in C, D, and E. In scenario K, the rows were instead oriented along the short sides, and L shows a combination of a centered row and a short side. G and J show luminaires oriented along all sides, either with a pair on the long sides or the short sides. These luminaire positions were found to constitute a larger circle, and illumination H was added to facilitate comparison with a smaller circle. F and I were chosen to represent illuminations with, respectively, light in the corners and light in the center of the room.

2.3. Procedure

Each session involved observing two of the scenarios and took around 20 min to complete. The session began with a 10-min period that allowed for the eyes to adapt to the light conditions of the room where the models stood, and also 5 min between each new pair of scenarios. The sessions consisted of two rounds of pair comparisons. In the first round, illumination A was compared to B, C to D, and so forth. The second round was constructed to investigate interesting phenomena observed in the first round (see Figure 4). Some of these pairs were revisited for additional observations. Scenarios with similarities or contradictions regarding depth, height, or width were paired and compared. During the observations, it was only possible to put one's head into one of the models at a time. Like a painter who alternates between looking at the model and the canvas, the researcher alternated between the two models and her notebook, sketching, and taking notes. The observations of the scenarios continued until there were enough findings to be sorted, interpreted, and discussed. The first phase in the observation procedure was to identify the spatial characteristics (See Tables 1 and 2). In the next step, an analysis of the relationship took over: height was related to vertical patterns, an inner light room to a small impression, and so on. This was continued through an interpretation of why they were possibly perceived like this, followed by describing the relationships (Figure 5). The scale models were observed by one person, the researcher, using a phenomenological approach [77–79]. In this study, there are many possible interpretations of how contrasts of light, size, and emphasis relate to each other and affect each other. The different stages of the phenomenological analysis process can reduce bias. These steps can be described as: (a) attend to the phenomena as they display themselves; (b) describe them, do not explain them at this stage; (c) make all phenomena horizontal. In the second stage, the phenomena are interpreted using hermeneutic rules, such as: (d) explore the basic essence of the phenomena; and (e) search for invariance, structures, and recurrent patterns [78]. By avoiding interpretations too early in the process, and by not drawing conclusions too quickly, a more exhaustive and intersubjective observation is possible. The attention was directed towards what was seen (*epoché*), to where the shadows and light fell, and what happened to the space [77]. If the attention wavered, it was redirected back to the scene. No attempts were made to explain or interpret phenomena during the actual session but were naturally allowed later in the analyzing phase. The object of the investigation is addressed in the way Don Ihde speaks of the phenomenological terms: *horizon* and *core*. The core is the tangible light zone, and the horizon is the physical space [78]. This corresponds to architect research by Peri Bader, who describes focal attention as shifting between figure and ground or between theme and field [79].

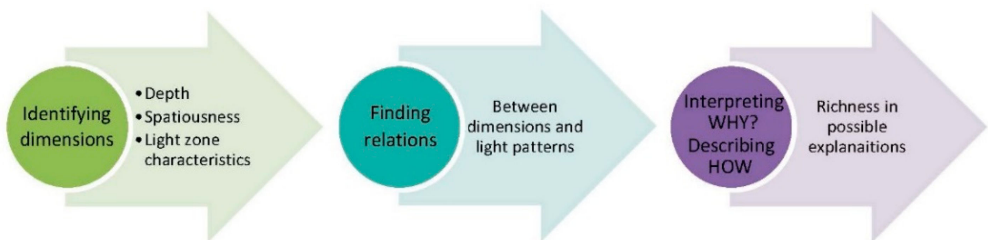

Figure 5. Observation process' three phases.

3. Results

In the Table 1 below, the most prominent spatial qualities are listed for each scenario. Note that the same scenario can simultaneously represent opposite concepts, depending on how they were interpreted in relation to the whole spatial context. It is also possible that a scenario is neither experienced as enclosed nor spacious.

Table 1. Spatial dimensions and spatiality experience are listed for each scenario (the scenarios A-L are described in Figure 4.).

	Spatial Dimensions					Experienced Spatiality			
Scenarios	**High**	**Low**	**Wide**	**Deep**	**Shallow**	**Small**	**Large**	**Spacious**	**Enclosed**
A									
B	B		B				B	B	
C				C					
D	D						D		D
E									
F		F	F	F	F				
G		G	G	G				G	
H		H				H			H
I					I				
J			J		J				
K			(K)						
L			L	L			L		

Table 2. Light patterns as vertical (Ver.) or horizontal (Hor.), separated (a) (Sep.) or as compound. (Com.) = connected (b)/overlapping (c) light zones. Spatial coherence describes relation to wall, if patterns relate to spatial structure, making it clearer (order) or confusing (Conf.).

	Patterns		Light Zones				Lit Walls		Spatial Coherence	
Scenarios	**Ver.**	**Hor.**	**Sep. (a)**	**Com. (b–c)**	**Inner**	**Wall**	**Yes**	**No**	**Order**	**Conf.**
A								A		
B			B			B	B		B	
C	C				C					
D	D				D					
E						E				
F			F			F			F	
G	G	G	G			G				G
H					H					
I		I	I			I			I	
J			J			J			J	
K		K		K		K				
L		L		L		L				L

In Table 2 below we can see that differences in patterns, light zones, clear spatial boundaries and spatial coherence are formed by the scenarios' various light distribution.

