The Sanctuary of Art
Images in the assessment and design of light in architecture

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Dissertation submitted for the degree of Doctor of Philosophy
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September 1997

Declaration
This dissertation is the result of my own work and includes nothing which is the outcome of work
done in collaboration, except where otherwise stated and referenced. It has not been and is not
being, in part or wholly, submitted for any other degree, diploma or similar qualification. It does not
exceed 80 000 words in length, including references, appendices and bibliographies.
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This research proposes a design method that enables quantitative and qualitative assessments of light in space. The simplicity of the approach facilitates its integration into the architectural design process by using available technologies. The methodology concentrates on the early design stage since it expresses the architect's intention of a particular atmosphere that will govern further developments of the project. It takes into account the increasing interest in the utilisation of photography as an important part of the design process, and adds a quantifiable aspect to light as it offers the possibility to integrate numerical values when required. The visual representation of light as a pattern, instead of numerical values, facilitates the quantitative assessment and relates to existing techniques of lighting analysis, such as the isolux contours. The research emphasises and develops the possibilities offered by a partially computerised approach using calculation method and physical modelling. It combines the use of physical models, video camera, and computerised image analysis as main tools for the evaluation of light. The resulting data collection and visualisation of the lighting effects constitute a bank of images for the generation of space from lights. The combination of images creates spaces issued from the nature of light, allowing new ideas in the development of the initial design stages. The research defines the potential and limitations of the use of images in the composition of space according to the physical properties of light. The lighting pattern also constitutes the basis for a classification of lights which relates to the design method using images. It proposes a link between quantitative and qualitative aspects of light stemming from spatial components and apertures. The classification acknowledges the architect's intuitive approach to design.

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ACKNOWLEDGEMENTS

This research was funded by the Université Laval for the Faculté d'Architecture et d'Aménagement, the SSHRC (Social Sciences and Humanities Research Council) of Canada, and the FCAR (Fonds pour la Formation de Chercheurs et l'Aide à la Recherche), Government of Quebec. I particularly thank Doctor Dean U. Hawkes, supervisor, for his interest and support in the research.
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Architects have an understanding of light that originates from their experience of space, an empirical knowledge based on intuition. Colquhoun [1981, p. 43] mentions that there is a common belief about the inefficiency of intuitive design methods traditionally used by architects of dealing with the complexity of existing problems. He also adds that precise design tools are necessary to avoid the architect's tendency to depend on previous examples, often referred as type-solutions, for the solution of new problems. Maldonado [1966] suggests that intuition must rely on a knowledge of past solutions applied to related design problems. He mentions that creation is a process of adapting forms derived either from past requirements or past aesthetic ideologies to present needs. The argument often disputed against the use of typologies in the design process is that they are a vestige of the age of craft [Colquhoun, 1981]. It states that the use of models by craftsmen became less necessary as technology developed during the pre industrial age and enabled designers to discover the physical laws of nature. Moreover, it appears the many tools and techniques have already been developed for a scientific integration of light in architecture, but their impact on the built environment is limited and sometimes negligible. Because of the multidisciplinary character of designing with light, some applications were unsuccessfully adapted to design objectives [Schuman & Selkowitz, 1989]. There are no simple techniques available for assessing the quality of light in space and most existing tools are solely concerned about quantitative aspects [Schuman & Selkowitz]. Moreover, those tools are seldom used among practising architects because they have a greater impact on the final assessment of a solution and very little on the early design stages.
Colquhoun [1981] states that the duality between art and science nowadays increases in significance as this distinction ignores the role of the message value added to the use value of a space. He adds that despite the development of the scientific method, the message issued from social or iconic values should also relate to light as a technological product and a generator of ambiances. The application of general laws or principles is a necessary part of design but it does not define the final form of the product, even in a technological context where the liberty of choice corresponds to an adaptation of existing solutions. The need to develop a classification of lights prevails, since architecture does not exist in a vacuum but is always found in a context that often embodies references from precedents [Bandini, 1993]. Huet [1993] mentions that because of its nature, the typology conditions the act of creative invention. Facing new constructive possibilities, the typology becomes a tool that could initiate a concept of light as architectural form. The typology constitutes a necessary beginning, but not an objective or a result since architecture consists in going beyond it [Huet in Bandini, 1993, p. 392]; “it plays a creative role by allowing the designer to begin the cycle of analysis and revision from a reasonably confident position” [Hawkes, 1976, p. 466]. The diverse environmental elements present in light and space ensure that morphological relationships are rarely dependant on physical laws alone [Colquhoun, 1981, p. 47]. Other laws relating to qualitative aspects should also contribute to the definition of typologies of light in architecture.

This chapter explores the ambient threshold between qualitative and quantitative aspects of light through evocations of typologies exposed by architects and scientists. It introduces a classification that characterises light in an interpretation of qualitative aspects and illustrates a perceptual experience of space.

"The design goes on and on; speculation of the ways you can do this thing in the most characteristic fantastic ways, because you recognise that structure has an order; that material has an order; that the construction has an order; the space has an order in the way of the servant spaces and the spaces served; that the light has an order because it has an order in the sense that it is given by structure, and that the consciousness of the orders be felt."

[Louis I. Kahn, 1969]

Kahn mentions the existence of order in architecture and suggests that light has an order because structure has an order (figure 1.2). Kahn implies that the order of light should emerge from the order of structure and affirms that “structure is the maker of light. When you decide on the structure, you’re deciding on light” [Kahn, 1969, p. 449]. This confirms the possibility to establish a classification of lights according to physical aspects, which also refer to the morphology of space and apertures. A classification based on the physical and morphological aspects alone could emerge from a parametrical study, but the result would only relate to the geometrical characteristics of space and apertures. This would indeed neglect the intuitive notion of space creation related to perceptual and emotive criteria, associated with the generated atmosphere. The existing literature
provides a basis to establish the premises of a typology that associates perceptual and physical characteristics of light. This would classify some of the variables that constitute the qualitative analysis related to specific atmospheres of light in space. The complexity of the classification relates to the variability of daylight and the various assessments of its visual perception in architecture, changing from one observer to another [Lam, 1977]. Typologies are usually based on quantifiable or measurable variables. Emotive and perceptual aspects of light are hardly quantifiable, but morphological aspects issued from a physical context are more easily compiled. It however appears that emotive and perceptual aspects relate to some physical and morphological characteristics of light in space [Flynn, 1992]. The identification of those relationships existing between qualitative and quantitative aspects of light can be established through the analysis of specific variables. This should contribute to a classification of lights and ambiences.

Ciriani [1991] mentions that nowadays, structural limits disappear, confirming their appropriateness to become the sole component to define the current architecture. Lighting patterns of different types of apertures were studied in a previous research [Demers, 1993]. Such quantitative investigations are interesting but restrain the exploration of light as matter since they only allow the experimentation of a limited range of possibilities. The problem is to define the experimental limits and the context of analysis where a given structure may generate many types of lights under different lighting conditions. Ciriani therefore suggests a classification that originates from the qualitative aspects of light and uses structure as a framework. Starting from within relates to the architect’s beginning of the design process. It has the advantage of describing ambiences in their essence, effects on human nature, after which it proposes a physical context that creates them. Structure remains the giver of light, but the essence of the classification should originate from lighting ambiences.

The study of precedent classifications allows a discussion on the emergence of a new classification of light. The following section explores the state of existing theories of light and seeks the importance of the definition of an order within the actual architectural technological context.
Light is an impalpable matter that brings spaces and objects into life. Its perception generates an infinite number of complex emotions that reach the senses and inspire artists and architects as its variability emphasises the uniqueness of the present moment. The poetic and symbolic nature of light as art influences the entire apprehension of space in creating ambiances, bringing a sense of passion to architecture. Art and architecture exist because of light. Through the liberated gestural act of painting and drawing, the expressive representation directly transposes the emotions where light acts as the generator of a new hypothetical world. Kahn has developed an interesting theory where light becomes a tool of expression which force stems from the unmeasurable. He describes the Sanctuary of Art as a "sort of ambience of a man's expressiveness" [Kahn, 1969, p. 449] and believes that art is the highest form of expression because it is the least definable. A major source for the theory of Silence and Light is Kahn's reverence for the spiritual quality of light, which he believes is "the giver of all Presences". Architecture transposes the essence of art into the built project where light becomes a true actor as its variability provokes different moods and sensations in a single space. The interaction of light with people's sensibility is significant since it affects the perception of space. The definition of the variables affecting sensibility is however vague. Le Corbusier mentions that:

"Sensibility of feeling is a categorical imperative which nothing can resist. Sensibility (...) is precisely not a thing of the senses and it cannot be measured. It is something innate and violent; a goad, an "urge". In weaker terms we might call it intuition."

[Le Corbusier, 1924, pp. 33-34]

Intuition is an important component of art since it leads the architect into the design process and encourages a concentration on the act of pure creation. Le Corbusier [1924] also emphasises that intuition could be expressed by "the sum of acquired knowledge". This confirms the importance of
precedents and continuity in architecture. The source of acquired knowledge is at the centre of this research as it becomes the essence of the development of intuition.

Light is the essence of an emotive response to architecture which determines the appreciation of space and influences perception [Millet, 1992, p. 67]. Barragan states:

"I believe in an emotional architecture. It is very important for humankind that architecture should move by its beauty; if there are many equally valid technical solutions to a problem, the one which offers the user a message of beauty and emotion, that one is architecture."

[Luis Barragan, in Ambasz, 1976, p.8]

Aesthetically, light is a significant matter of space creation since it affects all other architectural components and contributes to the definition of ambience. Le Corbusier recognises the importance of emotive aspects of architecture when he asserts that "the emotions that architecture arouses spring from physical conditions which are inevitable, irrefutable and to-day forgotten" [1923, p. 26]. Although the simulation of light is nowadays more common and accessible to the profession, architects tend to disregard their intuitive relation with light as a creative matter. New technological developments and the control of electric light by engineering have probably worsened the situation. Architectural criticism is also responsible when it ignores the role of light as architectural form [Zevi, 1991]. The lack of a theoretical basis for judgement contributes to the present ignorance of light as a generator of space.

Despite its immaterial and intangible nature, light is inseparable from the notion of architecture. It determines the spatial character and the relation with the elements that compose space. It plays a significant role in the utilitarian as well as aesthetic qualities of the designed environment. Light is a form giver for architecture but it is also an architectural form transformed by space. The duality of these functions is perhaps paradoxical, but it defines the intangible nature of light and emphasises its poetic connotation. Architecture can provide an aesthetic response, create an atmosphere and generate emotions with the utilisation of light as one of its fundamental elements [De Bruyne, 1993]. In this sense, architects have always perceived the importance of light for its aesthetic quality and the expressive character of interior space.

In architecture, qualitative and quantitative attributes of light should jointly define the ambience of space from the early design stages. It however appears that the technological dimension of light has become more developed than its qualitative attributes, creating and emphasising the dichotomy between art and science. Technology has modified our relation to light and created the necessity to reconquer and incorporate the lost intuitive aspects, the unmeasurable. There have been some attempts to define light in terms of ambience and atmosphere, but there exists a greater amount of research on the physiological aspect of vision, perception [Bloomer, 1990; Gregory,
and emotive aspects [Flynn, 1977]. The subjectivity associated with the human response to light contributes to limit its exploration. Robbins [1986, p. 18] mentions that the terminology to describe the human sensations associated with light cannot be assessed in absolute or objective conditions. He adds that understanding the distinction between the objective or measurable and the unmeasurable is critical to the development of a full appreciation of daylight. Quantitatively, the design of space for sharpness of vision involves the knowledge of amounts of light whilst the design of space for appearance or atmosphere essentially concerns brightness and colour [Hopkinson & Kay, 1969, p. 42]. The identification of specific qualities of light does not provide an accurate analysis since it omits the complexity involved in the overall perception, including other senses than the visual aspect. An analysis of qualitative aspects of light through scientific studies on groups of individuals could establish a tendency towards certain perceptual aspects of light. There is much discussion about the scientific validity of the interpretation of the results of such methods [Boyce, 1981, p. 259]. Light as architectural form has to globally integrate the scientific and artistic knowledge to articulate its concept through space [Lam, 1986], and continue to develop according to new technologies.

Some classifications of light related to qualitative aspects have been established by architects and artists. These classifications have no conventional scientific basis and the variables often associate with emotive factors, but they nonetheless illustrate some variables of interest to architects. Light is intemporal, perceptual, emotive, mostly relating to some alternatives of the physical environment. These qualitative aspects are found in the architects' recurrent explorations of atmospheres that transcend space from emotions. The investigation of the theoretical common basis between Ciriani’s classification of light [1991] and related classifications of atmospheres by Von Meiss [1990], Hogarth [1981], and others, combined with the literature where descriptions of moods and atmospheres are performed with precision, especially where physical and perceptual aspects are compared, allows the creation of a basis upon which the definition of types becomes possible. Moods and ambiances may thus be discussed throughout the interpretation of quantitative aspects of light such as the lighting pattern.

The qualification of light involves complexity because of the changing nature of light, creating varying lighting patterns, and ambiances. A space may indeed generate different spatial impressions throughout the day, as sky conditions vary. The typology of lights does not guarantee that specific ambiances will necessarily occur, but it can predict that some characteristics of light are likely to induce ambiances. The complexity of defining specific types of light is illustrated in Rasmussen’s description of the Pantheon [1959] (figure 1.4):

“As you enter the rotunda you are immediately aware of a mild light coming from a source high above you, three times as high as the ceiling of the peristyle. (...) The circular opening at the summit of the dome forms the only connection with the outside world- not the with the noisy, casual world of the streets but with a greater hemisphere, the celestial sky above it. When the sun does not enter in a slanting...
cylinder of rays, the lights is finely diffused because it comes from such a great height. But it all falls in the same direction, coming from a single source and producing real shadows. The floor, beautifully paved in a pattern of squares and circles of marble, receives most of the light and enough is reflected to brighten even the darkest spots so that there are no really black shadows anywhere. The wall recesses and tabernacles, with their Corinthian columns and cornices, receive enough light to bring out the architectonic forms in full plasticity. (...) The Pantheon's magnificent rotunda has often been copied in other dimensions. But this disturbsthe entire balance of the room, especially if the size of the light opening is also changed or if extra openings are added in the walls.” [Rasmussen, 1959, pp. 192, 193-194]

In this intuitive decomposition of light in physical events, Rasmussen states the importance of the morphological aspect related to the geometrical relation between aperture and space. He mentions that other dimensions of the oculus in relation with the space do not create the same atmosphere. In reality, even subtle changes may affect the entire balance of light in space. This description of the rotunda illustrates that many types of light may associate with a single space for different sky conditions. Even the night and day conditions affect the atmosphere of space where at night, the exterior is dark and artificial light reveals the interior of the dome, which is the opposite condition found during the day [Zevi, 1991].

This example highlights the importance of the morphological and geometrical properties of the aperture in establishing the mood and perception of space. It also illustrates the possible use of variables such as contrast and concentration to describe and identify a particular space and light relationship.

The comparison of Ciriani's approach [1991] with other classifications enables the definition of physical properties that relate to the identified specific atmospheres created by light. Ciriani's descriptions of light are particularly explicit, providing useful qualitative descriptions for the interpretation of images. Ciriani affirms that a confusion of appreciation appears as a source of the great cultural mistrust towards the modern movement in architecture. It stems from an incapacity of denominating and therefore affects knowledge. Since it is always easier to comment upon the result than to explain its sequence, Ciriani recognises the importance of denominating to avoid repetitions. In his early search, his preoccupation was to recognise the essence of space.
throughout the role of opacity and transparency. In architecture, light fixes opacity as it moulds, transforms and petrifies matter. Matter also modifies light depending on its physical attributes. Ciriani establishes the basis of a typology of lights with the recognition of the capacity of light to fix objects that would otherwise have no architectural materiality. His classification is not scientific nor systematic, but it reflects a sense of order issued from architectural experience and intuition. It gives prominence to the need for a more global and systematic classification and provides visualisation, an essential aspect of architectural design. From Ciriani’s writings, four types of light can be identified and outlined in figure 1.8: *Light-emotion*, *Lighting-lighting*, *Radiant light* and *Pictorial light*. These types are below summarised from Ciriani’s writings [1991].

*Light-emotion or feeling light* is at the origin of ambiances. It works with opacities and materialises them. It also defines a material light, as in the example of the sun light on a wall (figure 1.5). It designates the architectural objects that it puts forward, and designates itself as an architectural objective. It corresponds to a concentration towards the interior, and it also induces attention since the more its presence is felt, the more it excludes the exterior. It describes a stage-setting of nature in an interior representation of the exterior in the sense that the sun brings life to space. Queenly and easy to apprehend, it is the light of the cryptic space, the museum and the church as it stands for God.

*Lighting-light*, also called *hygiene light* originates from industrialisation, and is therefore a product of technology. It is a calculated light that associates with specific functions of space and relates to horizontal working planes (figure 1.6). It comes from the North and represents a state of balance between interior and exterior, a tendency to find the same light conditions inside as outside. Lighting-light produces the illusion
that the inside is still the outside, creating the exterior conditions in vitro and suppressing the difference between interior and exterior. It possesses as much strength as feeling-light, but it cannot be perceived and delimited because light is everywhere, which conditions an impression of discretion. Lighting-light originates from the disappearance of the opaque frame, as architecture began to liberate itself from light constraints. It is interesting that Ciriani includes this utilitarian light in the typology since some proponents of light as an aesthetic form tend to forget this reality.

Radiant light is an interpretation of Lumière radieuse which corresponds to the arrival of the modernist thinking and abstraction of space. The interior is filled with more light than necessary, even more than there is outside. White justifies the radiation of light, generating optimum internal intensity (figure 1.7). The interior weakens the strength of the exterior for its own benefit, provoking emotive reactions. The interior appears to advance towards the exterior, shedding light like the sun. Radiant light also modifies space by dilatation and fluidity.

Pictorial light propels abstraction to higher levels as light transforms the natural sense of equilibrium with colour and perspective, originating from the desire to transpose a bidimensional painting into a tridimensional space. Painting refers to an abstraction, a place of transmutation which enables the liberation of the conditions of reality. In pictorial light, space is not necessarily resulting from its envelope but tend to envelop the observer, creating a disorientation and a liberation from gravity. As in a painting, it becomes possible to conceive the totality of an architectural work by the recollection of images. In the same way that painting transforms the wall, pictorial light has the capacity to transform matter, to liberate it from its material conditions. Pictorial light and the composition of space from images, described in chapter 4, have some analogies. It is at the centre of the research on images and light, where an abstraction of space influences the creative intuition.
<table>
<thead>
<tr>
<th>CATEGORIES OF LIGHT</th>
<th>CHARACTERISTICS</th>
<th>REPRESENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light emotion</td>
<td>It acts on opacities without which it would not exist, excluding the exterior. Theatrical.</td>
<td><img src="image1.png" alt="Image" /></td>
</tr>
<tr>
<td>Lighting-light</td>
<td>Uniform light often found from the North. It suppresses the difference between interior and exterior.</td>
<td><img src="image2.png" alt="Image" /></td>
</tr>
<tr>
<td>Radiant light</td>
<td>There is more light than necessary. Experience of the brightness on surfaces.</td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
</tbody>
</table>
| Pictorial Light     | "To be pictorial is to imagine what it is to be in a painting. (...) Pictorial light has the capacity to transform matter, to free it from its materialistic conditions." | ![Image](image4.png) 

Ciriani, 1991

Figure 1.8: Interpretation of Ciriani’s categories of lights.