From these tables, some combinations of scenarios are chosen for discussing the themes, contrasts, light patterns, size, depth, height, and the interplay between these. The aim to find relationships in a spatial context is complex. It is not possible to pinpoint exactly what created what. The result is a combination of variables that together create patterns that we can identify and understand in the actual context.

3.1. The Play of Contrasts Affects How the Level of Light and Space Size Are Perceived

Now to the question of how illumination affects the perception of a space's size and height. Scenario B appears larger than scenario A because the walls in B receive more light and, thus, the space appears brighter to the eye. When the walls are illuminated higher up, the space also appears higher. The floor receives less light in B, but this seems less important for the total impression of brightness and perception of the size of the space (see Figure 6).

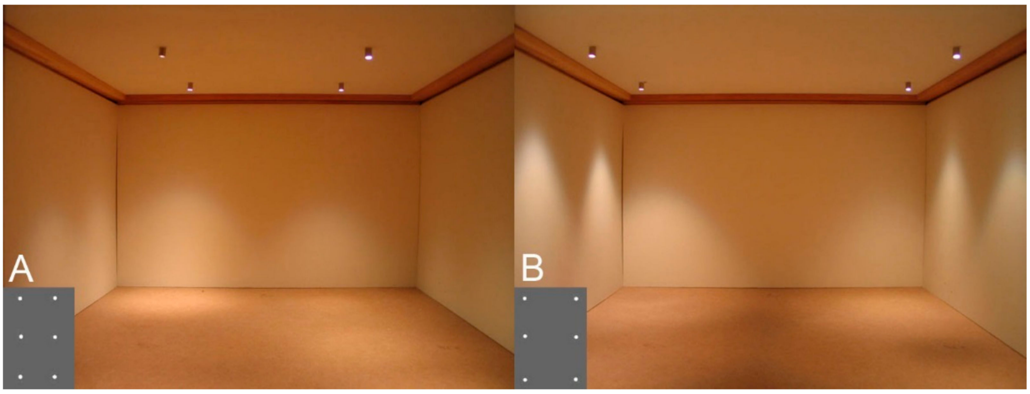

Figure 6. Examples of different degree of enclosure, which affects scenario's perceived size (scenario comparison (**A**,**B**). Photos by the author [13].

The play of contrasts between bright and dark areas in the space is essential for how the level of light is perceived. The contrasts affect how the spatial size is perceived. Very sharp or large contrasts strengthen each other. Dark areas appear darker and illuminated areas brighter. The dark area in D looks less visible, which makes its size harder to estimate, with the result that D appears as a large space. The dark zone seems to take over and looks more enclosed than the light zone. Contrastingly, the light zone in scenario H appears small, since what is regarded as the 'space' here is smaller, more enclosed, and united. Of importance in this observation is that the proportions of dark in the dark zone are large enough to enable an observer to experience it as a dark zone rather than a light zone. The relation between dark and light can be looked upon as a play of contrasts, where light and dark areas shift in importance from being figures to becoming interspaces—in other words, moving from positive to negative images (see Figure 7).

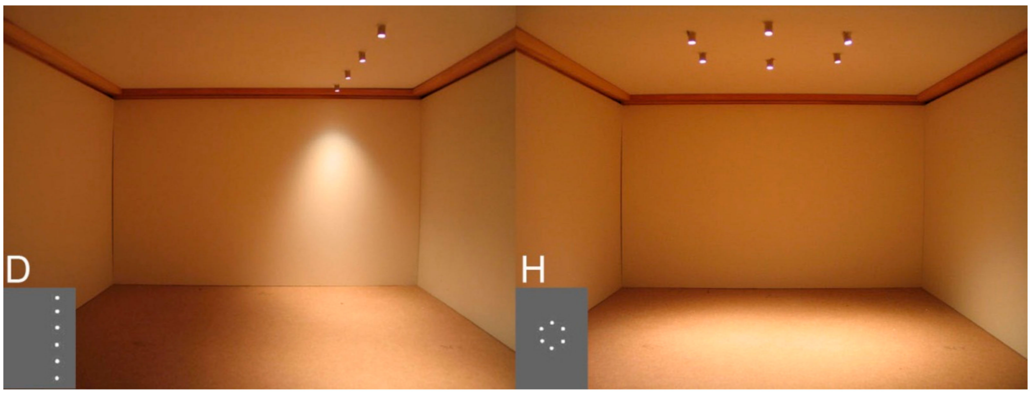

Figure 7. A tangible dark zone (**D**) compared to tangible inner light zone (**H**). Photos by the author [13].

3.2. The Effect of Emphasizing Light Patterns

Highlighted areas are usually seen as areas that were specially chosen, more important, and worth greater emphasis. The placement of such a chosen area in the center of the viewing field is important. The illumination and lighting in scenario C and scenario G, which has a rear wall and centrally illuminated areas, appears deeper than in scenario F and scenario I, which have dark central areas. This phenomenon occurs because the observer is accustomed to illuminations that emphasize a specific detail so that the illuminated area appears more important than the dark area.