Von Meiss [1990, pp. 121-124] describes four types of light that represent typical conditions of illumination at the basis of numerous possible combinations. His classification relates to Arnheim’s theory [1974] of the attribution of light sources to lit objects. He therefore considers architecture as the art of placing and controlling light sources in space. This approach differs from Ciriani’s classification since it relies almost entirely on the morphological aspects represented into four conditions of space related to source: light-space, light as an object, light from a series of objects...
and light from surfaces (figure 1.9). The classification does not establish the usual technical distinctions between the actual light source and the reflected light from the illuminated object or surface. This integration of the phenomena of source and reflector is essential for spatial composition by means of light.

<table>
<thead>
<tr>
<th>CATEGORIES OF LIGHT</th>
<th>CHARACTERISTICS</th>
<th>REPRESENTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light Space</td>
<td>Perceptible limits of light in space. Light is strong, indicating high contrast.</td>
<td></td>
</tr>
<tr>
<td>Light as Object</td>
<td>Light becomes a spotlight in a dark space, a candle in a room. It is a radiating light.</td>
<td></td>
</tr>
<tr>
<td>Light from a Series Of Objects</td>
<td>Light originates from a series of sources.</td>
<td></td>
</tr>
<tr>
<td>Light from Surfaces</td>
<td>It is the light of the open wall. The surfaces of space can also become sources of light.</td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.9: Interpretation of Von Meiss' categories of lights.
Hogarth's studies of light from pictorial representations [1981] establish an empirical classification. In works of art as in architectural perception, light is essential to represent the fundamental qualities that create a specific atmosphere or ambience (figures 1.10 and 1.11). Hogarth's order initially differentiates the types of sources that affect modelling (figure 1.12), suggesting five categories of light that correspond to types of shade. They tend to define almost all the light conditions that painters are likely to draw or paint. Hogarth's approach is very interesting since it works with images and compares with Ciriani's pictorial light.

<table>
<thead>
<tr>
<th>TYPE OF LIGHT</th>
<th>PHYSICAL PROPERTY</th>
<th>QUALITY</th>
</tr>
</thead>
<tbody>
<tr>
<td>(direct light)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Double Source Light</td>
<td></td>
<td>Combination of a strong source and a softer source.</td>
</tr>
<tr>
<td>(Overcast days)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sculptural Light</td>
<td>Combination of sources of different brightnesses.</td>
<td>Tactile because the designer voluntarily reveals forms and textures.</td>
</tr>
<tr>
<td>(An invented light)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.12: Hogarth's differentiation of lights.

Hogarth's classification also relates to photographic theories, which correspond to the methodological approach of this thesis in the visualisation of lighting effects with images. Hogarth defines other categories among which some are more relevant to architecture (figure 1.13). The
choice of variables is less systematic in these sub-categories because the descriptions include emotive aspects.

<table>
<thead>
<tr>
<th>TYPE OF LIGHT</th>
<th>PHYSICAL PROPERTY</th>
<th>QUALITY</th>
<th>EXAMPLE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Textural Light</td>
<td>Transmission of light by transparent objects and surfaces. Tend to absorb or diffuse light.</td>
<td>Reveals the surface quality. Suggests direct physical contact, as though the eye were a tactile organ.</td>
<td>Glass, water</td>
</tr>
<tr>
<td>Transparent Light</td>
<td>Instantaneous effect of reflected light that suggests disrupted or dispersed form.</td>
<td>Suggests motion, immediate, passing and tumultuous.</td>
<td>Splash of water</td>
</tr>
<tr>
<td>Fragmentation Light</td>
<td>Intensive source, more powerful than direct, single-source light. Excessive brightness. Can be of low or high intensity.</td>
<td>May cause glare. Viewer is dazzled and discomfited. Effects best seen against a dark background.</td>
<td>Rain, Sun, candlelight</td>
</tr>
<tr>
<td>Radiant Light</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expressive Light</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 1.13: Hogarth’s subcategories of lights.

Relations between the previous classifications of Ciriani, Von Meiss, and Hogarth, can be established. Figure 1.14 shows that the nature of light, whether direct or diffuse, is a common basis for all classifications. Von Meiss and Hogarth suggest the definition of sources. Radiant light is also a category identified in all classifications, perhaps because such light catches the eye and arouses deep inner feelings [Lam, 1986]. Hogarth’s fragmented and expressive types of light could correspond to all categories, which also appears with Ciriani’s pictorial light.

<table>
<thead>
<tr>
<th>PROPOSED CLASSIFICATION</th>
<th>CIRIANI</th>
<th>VON MEISS</th>
<th>HOGARTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct Light</td>
<td>Light Emotion</td>
<td>Light Space</td>
<td>Single Source Light</td>
</tr>
<tr>
<td></td>
<td>Moving Light</td>
<td></td>
<td>Textural Light</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Double Source Light</td>
</tr>
<tr>
<td>Diffuse Light</td>
<td>Lighting-Light</td>
<td>Light from Surfaces</td>
<td>Flat Diffused Light</td>
</tr>
<tr>
<td></td>
<td>Light as A Function</td>
<td>Light from a Series of Objects</td>
<td>Sculptural Light</td>
</tr>
<tr>
<td></td>
<td>Hygiene Light</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiant Light</td>
<td>Radiant Light</td>
<td>Light as Object</td>
<td>Radiant Light</td>
</tr>
<tr>
<td></td>
<td>Lumière Radieuse</td>
<td></td>
<td>Transparent Light</td>
</tr>
</tbody>
</table>

Figure 1.14: Proposed classification of lights.
Figure 1.14 therefore identifies two main categories of light that refer to the types of sources: direct and diffuse light. In photography, the main categories of light sources are also based on direct and diffuse illumination [Petzold, 1971, p.17]:

- Direct light reaches the subject from one direction, generally originating from a relatively small theoretical point source.

- Diffuse light reaches the subject through a diffusing surface or screen, which makes effectively the source much larger. It is the basic light of traditional portraiture.

The proposed classification (figure 1.14) will be discussed in chapter 3, in comparison with perceptual and physical aspects issued from the scientific approach.

Light as Science:
The measurable

Technology has considerably modified our relation to light, often inhibiting and diverting the role of light as architectural form in the new complexity of building [Zevi, 1991]. It has also enabled architects to explore new typologies of space and light as building science has allowed new assembling techniques and structures. In history of architecture, it has progressively led to greater levels of transparency [Mark, 1990]. Light as matter¹ remains unchanged but its use through space is evolving with technology. The notion of the pierced wall diminishes and the space opens out, allowing more light in architecture. Reinforced concrete, steel and glass have contributed to the extension of the architectural vocabulary by the elimination of the dependence of apertures upon structure, where the spatial limit no longer necessarily corresponds to the load-bearing structure. Constructive aspects have expanded the limits of transparency, and opacity is therefore not essential for structural support. The liberation of the space and façade offers the possibility of a new dynamic [Von Meiss, 1990, pp. 108-109] which is also responsible for

¹ Light as matter is described as material light, and is explored throughout the third chapter.
the new complexity involved in the design with light as there are fewer constructive limits. This technological era allows the possibility to extend the range of design solutions that were available in the past and to rediscover light as a constructive matter of space. Where most recent studies discuss light as science in an exclusively quantitative manner [IES, CIBSE, CIE], very little research relates to the aesthetic expression of light, apart from Bell [1988] and Frandsen [1990], to name the most challenging ones. Le Corbusier [1923] mentions that construction has undergone innovations so great that the "old styles" become unsuitable. He argues that these constructional methods have created a state where architects are no longer able to "close their minds to the true and profound laws of architecture which are established on mass, rhythm and proportion" [Le Corbusier, 1923]. Nowadays, architectural creation is linked with the necessity to reinvent forms, morphologies and hence, lights, to make the most of new technological knowledge [Gaudin in Robert, 1991, p. 94]. The need to initiate a theory of light as architectural form is therefore a necessity as architects are already creating their own classifications to demystify the nature of light as art [Ciriani, 1991]. The need to explore and rediscover light as architectural form in a more systematic manner is eminent since most recent researches concentrate on the technical aspects of task lighting and the horizontal working plane [Moore, 1985]. This implies the promotion of an integration of the intuitive and empirical knowledge of Masters of Architecture to the present context.

Since 1936, the Illuminating Engineering Society (IES) of North America has produced a series of codes for lighting the interiors [Waldram, 1969] that summarise the results in the field of lighting research on building applications. An important part of the work consists of a tabulation of currently recommended illuminance categories and illuminance values for different types of spaces and activities, presented in three important categories of light:

- general lighting throughout spaces
- illuminance on task (figure 1.15)
- illuminance on task obtained by a combination of general and local lighting

The IES generally recommends a higher illuminance level where tasks of acute visual capabilities are performed. In many cases, the tables are useful for establishing the lighting levels related to task lighting, assuming a proper lighting design that emphasises the visual characteristics related to the task. The IES recommendations do not provide any information about the utilisation of certain types of lighting systems, nor on the visual qualities of space. The Daylighting Network of North America (DNNA) also produces numerous publications on the vulgarisation of scientific researches and transposes them into tables and graphs that are easier to use than the more precise and complicated original works. Similarly, there is no visualisation nor aesthetical considerations about
light. Research on the scientific aspects of light has produced design tools relating to the initial design stages. They respond to the need to facilitate the integration into architectural practice and provide more information on the visualisation of light. They are mostly popularisers of the science of light since they are limited to functional light and therefore focus on the horizontal working surface. There are presently two types of prediction techniques for a quantitative evaluation of light: the experimental method using scale model photometry, and the theoretical approach using calculations [Spitzglas et al., 1985]. Scale models are based upon an analogue simulation including physical models and photometric measurements, which approach is considered as a traditional method throughout the history of modern lighting design. Calculation methods are mathematical simulations based on the physics of photometry, and have been performed for many years, predating the invention of electric light. In their latest form such as computer codes, these methods are evolving rapidly. The two approaches compete in accuracy and convenience of application, leaving potential users undecided about which method they should use.

Even though computerised methods can analyse extremely complex situations with greater efforts, experimental tools still have the important advantage of being part of the common architectural practice by the act of designing with physical models [Scartezzini et al., 1994, p. 2]. An advantage of the physical model is the involvement of a qualitative dimension [Spitzglas et al., 1985, p. 41]: subjective appraisals are possible and provide an accurate representation of the future construction [Hopkinson et al., 1966, p. 379]. Also, physical modelling has the theoretical potential to respond to any design problem and is only limited by the precision of the model and the measuring tools. Moreover, the physics of illumination shows that light behaves identically at different scales of space [Schiler, 1987, p. 13; Lam, 1986, p. 189]. The reduction factor absent, photometric measurements in proportionally identical spaces are also identical. Lau [1972] mentions however that any tool of representation may lead to a reduction of information in the sense that the information becomes more abstract than in the full size real space (chapter 2, figure 2.1).

Calculations of scalar and vector illumination are nowadays applied to computer programming to create software for light modelling [Holmes, 1975]. Computer-based daylight tools provide precision data but in an obscure numerical format which hinders the communication and perception of the contained information, or in static but compelling rendered images that hide the dynamic qualities of light [Haglung et. al., 1991]. Computerised calculation methods offer mathematical precision but they are practically limited to simple design solutions since their utilisation demands great amounts of time and labour [Millet in Schiler, 1987, pp. 13-14]. Superlite is an example of advanced program which was developed by the Lawrence Berkeley Laboratory. It has a capacity to analyse with precision the geometry of complex spaces. The introduction of data into the computer is intended to be performed by experienced users and involves much time, discouraging many
practitioners [Haglung et al., 1991]. It therefore mainly constitutes a tool of refinement for an almost fully developed concept where only minimal changes are expected. Ward [in LaMacchia, 1992, p. 20] states that *Radiance*, the program he created, provides the qualitative aspect of light that renders scenes with millions or even billions of surfaces producing numerically accurate results, with a percentage of error within 1%. In spite of the recognition this tool has received, researchers are not satisfied with the effectiveness of accessibility in the early design stage. The user of a software such as *Radiance* still needs an excellent knowledge of the program to obtain accurate performance [Schiler et al., 1991]. The data processing is so slow that the integration within the design process is arduous, even with the production of low quality images that involve a shorter generation time [Everett, 1994]. ARUP Research & Development, based in London, is developing a similar approach of computerised simulation called the Lighting Visualisation Simulation program (LVS) where similar disadvantages arise on the user interface [Venning & Blackmore, 1992]. Calculation methods are therefore mostly employed by consultants involved in later design stages. Researchers are presently working on calculation methods for architects involved in the earlier design stages to enable a better visualisation of the project and afford sensible critical decisions [LaMacchia, 1992, p. 21].

Many tools and techniques are already available for a scientific integration of light in architecture but their impact on the built environment remains negligible [Schuman & Selkowitz, 1989]. Some applications have even failed to meet design goals because of the misunderstanding of lighting design as a multidisciplinary activity. There are presently no simple techniques available for assessing the quality of light, and most existing tools are solely involved with quantitative aspects [Schuman & Selkowitz, 1989]. Moreover, those tools are not much used by architects because of the greater impact they have on the final assessment of a solution and because of the very little contribution they produce on early design stages. Unfortunately, they are also more frequently used as representation tools than as design aids. Some of the limitations of these tools are [Schuman & Selkowitz, 1989]:

- The lack of integration into the overall design process: Because of the inadequacy to integrate the early design stages, the tools become too specialised to offer opportunities of exploring new design strategies.

- Time consumption: The tool that requires special knowledge, much time, and skill for inputting and manipulating the information to analyse a problem is seldom ideal. The procedure of utilisation needs to be simple and easily accessible for an optimal integration into the architectural practice.

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*Radiance has been developed by the Windows and Daylighting Group of the LBL and is presently widely distributed.*
• Non-architectural format: Current computer-based tools are conceived for quantifiable data, implying that very little reference applies to aesthetic design criteria. Tables and graphs are not commonly employed by designers and architects in the evaluation of building design decisions. The visual nature of architectural design needs to be recognised, which should lead to a more extensive use of images as design tools.

There should however exist a solution that would take advantage of light as an Art and a Science to produce a design method that would correspond to early design stages. The following section explores the potential to reach Kahn's notion of the Sanctuary of Art, which consists in the balance between Art and Science.

Light as Art and Science

"I only wish that the first really worthwhile discovery of science would be that it recognises that the unmeasurable [you see] is what they're really fighting to understand, and that the measurable is only a servant of the unmeasurable; that everything that man makes must be fundamentally unmeasurable."

[Louis I. Kahn, 1969]

Youngblood [1970] mentions that artists have traditionally looked upon science as being more important to mankind than art, whereas scientists have believed the reverse. He adds that in the confluence of art and science, the art world is understandably delighted to find itself suddenly in the company of science. For the first time, the artist is able to deal directly with fundamental scientific concepts of the twentieth century, allowing to enter the world of the scientist and examine the laws that describe physical reality [Youngblood, 1970, p. 192]. It therefore appears essential that artists and architects have a correct understanding of those fundamental scientific concepts, and that their application to art becomes effortless.
Kahn [1969] states that “the highest form of expression is art because it’s the least definable”. Art emerges from deep emotions and inner feelings. In Kahn’s view, architecture becomes art when it achieves a balance between silence and light, between the desire and the means of expression, between the measurable and the unmeasurable (figure 1.17). The creation of space that acknowledges the significance of the qualitative aspects of light can lead to Kahn's “Sanctuary of art”.

“I turn to light, the giver of all Presences; by will; by law. You can say the light, the giver of all presences, is the maker of a material, and the material was made to cast a shadow, and the shadow belongs to the light. (…) everything here stems from the unmeasurable. Everything here promises the measurable. Is there a threshold where they meet? Can a threshold be thin enough to be called a threshold in the light of these forces; these phenomena? Everything you make is already too thick. I would even think that a thought is also too thick. But one can say, light to silence, silence to light, has to be a kind of ambient threshold and when this is realised, sensed, there is Inspiration.”

[Louis I. Kahn, 1969]

Kahn does not believe in an identifiable threshold between the measurable and the unmeasurable, but suggests an ambient threshold that leads to Inspiration (figure 1.18). The definition of the qualitative aspects should therefore not obscure the quantitative attributes. This implies the existence of associations between measurable and unmeasurable aspects of light. Kahn often cites the contrasting example of the poet and the scientist to illustrate the different manners of using inspiration. He explains that the poet, comfortable in the realm of feeling and intuition,
lengthily follows an urge to express before finding the means of expression that would transpose his images into concrete words. The scientist, in his rational world, remains for a long time in the realm of light, collecting facts and figures to prove his hypothesis before acknowledging its connection with wonder and mystery. Kahn emphasises that everyone has this balance of the measurable and the unmeasurable, and that it is virtually impossible to identify its threshold. Architecture should consist in the research between Silence and Light to reach Kahn's notion of the *Sanctuary of Art*.

Unfortunately, the tendency to enquire about the measurable is much greater than the research on the unmeasurable. Lynes [1968, p. 138] mentions that “we must beware lest an infatuation with photometric or mathematical techniques should tempt us to concentrate overmuch on daylight factors merely because we can calculate and measure them.” The measurable provides defensible arguments whereas the unmeasurable is arguable. Many lighting researchers are interested in qualitative aspects of light, but the difficulty to assert and verify some hypothesis diminishes their impact on the scientific community. Some aspects of light are measurable and quantifiable, but others are not. Lynes [1968] emphasises that there is no reason that supports the possibility to physically measure the magnitudes that the eye perceives. Similar difficulties occur for instance in the study of taste, warmth, and noise. Generally, the optimal achievements consist in the tentative construction of scales of measurement according to certain experimental ranges of circumstances. These may prove to be valid, referring to the range within which arithmetical operations such as addition, multiplication or integration to the numbers derived would generate consistent predictions with the actual perception of space. Research on perception may enable an understanding of some of the properties of light [Lam, 1977] but on the aesthetic aspects related to visual appearance, there are very few developments because of the involved subjectivity [Flynn et al., 1992].

"In modern spatiality, the frame is no longer the necessity. The main problem has become the placing of the first opacity. The vital difference of this new condition thus depends on light, whose role is to fix opacity. (...) Once recognised the capability of light of fixing objects that would have otherwise no materiality, it becomes possible to differentiate lights."  

[Ciriani, 1990]

Ciriani mentions that the problem of modern architecture consists in the definition of the initial design motivation to determine proper opacities. There is a fundamental need to redefine the function of the wall as a physical limit that varies in transparency. The control of opacity should concern the actual search for architectural form, reintroducing the need for shadows that highlight the presence of light in space. The research for a balance between opacity and transparency, so fundamental to light, could be initiated by the establishment of an order of its expressive utilisation in architecture. The quest for natural light originates from a profound love of the natural
environment, a desire for change and variety during the day and a search for spatial unity [Philips, 1964, p. 7]. Kahn [1969] believes that "natural light is the only light that makes architecture architecture". Contemporary architecture, often conceived with little concern for natural light, depends almost entirely on artificial light that negates the shifting effects occurring throughout the day. Spaces that ignore the essential role of natural light as a major source of illumination are not suitable for human activities [Alexander, 1977, p. 525].

Architecture should integrate all aspects of light, including the unmeasurable. Much technical information and data are available, but the architect's experience, awareness, and sensitivity of the whole environment enhances and refines the results throughout the design [Hopkinson & Kay, 1969, p. 19]. There is therefore a subjective factor involved in the integration of light to architecture. Prescriptive directions are then inappropriate. The complexity of the human environment does not allow any subdivision into independent components since the ultimate motivation consists in the creation of a harmonious whole [IES Daylighting Committee, 1979]. Intuition and subjectivity acquire more importance in the design process with the diminution of spatial specificity. There is hence a need to facilitate the design in that regard. The development of a methodological approach to lighting design seems appropriate to achieve that objective. Such approach should not be prescriptive but favours the creation of a design context that increases the balance of Le Corbusier's "achieved knowledge through experience" [1924, pp. 33-34]. Le Corbusier would also emphasise that the approach could then increase the intuitive power of the user of such tool.

The great amount of research in the field of perception of light and space has enabled a better knowledge of the mechanisms of vision, which aspects relate to the qualitative analysis of light. The development of a classified source of basic knowledge and the elaboration of design tools in the field of light as architectural form is however very limited compared to the development of functional lighting. The facility to quantify physical variables of light has probably contributed to the neglect of its qualitative aspects. As a result, most researches consist in the analysis of the physical properties of light involving variables related to vision, and the absence of design criteria confine them to specific functions of space. The application of the results is generally a concern for specialists or engineers, as the decisional process often implies a scientific background. Moreover, there is a considerable lapse of time involved before the obtainment of the results. The major problem however deals with the establishment of the quantitative variables in a space devoid of any specific function. It causes a dilemma in most methods of analysis since no precise answer is attached to the initial problem. The following researches are particularly relevant since they tend to encompass qualitative as well as physical aspects of light. Other researches are also mentioned because of their important impact on the present thesis.
Waldram [1969] states that "it is the eyes and not the photometers, that lighting must satisfy". Early daylight investigators used the photometer to make relative measurements instead of absolute measurements because of the variability of daylight, which led to the elaboration of the daylight factor [Hopkinson, 1966] to obtain fairly stable values as daylight varies. These new values were found to correspond more accurately to the perceived values rather than the single values obtained with the photometer. The daylight factor does however not really provide qualitative assessments of light in space, but constitutes a basis of comparison that involves an understanding of light as a pattern instead of numerical values. The glare index, later developed by Hopkinson [1950], provides a quantitative assessment of a subjective phenomena such as brightness. But even after its acceptance amongst scientists, Hopkinson believes that the glare index does not always predict correct assumptions about glare. He states that according to the glare index, a beach under a bright sun would for instance become a visually unbearable experience, whereas most people can cope with that situation.

The Designed Appearance method, created by Waldram [1954] to bridge the gap between the art and the science of light, emerges from the concept of the final appearance of the lighted interior arising in the designer's judgement and aesthetic sense (figures 1.19 and 1.20). It begins with the architect's idea of the visual appearance of light and shade in the form of a sketch or a perspective of an interior space. Apparent brightness values are associated with the most critical surfaces of space. The brightness data and inter reflectance calculations can then be applied to determine the illumination that must be provided for each surface to achieve the desired brightness pattern. The methodology is most valuable, and because of its advantage to save time in eliminating full scale simulations, it becomes economical in operation. The major problem however remains the
visualisation of the interior space in terms of light and shade and the time involved to make the necessary calculations [Philips, 1964, pp. 295-299].

Most conventional lighting research deals with the working plane. In their paper entitled "Beyond the working plane", Cuttle, Lynes, and others [1967] introduce the idea of scalar illumination to provide a criterion of the subjective adequacy of the illumination in an interior space at the eye level [Lynes et. al., 1966]. These researchers had recognised the occasionally misleading utilisation of horizontal illumination as it tends to exaggerate the effectiveness of overhead lighting and conceals the important effect of light-coloured floors or working surfaces on the overall impression created by interior light [Lynes, 1968, p. 47]. The concept of the flow of light [Lynes et al. 1966] describes subjective assessments of the strength and direction of lighting either at a specific point or within an entire light field (figure 1.21). The illumination vector indicates the directional qualities of light, and the ratio of vector to scalar illumination may serve as an index of modelling. The advantage of this approach is that it recognises the third dimension of light instead of concentrating exclusively on the horizontal working plane. A number of proposed measures of the distribution of light in predicting visual effects were evaluated on the appearance of three-dimensional objects. Observers were asked to associate the appearance of a model interior under different forms of lighting to that of a similar model under fixed lighting. The relationship between various measures, namely the horizontal illuminance, the mean spherical illuminance and the mean cylindrical illuminance were measured. The most consistent relationship was the mean spherical illuminance and considered as the best predictor. These experiments are widely known in the field of lighting studies and criticism can be made on this type of experiment. The interesting aspect of the research is the relationship between subjective judgement and physical descriptors of light. Similar approaches have later been undertaken by Flynn [1977]. The research provides a nomograph of the subjective impressions of the modelling of the human
features, expressed with vector directions and vector/scalar ratios, and a histogram of preferences for vector directions [Lynes, 1968, p. 49]. The problem of applying the method remains its lack of visualisation of the effects.

Following the concept of scalar illumination, Cuttle [1971] develops the idea of the lighting pattern, emphasising on the relation between the quantitative and qualitative aspects of light according to visual rendition (figure 1.22). This is particularly useful in the elaboration of a lighting concept with different sources that enhance the particular qualities of space and objects. It introduces the notion of three main lighting patterns: the illumination, the highlight and the shadow patterns. It is interesting in providing information on the plasticity of light relating to the visual appeal on objects, and on the manner in which objects are affected and transformed by light, referring to notions of aesthetics. The main disadvantages of the approach relate to the need for elaborate calculations and the lack of support to enable the visual representation of the lighting effects.

The morphology of space related to a system of apertures may create specific lighting effects. The configuration of light is based upon the geometric relationships between space and the various sizes, shapes and locations of apertures [Robbins, 1986, p. 63] (figure 1.23; chapter 2, figures 2.15 and 2.16). By extension, lighting patterns, known as isolux contours, can express the morphology of light. The understanding of the morphology of light according to apertures and space allows the designer to manipulate light with more ability and encourage greater explorations of different alternatives of penetration, distribution, quantity and quality of light [Egan, 1983]. In the development of a lighting concept, it is essential to establish the geometrical relationships between space and apertures before the evaluation of the effects of the different
The notion of space and aperture morphology is therefore fundamental to lighting theory, which needs to be ordered in an accessible format for designers. Lam [1986] and Robbins [1986] have elaborated typologies of apertures in relation to lighting effects on the working plane. These typologies demonstrate the influence of various design variables related to apertures and their effect on the overall intensity of light on a horizontal surface, at the height of the working plane. They introduce graphs that indicate relationships between variables, which formulate a vocabulary of different types of light related to defined variables of apertures. The morphological vocabulary is simple, but the only possible visualisation of the lighting effects arise from graphs since the aim of the classification is purely functional, relating to desired levels of illumination on a working surface. Vertical surfaces are therefore not included in the typologies, nor the overall atmosphere created by such systems. These researches are also limited to the quantity of light, rather than to its visual quality.

A simplified method using isolux lighting patterns allows a preliminary evaluation of alternative designs [Millet & Bedrick, 1980]. The proposed technique is based on lighting patterns from selected single apertures projected on the working plane (figure 1.24). The plots or patterns are catalogued according to the shape and location of the aperture on the reference working plane. Although the research is meant for an analysis of light on horizontal surfaces, the principle is pertinent in its desire to provide a simple and efficient graphic technique rather than numerical calculations for the formulation and evaluation of significant alternatives at the early design stages. This method of analysis enables the obtaining of lighting patterns, also referred as isolux curves, resulting in interactions with the user.

The main advantage of the method is that the process of utilisation instructs the designer in the rudiments of daylighting distribution resulting from size, shape and placement of apertures. Millet and Bedrick [1980] mention that this type of cause-and-effect procedure informs designers of basic principles that can then intuitively be applied in subsequent designs. The main disadvantages of the approach is that it only develops patterns for the overcast sky condition and the authors' acknowledged discomfort about the "black box" computational techniques. Also, the limited
number of types of apertures and the lack of visualisation of the lighting effects remain problematic. Unfortunately, no further developments of the method have been undertaken because of the complexity of dealing with more complicated situations.

Flynn [1977] states that the emotional component of light constitutes a more subjective matter but, to some extent, the lighting pattern enables reasonable predictions. His studies on perception were undertaken with specific groups of observers and concerned affective or evaluative response to stimuli that determine the environmental influence of light on people. He affirms that the information to establish the frame of expectation and relevance of interest is not contained within the lighting pattern, but it is possible to extrapolate sensations relating to brightness distribution. Flynn's research [1992] on impressions of activity setting and mood identifies the influence of some physical parameters in the generation of ambiences. Criticism can be asserted on the particular methods used to assess subjective aspects of light, but the correlation approach is recognised as most valid [Boyce, 1981]. The evaluation and quantification of the perceptual response to light is sometimes controversial since the observer, the principal element of analysis, may be influenced by previous experiences [Poulton, 1977]. Most criticisms relate to the lack of specific context of the conditions used and the unrepresentative nature of the observers [Boyce, 1981, pp. 258]. Another criticism involves the usual means of obtaining the subjective judgement through rating scales. Poulton [1977] asserts that an observer's use of rating scales is strongly affected by the range of conditions experienced, either in the experiment itself or, if no range is available, in everyday life. These criticisms show the apprehension often associated with researches that tend to associate physical and subjective variables that relate to vision and perception of light. They are highly controversial and architects rarely dispose of formal studies to assess impressions of light in space. Perhaps, in a sense, the architect's experience of space must allow some interpretation and a certain amount of subjectivity.

Light as Art and Light as Science are two complementary components of space that could become more effectively integrated to architecture with the development of proper design tools, ultimately leading to a theory of light and space. The actual knowledge within the field of lighting design is mainly based on quantitative considerations, ignoring the important role of qualitative aspects. Most researches related to both aspects however lack in the visualisation of the lighting effects. Also, they provide very little interaction with the architect and mitigate the importance of intuition within the design process. Some researchers believe in the need for typologies in the architectural design process and create classifications relating to light and interior space. There are, at the moment, only a few of these researches and they are still in an early stage of development. Some of the researches are discussed below.

Raphael Serra [in Baker et al., 1993] introduces a typology based on the elements composing and modifying the aperture (figure 1.25). It analyses different daylighting components and differentiate
two main groups: the conduction components and the pass through components. This classification does however not really inform the designer on the effect of the developed typologies of light. In some ways, it remains an enumeration of solutions with little answers. The typology mostly relates to the composition of the system of apertures but ignores the effects on interior daylighting. Graphically, the visual description of the typology is often difficult to interpret and is not meant to evaluate their visual effects in space.

The morphological box [Los in Baker et al., 1993] (figure 1.26) offers an interesting scheme for describing daylight in existing building, but does not constitute a typology in itself, since it fails to identify major types or categories. It is not a classification but rather a systematic description based on variables carefully chosen to define daylight at different architectural scales: the scale of the room, the scale of the entire building and the scale of urbanity.

The LUMEN interdisciplinary program [Golay, 1994] has developed typological studies of light and space through hypothetical and practical approaches. Calculations are obtained from the Radiance software of analysis. This team of architects and engineers propose an interesting visualisation document that constitute an informative tool for designers (figure 1.27). It takes the advantage of using the information obtained from the software without involving any computing from the designer. The only limit is the number of possibilities that may be
modelled, but the references chosen correspond to many general design applications. The hypothetical studies are particularly interesting because the simplicity of the modelled space constitutes typical design solutions and allows different contextual interpretations.

The typological researches of Serra [1993], Los [1993] and Golay [1994] relate to specific physical conditions of space and aperture to lighting systems and typical daylight distributions. Frandsen [1987] introduces his research as the first method relating the balance use of ambient vision and focal vision, providing a feeling of space versus an interest in objects. He proposes a categorisation of shadows in interior space according to the human scale, and defines the limit between ambient and focal vision. Frandsen uses the shadow to develop a scale of light (figure 1.28). Furthermore, he defines a scale of shadows according to geometrical relations existing between the source of light and the object (figure 1.29). This scale is defined by the angular relation between source and object. In that sense, it much relates to Lynes' research [1968] on scalar illumination as an index of quantity of light, except that Frandsen’s work emphasises a visual expression of the effect of lighting patterns. It uses the scale of shadows as a description of the luminance distribution on a sphere to derive the scale of light, indicative of the theoretical description of light and its degree of diffusion. The two extremes of the scale are dominated by parallel and diffuse light. In parallel light, shadows are very sharp and dense while in diffuse light, the lack of shadows corresponds to a lack of three dimensionality. Curves of the pattern represent the different steps on the scale of shadows and provide an indication of the morphology of light which should be interpreted as three dimensional patterns of light [Frandsen, 1990]. It becomes possible to trace a lighting pattern to understand the mechanisms affecting the visual quality of objects and space [Lynes, 1968, p. 49]. In the continuation of Frandsen’s research, a methodological approach was developed for the evaluation of contrast levels in interior space on vertical surfaces [Demers 1993]. The research introduces the notion of an index of contrast, calculated from the brightness of lighting patterns on
surfaces. The method enables architects to have a quantitative and qualitative assessment of the lighting effects they create. It also provides tangible knowledge of the morphological behaviour of light as an aesthetical form. A scale of contrast was established according to fundamental types of apertures. Groups of apertures that offer similar contrast levels constitute the basis of a classification of morphological and physical aspects of space and light.

The scientific approach involves a more technical discussion that nevertheless combines quantitative results with qualitative assessments relating to perception and brightness patterns. Flynn’s research [1992] on impressions of activity setting and atmospheres identifies the influence of some physical variables in the generation of ambiances (figure 1.30). It is part of the official literature of the Illuminating Engineering Society (IES) and therefore constitutes a well recognised basis. Flynn mentions that light is a medium that communicates spatial ideas and moods and has the potential of creating impressions such as sombreness, playfulness, pleasantness, and tension, among many qualities. Light influences psychological impressions such as intimacy, privacy and warmth. He suggests that these impressions should be recognised as more than aesthetics to constitute a tool for influencing human behaviour, performance, and productivity [1992, p. 18]. He recognises three brightness parameters affecting subjective impressions of observers:

- brightness uniformity (uniform to non uniform): uniformity is associated with minimal brightness variations over the entire space.
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- brightness uniformity (uniform to non uniform): uniformity is associated with minimal brightness variations over the entire space.

Figure 1.30: Light structure model: impressions of visual clarity [Flynn, 1992].
Light as Architectural Form

- brightness location (overhead to peripheral): location relates to the primary spatial zone at which the suggested “uniformity” and “intensity” should occur to elicit a given impression.

- brightness intensity (bright to dim): intensity is the relative level of brightness necessary to elicit a given impression.

Flynn indicates that the various combinations of these patterns may structure specific impressions of visual clarity, spaciousness, relaxation and privacy. The resulting light-structure models were developed to assist designers in the use of ambient light for various tasks and non-task applications. Flynn’s research is based on relative scales since no quantitative data have yet been estimated. They illustrate the interaction of the three brightness modes (uniformity, location, intensity) with the following subjective impressions:

- Visual clarity is determinant of the perceived distinctiveness of architecture, human features, and details. Clear qualifies the luminous environment that relates to the distinct visual perception of space and its content. Hazy signifies the impression of clouded or fuzzy visual perceptions.

- Spaciousness refers to the relative perceived dimension of a space and its surroundings. Large qualifies the luminous environment that relates to the impression of expanded spatial limits, the appearance of the increased volume. Small signifies the impression of confinement.

- Relaxation refers to the perceived intentions of human function. Tense qualifies the luminous environment that relates to impressions of fast-paced visual work. Relaxed signifies the impression of rather comfortably paced activities, including visual work.

- Privacy and intimacy refer to the perceived intentions of spatial use. Public qualifies the luminous environment that relates to impressions of extroverted and deliberate activity. Private signifies the impression of introverted and subdued activity. Expectation, visual order, and the appropriateness of the inherent hierarchy of foci in the luminous environment influence the affective evaluation of intimacy and publicness [Lam, 1992, p. 54]. Intimate spaces are generally perceived as private, closely personal, or cosy, but not necessarily dark.
Towards a Classification of Lights

Subjective impressions generated by light in interior space can be divided in two related to human behaviour and emotional response: uniform and non uniform light [Flynn et al., 1992]. Uniformity and non uniformity of light refer to the types of sky, but the terminology can also suggest the combination of types of light and apertures. These categories also associate with the types of light previously identified in the creative approach (figure 1.32):

<table>
<thead>
<tr>
<th>TYPE OF SKY</th>
<th>TYPE OF LIGHT</th>
<th>APERTURE</th>
<th>BRIGHTNESS DISTRIBUTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>clear sky</td>
<td>direct</td>
<td>single/many</td>
<td>non uniform</td>
</tr>
<tr>
<td></td>
<td>diffuse</td>
<td>single</td>
<td>not applicable</td>
</tr>
<tr>
<td>overcast sky</td>
<td>diffuse light</td>
<td>many</td>
<td>uniform</td>
</tr>
</tbody>
</table>

Brightness location and intensity will also affect the brightness distribution, but in a more complex manner. Figure 1.33 resumes Flynn's dominating patterns that reinforce those four impressions, presented on the horizontal axis. The symbol √ indicates the presence of a dominating pattern.

<table>
<thead>
<tr>
<th>CATEGORIES OF VISUAL EXPERIENCES</th>
<th>IMPRESSIONS OF ACTIVITY SETTING AND MOOD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniformity</td>
<td>Visual Clarity</td>
</tr>
<tr>
<td>uniform</td>
<td>✓</td>
</tr>
<tr>
<td>non uniform</td>
<td>✓</td>
</tr>
<tr>
<td>Location</td>
<td>✓</td>
</tr>
<tr>
<td>peripheral</td>
<td>✓</td>
</tr>
<tr>
<td>overhead</td>
<td>✓</td>
</tr>
<tr>
<td>Intensity</td>
<td>✓</td>
</tr>
<tr>
<td>bright</td>
<td>✓</td>
</tr>
<tr>
<td>dim</td>
<td>✓</td>
</tr>
<tr>
<td>Concentration</td>
<td>✓</td>
</tr>
<tr>
<td>focal</td>
<td>✓</td>
</tr>
<tr>
<td>ambient</td>
<td>✓</td>
</tr>
<tr>
<td>Colour</td>
<td>✓</td>
</tr>
<tr>
<td>warm</td>
<td>✓</td>
</tr>
<tr>
<td>cool</td>
<td>✓</td>
</tr>
<tr>
<td>Brighter</td>
<td>✓</td>
</tr>
<tr>
<td>Surface</td>
<td>✓</td>
</tr>
<tr>
<td>horizontal</td>
<td>✓</td>
</tr>
<tr>
<td>vertical</td>
<td>✓</td>
</tr>
<tr>
<td>Luminance</td>
<td>✓</td>
</tr>
<tr>
<td>Local Of User</td>
<td>✓</td>
</tr>
<tr>
<td>Luminance remote from user</td>
<td>✓</td>
</tr>
</tbody>
</table>

Figure 1.32: Synthesis of the main categories of lights.