The C and G scenarios can also be described as deep, tangible, and spatially enclosing spaces because the light emphasizes the spatial limits. If the transition to the floor had not been so distinct, the illuminated areas in scenario G would were perceived as positioned in a row and at an equal distance from the observer. Scenario F also appears lower, possibly because of its characteristically dynamically patterned floor where illuminated areas in corners and in the middle of the floor form the shape of an X; this highlights the floor somewhat.

In scenario H, which is a space that also appears low, the floor receives more light than the walls (see scenario H in Figure 7 and the other scenarios in Figure 8).

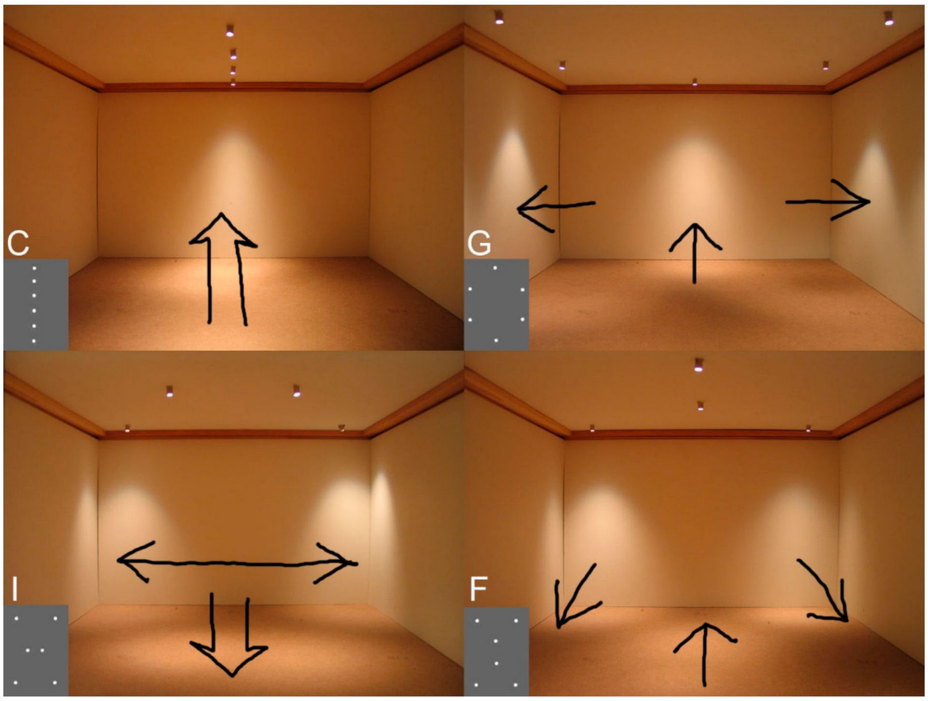

Figure 8. Perceived depth related to emphasized illuminated areas (**C**) is deep; (**G**) is deep and wide; (**I**) is shallow and wide; (**F**) is contradicting, both deep and shallow). Photos with sketches, by the author [13].

3.3. The Relationship between Size of Illuminated Areas and Spaciousness

A space appearing to be smaller than it is, can depend on the size of the illuminated areas. Scenario F appears shallow (short); this is related to the size of the illuminated areas, which are large, and, when contrasted to the dark areas in the space, the overall impression is that the walls appear shorter (see Figure 8). Additionally, since the corners of the side walls are read together with the illuminated areas on the rear wall, this causes the rear wall to look wider. Therefore, the width becomes more prominent than the depth.

3.4. Compound Illuminated Areas Increase Depth and Width

Compound illuminated areas (category b) can also have an enlarging effect. The space can appear deeper if it has a long, illuminated area that guides the eye. A compound illuminated area from the front to the rear wall, as in C and L, makes the space appear deeper (see Figure 9). Scenario L appears larger than scenario K, where the dark area interrupts the spatial connection (categories a + b). Scenario L not only appears deep but also wide: here the long sides of the space are not illuminated; rather, it is the whole rear wall with the corners of the space that are illuminated. In both these cases, an observer's gaze is guided with the help of compound illuminated areas (category b) from the front to the back of the space. On the other hand, scenario K, with a rear wall illuminated in a similar manner to scenario L, is not perceived as especially wide. An important difference is the centered row of luminaires that illuminates the middle part of the space in scenario L. In scenario L, the illuminated areas form a coherent light zone (category c), in contrast to scenario K, where the illuminated area closest to the rear wall is isolated (category a). If one only regards the further illuminated area in scenario K as a light zone, the distance in between this light zone and the foreground of the space as a whole, or an interruption in the illumination of the surface, this results in the space as a whole is perceived as less wide than scenario L (See Figure 9).