Figure 1.33: Categories of visual experiences. (Derived from Flynn [1977])
This categorisation provides a basis upon which a vocabulary of impressions can be established in association with physical aspects relating to space and light. The following chapters propose method of analysis that incorporates the notion of light as an aesthetic element and constitutes an introduction to light as art and science. Light, by nature, becomes the generator of space. A methodological tool developed in this research provides the first approximations to enable designers to establish a lighting concept. It integrates the qualitative and quantitative aspects of light in an orderly system of appraisal. The approach takes advantage of the new possibilities offered by multimedia architecture with the image as a basis for assessing the qualitative and quantitative aspects of light. The pattern resulting from different surfaces can be morphologically interpreted. It becomes the essential representation of light and a tangible expression of visual perception that directly relates to the appearance of space. There is a variety of patterns that influence the perception of space relating to visual qualities of light which may provide some indication on specific emotions.

Expressive aspects of light, often associated with the creative intuition of the early design process, are of great interest for architects, especially since they are also inclined to construct their own theories. It appears that technological developments have reduced the intuitive relationship that existed between architects and light. There are much research developments on a scientific utilisation of light, but the artistic aspects have yet been neglected. Past researches have favoured the quantitative aspects of light since they allow more objective experiments and assessments. Classifications of light explored by architects and scientists indicate the continual absence of visualisation. The thesis ultimately presents a classification that tends to abstract the function of space to concentrate on visual aspects of light. It therefore seems appropriate to constitute a visualisation system where technical answers can be provided when needed.

The horizontal surface at the height of the working plane is generally studied since it corresponds to specific functions of a space and relates more appropriately to established quantitative criteria. Few researches have explored the modelling of light on objects and architectural elements [Frandsen, 1990; Cuttle, 1971; Waldram, 1954] that emphasise a sense of aesthetic and an awareness of its qualitative aspects. Technologies have also contributed to the development of softwares for lighting assessments, but they do not respond entirely to the architect's needs, especially in the earlier design stages. These existing techniques are mostly time-consuming and provide a limited visualisation of light. Photography is still an ideal mean for light representation and therefore, this research proposes the use of the image for qualitative and even quantitative assessments of light. The visualisation of lighting effects is an important aspect of the research since it ensures an integration at the earliest design stages. The analogy of the eye and camera needs careful consideration, but reasonable approximations should be possible to provide useful results of analysis.
The aim of the thesis therefore consists in defining the relation between qualitative and quantitative aspects of light. The development of a design tool should allow for a qualitative interpretation of light as well as for a quantitative assessment. It should also acknowledge the architect’s use of intuition within the design process. A classification of lights should provide a basis for visualisation and ease of the design process. Such classification should only consist in the essential elements that affect light to avoid the finite number of possible geometrical combinations. The lighting pattern will constitute the basis of the classification since it is the most accurate representation of light and it proposes a link between quantitative and qualitative aspects of light. The limitation imposed by the bidimensional representation of space will also be considered in the definition of the classification of lights.

Chapter 2 therefore introduces a design methodology and exposes the advantages and limitations of the approach that uses images in lighting studies. Chapter 3 describes the use of the lighting pattern and the importance of contrast in the interpretation of images. It concludes by an essay on more subjective aspects of light in relation with qualitative aspects. Chapter 4 evokes the interest of the image as a design tool and describes the interaction of images in lighting design and space generation. And finally, chapter 5 introduces a classification of images based on the role of the methodology in future research developments.
A proposed framework for design and analysis

On visual representation
On Photography
On the Video

The Image as Art and Science
Discussion on the Approach
Advantages
Limitations

Description of the Methodology
Physical Context
Simulation with an Artificial Sky
Experimental Installation
The digital image

Image Analysis: Quantitative Assessment of Light
Data Acquisition: the Camera as an Observer
The Surface of Analysis
Simulation of Space: the Physical Model
Storage of Data and Experimental Manipulations
Resolution of an Image
Exposure and Sensitivity to Light
Effect of Adaptation on the Photographic Method
Glare
Effect of the Location of the Observer

Summary

The Lighting Pattern

Other Lighting Patterns
The Illumination Pattern
Concept of the Three Lighting Zones
The Nine Brightness Zones
The Shadow Pattern
Photography and the Shadow Pattern
The Highlighting Pattern

Summary

Correlation between Photometric and Photographic Methods
Types of Measurements
Photometric Approach
Single Point Measurement
Line Measurements
Grid Measurements
Photographic Approach
The Experiment

Conclusions
This section establishes the potential and interest of developing a methodological approach that closely relates light and architectural design. The reference to light as science is ensured by some correlative investigations and the use of a software of image analysis for the interpretation of lighting patterns. The integration of light as art emerges from the visual representation of the qualitative aspects by the use of images. Drawings can approximate some of the visual qualities of light, but images can also be genuinely poetic since some aspects may be enhanced to promote an ambience related to the mood of the creator. The representation of light as a form has been part of the visual arts throughout history. Painting, drawing and eventually photography have contributed to the definition of ambience created by light and have influenced architecture. Photography has already been much integrated into the architectural practice as it often constitutes the final representation of a design. This research uses the image to initiate the design process through evocations of space. The imagery offers a more tangible definition when it is complemented by other means of representation such as a physical model. This ensures an ideal communication of ideas since the subtleties of light are modelled to produce a good qualitative assessment. Moreover, there is no need for a conversion or scale factor, which simplifies the quantitative analysis.

A Proposed Framework for Design and Analysis

The term image usually defines the visual representation of an object but it can also characterise a form that acts as a symbol. Images may elicit feelings and emotions from the human experience and confer them a new dimension. The image, in its capacity to initiate a knowledge and feeling response, may be selected and arranged so that it arouses deep layers of awareness, affording insights into personal identity, and even bonds with nature and light [Greene, 1976]. The resulting
composition provides an exploration, sustained by an intuition and curiosity about the symbiotic relationship between images and the mind. This knowledge and feeling response is an important aspect of the methodology where the image becomes a design tool for assessing light in space.

Since the development of computer digitalisation, the image becomes more than ever a design tool that simulates and creates specific activities in the design process [Zeitoun, 1990, p. 541]. The utilisation of the image as a design tool is promising because of the difficulty to represent the immaterial qualities of light. The image provides a tangible expression that relates to the physical nature of light. It has mostly been employed in space representation through photography, but nowadays, it interacts with scale models and drawings, complementary for architectural creation (figure 2.1).

**On Visual Representation**

The term *photographic technique* relates to the category of realistic two-dimensional representations, which include other types of representation. It divides into sub-categories that represent different states of imagery such as black-and-white versus colour representation, line drawings, plans and elevations versus perspective, computer displays versus holographics. Figure 2.2 illustrates a hierarchical structure of simulation of the visual environment. The first, and highest level consists of the actual environment, which is the best possible source of experimental information. Its major source of error however relates to the physical conditions, which are frequently difficult to control, in particular for daylight. The second level consists of the tridimensional representation, and the third and least precise level is the bidimensional representation. The diagram assumes that photographs should provide more information about light than single line drawings, but less accuracy than a physical model. Photography therefore constitutes the most accurate bidimensional simulation, but the tridimensional representation and the actual environment remain the best sources of simulation. This research proposes the combined utilisation of the tridimensional and bidimensional representations, further discussed in chapter 4.
Perception goes beyond the available sensory information, and in the representation of spaces with images, the eye functions with the brain's experience. Images are not exact representations of the real world, but they constitute a simplified information that can be translated by the observer's experience of space. The brain abstracts the simplification of information to provide a more vivid picture of the possible reality, and the observer builds up a *predictive hypothesis* selected by available data [Gregory, 1971]. *Predictive hypothesis* have similar effects than scientific hypothesis in predicting the future and symbolically creating possible futures that could exist [Gregory, 1971]. Disparities between the image and the real world therefore provide amplitude for different interpretations. There are some advantages in using a system that allows such an interpretational latitude. For instance, the very abstract image allows the suggestion of almost anything, depending on past experience, hence providing an important source of inspiration and creation to an architect. That notion is especially relevant to initial design stages. More interpretations can be asserted as the level of abstraction of the image increases. There could however be some predictions that result in false interpretations because of the lack of information. The highly precise representation provides less liberty of interpretation but it is more detailed and conforms more closely to reality. The level of abstraction of the representation of light should relate to the type of information needed. A final assessment would need more precise information about the behaviour of light, providing facts that allow further modifications of a design. However, the ideal balance of information also influences the system of analysis which usually becomes heavier as the precision of the visual representation increases. A simplification of information allows more misinterpretations.
but provides, to some extent, more useful information for the initial design stages when a concept is still developing.

On Photography

Gombrich [1995, p. 17] affirms that the world is often conceived as stable and fixed through memories, even though it constantly changes under the different lights that emerge throughout the day. He adds that photography provides a picture-making process based, not on synthesis, but on selection: "paintings are made but photographs are taken". The photograph is a fixed perception of the world in time, and the camera is the instrument that enables the photographer to arrest all visual changes that relate to the climate and the position of the sun in the sky. Barthes [1993] identifies three levels related to photography: the operator, the spectator, and the spectacle:

"The Operator is the Photographer. The Spectator is ourselves, all of us who glance through collections of photographs (...). And the person or thing that is photographed is the target, the referent, a kind of little simulacrum, any eidolon emitted by the object, which I should call the Spectrum of the Photograph, because this word retains, through its root, a relation to "spectacle" and adds to it that rather terrible thing which is there in every photograph: the return of the dead."

Barthes, Camera Lucida, 1993 (p. 9)

These levels are indissociable because photography would otherwise have no meaning. Barthes' definition of photography goes beyond the fixed perception evoked by Gombrich. He relates the spectacle of a photography to "the return of the dead", expressing the ephemerality of a moment. There is a uniqueness present in the photographic instant that may never be reproduced again. The subject and the picture are not the same entity although they would afterwards appear to be. It remains the photographer's problem to see not simply the reality before him, but the still invisible picture, and to make choices according to the latter. This aspect raises questions about the validity of a photography to represent a condition of space, since this occasion, this encounter, as Barthes puts it, could perhaps only relate to a specific human experience. The photograph represents an instant in the photographer's perception of an ambience, an image fixed in time. The photographer determines the view point that becomes, in a sense, part of the representation of a specific scene. Because the photographer controls the camera and only selects the portion of a space that he considers important, there is a personal aspect about photography. The photograph is an important mean of representation and it therefore remains a conservative medium of realism. Le Corbusier did carry a camera and took many photographs. He placed little value on their usefulness, much preferring his carnet filled with sketches. Of this process and experience he later wrote, in Creation is a Patient Search (trans. James Palmes):
"When one travels and works with visual things - architecture, painting or sculpture - one uses one's eye and draws, so as to fix deep down in one's experience what is seen. Once the impression has been recorded by the pencil, it stays for good, entered, registered, inscribed. The camera is a tool for idlers, who use a machine to do their seeing for them. To draw oneself, to trace the lines, handle the volumes, organise the surface... all this means first to look, and then to observe and finally perhaps to discover... and it is then that inspiration may come. Inventing, creating, one's whole being is drawn into action, and it is this action which counts."

[Le Corbusier, 1911]

The photograph can radically transform a perception of reality [Beloff, 1985, p. 19]. It also offers the possibility to use the camera in a more scientific manner, where it simply becomes a tool for analysis and comparison. This was the main concern of a previous research on contrast in interior spaces [Demers, 1993]. Results indicate that representations of different configurations of apertures in a given space are more relevant to the imaginary and the creative process than quantitative calculations. Although taken in a purely mechanical manner, the image suggests an ambience and preserves a certain latitude for interpretations and further speculations. It contains the potential to reveal some aspects of the future and stands as a record of a probable atmosphere that could emerge from space. Moholy-Nagy [1967, p. 145] realised that photography was not only a mean that reproduced reality to relieve the painter of this function, but he also recognised its power for discovering reality.

The camera can be described as an extension of perception whereas a photograph is an extension of memory. The persuasive character of a photograph is as much important as a visual representation, but it can also delude and mislead. Beloff [1985] argues that people adulterate sensory information with their goals, needs, attitude and expectations, attending selectively to all the things around them. Objects are noticed because they correspond to a present interest, and perception is influenced by a state of being [Beloff, 1985, p. 17]. Szarkowski [1980] mentions that faith in the truth of a photograph rests on a belief of the impartiality of the photographer and the lens, creating a context where the subject is represented as it is, neither nobler nor meaner. He adds that this faith may be naive and illusory, but it persists:

"More convincingly than any other kind of picture, a photograph evokes the tangible presence of reality. Its most fundamental use and its broadest acceptance has been as a substitute for the subject itself - a simpler, more permanent, more clearly visible version of the plain fact."

[Szarkowski, 1980, p. X]

Kozloff [1979] identifies the camera as a mirror with a memory whose image proves that people have not been "hallucinating" all their lives. Photographs therefore become refugees from their moment where the camera absorbs the complexity of spaces and human actions. Through photographs, a radical fragment separates from the unlimited flux of reality. Kozloff mentions that this provides alertness without attention and a perfection of looking without effort. Beloff recalls that nowadays, the disappearance of photography would lead to the impression of imprisonment into people's immediate surroundings. Photography can be a purely artistic medium, but the technical
aspect of surface and object modelling has created a distinct vocabulary of lights. It allows light to be controlled and in that sense, much aesthetical and technical experience has developed because of photography. This control of light implies the notion of an aesthetical knowledge enabling more creativity and explorations. Light and shade are important aspects of photography since they become essential means of expression. They contribute to the modelling of an object relating to the quantity of light sources, their relative intensity, and location. Architecture does however not have as much control over light because it may be exposed to varying sky conditions over a single day.

The mechanism of the camera is based on simple physics relating on the availability of light. The black box with a hole was the perfect simplification of what would become a sophisticated instrument. Nowadays, the functioning of the camera still relates to the basic relationship between light and exposure of the photographic emulsion, except for new features that have produced an instrument relatively easy to use, promoting the instantaneity of the image capture. The cine-camera provides the possibility to group a sequence of images taken in a relatively short time. This way of looking at the world relates to the development of the video. The sequence of images reflects an even more tangible reality than the photograph as it demystifies the context and the fixation of space in time. It also provides the information that will construct our perception of that reality.

Light is a form of energy whose special property is to stimulate the receptors of the eye and to enable the brain to register a visual image. Light must therefore be measured by an instrument which sees as the eye does. It is customary to discuss the eye in comparison with the camera. Hopkinson [1963, p.19] mentions that the analogy must remain illustrational because the eye is much more complicated and delicate than the camera since the visual performance of an individual is determined by the eye and brain. He states that the understanding of vision is linked with the consideration of the eye and brain as part of one mechanism. He also adds that the interpretation of an optical image by the brain is not merely a function of the eye itself, but of the intelligence. Walter Benjamin mentions that “the nature which speaks to the camera is a different nature from the one which speaks to the eye” [in Maholy-Nagy, 1967, p. 145]. Technology has not yet approached the combined effect of the eye and intelligence [Hopkinson, 1969]. The eye is generally more sensitive to brightness variations than the photographic emulsion [Naavab in Schiler, 1987, pp. 95-96; Luckiesh, 1916, p. 24]. To a certain extent, the eye compensates for different amounts of light and consequently, its consistency affects perception. The eye scans the environment instead of concentrating on a single point, balancing light levels and reducing the glare of strong sources. Moreover, the brain is constantly and actively organising and making sense of the visual world [Kosslyn & Chabris, 1993, p. 34]. The reflected light from the various surfaces forms a geometrical projection that reaches the eye [Gibson, 1950]. Gray Read [in Hochberg, 1978, p.7] notes that if a film were able to reproduce what the eye receives in its normal course of exploration, we could find
ourselves confronted by a rhythmic flicker of select but barely related images, shifting about in a loose sequential montage. Only the small centre of each image would be in clear focus and its periphery would soften into a blur of colour that finally fades to soft greys near the edge of the frame. Images would succeed one after another at a rate of about four each second, too fast to enable their individual recognition. The camera however remains one of the most versatile instruments to approximate and communicate visually some aspects of light in space. Researchers consider that photography is still ideal to represent qualitative and even quantitative results [Naavab in Schiler, 1987, p 94]. Breslow [1991, p. xi] states that there is presently a new era where rules of photography need revision, new abilities are learned, and old ones retire. This era arose from the personal computer revolution, and more specifically, from the availability and affordability of equipments that allow the insertion of an image into the computer, its manipulation, transformation, extraction and even transfer on paper. The computer therefore becomes an extension of the traditional techniques of film development, proposing a promising field of work and new discoveries about images and light.

On the Video

"In fact the eye seems to work not like a photometer but like an automatic cine-camera, in which the lens aperture is controlled by a photocell. All you have to do with a modern camera, after remembering to put some film in and to wind it up, is to point the camera at the scene and press the button; the camera does the rest, adjusting itself to the scene; and one can forget about the technicalities of photography and concentrate on the scene being recorded."

Waldram, 1969

The potentialities of the film involve reproducing the dynamic of different movements. Maholy-Nagy [1967, p. 36] mentions, that this dynamic can be represented by the scientific observations of a functional type, in quick and slow motion. The interest of the video has considerably grown with the development and the commercialisation of the video camera. The home movie becomes part of a culture of images where everybody is entitled to capture a moment of life. This new interest reflects the desire to fix in time an entire sequence of an event in space, visually and auditorily [Beloff, 1985]. Architects perceive space in an often kinetic manner and in this sense, the video becomes an interesting medium of representation. Le Corbusier's description of space and light is also based on a kinetic perception:

"Then you can feel the noble size of the Mosque and your eyes can take its measure. You are in a great white marble space filled with light. Beyond you can see a second similar space of the same dimensions, but in half light and raised on several steps; on each side a still smaller space in subdued light; turning round, you have two very small spaces in shade. From full light to shade, a rhythm. Tiny doors and enormous bays."

Le Corbusier 1923 (1989, pp. 181-183)
Through such a vivid description, it is possible to imagine the movement of the sight and the kinetic of the observer within space. The video culture needs movement to comprehend and appreciate a specific context. It reflects a reality that is a closer representation of our perception of the world. Contextually, it does not abstract time as does the photograph. It however has the capacity to abstract a reality by using a specific visual framework, and most powerfully, by the interaction with numerous modifications of the image through computer image manipulations. Maholy-Nagy [1967, p. 36] mentions that even a proper understanding of the material, speed and breadth of thought do not suffice to predict all the obvious potentialities of the kinetic image.

The Image as Art and Science

This research introduces a method that uses images to provide a qualitative and quantitative analysis of light. The simplicity of the approach facilitates its integration into the architectural practice and initiates the design process by using available technologies. Design tools should have the advantage of being versatile to create a basis for technical knowledge, indispensable to design. A main problem is the lack of integration of tools into the design process. Design tools should also intervene at the right stage of the project for an efficient utilisation. Some design tools are more suitable for approximations, whereas others are more appropriate for final assessments. The nature of the required information corresponds to different stages of decision making referred as decisions of principle and decisions about certain details of the project [Schuman & Selkowitz, 1989]. The earlier stage, particularly, constitutes a major concern in the development of the methodology since it relates to the architect's initial expression of ambience that will affect the entire development of the project. The design tool should intervene in the earlier design stages relating to decisions of principles, and should also offer the more precise analysis required in further design developments. The choice of a tool is also dictated by other considerations such as flexibility of utilisation, integration to the common architectural practice, nature of the problem, and the required information [Scartezzini et al., 1993, p. 2]. The flexibility of utilisation of the tool is important since it relates to the learning process of the user. An ideal design tool should therefore allow learning rapidity and simplicity of utilisation to facilitate its integration into the architectural practice. There should be minimal restraints to avoid limiting explorations that could occur within the framework of a commencing project. The utilisation of physical models is also an important aspect of the methodology since it responds to the complexity involved in the creative process and allows qualitative assessments of light at the initial design stages. The nature of a problem dictates the utilisation of a particular tool in relation to different levels of complexity and design scales.

The rapid and complex development of the architectural project during the design stage requires intricate computerised calculations [Novitski, 1990, p. 32]. Physical modelling however, allows
qualitative and quantitative analysis of space, whatever the level of complexity involved [Robbins, 1986, p. 221; Millet in Schiler, 1987, p. 13]. There are software packages for image analysis which are presently employed in various fields of applications, but none is specifically meant for light analysis. Previous research has shown the possibility to combine computerised image analysis with the experimental method [Demers, 1993]. The combined utilisation of physical modelling and computerised image analysis should provide a simplified design tool for analysis for early design stages as well as for further development of a project. Figure 2.3 summarises the differences between the entirely computerised method of light analysis and a new alternative involving the use of photography in physical models with the computer as a tool for image analysis. The proposed, partially computerised method relates more closely to earlier design stages than entirely computerised methods, which are more appropriate for a final assessment of space. It offers more flexibility, learning rapidity, and higher levels of precision than entirely computerised models. This research emphasises and develops the possibilities of a partially computerised approach using calculation method and physical modelling at different design stages.

<table>
<thead>
<tr>
<th>DESIGN METHODS</th>
<th>PARTIALLY COMPUTERISED METHOD (developed in this research)</th>
<th>TOTALLY COMPUTERISED METHOD (example: Radiance)</th>
</tr>
</thead>
</table>
| Correspondence with Reality | • Simulation with physical model under real sky or artificial sky.  
• The qualitative assessment is almost as it would be in the real space (Lau, 1972).  
• No need for a conversion factor. At different scales, light behaves similarly. | • Simulation of light through a mathematical model for a selected distribution for direct or diffuse sky.  
• The qualitative assessment of light depends on the program and the level of precision needed. Precision is also proportional to the time taken to produce an image (Spitzglas, 1986). |
| Modelling            | • Need for a physical model.  
• May be part of the early design stage.  
• Already a well established design tool. | • Need of a numerical model located in the computer.  
• Not part of the early design stage.  
• Much time involved in the modelling which makes it an unlikely tool for early design stages. |
| Data Acquisition     | • Photographic data from fixed images.  
• The precision of the method relates to the correspondence of pictures taken on different films.  
• The design stage may require less precision.  
• The visual image may originate from prints, negatives or a frame taken from a videotape. | • Data are issued by the computer after inserting the building configuration.  
• Higher precision depending on the simulation program and the accuracy of the mathematical model.  
• Need for a sophisticated printer or camera to extract the visual information from the screen of the computer. |
| Utilisation and Support | • Simple utilisation.  
• Need for a personal computer, a scanner or a video card, and a 35mm reflex or video camera recorder. | • High level of expertise and skills in computing are desirable.  
• Need of a powerful computer working station to support heavy calculations. |
| Processing and Analysis | • Excellent qualitative analysis through the medium of photography.  
• The software is not especially designed for lighting calculation but some functions can be adapted. | • The more realistic computer images involve much calculation that needs long hours of processing.  
• Software especially designed to provide lighting intensities, daylight factor and glare analysis. |

Figure 2.3: Comparative table of partially and entirely computerised methods of lighting analysis.
Discussion on the Approach

Advantages

The methodology takes into account the increasing interest in the utilisation of photography as an important part of the design process. The photographic emulsion may be considered as a material sensitive to light as it indicates, after a chemical processing, the quantity of effective light to which each area has been exposed [Evans, 1959, p. 77]. A properly exposed and developed photographic image is a direct record of the amounts of light exposure at each point of its surface. A photographic approach provides a basis for the comparison of different lighting conditions. The methodology therefore adds a quantifiable aspect to lighting design as it offers the possibility to integrate numerical values when required. The utilisation of the pattern as a visual representation of light instead of numerical values facilitates the quantitative assessment and relates to existing techniques of lighting analysis such as the isolux contours. The method is easily assimilated into architectural practice since physical modelling is already an integral part of the design process. The images employed for the quantitative analysis can also serve as representations of the quality of space. The method also offers the possibility to analyse real case studies without having to model anything, and allows the creation of other typologies of light whenever transformations occur.

- The application of the method is rapid and simple, especially when a library of images is available to the designer.
- Light appears more realistic and tangible on photographs than in sketches and drawings. Images and drawings however become complementary design tools.
- It is possible to combine and modify different typologies of light for the creation of space. This may become an interesting approach to light as a generator of space.
- Different configurations of spaces may be obtained.
- Considerably less time is involved in the collection of data in an artificial sky.

Limitations

The validity of the analysis of a perceived scene where different colours and textures of varying sizes and luminances are translated into a series of values could be questioned by the perceptual psychologist. Some objections could be raised relating to such simplifications in referring to light as
a part of a grey scale array of brightnesses since, for instance, two different colours could be assigned similar values. The simplification of the tridimensional world into a bidimensional black and white scene fixed in time could also cause some disapproval. Marsden [1969, p.171] notes that "a reduction of the complex visual scene into a series of numbers is certainly a prostitution of the psychology of perception and the immorality must be recognised at the outset". There is no doubt that a simplification of the visual world into a series of data and flat images could lead to a false perception of space and light. Marsden however recognises that the simplification of the relationship between perceptual and physical aspects is desirable to establish the basis of engineering design. Architects are also trained to work with simplified representations of the visual environment. It is in this context that the methodology abstracts colours to isolate the flow of particles in the generation of lighting patterns to identify the relationship between the space morphology, the type of apertures, and the resulting ambience created by light. The methodology also abstracts the third dimension as architects are aware of notions of space representations, such as elevations and perspectives. Therefore, the method develops an approach where the design tool should not exclusively constitute a visualisation of space, but a source of inspiration to assist the architect in the early design stages. Computer images complement the use of plans, elevations, perspective drawings, and sketches, to create new interactions between architects and the media of representation and creation. This should provide a basis for a global interpretation of a project and acknowledge the architect's experience of space and light.

- The image illustrates a single surface of space. It is however possible to combine all the elevations of a space to obtain a global view of the design proposition.

- Images should mainly be issued from the overcast sky condition since the implication of the sun path in the interior involves the notion of orientation. Modifications of those images would not correspond to an approximation of reality. This does not constitute a limitation in climates where the overcast sky condition predominates.

- Software for image analysis is not conceived to compute light. In some cases, this will imply some modifications of the image to reduce the error.
Description of the Methodology

The methodology responds to the need for a design tool that facilitates the realisation of an ambience created by light, early in the design process. It also responds to the need of visualisation of light. This problem of visualisation has been tackled in a past research on image analysis that was based on aperture variables, and which led to a classification of lights based on contrast [Demers, 1993]. Combination of apertures could create multitudes of new images and ambiances, and eventually become part of an educational tool to offer a visual understanding of light as an aesthetic element and a physical matter. The present methodology reinforces the importance of using physical models in the early design stages, and proposes the utilisation of a software of image analysis to quantify some aspects of light. Multimedia architecture is at the basis of the methodology where physical models, video camera and computer become essential components of lighting analysis. The method uses tools that are already familiar to architectural design to facilitate its integration to the design studio: drawings, models and images obtained through photography and video under an artificial sky. They become the essential support of data collection and visualisation of the experimented effects of light, leading to the creation of a library of images for further developments of specific ideas. The methodology involves the importation of images into a computer to perform the analysis with a technique developed in this research. The software of image analysis employed in this research is Photoshop, created by Adobe Systems Incorporated. It is presently used by experts as well as novices in art production. It allows photographic retouching, collages, photomontages, colouring of images, separation of colours, and creation of images using media and custom tools. This research uses the software to provide a visual representation of light and the quantitative information on the lighting pattern. Images can also be transformed using the tools within the computer software of image analysis to create new design alternatives. It allows the creation of spaces as if they would appear from the dark and lights were progressively added. In this context, images respond to their traditional function of illustrating qualitatively a lighting concept but moreover, they also become part of the quantitative comparison between different design solutions through computer image analysis. The approach therefore emphasises the creation of space from light in the early design stages.

Physical Context

Interior space remains the focus of the analysis since light as architectural form is mainly concerned with space within, "space that can be lived in a dynamic way" [Zevi, 1991]. Le Corbusier also suggests the primacy of the interior and its generative capacity in spatial design:

"A plan proceeds from within to without. A building is like a soap bubble. This bubble is perfect and harmonious if the breath has been evenly distributed and regulated from the inside. The exterior is the result of the interior."

Le Corbusier 1923 [1989, p.181]
Architects have traditionally understood that whilst the exterior is created in light, the interior is a world of shadows, in which inhabitants may control the dramatic effects of light and physical comfort [Malnar & Vodvarka, 1992, p.20]. In interiors, volumes and shapes usually have a different effect than in exterior light, since light coming from the apertures is weaker and more diffuse. Interior space allows architects to control the effects of light since the source is modulated by the aperture, and where each aperture can be considered as a source [Lam, 1986]. Light as architectural form only exists when intrinsic qualities of architecture are combined [Zevi, 1991, p.56].

Lynes [1968, p. 47] mentions that the visual evaluation of the brightness of space depends as much on the appearance of vertical surfaces as on the horizontal illumination. In spaces devoted to ritual, social contact and recreation, the conventional horizontal working plane has little meaning. Lynes emphasises that better criterion of the subjective adequacy of the illumination is the scalar illumination at eye level. In some cases the horizontal illumination is even positively misleading, tending to exaggerate the effectiveness of overhead lighting, and concealing the important effect of light-coloured floors or working surfaces on the overall impression created by interior light.

Chapter 1 was emphasising that light as art creates ambience and generates emotions, whereas light as science establishes a quantification of light mainly on horizontal surfaces. Light as art and science should provide some type of quantification for vertical surfaces since they are mostly involved with vision and occupy the greater part of the visual field.

Simulation with an Artificial Sky

A mirror-box type of artificial sky simulates diffuse light. The accuracy of the lighting pattern issued from a bank of images is important and depends on the building precision of the physical model. Recommendations from the DNNA (Daylighting Network of North America) [Schiler, 1987] and Littlefair [1989] have directed the construction of the models for the present research. The principle of the mirror-box lies on infinite reflections on the horizon, causing the only significant error related to the multiple reflections of the model in the mirrors [Littlefair, 1989]. It is necessary to have specular or great exterior surface reflectances [Loveland and Naavab in Schiler, 1987]. The size of the artificial sky also limits the dimension of the model.

Experimental Installation

The utilisation of a video camera recorder implies the installation of an audio video card into the computer to directly obtain the visual information without intermediary. Previous research [Demers,
1993] used a 35mm camera, which had the disadvantages of lengthening the stages of data processing and needed accurate calibrating between different lots of negatives. It also required processing the film, scanning the negatives, and involved the construction of reasonably large models to ensure a correct minimal focal distance of the camera (figure 600). The use of the video as an image grabber offers a lower level of visual definition than the 35mm reflex camera, but the result is almost instantaneous and the minimal distance of focus can be as short as a few centimetres, enabling a more rapid and efficient construction of models. Larger physical models need additional construction time and are therefore usually employed for final assessments. The advantage of the methodology is to facilitate the integration to the design process in the earliest stages, as soon as an alteration of a model can be directly recorded into the computer and immediately analysed. It also promotes some interaction between different images since combinations and transformations through the software of image analysis are always possible. A perfect experimental installation would consist of a model filmed under a source of light with a camera connected to a computer (figure 2.4). This constitutes a working station for an interactive context of creation of space from light. This interaction between different media of architecture favours a global approach to design, which is an important advantage of the methodology.

![Diagram](image.png)

*Figure 2.4: Experimental installation.*

**The digital image**

The image is digitised through a scanner, or more directly originates from a video camera recorder. The most immediate, least expensive way to capture a bit mapped image is to translate a video signal into an array of pixels [Mitchell, 1991, p. 74]. The signal may come directly from a video camera, from a videocassette recorder, from a videodisk player, or from a still-video player. The
necessary analogue-to-digital conversion is accomplished through the use of a video frame grabber. The signal from a video camera records light intensity which may be sampled with precision at discrete intervals [Mitchell, 1991, p.73]. Unlike a normal photograph, the digitised image has proprieties which enable quantitative analysis. Images can be formed from many different energy distributions, including visible light. Digital images consist of discrete picture elements, the pixels. The image is treated as a series of points or pixels, each having a value that corresponds to the intensity of light. The arrangement of a series of pixels into a matrix forms a digital representation of the image, a simplified numerical model (figure 2c). The advantage of representing a picture into a matrix form is that the potential of the well developed matrix theory may be applied to the analysis of picture processing operations. It may be argued that a picture is not merely an array of numbers. Undoubtedly, a matrix does not necessarily generate a familiar image, although every matrix does represent a computer picture function [Hall, 1979, p. 102].

In computer imaging terminology, matrixes are called raster graphics, which consist of bit mapped images displayed in a square array issued from a video camera signal and sent to a monitor. Each square (of figure 2.5.b) and c)) represents the mean brightness of all the pixels it encompasses, for each section of the photograph of figure 2.5.a). In a lighting study, raster graphics can be created to obtain a sectorial verification of the distribution of brightness values on surfaces. They provide a similar type of information to the punctually taken measurements of intensity recorded by photocells into a model under real or artificial sky. The main difference is that each square of the raster graphic represents the mean value of all the pixels situated within that area whereas, for the manual technique using photocells, the data represent the intensity of light received on the surface of the cell. This chapter presents a comparative study between photometric and photographic measurements. Chapter 3 explores a punctual method of analysis of contrast using matrixes.

![Image](a) Original Image  ![Image](b) Mosaic Representation  ![Image](c) Matrix Representation

*Figure 2.5: Conversion of an image into a matrix representation.*
Images can be analysed in colour or monochrome in any shade of black and white, but a convention in the world of image processing favours the use of the grey scale to represent the energy level of a pixel, regardless of the colour of the original image [Joyce-Loebl, 1985, p.78]. An important distinction should be made between colour as a sensation and colour as a wavelength (or set of wavelengths) of light entering the eye. Light itself is not coloured, but provokes sensations of brightness and colour, in conjunction with a suitable eye and nervous system [Gregory, 1972, p. 73]. Hopkinson and Kay [1969, p. 60] mention that colour is more associated with the emotions than with the efficiency and comfort of the individuals. It consists of a radiant energy which relates to human perception rather than to properties of surfaces or objects. The entire experience of colour is influenced by light energy entering the eye, but also by subjective factors that arise from within the brain [Birren, 1961, p.16]. Colour is seen and also felt emotionally, which adds a further variable to the quantification of light, but the camera tends to exaggerate some parts of the spectrum. The photographic interpretation of colour images may become problematic for other reasons. For instance, the balancing of colours is much more delicate than it is for the grey scale. Calibration between different light temperatures and types of images demands meticulous attention to ensure validation of the results. Also, the appearance of any surface colour depends on its own reflecting properties, but also upon the nature of the ambient light [Hopkinson & Kay, 1969, p. 61]. Moreover, since chromatic vision relates to the visual capacity of observers, the evaluation of contrast is difficult [Luckiesh, 1965, p. 127]. Modelling, the ability of light to reveal forms and textures by creating a brightness contrast, does not necessarily imply the need for chromatic contrast in simplified qualitative assessments [de Boer & Fisher, 1978, pp. 42-43]. This research therefore concentrates on a grey scale analysis of the image to reduce such factors as subjective interpretations. In the present approach, the reflectance refers to chromaticity in the study of lighting patterns. Notions of colour are more important when the architect uses subjective assessments and intuition to design space with a specific type of light. Robbins [1986] emphasises the importance of black and white photographs in the qualitative analysis of light. He maintains that it provides "considerable information about contrast, glare, and light or dark spots that is less evident in a colour photograph" [Robbins, 1986, p. 232]. The qualitative analysis of a photograph provides a preliminary information that will direct the quantitative analysis using computer image processing.

In the analysis of images, pixels are associated with a number that represents an average radiance (or brightness)\(^1\) of a relatively small area within a space. The size of a pixel area relates to the precision of the digital representation. A relatively small pixel area is desirable for a qualitative assessment of the visual aspect of light in space since it provides a higher visual definition of the image. The smaller pixel area has the quality of a photograph, approaching the individual's visual ability to perceive space. A larger pixel area may be used for a quantitative assessment, provided

\[^1\text{A discussion on the issue of the representativity of the pixels values can be found in chapter 3.}\]
the extraction of enough information to determine the brightness contours of light in an image. Images of higher precision offer an excellent visual representation but they also require large amounts of computer memory and may lengthen the manipulations involved within the software of image analysis. Digital theory recommends that the pixel resolution should not surpass the half width of the smallest element to ensure minimisation of the size of an image [Joyce-Loebl, 1985, p.78]. Images issued from such a rule may not necessarily provide a visually good resolution but they should produce reasonably accurate quantitative results. It can be assumed that any image that tends to equate the minimum resolvable fraction of the field of view has many more pixels necessary for the quantitative analysis but produces a visually more accurate qualitative representation. It is thus recommended to choose the minimum pixel resolution to obtain reasonably good visual representation, or to file good resolution images for qualitative purposes and work with lower resolution images for the quantitative analysis.

A finite number of bits represents the spatial radiance for each pixel within a digital image which can be described in computer memory as an array of integers, and where each integer specifies an intensity [Mitchell, 1991, p. 73]. The continuous radiance of the analysed space is therefore quantified into discrete grey levels in the digital image. By sampling intensities with greater precision and at closer intervals, this digital approximation may reproduce the original continuous surface as closely as an original photograph [Mitchell, 1991]. A visually continuous range of brightness requires only 5 or 6 bits per pixels to obtain respectively 32 or 64 grey levels [Schowengerdt, 1983, p. 8], but more bits per pixels are desirable for a numerical analysis. This research uses 8 bits per pixel resulting in 256 grey levels to ensure good image rendition for the qualitative and quantitative analysis.
Image Analysis: The Quantitative Assessment of Light

Techniques of image analysis have developed with the technology of satellite photographs. The interpretation of such photographs presently relates to various scientific applications, but it should be possible to use this knowledge for assessments of light. The usual practice of photographic photometry involving the use of film development techniques can only produce an accuracy with 5% to 10% of probable error [Dobson et. al., 1926, p. 14]. It is although possible to obtain a probable error of about 1% when proper precautions are taken. This becomes even more possible when development manipulations are avoided, such as in digital photography.