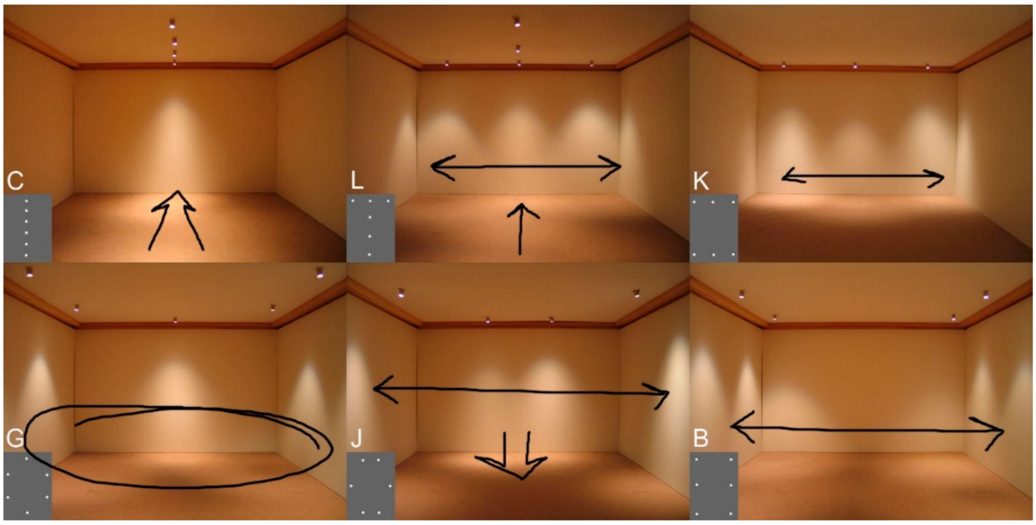

Figure 9. Perceived depth and width related to size of and distance between illuminated areas (**C**) is deep; (**L**) is wide and deep; (**K**) is wide; (**G**) is wide and deep; (**J**) is wide and shallow; (**B**) is wide). Photos with sketches, by the author [13].

The space can appear wide because of compound illuminated areas (categories b + c) and/or separated illuminated areas (categories a + b). In scenario L, the width is highlighted by illuminated areas on the whole rear wall and the corners. There is a continuous field of light both width- and depth-wise (category c). In addition to scenarios G and J scenario B also appears wide, which is because this space has bright walls, but even more so because this space has separate illuminated areas (category a) (see Figure 9).

3.5. Separate Illuminated Areas Seem to Increase Space Size

The size of a space is perceived as larger when illuminated areas are spread out as separate entities (category a). When walls are illuminated with light beams that are spread out and that emphasize each illuminated area as separate figures (category a)—such as in scenarios G and J—the depth between the observer and the rear wall increases, and the distance between each long side appears longer. In addition, the illuminated area on the rear wall gives the space depth because the rear wall is emphasized (see Figure 9).

3.6. Interplay of Width, Height and Depth

The interplay of width and height affects the way a space is experienced. The width between the illuminated areas on the sidewalls of scenario G appears to make the ceiling of scenario G appear lower. Conversely, in scenario J, where the rear wall has two light beams that form a wider light zone and a brighter rear wall, the rear wall appears closer to the observer than the rear wall in scenario G, probably because of the brightness of the light on the wall (see Figure 9).

3.7. Patterns Composed by Light or Luminaires—For a Tangible, Clearly Defined Space

The study also gave unexpected answers, which were not searched for. Two examples are shown here, about patterns of light respective luminaires, and about the possible deforming effect by shadows. In addition to the pattern of light that falls on spatial surfaces, luminaire openings also form patterns. These interior elements often form figures, most commonly on the ceiling with a more or less defined shape. From the Gestalt theory, we can learn that it is easier to read together a shape with a known, and geometric simple form, like a circle [4]. The luminaire pattern does not always correspond to the light pattern of illuminated surfaces or to the shape of the physical space. If the luminaire pattern does not match the pattern of light on spatial surfaces, as in scenario G, the result becomes confusing. The illumination in scenario G appears to contradict the shape of the physical space instead of reinforcing it. In scenario G, sparsely distributed light areas surrounded by dark areas form an incoherent pattern. Wider beam angles could possibly give another result, as a wide light zone could connect to other light zones. The luminaire placement in scenario J forms a circle of similar size, as in G, but since the dark corners appear more united, the light zone appears to be more enclosing. In G, the shadow zones in both corners and in the middle of the long sides appear to be of equal importance compared to that of the light zones (see Figure 9).

3.8. Perceiving the Shape of a Space: Deformation Effect Related to Shadows

Illumination affects the perceived shape of the ceiling. In scenario D, the ceiling appears to be vaulted upwards, while in scenario F the ceiling appears concave (see Figure 10). These phenomena may be explained as follows: the light pattern in scenario F emphasizes the lower part of the corners and the floor, while the illuminated area in scenario D emphasizes one of the long side walls, which also appears higher. The direct light on the floor in scenario D, the indirect light on the ceiling, and the illuminated wall together make the space appear higher.

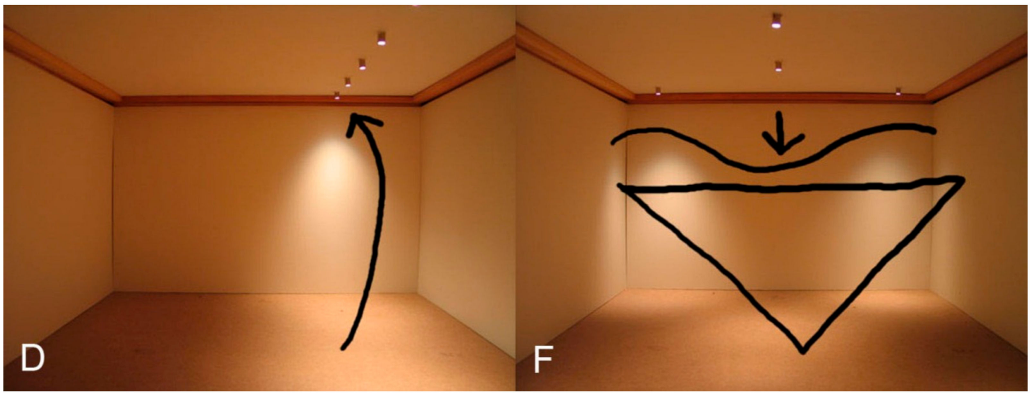

Figure 10. A perceived vaulted ceiling, convex in (**D**), and concave in (**F**). Photos with sketches, by the author [13].

4. Discussion

4.1. Discussion of Results

Most prevailing research commonly addresses brightness as a factor that increases perceived size and spaciousness [29,31]. This scale model study indicates that brightness is an enlarging factor (scenario comparison A–B, discussed in 3.1), but also the opposite: that darkness can increase the size (scenario D, also discussed in 3.1). Darkness can be an enlarging factor when the spatial boundaries become unclear and the distance more difficult to estimate, while bright walls can appear to be closer if the brightness sharply contrasts with the surrounding region [19,20]. If contrasts become too strong, the light zones are seen more as objects on their own regardless of the physical space [13]. That strong luminance contrasts made the space appear smaller corresponds with Matusiak's and Sudbø's conclusion that small luminance contrasts in combination with higher surface luminance will make an impression of a larger space [12]. Horizontal and vertical light patterns appeared to influence height and width, which agrees with architectural praxis as well as with Matusiak's research (see scenario B, respectively, L, G, and J) [8,12,31,40]. The following images show similarities between the scale model observations and examples from existing architectonic masterpieces. In these complex sites several factors—daylight, colors, room shape, and context—interfere with the light patterns. The similarity is primarily related to lightness patterns, not light zones as such. The scale model scenario H has a concentrated ring of light in the ceiling which connects to the light zone at the floor, giving a higher impression. Saarinen's chapel is characterized by the vertical light above the altar, where the reflective, translucent curtain adds to the impression of light beams from heaven. In the image of the Örestad's school ceiling, we see a dotted light pattern that attracts the attention towards the ceiling, reinforcing the high, airy, and spacious expression further. A previous study indicates that gaze attraction can change the perceived room dimensions [20]. In the church park experiment, interviewees assessed the light scenario with separate light zones as higher [19]. In these four images, we see examples of factors that strengthen a height impression: a compound vertical pattern, corresponding patterns at the ceiling and floor, and patterns of luminaires or window openings in the ceiling, which attract the gaze (See Figure 11).

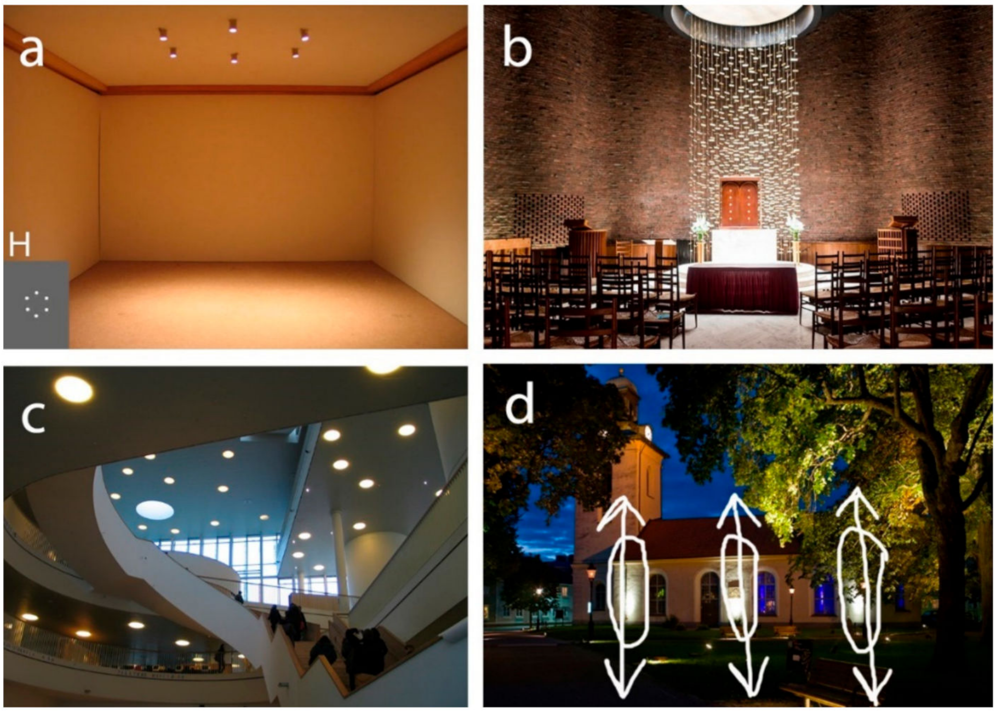

Figure 11. Verticality and height examples. (**a**) Scale model H, (**b**) Eero Saarinen's chapel built 1955 at MIT in Boston, (**c**) Örestad's School in Copenhagen, which was designed by architects 3XN in 2007 and (**d**) Church park study [19]. Photo B is from Le Corbusier's Chapel Notre Dame du Haut in Ronchamp, France. It was downloaded from Flickr, 21-07-05. The photographer is Jean Pierre Dalbéra (2016). The other photos in Figure 11 are taken by the author [13].