Data Acquisition: the Camera as an Observer

The photographic method uses the camera to simulate the eye of the observer. Previous research [Demers, 1993] used a 35mm camera, but for the present research, the video camera recorder is preferred. Table 20 compares the utilisation of the 35mm camera and the video camera recorder for lighting analysis. The video camera recorder connects to a computer that incorporates a video card. The image appears directly on the computer screen, which is connected to a video camera recorder. An image grabber software selects one or several frames and a software of image analysis enables a quantitative evaluation of light (figure 600). The 35mm negatives are inserted in slide frames before digitalisation and analysis with a computer and the Adobe Photoshop software. Photographs could alternatively be digitised with the disadvantage of incorporating an additional stage of film development and inducing a greater percentage of experimental error. Slide scanners offer higher quality images than image scanners. Scanning functions such as contrast and brightness must remain constant throughout the experimentation, and precision of the scanning is fixed at 500 dpi, which produces enough accuracy for the analysis. This level of precision depends on the type of information needed, mainly dictated by the desired visual quality of the resulting image. Quantitative analysis are achieved with minimal image precision whereas qualitative analysis may need more precision, especially when visual representation and good quality images are important. Figure 2.6 illustrates the stages of data acquisition for the 35mm camera and the video camera recorder. It shows the simpler and more straightforward process of data acquisition for the video camera recorder. The 35mm camera involves much more manipulations and intermediate supports before the computer analysis. This may result in a higher percentage of error and longer preparation time. It has the advantage of offering an initial image with excellent quality, but the modifications of images through the computer analysis are not available at that stage. The final presentation from the computer may result in a digital image on a disk or on a hard copy.
The system of visualisation must facilitate the comparison of the results of analysis so that the only acceptable variable between photographs relates to the different configurations of space and apertures. The technique of data acquisition must be constant throughout the experiments.
The Surface of Analysis

Lighting analysis from images requires surfaces to materialise light and record its distribution. The notions of scalar and vector [Lynes et. al., 1966] are valuable in the understanding of daylit interiors, particularly for the prediction and visualisation of light in space. Light flows principally downwards under an overcast sky, which may emphasise the need to adopt the horizontal plane for its evaluation. It also appears that daylight flows obliquely from vertical windows and sometimes almost horizontally. Therefore, light from the window source is not realistically represented by the only measure of illuminance on a horizontal plane [Holmes, 1975]. This argument reinforces the importance for the introduction of an assessment of light on other surfaces than the horizontal plane. In the context of this thesis, the surface of analysis mainly consists of a vertical wall since verticality favours expressivity light [Ching, 1979], whereas the horizontal surface relates to task lighting. In interior spaces, vertical surfaces occupy most of the visual field and therefore affect more directly the atmosphere of space. The method also applies to horizontal surfaces by modifying the viewpoint of the camera. The viewing position needs to minimise any distortion that could occur because of the convection of the lens of the camera, and ensure correct representation of the lighting patterns to facilitate the comparison between design solutions. The surface of analysis is ideally perpendicular to the field of view of the camera to minimise these distortions. Different viewing positions could be experimented to provide more flexibility in the design of the physical model, also allowing the construction of more simplified models when possible. The positioning of the viewpoint of the observer, hence the camera lens, is defined in terms of vertical height and horizontal distance. The model does not necessarily need a specific scale, in which case, it relates to different types of spaces. The positioning of the observer is crucial in the determination of glare and needs to be carefully considered. A zone of glare could be defined according to the location of a potential observer in relation to a specific aperture, allowing some flexibility in the orientation of the camera. This zone of glare would relate to specific types of activity in space. The construction of the physical model should ensure that all the possible viewpoints are accessible when many surfaces of analysis are considered. The photographic method may limit the number of viewpoints, as for instance in the case of an aperture situated directly opposite to the surface of interest or when the viewpoint is located exactly in the centre of an aperture. The method therefore limits the number and location of viewpoints available in the model.
### INSTRUMENTS OF DATA ACQUISITION

<table>
<thead>
<tr>
<th></th>
<th>VIDEO CAMERA RECORDER&lt;sup&gt;2&lt;/sup&gt;</th>
<th>REFLEX CAMERA</th>
</tr>
</thead>
</table>
| **MINIMAL DISTANCE OF FOCUS** (Limits the minimum size of the model) | *Integrated lens<sup>2</sup>*  
*Wide angle lens<sup>3</sup>* | *300 mm with 28mm lens* |
| **STORAGE OF DATA** | *As a sequence of images that constitutes a moving sequence.*  
*Limited to a two hour cassette.*  
*Number of images on a cassette depends on number of seconds needed to capture the scene.* | *As a single negative image.*  
*Limited to a 36 exposure film.* |
| **COMPARISON BETWEEN IMAGES** | *Less calibration needed since more images are stored on a single video band.*  
*Calibration not essential between cassettes issued with identical serial numbers since no processing is involved.* | *Calibration is needed between every film of 36 exposures.*  
*Calibration is essential because of differentiation occurring during processing of films separately.* |
| **RESOLUTION OF THE IMAGE** | *Quality of the video film is less than the 35mm film.*  
*Quality of the video image grabber influences the quality of the image.*  
*The addition of a video card improves considerably the situation.* | *Quality of the 35mm film is better.*  
*Resolution of the scanner is the prime source of error, particularly when the negative is processed before being scanned (usually up to 300dpi).*  
*Resolution of the slide scanner can be excellent for negatives and offer the best visual quality (usually up to 1000dpi).* |
| **EXPERIMENTAL MANIPULATIONS** | *Immediate results.*  
*Minimal installation, no need of a scanner.* | *More manipulations.*  
*The film needs to be processed.*  
*The support (photo or negative) needs to be scanned before importing the image into Photoshop.* |

Figure 2.7: Comparative table of the video camera and the 35mm reflex camera for lighting analysis.

<sup>2</sup>The video camera employed for this research is a Sony Hi8 Handicam model CCD-TR81. The electronic viewfinder of 62,4mm may be multiplied eight times when using the zoom. The aperture of the lens varies from F1,6 to F2,2. The minimal lighting for the F1,6 aperture is of 2 lux and the maximal lighting recorded is of 100 000 lux. Optimal results of data acquisition are obtained with a light of at least 100 lux. The automatic setting for the colour temperature is 3200K for the interior and 5800K in the exterior.

<sup>3</sup>The Sony (VCL-R0737) wide angle conversion lens power is 0,7.
Simulation of Space: the Physical Model

The minimal distance of focus influences the minimal size of the experimental model. Since the minimal distance of focus of the video camera is very short, it is possible to construct much smaller models. A wide angle lens can capture a realistic view of the model with limited deformation but the effect of parallax needs to be minimised to obtain relatively accurate quantitative results and facilitate possible interplay between images. For the 35mm camera, the 28mm wide angle lens seems most appropriate since it minimises the effect of parallax. The minimal distance of focus for the 35mm camera with a 28mm wide angle lens is approximately 300mm, which is also the minimal distance between the observer and the vertical surface of analysis. Figure 2.8 represents the size of a model where the vertical surface of analysis would be as large as possible and entirely seen through the viewfinder of the camera at the minimal distance of focus. The planar projection indicates that the horizontal viewing angle is 45° and the vertical viewing angle is 30° (figure 2.8.a). The minimal size of the model in these conditions would be as illustrated in figure 2.8.b): 165mm x 250mm x 300mm. Figure 2.8.c) shows the minimal size of a physical model when the surface of analysis is a square. In that case, the floor plan of the physical model is a rectangle about twice as long as the side of the square.

A wide-conversion lens specially designed for use with a camera recorder increases the focal length of the incorporated lens by 0,7 times, allowing a wider view. The attachment of the lens onto the video camera recorder has no effect on light transmission nor on the sharpness of focus. The only disadvantage is that the corners of the screen may be darken when the zoom is at its widest viewing angle. The video camera recorder offers more flexibility to the size of the physical model (figure 2.9). The minimal distance of focus can be as short as 25mm, but this may not necessarily result in proper simulation since the camera could interfere and even obstruct some light. Figure 2.9 shows the size of a model for an hypothetical distance of 100mm between the observer and the surface of analysis. A model as small as 100mm x 100mm x 100mm could be large enough to record some images, provided there are no obstructions. This size of the model may be large enough to capture images, but a larger model would provide more precise measurements since the quality of the construction is more crucial in a smaller model. The planar projection indicates the horizontal viewing angle at 49° and the vertical viewing angle at 40° which are slightly larger than for the 35mm reflex camera with a wide angle (figure 2.9.a). The proportions of the viewing frame of the 35mm reflex camera however approaches more realistically the field of view of the human eye than the video camera recorder.
The Image of Light

Figure 2.8: Field of view and size of model for a 35mm reflex camera.

(a) planar projection
35 mm camera
with 28mm wide angle lens

(b) size of model
with minimal distance of focus

O: observer
O': projected observer on centre of screen

0 100 200 mm
The construction of a physical model enables possible transformations of space to experiment different proportions and configurations. The choice of material employed for the construction of the models needs to relate to desired luminance values for each surface of analysis. For instance, in most images of this thesis, the reflectance of surfaces are 2% (black), 80% (white) and 55% (grey). The conventional method of verifying the reflectance of a material with a photometer and an artificial sky probably provides the best accuracy, but since the methodology refers to photographic techniques, it is important to acknowledge the tools available for photographers since they contribute to a simplification of the experimental manipulations. For instance, the evaluation of the reflectance of a cardboard can sometimes be difficult to assess with the limited availability of technical material. A reflection density card can establish the density value of a specific material, which can be translated into a reflectance value by using a correspondence graph. The graph shows the percentage of reflectance and the reflection density of a density card in relation to light wavelength. The grey cards however have the disadvantage of deteriorating after a certain period of time but this can be avoided if they are periodically replaced.

The choice of the construction material depends on the need for flexibility during the manipulations of the models in the design process. The material also needs to respond to the experimental method by being totally opaque to light and easily altered when needed. The advantage of cardboard is that it is easily cut or pasted without any sophisticated tools. More sophisticated

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4 This corresponds to a 0,25 reflection density.
5 The reflection density guide is available from the Eastman Kodak Company, CAT 146 5947, Kodak Publication No. Q-16.
materials such as wood could also be employed but they do not have the flexibility that cardboard can offer, and they are mostly suitable for a final assessment or for a limited number of experiments. The method aims to develop a tool of analysis that could be employed from the very first moment a design idea emerges and therefore, the model has to be part of the design process and should be fast and easy to build. The video camera, with its short distance of focus can provide the flexibility to experiment different design solutions within a limited time since the models can be much smaller than with a standard 35mm camera. The only inconvenience consists of deciding on a point of view which will determine the location of an opening to introduce the lens of the camera.

Storage of Data and Experimental Manipulations
In computerised photography, the image on the exposed film is merely the commencement of the process. All images do not need to exist simultaneously since they can be arranged together in a later stage. Images may be transposed on a video tape, allowing 30 frames per second. Two hours of tape can support about 216,000 images. The tape does not have to go through the development process, but can be viewed immediately, in the studio or even in the camera’s viewfinder. Unlike film, the tape can be reused several times. The 35mm reflex camera only allows the storage of 36 images on a single film. The storage capacity of visual data on a single support is therefore much higher for the video than for the 35mm reflex camera. The use of the video image minimises the manipulations of the data before utilisation in the software of image analysis. The processing of the 35mm film is extensive and affects calibration, whereas no processing is involved with the video cassette since images are immediately available. Moreover, the processing of the 35mm image from negatives may often interfere with the need for an immediate access to quantitative results, hence reducing the effectiveness of the integration to the methodological approach, especially in the early design stages.

Resolution of an Image
The resolution of the image depends on the number of pixels for a certain area. Although higher numbers of pixels offer a better resolution of the image, a relatively low resolution will provide reasonably accurate results. The resolution of an image is particularly important for the qualitative assessment of light. It does not have the same significance when it is used for limited modifications of an image or for a quantitative analysis.

Exposure and Sensitivity to Light
The photographer is responsible for the exposure of a scene whereas the brain regulates the eye. The automatic light meter of a camera can also correct the exposure within certain limits. Most automatic exposure meters produce optimal results for spaces with an 18% average mid-grey
reflectance [Holden, 1986]. This is also confirmed by the photographic equipment and development industry. In some specific cases, the 18% average reflectance is not an accurate measure, often occasioning an image to appear too light or too dark. The photographer may deliberately produce an image which is under or overexposed, and has the choice of exposing correctly a portion of an image. The photographer adjusts the exposure according to what is 
thought to be seen. But in a scientific use of photography, the choice of exposure has to remain mechanically determined, to eliminate the interpretation of the photographer and avoid situations where concerns about style could affect the visual result. There are three basic methods of metering light with a camera:

- average reflectance
- incident light
- spot metering

Averaged reflectance calculation is where the full range of tones of a scene are uniformly interpreted without discrimination and the reading is assumed to be an 18% light reflectance [Holden, 1986]. The meter is calibrated so that a camera exposes the film to the right amount of light to produce a good standard negative. The technique is excellent for most photographs, but extreme cases will not produce acceptable results. Shadows and highlights, for instance, may not receive an accurate evaluation. In this type of exposure, very high or low contrast levels may become affected. The average range of reflectance is equally important because any deviation from the standard 18% affects the resulting exposure of all the tones of the image. This produces less accurate images and may reduce contrasts and highlights. The average calculation guarantees a high percentage of successful exposures because most everyday scenes are about the 18% light reflectance, and contrast is well within the film's range to record both highlights and shadows. Exceptions would for instance relate to bright light sources, excessive expansion of shadows, or a large proportion of the sky appearing on the image. In almost all cases where the standard 18% reflectance fails, the range of luminance becomes a problem since the acceptable range of luminance is regulated by the film’s response to light. It is however not possible to represent the exact image produced on the retina in a single photograph, but some parts of the scene must be favoured to ensure visibility of the image. In absolute terms, film emulsions ranging from ISO 125/22° to 400/27° are able to reproduce a luminance range of about 1000:1, whereas the eye can record much higher ratios, of the order of 10000:1 [IES, 1984, p. 3-24].

Incident light meters assess the total light received by a surface rather than the reflected light. The received light is reinterpreted to correspond to the average 18% light reflectance. Incident metering is reliable in most circumstances with the advantage of not being affected by a preponderance of light or dark tones, which affect an average reflectance meter in misinterpreting tones. High and low contrast objects are more accurately exposed because the meter corresponds
to the film's response curve. In black and white photography, the film's response may affect the representation of shadows and black objects by a reading of incident light. Incident meters allow tones to be evaluated more correctly when overall reflectance values deviate from the standard 18% average light reflectance [Holden, 1986]. The use of an incident light meter is not well suited for physical models since their introduction in space can alter the correct reading of light. In some specific cases, it would not even be possible to introduce them without falsification of the results. They are however recommended for real scale studies.

Spot metering is the only measure that calculates an individual tone's reflectance value and overall contrast. The others are calibrated on assumed values and balanced to the 18% light reflectance [Holden, 1986, p. 30]. The spot meter operates on reflected light but in a more precise manner than the integrated meter of the camera. It measures elements individually to reveal their luminance values within a range of 1°. It also provides a direct reading of the overall contrast. The spot meter has the advantage of ensuring the adequate representation of a specific tone of the grey scale. It therefore constitutes a selective mode of metering that relies on the photographer's interpretation of space and is perhaps not the ideal mean of metering for the present methodology since its precision involves the correct determination of the surfaces to be evaluated. The spot meter can easily be operated within a physical model since it can be pointed to a surface directly from the aperture created to introduce the lens of the camera. Although it offers an enormous capacity to measure and interpret, it does not respond to an objective approach of photography as a scientific tool because it demands a thorough understanding of exposure principles and a fair amount of practice [Holden, 1986].

In this research, the exposure meter of the camera is employed for the analysis of a physical model because the average type of metering best corresponds to the design methodology using images, abstracting the architect's interpretation of light in space. Incident light meters are not appropriate for scale modeling and the high precision of spot meters does not correspond to a global evaluation of light in an entire space. The calculation of the average reflectance is generally more precise in the centre of the lens [Holden, 1986]. There may appear a false reading when the position of an aperture is directly in the field of view of the camera, which option would need a special evaluation. Exposure perfection is unattainable in everyday photography because the control over the various processes is nowadays automatic and the quality of the visual result depends on the photographer's judgement of the final image [Holden, 1986]. The comparison between different films is difficult since it is almost impossible to recreate the exact conditions of the processing of a film from one lot to the other [Demers, 1993]. The video camera simplifies the entire process since no development or printing is involved to obtain the visual results. The video appears to be the most appropriate for a scientific use of photography in the present approach, except for the quality and precision of the image which is not as good as for the 35mm reflex camera. There are however professional video cameras that enable the filming of fixed images with a much better quality, but
these are sophisticated and more appropriate for laboratory equipment than for most architectural practices.

**Effect of Adaptation on the Photographic Method**

The video camera offers the possibility to measure light from the translation of the observer through different spaces associated with different lighting conditions, inducing the importance of adaptation. The eye has the capacity to adapt to different conditions of light, and so does the camera, but on different levels. Adaptation alters the sensitivity to the amount and the sensitivity to a change or a contrast [Hopkinson, 1963]. The overall rate of adaptation to a steady state stimulus is governed by a slow photochemical phase, the actual time depending on the starting and final adaptation luminances. This is because the adaptation processes for rods and cones have different time constants, of the order of seven to eight minutes for rods and two minutes for cones [Boyce, 1981, p. 45]. Therefore, when both the starting and final luminances are high, adaptation is rapid since only the cones are involved. When the starting luminance is high and the final luminance is low, a much longer process occurs, the first stage involving the cones, the second the rods. When both starting and final stages are in the low luminances only the rods are involved and adaptation is fairly rapid [Gregory, 1972]. In these terms, the camera has an exposure meter that automatically adjusts its aperture to regulate the exposition of light on the film. The exposure meter does not have the same sensibility and threshold than the eye. Instead of several minutes, the exposure meter adjusts to different luminances in seconds. This aspect does not affect the visual representation in the case of fixed images but in the case of the moving image that records a movement in space, exposure would not exactly reflect the human response to adaptation.

**Glare**

The photographic method of lighting analysis may be limiting in situations where the direct view of excessively bright sources inadequately screened can cause glare. This situation may even be emphasised by high contrasts. For instance, a bright light seen in dark surroundings will cause more glare than if seen in light surroundings. There are hence two physical conditions that create glare: the first arises because of harsh contrasts between juxtaposed areas, and the second is induced by areas of excessive brightness, causing the saturation of the visual mechanism [Hopkinson, 1966, p. 304]. Hopkinson [1963] acknowledges the difficulty to precisely measure the difference between glare and brightness. The photographic method of analysis could however provide some indications on the sources of glare in space. Lam [1986] relates glare and brightness to the occupational nature of a space and establishes that glare corresponds to a source of distraction whereas brightness corresponds to the main source of interest, and hence enhances concentration. The technique of image analysis identifies high brightness areas on surfaces but makes no assumptions whether the source is of any interest to the user. The light distribution in
relation to the viewpoint of the observer or camera is the only considered variable. The evaluation of glare relies on visual perception whereas the photographic method relates to the camera. In a photographic standpoint, the exposure of the image is much affected by glare, often overevaluating the need of light.

Effect of the Location of the Observer
The location of the observer influences the measure of light since the exposure meter calculates reflectances causing a single space to generate different exposures depending on the location of the camera. The acquisition of an accurate reading through the camera is even more difficult when the scene includes a direct view of an aperture. The right balance of light becomes difficult to assess and overexposure is imminent, often associated with effects of glare. Interestingly, this supposes that the photograph could provide some information to assess glare, but because of problems related to the exposure, this could be difficult to verify.