The Scale model scenario K has a compound light zone that appears to widen the room (see Figure 12). In the image of Corbusier's chapel, we see a horizontal emphasis giving a wider impression, since both side walls are brighter (see Figure 12). The daylight slits between the ceiling and rear wall strengthens this impression. In this Örestad's school image the room's width is emphasized by the windows (see Figure 12). It is related to boundary permeability. Through the windows, the space continues outside, following the gaze. Therefore, it emphasizes the horizontal pattern and the width. The church facade lighting was assessed by 222 participants [19]. The results show clearly that this scenario with connected light fields (category b) (see Figure 12d) appears wider than the scenario shown in the image with separated light zones (category a) (see Figure 11d). In these four images, we see three examples of factors adding to a width impression: a compound horizontal light zone, horizontal lines, and brighter areas on the sides.

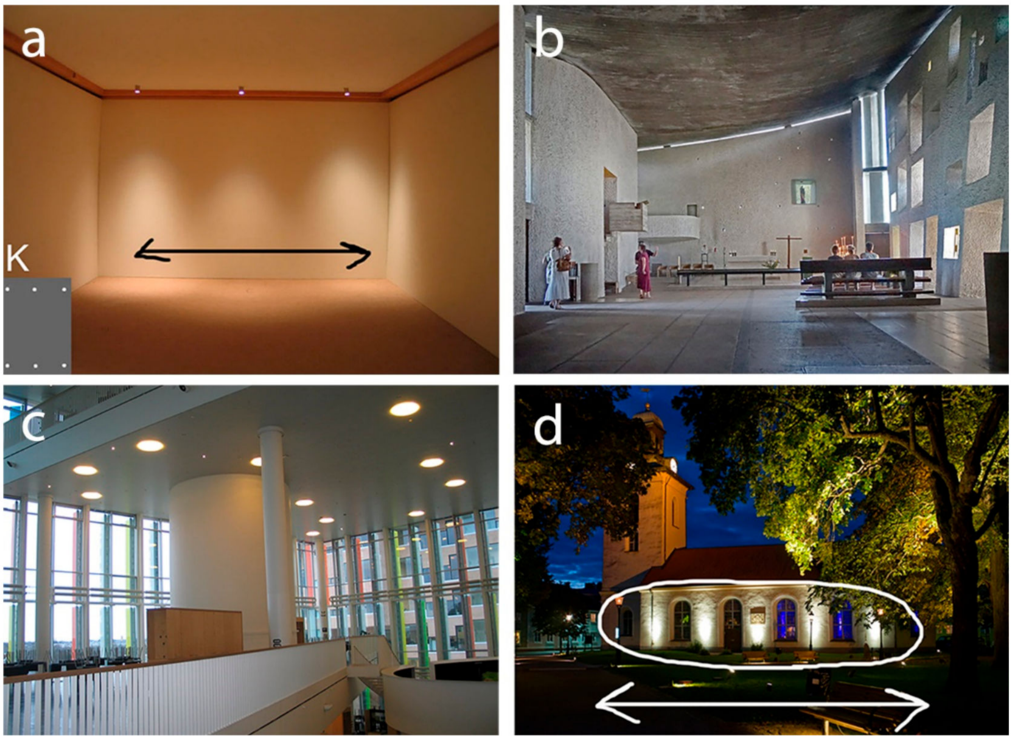

Figure 12. Horisontality and width examples: (**a**) Scale model K, (**b**) Corbusier's chapel Notre Dame du Haut, (**c**) Örestad's school and (**d**) Church park study [19]. Figure 12. Horizontality and width examples. Photo B is from Eero Saarinen's Chapel at MIT, Boston. It was downloaded from Flickr, 21-07-05. The photographer uses the signature "Freshwater2006". The other photos in Figure 12 are by the author [13].

The perceived depth in the scale models corresponded to the pattern of a compound illuminated area on the floor (categories b–c), from the observer to the rear wall. An impression of depth was created when centered surfaces on the rear wall were emphasized (scenario comparison C–G, discussed in Section 3.2). However, there were also some examples where illuminated surfaces appeared to decrease depth rather than increase it. A wider illuminated area on the rear wall makes the rear wall appear closer (scenario J compared with G, discussed in Section 3.6). The interplay of contrast between the light beams and the dark areas can cause either the illuminated areas or the dark areas to be interpreted as openings in the wall.

There are some examples where a light zone appears to reduce the depth of the space rather than enhance it. A wider illuminated area on the rear wall seemed to make the rear wall appear closer, most likely because of the total higher level of light on the wall, but also because of the wider compound light zone (categories b–c). Scenarios with illuminated areas centered on the rear wall seemed deeper than scenarios with correspondingly centered dark areas; a qualified guess is that illuminations that emphasize something chosen are more common (as a figure), so that the centered light zone seems more important than the dark zone (see Figure 13 below). The shifting object in focus connects to the figure-background theory as well as theories of attention [48,79].