The video camera viewing an illuminated scene often generates an effect known as shading. This causes the video system to record different positions in the image even though the object being viewed is of uniform reflectivity. There are three causes associated with the shading effect [Joyce-Loebl, 1985, p.80]:

- The unevenness of the illumination that does not affect the processor of the camera even though the eye would accept a microscope field in which one side is 50% brighter than the other.
- Video images have a tendency to produce images of greater quality at the centre than at the periphery.
- Optical lenses generally pass more light to the centre of the image than to the sides, but good coating technology tends to minimise this effect in modern, high quality lenses.

It is possible to apply a shading correction to an image by subtraction of grey values on a pixel-by-pixel basis from an image. More accurately, the information would be employed to vary the grey values multiplicatively, which takes much computing power, especially for large images. The importance of limiting the size of the image to the minimal number of pixels is therefore primordial for this operation. The reference image should be smooth to avoid the effect of noise, which would occur if individual pixels were treated in isolation [Joyce-Loebl, 1985, p.80]. Commonly available softwares of image analysis allow some corrections that apply to individual pixels, but because corrections of this nature take a long time to process, they are not really ideal for initial design stages and everyday architectural practice.
Summary

This section has proposed a combined utilisation of the computer and physical models, which is described as a partially computerised design method. The camera provides the visual data and the computer performs the analysis. The method offers the main advantage of providing easily accessible information and the integration to early as well as later design stages. Even with further developments of actual lighting design software, the method will remain valid as a design tool since it encompasses aspects of the design process that are specific to the creative and intuitive approach of the architect. These aspects are further developed in chapter 4 on composition. The limitation of the use of images mainly relates to the bidimensionality of the representation, but as architects are already familiar with abstract representations such as elevations and perspectives, this does not seems problematic. The use of the 35mm reflex camera and video camera recorder as data acquisition supports are compared. It appears that for a more immediate and straightforward approach, the video camera is more effective. It also allows more flexibility of utilisation and construction of small scale physical models. The use of a camera as an instrument of data acquisition is explored throughout discussions on the limitation of exposure of the film and effect of the location of the observer on the light received through the lens. These limitations should be taken into consideration in the interpretation of the results of image analysis.
The Lighting Pattern

Brightness is perhaps the simplest of the visual sensations [Gregory, 1972]. It consists of an experience, whereas intensity is the physical energy of light that may be measured by a photometer, including the photographer's exposure meter. It is virtually impossible to correctly describe a sensation and therefore, brightness is only roughly related to the intensity of light entering the eyes. Hopkinson [1963, p. 19] mentions that we see things because of their brightness, and that strictly, the physical brightness should be termed the luminance. The term brightness therefore usually refers to the strength of sensation resulting from viewing surfaces of spaces from which light comes to the eye [IES, 1984, p. 1.20] and is partly determined by conditions of observation such as adaptation. In fact, the brightness obtained by a given intensity depends on the state of adaptation of the eye, and on various complicated conditions determining the contrast of objects or patches of light Hopkinson [1970]. It is a function of three variables [Gregory, 1972, p. 74]:

- The intensity of light falling on a given region of the retina.
- The intensity of light that the retina has been subject to in the recent past.
- The intensities of light falling on other regions of the retina.

The brightness sensation cannot be measured in the same manner as physical quantities are measured [Moon, 1961, p. 421]. However, this research uses the exposure meter of the camera to interpret brightness sensations. It therefore excludes the individual sensation as the camera provides the mechanical interpretation of brightness, which refers to the photometric brightness, or radiance of an image.

Grey scales are available for the analysis of brightness zones on a photograph. The zone system of the photographer is based on the principles of sensitometry, but it is essentially a visual procedure [Michel, 1996, p. 70]. Photographers compare brightnesses on a black and white photograph with the grey scale. The aim is not to describe precise separations between brightness zones, but to define the final quality of the image, and the expected grey values for different photographs. The directional characteristics of light reveal textures and volumes which cannot be measured in terms of the illuminance on any single surface, because this would neglect the third dimensional aspect of light flowing into space. The flow of light, a concept developed by Lynes et al. [1966], consists of subjective assessments of the strength and direction of lighting either at a point or within a light field. Holmes [1975] states that it could be measured by the difference in the amounts on the front and back of a plane surface. The lighting pattern could then assist in the definition of modelling.

The study of lighting patterns allows an understanding of the properties of a space-aperture configuration that defines possible modifications and enhances some of the qualities of space. The directional aspect of light can therefore indirectly be measured on a surface with the grey scale.
The image can generate the lighting pattern of a surface. It is possible to analyse a bit mapped image and to establish the lighting pattern that emerges from the classification of pixels into groups of brightness values defined within certain boundaries. This process is instantaneous within the software of image analysis when applying a posterisation command. The pattern reveals the morphology of light and provides an indication of the intensity contrast levels. It also illustrates the notion of concentration of light, in the sense that it relates to focal aspects of vision. The more concentrated light has a tendency to *focalise* vision whereas the more disperse light expands the visual field. Lighting patterns may also refer to intensity levels on surfaces and can be indicative of the following variables:

- The morphology of light and its dispersion on surfaces.
- The relative contrast levels on surfaces.
- The relative concentration of light on surfaces.
- Gradation or uniformity of light on a surface.
- The relative intensity levels between surfaces.

In photography, the posterisation technique corresponds to a division of an image into a few flat tones by making two or more high-contrast negatives. The same result is obtained from the software of image analysis. In this research, posterisation is an important function of the brightness separation that generates lighting patterns obtained from the classification of pixels into groups of pixel values defined within certain boundaries. The operator has the opportunity to decide on the refinement of the lighting pattern by choosing the number of categories for the classification of brightnesses. For two brightness levels of 0% and 100%, the pixels of the image are divided into these two categories and constitute a pattern of black and white patches (figure 2.10.b). In that case, the threshold of the pattern is at the 50% brightness value, middle brightness of an absolute scale. An image that contains 256 grey levels, from 0 (black, 0% brightness) to 255 (white, 100%) has a threshold grey value of 128 (50% brightness). This absolute scale enables the comparison between different parts of an image, and also the comparison of lighting patterns between different images.

![a) Original image](image1.jpg) ![b) Modified image](image2.jpg)

*Figure 2.10: Separation of an image in two brightness levels: 0% and 100%.*
In the analysis of an image, the surface of interest can be isolated (figure 2.11) to compare the pattern difference between design solutions and lighting systems. The entire image could also be selected, which would not affect the result. In the isolation of the surface of analysis, the meticulous selection of the surface is important to ensure that only relevant pixels become part of the analysis. The separation of the image into three levels divides the images in categories of 0%, 50%, and 100% brightness (figure 2.12 centre). The separation in five levels leads to categories of 0%, 25%, 50%, 75%, and 100% brightness (figure 2.12 right). Any number of levels could also apply, depending on the nature of the image and the type of analysis that needs to be performed. The contour of the pattern can be traced by the computer, although roughly, when using the command find edges after posterisation of the image (figure 2.13). In the present version of the software, the quality of the line can not be adjusted, but this could eventually become possible by reducing the pixel tolerance of the function.
The following scale (figure 2.14) illustrates the grey values attributed to each of the five brightness levels. The percentage of these grey values does not exactly represent the theoretical perceived brightness, but it constitutes a basis for the comparison of images. However, the Luminance Brightness Rating System, discussed in the following section, identifies the relation between the perceived brightness and the grey scale values. The perceived brightness could be useful in studies relating to perception, but it is not necessary to establish the correlation between photographic and photometric methods since the aim of the present context of analysis is to establish a basis for the comparison of contrast (refer to chapter 3).

![Grey scale values](image)

*Figure 2.14: The five lighting zones (Demers' approach).*

### Other Lighting Patterns

Luckiesh [1916] recognised that the problem of light affecting the appearances of objects could be divided into two parts; the consideration of the quality, and the distribution of light. He associates the former with colour and the latter with light and shade. Although light and shade do not always definitely reveal the form of an object, it is of great importance in vision, playing a leading role in nearly every visual impression [ Luckiesh, 1916, p. 22]. Cuttle [1971] has developed an approach to patterns of light and shade and the appearance of objects. He argues that lighting patterns on a solid object under a directional light are the combined effect of three patterns:

- The illumination pattern.
- The shadow pattern.
- The highlight pattern.

Each pattern has its own characteristics of appearance and relates to specific light conditions, as described in the following sub-sections. The light field, total distribution of luminous flux within a finite space, relates to the three lighting patterns and may be manipulated to produce an infinite variety of configurations. The attainment of a particular balance of the lighting patterns is appropriate as a design objective when a specific object, at a fixed position, is identified as being of particular visual importance, and preferably when the principal direction of view is specified [Cuttle, 1971]. In spaces where objects have an equal visual importance, the variations of the appearances of the lighting patterns from object to object mostly correspond to variations of object characteristics than to variations of lighting. The directional nature of light, the form and surface reflection properties of
an object, and the viewing angle of the object are determinant of the formation of lighting patterns. Sections 1, 2 and 3 discuss Cuttle's lighting patterns with reference to other theories on patterns.

The Illumination Pattern

Objects produce illumination patterns that are specified by their orientation and the illumination value for that orientation, provided that objects are not re-entrant [Cuttle, 1971]. The re-entrant object corresponds to a configuration that causes no partial shading on any of its surface element. The illumination pattern is obtained from the interaction of object form and illumination solid, this latter being a product of the illuminance solid. The illumination is therefore a form-related pattern, and will determine the surface luminance pattern of diffuse-surface non-re-entrant objects having uniform surface reflection properties. The variation of surface reflection properties is largely irrelevant in this context except when related to the form of objects. The strength of the illumination pattern is directly related to the strength of the flow of light [Cuttle, 1971]. The illumination pattern does not refer to the horizontal plane, nor to functional lighting, but simply to the appearance of objects under light.

Concept of the Three Lighting Zones

In relation to the illumination pattern, Robbins [1986] has developed the concept of the three lighting zones to establish a morphological relationship between apertures and space. Robbins argues that the lighting pattern remains relatively stable even when the absolute illuminance is changing. The study of relative illuminance provides a reasonable comparison for the evaluation of a daylighting concept and does not require the analysis of hourly or seasonal simulations, nor the absolute illuminance in space [Robbins, 1986]. The lighting pattern corresponds to the illumination on an entire horizontal surface instead of single objects, which confers a global approach to the analysis of an entire space. Although the concept refers to task lighting, it could be possible to develop a similar approach to the design of vertical surfaces. The three lighting zone concept provides a context of analysis where different illuminances are classified into the primary (1), secondary (2) and tertiary (3) zones to constitute a basis for discussion about the lighting distribution (figures 2.15 and 2.16). The zones generally relate to functional aspects of space and represent specific types of activities for the occupants. The primary zone has the highest illuminance and usually relates to the main occupational area of a space. The tertiary zone, usually non-daylighted, is often used for circulation. This concept enables a classification of lights and becomes a tool of analysis. A more detailed analysis of the actual lighting performance can be undertaken after establishing the daylighting concept.
There are noticeable differences between the patterns for lateral (figure 2.15) and zenithal lighting concepts (figure 2.16). One of the differences is that the latter generates stronger primary zones located directly under the apertures with the other zones generally concentric (figure 2.16). Figure 2.15 illustrates different combinations of apertures in lateral light. The primary zone, generally larger than the second and tertiary, is located near the source of light. The same configurations of space and aperture would however create different patterns on vertical surfaces.

Figure 2.16 illustrates some zenithal lighting concepts where the dotted lines represent the zenithal apertures. In zenithal light, the longitudinal and latitudinal spreading of the pattern are indicative of the distribution of light [Robbins, 1986]. The longitudinal spread represents the daylight distribution along the length of the aperture and the latitudinal spread relates the distribution normal to primary apertures. This research adapts the spreading concept of the lighting pattern to characterise vertical surfaces in lateral and zenithal lighting systems, as indicated by the arrows in figure 2.16 (refer to chapter 3). The vertical spread could describe the distribution on vertical surfaces. The computer image analysis allows the determination of a desired number of zones. As the designer uses the system, the concept of zones becomes familiar and use of the computer becomes mainly important for the final refinement of a project.
In the present research, the image is subdivided into five brightness levels for a relatively accurate interpretation of the pattern. Robbins’ concept of the three lighting zones is mainly based on the physical occupation of a space. As earlier demonstrated (figure 2.12), it is possible to divide the image into three zones, or any number of zones, to establish a comparison with the functional lighting pattern developed by Robbins, but functional aspects are not relevant to the analysis of vertical surfaces. The subdivision into five levels produces a still rather simple pattern, with the advantage of offering more precision, particularly on the number of light gradients or zones on the image. Since Robbins’ approach uses functional aspects, these three brightness levels could also be converted into desired brightness levels, as in the Luminance Brightness Rating System, discussed below.

The Nine Brightness Zones

A scale of brightness called the Luminance Brightness Rating (LBR), similar to the grey scale of photography, was developed for the design and fabrication of the illuminated architectural environment (figure 2.17). It was derived from the Munsell Neutral Value Scale, and determined for the simultaneous interaction of surface and light [Michel, 1996, p. 72]. It acts as a measuring instrument for judging the relative brightness of a building material, and as a measure for predicting proportional shifts in brightness when the material is subjected to changes in illumination and angle of slant in architectural space. There are nine zones, which number was defined for ease of remembering the scale. The two extremes represent the highest and lowest brightness, respectively white and black, whereas the middle grey is in the centre. The Luminance Brightness Rating System has a middle grey value of 30%, based on Munsell notation, since it appears that the human eye perceived the middle grey as such, instead of the actual grey value of 50% obtained from the computer analysis [Michel, 1996, p. 72]. The nine brightness zones that constitute the LBR System can also apply to the analysis of the lighting pattern with a posterise command of the software of image analysis. The brightness levels could also be converted into perceived brightness percentages, as described in figure 3. This scale is similar to Robbins’ three lighting zones, and to the earlier discussed concept of the five brightness zones. All these scales have odd numbers of zones to ensure the location of the middle brightness value. The computer software of image analysis also enables the more traditional practice of brightness determination on original black and white photographs.

<table>
<thead>
<tr>
<th>white</th>
<th>100%</th>
<th>87,5%</th>
<th>75%</th>
<th>62,5%</th>
<th>50%</th>
<th>37,5%</th>
<th>25%</th>
<th>12,5%</th>
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<tr>
<td>middle grey</td>
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Corresponding perceived brightness, according to the Munsells values:
3,1% 6,6% 12,0% 19,8% 30,0% 39,5% 50,7% 68,4% 90,0%

*Figure 2.17: Nine lighting zones (Luminance Brightness Rating system).*
The Shadow Pattern

Shadows create patterns on surfaces and objects. The cast shadow describes the shadow of an object cast upon its background. Shadows are predictable and their strength relates to the directionality and intensity of the light source. Stronger shadows that have well defined contours are associated with higher contrast levels, and in art, they create chiaroscuro (figure 2.18). It is a form related pattern that is employed in lighting design to modify the appearance of objects within the shadow, rather than the appearance of the shadow caster itself [Cuttle, 1971]. The cast shadow also represents the contained shadow to shadows that occurs on surfaces of re-entrant objects [Cuttle, 1971]. Cuttle's definition of the shadow pattern differs from the known cast shadow. The shadow pattern appears only when the surface textures of an object are suitable. It consists of a contained shadow on an object's surface, which differs from the definition of the cast shadow that represents the projection of an object on other surfaces. The shadow pattern is produced by the interaction of object, form, and luminance solid, but unlike the illumination pattern, it responds to influences of the light field that are not specified by the illumination solid. Its formation is due to a variation of surface illumination, distinct from the illumination pattern.

Photography and the Shadow Pattern

Nurnberg [1968] presents a classification of shadows that relates to the practice of photography. The two main types are the cast shadow and the bogus shadow (figure 2.19). Photography also distinguishes between pure and diluted shadows. The pure shadow is completely black and the diluted shadow is lightened up to varying degrees [Nurnberg, 1968, p. 94]. These characteristics apply to the cast and the bogus types.
The cast shadow is an area from which light is partially or totally eliminated by a more or less opaque obstacle introduced between the light source and the base of projection. The characteristic of the cast shadow is its dependence on the existence of a light-obstructing substance. It will therefore have a definite shape. The shadow may vary in its definition, size and shape. The shadow definition refers to either the hardness or softness of a shadow, which corresponds to the characteristics of sharpness and fuzziness. It depends on the size of the light source and the distance of the obstruction from the projection base [Numberg, 1968, p. 96]. The shape and size of a shadow depend on the following factors: the distance of object to base of projection, the relative position of the light source (angle of light-incidence), the angle of object to projection-base, and the surface-form of projection-base, which may be plain, convex, or concave [Numberg, 1968, p. 97].

The bogus shadow is an absence of light caused by a bend in an object’s surface or by the limited range of illumination from the source. The degree of hardness of the shadow edge is determined by the form of the object itself, and by the quality of light. The bogus-object shadow is instrumental in rendering form. The softer its edge, the softer and rounder will the object appear; the harder its edge, the more angular the result. The degree of hardness of the shadow edge is determined by the form of the object and the quality of light. The bogus-source shadow occurs when the area outside the field of illumination appears to be dark or in shadow [Numberg, 1968, p. 99]. The shape of the bogus shadow depends entirely on the angle at which light meets the projection-base.

The Highlighting Pattern
The highlighting pattern is generated by a specific form and source of light. It consists of a reflected image of the surrounding light field superimposed on the illumination pattern [Cuttle, 1971]. It is only apparent when the surface has an appreciable gloss, often relating to reflections of light sources and other surfaces of high luminance. Complex patterns of light and shade can be found
on surfaces of highly reflecting materials such as aluminium and other reflecting surfaces (figure 2.20 and 2.21). Such materials produce highlights which can be evaluated through the software of image analysis since they directly relate to gradients of light on a surface. The detection of the highlighting pattern is possible when a brightness separation occurs, but the problem with actual softwares of image analysis is that other similar brightnesses issued from other patterns also appear. The highlighting pattern could therefore become an integral part of the illumination pattern. The resulting image however emphasises the highlighting pattern well enough to allow calculations and evaluation of its size and visual impact. Figure 2.20 represents a sheet of aluminium paper with a limited number of folds whereas figure 2.21 shows the same sheet of aluminium subjected to more manipulations and deformations. This illustrates the potential of a single material to produce different impressions and highlighting patterns, depending on the level of transformation and alteration. Lighting effects are much different between the two images although the source of light is constant. This also relates to the orientation of the highly reflecting material according to the light source and position of the observer.