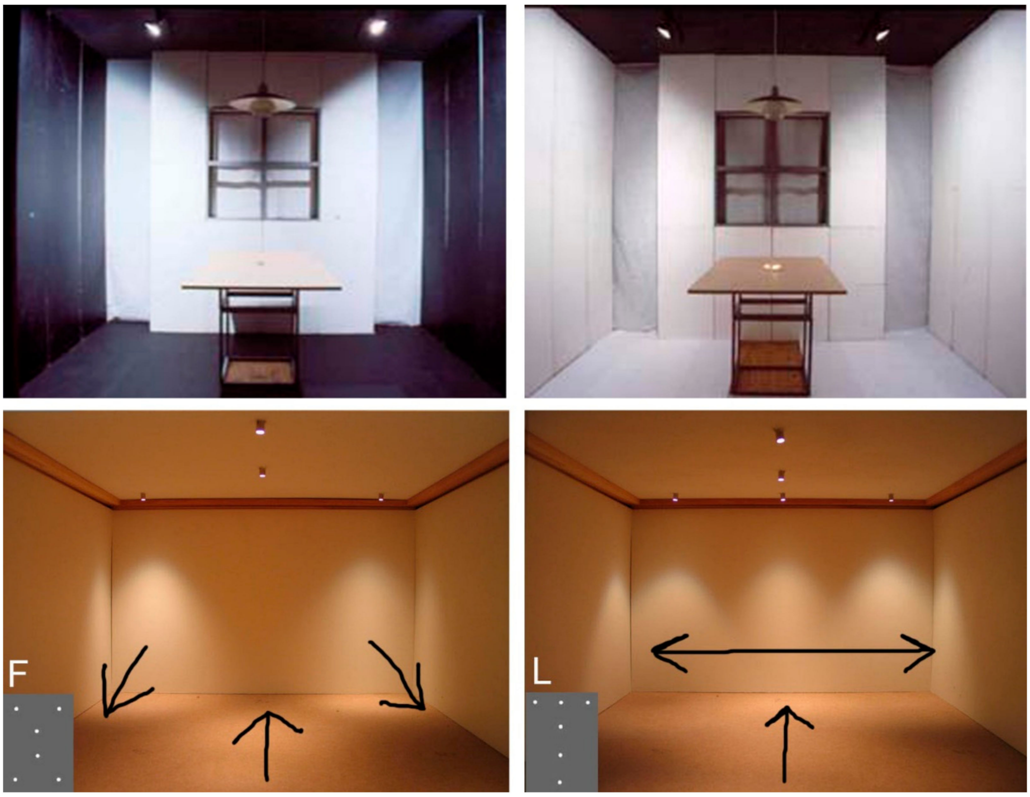

Figure 13. Comparisons with a full-scale study. In Barbara Matusiaks's study with full-scale rooms (**above**), upper-left room is assessed as narrow, short, and low [31]. Scale model room (**F**) is observed as wide, short (+ long), and low. Matusiak's right upper room is assessed as wide, long, and high. Scale model room (**L**) below was observed as wide and long. Photos A and B are from a study by Barbara Matusiak, Professor at NTNU, Bergen, Norway [31]. The other photos with sketches in Figure 13 are made by the author.

Matusiak's study shows the spatial complexity, how the colored room surfaces, interact with the light patterns (Figure 13) [31]. Twenty informants assessed these rooms in 18 different scenarios. To the left, the rear wall displays fewer contrasts differences, which make it appear flatter and the room looks shorter. This simultaneously makes the room appear wider. The room to the right, with shadows in the corners, feels longer, it is possible that there can be something behind the centered rear wall. To the right, the walls create a continuous light-colored band emphasizing the horizontal character which can be associated with width. In the left image above, the large color contrasts between floor and wall breaks the continuity of the vertical pattern, so it does not reinforce the room height. The right image floor lines are easier to detect, important for the perspective and the impression of depth. Matusiak also saw that the floor reflectance has a large impact on the size impression of a room. However, in the scale models, the floor did not influence the impression of height (scenario comparison A–B, discussed in Section 3.1). Oberfeld, Hecht, and Gamer found that the lightness on the floor has less of an impact on the perceived spatial height [44]. Contrastingly, the scale model study described by Billger indicated that ceiling and floor held greater importance for the impression of size than the walls [66]. This issue requires further studies.

In one scenario, the ceiling was perceived as convex, and in another scenario as concave (scenario comparison D–F, discussed in Section 3.8). This may be explained by the well-known phenomenon of a convex shape appearing concave when the light direction shifts from an upward to a downward direction [51]. In the convex example, more light is reflected indirectly from one side of the floor, and there is one wall that reflects light up onto half of the ceiling, while the lighting design in the concave example emphasizes the floor and makes the ceiling appear darker, which creates an impression of a more downward-oriented light. The vaulted impression may also be because brightness contrasts disappear in uniform light. However, this phenomenon must be studied further since several factors must be taken into consideration: the figure-ground relation of the illuminated areas, the perception of the ceiling corners as being more illuminated than the center of the ceiling, and the center of the floor is perceived as brighter than the rest of the space. Also, in other studies, shadows have impact flat surfaces to appear bended (Figure 14) [19,20].

Figure 14. Shape transformation. The scale model scenario D (**a**) is here compared with other studies. Interviewees perceived this church facade illumination as convex (**b**), and this auditorium ceiling lighting (**c**) as giving a concave impression. For church facade, bright corners seem to approach. In auditorium, brighter centered ceiling spot together with surrounding shadows created an impression of a vault [20]. Photos by the author [13].

In the scale model observations, the light zone was most often regarded as the important space, while the physical space was seen as less important. Illuminated areas are usually perceived as areas that were specifically chosen, that are more important, and are worth highlighting. This can cause the pattern of light to be seen more clearly than the pattern of dark areas. If the contrast between light and dark becomes too great, the areas that are illuminated can pop out from the physical space. Similarly, if brightness contrasts disappear in a uniform distribution of light, the physical space becomes more important than the light zone. The shape of the arches of light may also be wider or narrower, less round, more asymmetric, or less defined or varied in other situations, and all this affects what is seen.

Light distribution, contrasts, shadows, and many more factors impact size perception, however, that is not all. The observer's preunderstanding is also highly important.

4.2. Method Discussion

Naturally, there is the possibility that the observer was influenced by conventions within design practice, just like every person has their frames of reference. In this case, the researcher is the observer. That means that the initial hypotheses from experience can influence the analyses. Without informants, we cannot know if the perceived phenomena would be perceived in the same way by other people, with different frames of preferences, various professional and cultural backgrounds, and their individual lived experiences. Experiences are always subjective. The findings in this article shall followingly not be taken for granted. In this regard, the main contribution by this article may not be the observations and interpretations as such. More important is that this study exemplifies a methodological approach for observing lit spaces. We have a mutual cultural understanding about spaces that can be regarded as intersubjective, neither subjective nor objective, but something that we usually agree on [18]. This is, for example, the perception that a specific room is deep or shallow. If we have observations from many informants, similar experiences could be defined as an intersubjective agreement. To be able to verify if also other people have similar experiences, there is a need to use informants. Using only a single observer, the researcher, can be both a weakness and a strength. The strength of using a single observer is that he/she can use plenty of time, something you seldom can demand from an informant. A study with informants is usually predefined and framed. This kind of observation needs trained observers, skilled in architecture and visual perception. The open approach, not limited to predefined questions, stimulate finding answers to questions that were not even formulated in advance. For example, these about patterns of light, or luminaires, and deforming shadows. This study shall be regarded as explorative for generating hypotheses, by finding patterns. It can be seen as a pilot study, which not only needs to be verified with other people but also in different kinds of spatial contexts, real-life settings, interiors as well as exteriors. Similarly, quantitative studies can be verified afterward by a qualitative visual observation [69]. No method is superior to another. However, a qualitative approach will not give the same kinds of answers that a quantitative approach gives. The method we choose determines what kind of findings we will get. The scale models of spaces must be observed in person and not in photos, where the contrasts are often perceived to be stronger. The experience of the scale models is discussed as though it were possible to be inside the models. The models were large enough to comfortably fit one's head inside. Experiencing the scale models is close to being inside these spaces, although one cannot turn around. As Holmberg et al. found, people are more affected by spatial proportions in a scale model, there you can get a better overview, than in a full-scale room, which is hard to grasp fully by a glance [75]. They suggest that the position of the viewing opening/the door impacts the experience of a room volume. If the door is located on a long wall instead of a short wall, it probably makes the room feel smaller, since the distance to the walls impacts the size impression [75]. Neither scale figures nor furniture helps the observer get an indication of the scale of this model space, but the light and the size of the luminaire openings, which are similar to semirecessed downlight luminaires. There is an interplay between the different levels of contrast and the 'scale of light': the relationship between the size of the light beams, as well as the scale and size of the space. If furniture was included, it would have created associations of how the space was used, which in turn possibly affected how the scale of the space was experienced.

5. Conclusions

This study describes examples of how luminaire position, light distribution, contrasts, and room surfaces interact within the spatial complexity. These observations describe that illuminated walls increase spaciousness; yet darkness also impacts perceptions of spaciousness. The distances between the illuminated areas, particularly when these areas are made up of a coherent pattern, were found to influence the perceived size. A compound illuminated area from front to back increased the depth. Additionally, a rear wall with central illuminated areas appeared farther away. A floor that was emphasized by a characteristic pattern of light appeared lower. The shape of the ceiling can be perceived as concave or convex, depending on the shadows. Additionally, luminaire openings form a light pattern that does not always correspond to the illumination pattern on the room's surfaces. These findings contribute to expanding the vocabulary for lighting spaces and can serve as educational examples.

After identifying basic types of spatial phenomena regarding room dimensions, these need further analyses of more complex spaces, for hypotheses testing in controlled experiments with informants in various contexts.

The findings in this article show how several factors interfere with each other. Relationships like these are commonly discussed in architectural praxis; yet they are rarely discussed according to lighting research findings. The awareness of possible ambiguity related to contextuality when a lit room is visually perceived, needs to be raised. In all scenarios presented here, the number of luminaires and the amount of added light was the same. Yet, the varied light distribution on room surfaces created large differences in spatial appearance. According to this, the lighting research community as well as practitioners need to put more focus on the light distribution than before [5].

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M.B.; project administration, U.W.L. All authors have read and agreed to the published version of the manuscript.

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