![Figure 2.20: Aluminium foil with folds.](image1)

![Figure 2.21: More manipulations with aluminium foil.](image2)

The lighting pattern indicates the presence of more surfaces of high brightness in figure 2.22 than in figure 2.23. These high brightness zones are identified through the posterisation of the image, which could define highlights on the reflecting surface of aluminium. The posterisation into five or even three brightness zones is sufficient for the analysis, but the separation into only two zones would not identify precisely enough the limits between the highest and middle brightnesses. The highlights are presented with much higher brightnesses than for other areas of the reflecting aluminium, and are therefore, relatively easy to identify.
Summary

This section has proposed a method to obtain a lighting pattern from a bit mapped image with the computer software of image analysis. The technique is simple and proposes a brightness separation of pixels into different grey values. It has the advantage to divide the image into different numbers of brightness zones, according to the type of analysis needed. This section has also explored other theories related to the methodological approach about lighting and shadow patterns. Robbins' theory [1986] shows patterns obtained from horizontal projections in space and proposes an evaluation of the spreading of the pattern in relation to the type of apertures. This concept is particularly relevant to establish the theoretical approach to the overall evaluation of contrast on an entire surface (refer to chapter 3). Cuttle's approach [1971] is specific to the nature of objects and their textures. It identifies three patterns that influence the visual appearance of objects. It does however not propose a schematisation of the pattern such as Robbins, but the approach could eventually apply to late design stages. The lighting patterns obtained from images could also relate to Cuttle's three lighting patterns, as described in the sub-section on the highlighting pattern. The lighting pattern from an image could provide an analysis of light in space. The next section will establish a correlation between photographic and photometric methods of obtaining the pattern.
The Image of Light

Correlation between Photometric and Photographic Methods

This section verifies the correlation between the illuminance isolux curves and the lighting pattern. It examines the results obtained from the traditional photometric experimentation compared to the results using the proposed method of analysis of images obtained from the brightness zones of video images taken in the model. This suggests that it would be possible to extrapolate the value of the photometric data to determine other points of space without actually needing to perform any grid measurements.

The camera possesses a photometer which also responds to light. It is generally assumed that the camera offers only a limited accuracy as it is not as precise as laboratory instruments. Laboratory photometers are highly precise and are usually fixed in position to provide accurate results [Hopkinson, 1963]. Portable photometers of lower accuracy are most useful for photometric surveys on site, outside the controlled conditions of the laboratory. They offer more versatility but less accuracy than laboratory instruments. The cosine effects related to the angle of incidence between the luminous flux and the receiving surface of a photocell may occur for the camera as it occurs for photocells. The "cosine rule of illumination" is one of the fundamental rules of photometry [Pfitzman, 1970]. It appears that because photocell surfaces offer a proportion of specular reflection, and are therefore not uniform diffusers, their response for large angles of incidence is substantially inferior than what is required by the cosine rule [Pfitzman, 1970, p. 16]. In the case of a camera, the related error is partly due to the obstructed light caused by the rim of the lens. The resultant error increases with the angle of incidence, and for photometric and even photographic measurements where the luminous flux comes at wide angles, an uncorrected meter may read a lower value often 25% below the normal expected result [IES, 1984, p. 4-6]. It is not possible to correct the lens of the camera in the same manner as for the photocell. For instance, the addition of a diffusing cover to the lens of the camera would not allow any possible image. It is also difficult to have any control over the rim of the lens since it is manufactured to allow the addition of other accessories.

In photometric measurements, the size of the model relates to the size of the photocells that record the illumination. The video camera recorder has the advantage of offering the possibility to use smaller models since the error relates more to the precision of the image and the quality of the fabrication of the models than to the size of the instruments. Only the type and quality of the lens of cameras affect the size of models. When a study requires the fabrication of a large number of models, it is particularly advantageous to reduce the size of the physical models. The video camera also allows even shorter distances of focus than the conventional 35mm camera. For the present
The purpose of validation, a large model is used to accommodate both photometric and photographic measurements. The illuminance is recorded from a laboratory photometer with the use of two photocells to produce a pattern of isolux curves. The lighting pattern issued from brightness data is obtained from the analysis of an image taken in the same model with a video camera recorder. The model is placed into the artificial sky to ensure modelling of the CIE (Commission Internationale de l’Éclairage) overcast sky condition, allowing consistency of the results.

Types of Measurements
Two types of measurements are compared: the photometric and the photographic approaches. Photometric measurements are obtained from the illuminance recorded by photocells inside the model. The photographic method depends on the computer analysis of a photograph taken in the model, and is also referred as the partly computerised method of lighting analysis previously exposed in this chapter.

Photometric Approach
Photocell measurements involve time to obtain the required number of datas and precision in the placing of the cells within the physical model. The experimental approach includes an error factor associated with the added reflectance of the white surface of the probe reflecting light towards the top of the model. The larger the amount of surfaces of the probes inside the model, the greater is the effect on the lighting pattern since the reflectance of the horizontal plane becomes affected by the great amount of the white diffusing covers of the photocells. The diameter of the photocells used for the experiment is 20mm, which is suitable for the study of scale models of a minimal scale of 1:50. Correct position and orientation of the photocells inside the model is important to ensure precision in modelling different lighting conditions. There are three different types of photometric measurements involving more or less manipulations: single point, line, and grid measurements [Robbins, 1986].

Single Point Measurement
There is only one probe located at a predetermined reference point in the model, which could consists in the centre of space, to establish a rough comparison between different systems of apertures [Robbins, 1986]. It may appear that in certain cases, the light source is centred on space whereas in other cases, it is not. Asymmetrical lighting patterns induce the problem of finding the right location for the probe inside the model. This suggests that the location of the probe depends on the type of lighting system. The photometric method using images can provide a single point measurement at any location on the surface of analysis. It can even be performed after the
experimentation to locate the lighting pattern, which can considerably reduce the time spent in the artificial sky. This also applies for the line and grid types of measurements.

**Line Measurements**

The line measurement is most commonly performed by measuring the absolute illuminance at predetermined reference points in a row, either perpendicular or parallel to the aperture. The row is also usually centred on the aperture, and the minimum number of reference points in a line is three [Robbins, 1986, p. 229]. Line measurements should correspond to the daylight system of the space as this would best define the characteristics of the system. To establish the location of the probes, a rough idea of the lighting pattern is needed.

**Grid Measurements**

Grid measurements usually involve probes that are equally spaced in columns and rows. Although they constitute the most complex and time-consuming method of measuring illuminance in space, they also provide the most useful information to constitute the curves of equal daylight factor values on isolux curves [Robbins, 1986, p. 230]. It is this type of measurement that is used for the correlation.

**Photographic Approach**

For the method using image analysis, the positioning of the camera is the most critical aspect of the manipulations since it influences the direction and the field of view in which the integrated posemeter will record its lighting measurements. The advantage of the photographic method is that all the possible points are instantaneously recorded on the film, hence providing all types of measurements when required. The image analysis provides results that can be arrayed in a matrix or, in computing terms, raster graphic. The advantage of raster graphics over photocells measurements is that they provide grids of different sizes, according to the complexity of the image, and therefore offer different levels of precision in displaying the quantitative information.

**The Experiment**

The size of the model is 300mm x 300mm x 450mm, made of 3mm heavy cardboard painted mat black in the inside and glossy white on the exterior. The mat black reduces internal reflections and the glossy white optimises reflections and avoid absorption of light in the mirror walls of the artificial sky. An aperture of 110mm x 110mm is located on a vertical surface. Figure 2.24 illustrates the experimental setting.
In photometric measurements, two photocells are inserted inside the model on a grid where sixty-four different measurements are eventually taken. The work is considerable because the displacement of each cell needs to be carefully accomplished since an error of alignment of a single millimetre can affect the recorded illuminance for a given location. The use of two probes instead of sixty-four lengthens the experimental process of data acquisition, but it minimises the error associated with the simultaneous insertion of many photocells caused by the high luminance of their combined surfaces. There is a 5mm height difference between the surface of the photocells and the floor. The horizontal surface was chosen for practical reasons and because it is where most quantitative data are prevailing in actual daylighting studies. The 64 values are classified according to their co-ordinates into a worksheet and the data are processed using the Microsoft Excel software. It produces tridimensional graphs and even bidimensional views of the plotted data.

<table>
<thead>
<tr>
<th>Vertical axis (position in mm)</th>
<th>Horizontal axis (position in mm)</th>
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<tbody>
<tr>
<td>281.25</td>
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<tr>
<td>243.75</td>
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<td>206.25</td>
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<td>168.75</td>
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<td>131.25</td>
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<td>56.25</td>
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Figure 2.25: Photometric data according to vertical and horizontal coordinates.
For photographic measurements, a video camera recorder is mounted on the top of the model, viewing the horizontal surface of analysis (figure 2.24). It is recommended that the field of view of the camera encompasses a slightly larger area than the surface of analysis to minimise the effect of parallax, which consists in the curving of straight lines towards the edges of the photograph, caused by the lens. This also facilitates the selection of the surface of analysis into the software of image processing (figures 2.26). The average brightness of the corresponding location previously occupied by the photocells can be extracted from the photograph to compare the data between the photometric and photographic methods. The centre of each square of the grid represented in figure 2.26 corresponds to the location of the photocell for the photometric measurements. The image analysis of the lighting pattern is performed with the Adobe Photoshop software. It is also possible to divide the photograph into different brightness levels to verify the correlation with the illuminance data.

The computer analysis enables the isolation of a surface from the rest of the image to evaluate its content. Figure 2.27 shows the pattern when the pixels of different brightnesses are divided into five levels (0%, 25%, 50%, 75% and 100%) with the *posterise* function of the software of image analysis. It takes into account all the pixels of the entire surface of analysis. The selection of the entire image instead of the selected surface of analysis would however not alter the lighting pattern.
For the purpose of the correlation it is possible to divide the horizontal surface of analysis into a certain number of squares, each containing an identical number of pixels, and each representing the location of a photocell. Photometric data are therefore associated with a square of the grid, and each corresponding square of the bit mapped image is converted into the average grey value for the area it covers (figure 2.28). The software of image analysis provides the brightness for each of these square surfaces.

The matrix (figure 2.29) consists in the numerical representation of the grey scale mosaic (figure 2.28) where numbers define the brightness percentage of each square. Figure 2.30 shows the matrix of data obtained from the photocells measurements, expressed in lux. The grid of figure 2.29 is apparent to a layout of photometric measurements (figure 2.30) taken with photocells, but expressed in brightness percentage.

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Figure 2.28: Mosaic representation of brightnesses issued from the photographic representation (of figure 2.26).

Figure 2.29: Photographic data: matrix of brightness mosaic representation (%).

Figure 2.30: Photometric data: matrix of data obtained from photocell measurements (lux).
It is assumed that the photographic data should provide more accuracy towards the centre of the image since the photometer of the camera provides a central measurement of light instead of the local measurements obtained from the photocells. The matrix data are therefore presented into four zones or levels of precision (figure 2.31) where the data in zone 1 and 4 would respectively have the highest and the lowest levels of precision. This also refers to the physiology of the eye since the centre of the binocular field consists in the central *foveal vision* where most focus seeing occurs (figures 2.32 and 2.33, zones a) [Robbins, 1986, p. 24], and corresponds roughly to zone 1 in the matrix (figure 2.31). Vision within a 30° angle in any direction around the centreline of foveal vision is the *near surround* (figures 10 and 11, zones b), and relates to zones 2 and 3 on the matrix (figure 2.31). Within this region, the eye can discriminate brightness differences between an object and its background [Robbins, 1986]. The *far surround* at the edge of binocular vision (figure 10 zones c and d, and figure 11 zone c) relates to the peripheral vision which offers less precision. It corresponds to zone 4 of the matrix (figure 2.31).

![Figure 2.31: Four zones of precision.](image1)

![Figure 2.32: Typical binocular visual field: (a) foveal vision; (b) area seen by both eyes; (c) area seen by left eye only; (d) area seen by right eye only. (adapted from Robbins, 1986).](image2)

![Figure 2.33: Visual range: (a) foveal vision; (b) near surround; (c) far surround. (adapted from Robbins, 1986).](image3)
The regression curve (figure 2.34) is drawn from the photographic data obtained through the computer image analysis against the photometric data of photocell measurements. The difficulty with a regression relates to the non-independence of neighbouring pixels [Aylsham, 1996], but it is still interesting to verify if any correlation between the two methods is possible. The vertical axis of photographic measurements is limited by the 0% and the 100% brightness values whereas the horizontal axis of photometric measurements has a lower limit at 0 lux, but there is no maximum.

\[ y = 20.21 + 0.92x \]

**Figure 2.34: Regression curve of photometric data in function of the photographic data.**

The curve of figure 2.34 indicates a linear tendency of the grouping of most data with properties of direct proportionality. The equation of the mathematical regression of the straight line is indicated on the graph. The graph also shows a horizontal grouping of some of the data that have higher photographic and photometric values, and which are mostly situated within zones 2 and 3 near the centre of the lighting pattern. This horizontal grouping relates to the photographic method. The photometer of the camera is indeed not as precise as a photocell, especially for the highest and lowest values. Also, the film of the camera records the best results for mid-brightnesses, leaving less precision for extreme values [Holden, 1986]. The horizontal grouping is therefore probably related to the maximal sensitivity of the photographic emulsion. This also explains the fact that the curve of the equation does not reach the origin of the graph as it should, since 0 lux should theoretically equal 0% brightness. The separation of the matrix into the 4 zones of precision reveals that the most scattered values are located within the perimeter of the surfaces of analysis (zone 4). This may occur because the highest brightness values are located towards the centre of the image.
Figure 2.35 represents the lighting pattern on the horizontal surface of analysis, obtained from the matrix data (of figure 2.29) by using the photographic method. The pattern was traced from the 64 data recorded in the matrix. A more precise pattern can emerge from all the pixel data of the image, as shown in figure 2.28, but the simplified representation from the matrix data is conveniently used for the correlation in accordance with the mathematical regression (figure 2.34). Figure 2.36 represents the corresponding lighting pattern obtained from the photometric data using photocell measurements. The categories that were used to define the limits of the zones are defined in the table (figure 2.37). The pattern is divided into five categories of brightnesses (0%, 25%, 50%, 75%, 75%, and 100%). The dotted lines (in graph 4) indicate the separations between the brightness zones on the image. The corresponding categories for photocell measurements were defined according to the curve equation of figure 2.34. The patterns are very similar, considering the limitations previously expressed about the regression curve of figure 2.34. The 0% lighting zone disappears on the pattern of figure 2.36 since the mathematical regression suggests the non-existence of such low values. This reflects the limitation of the correlation for extreme values.
It is also possible to compare the lighting patterns on a tridimensional scale of analysis (figures 2.38 and 2.39). This does not illustrate the spatial distribution of light in space, but it is useful in expressing the correspondence between the photographic and photometric measurements. The square base of the graph represents the horizontal plane of the surface of analysis. The horizontal projection of the tridimensional graphs would therefore produce the lighting patterns of figures 2.35 and 2.36. The tridimensional representation of the photographic method (figure 2.38) is much more compact than for the photometric representation (figure 2.39), illustrating the effectiveness of the photographic method for middle brightness values.

Figure 2.38: Photographic method: tridimensional representation of the lighting pattern (matrix figure 2.29).

Figure 2.39: Photometric method: tridimensional representation of the lighting pattern (matrix figure 2.30).
The Image of Light

Conclusions

The correlation between photometric and photographic methods has been demonstrated for middle brightness values. The regression curve suggests that the highest and lowest values offer less precision for the photographic method. Additionally, there is a limit to the precision of single point measurements transposed into curves of isolux data, although the sixty-four data provide a relatively accurate lighting pattern. The positioning of the photocells inside the model can itself considerably affect the precision of the data acquisition. Also, the fact that the lateral location of the aperture in the experimental setting may have increased the error on the measurement of light received on the photocells due to the cosine factor. The number of data acquired on a surface greatly influences the precision of the curves of analysis. More exhaustive tests with different types and locations of apertures would establish the main factors affecting the correlation and establish with more precision the brightness levels at which the camera performs differently from the photocell measurements. It would also be interesting to verify the correlation with a zenithal aperture, but, because of the photographic technique, this may become problematic if the camera needs to occupy the centre of the actual zenithal aperture to record a picture of the floor area. It would also be interesting to verify the incidence of a surface placed at a slant to record and compare the performance of photographic and photometric measurements. This suggests that a more performant camera posemetre combined with a type of film that allows a wider range of brightnesses could eventually enable the perfect correlation between the two types of measurements.

The mathematical regression curve (figure 2.34) confirms that there are some relations between the photographic and the photometric methods which are especially concordant in defining the lighting pattern. The correlation shows that it could be possible to extract photometric information about the illuminance of a surface without the need to proceed exhaustive photocell measurements, especially within middle brightness values. This information is much valuable at the earlier design stages since it allows to obtain, in a minimum time and physical means, some idea of the characteristics of light received on the surface of analysis. The photographic method could become a design tool that allows as much precision as photometric measurements when a more performant camera will be available. This will contribute to new developments in lighting science and design, and allow perhaps even more precision than the traditional photocell measurements since much more data are taken into account, combined with much less experimental manipulations. Moreover, the photographic approach allows much more flexibility of utilisation than the photometric method. The next chapter presents a method of analysis of photographic images based on contrast values.
# Contrast as a Global Integrator

## Chapter 3

### The Evaluation of Contrast

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### Contrast and the Lighting Pattern

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### Conclusions

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This chapter suggests a quantification of the information provided through the analysis of the lighting pattern relating physical and perceptual aspects of light. The following concepts should therefore be considered as a guide for a more objective evaluation of lighting conditions. The morphological analysis of the lighting pattern leads to a visual classification of lights which introduces some applications of the lighting pattern for the quantification of subjective matters. This approach acknowledges the importance of the unmeasurable, but recognises that some morphological aspects of light affect the perception of space. The exploration of subjectivity involves emotive aspects of light, allowing for individual interpretations and non prescriptive results. It will be argued that light as art must remain unmeasurable, impalpable, to preserve its poetical connotation. The following chapter suggests that some aspects of light are easily qualifiable through the interpretation of quantitative parameters issued from morphological factors such as the lighting pattern. The brain is much more complex than a computer and its refinement encompasses the unmeasurable, which the machine can not comprehend. The pattern constitutes a graphic representation of the physical behaviour of light on surfaces. Perception of a particular ambience could associate with different lighting patterns interpreted through spatial configurations [Demers, 1993]. Whilst the emotional component of light is highly subjective, the pattern enables reasonable predictions. Contrast becomes the main integrator of visual aspects of light and provides a quantification of the results. The perceptual aspect concerns affective or evaluative response to stimuli that determine the environmental influence of light on people. The information to establish a framework of interpretation, expectation and relevance of interest are not contained within the lighting pattern, but some contrast particularities nevertheless enable the association of lighting patterns with perceptual sensations.

Contrast is a physical variable that relates to most aspects of light. The visually perceived contrast on the image depends on its grey level range, but also on psychophysical factors such as the spatial structure and the ambient qualities of light in a selected viewing area of a space [Schowengerdt, 1983, p. 13]. Furthermore, both visual and numerical contrast depend on the quantification of an area in relatively small portions of an overall high contrast image, which may have low, high, or
Contrast as a Global Integrator

intermediate contrast [Schowengerdt, 1983]. Contrast associates with modelling, which is important to reveal details in the visual field. The proportions of direct and indirect light have a marked effect upon contrast and the character of space. Much direct light generates strong modelling and a rather dramatic character whilst indirect light generates lower contrast and a softer, more restful character [Hopkinson & Kay, 1969, p. 69]. Notions of scalar and vectorial illumination are more relevant to the visual appearance of the luminous environment than measurements of illumination on a surface, which rarely correlate with the subjective assessment of the quality of light in space [Lynes, 1968]. In certain situations, similar scalar and vectorial values could produce different lighting effects. The differences in modelling and shadowing which would result from a single large source would tend to produce very little shadows, where smaller sources distributed over the same area would tend to produce multiple shadows [Hopkinson & Kay, 1969, p. 30].

Contrast is easily identifiable with the image processing software that produces lighting patterns, indicative of the light distribution. There are different means for evaluating contrast, depending on the type of space and aperture system, and also on the type of information needed for the assessment of a design solution. There are more than one descriptive of contrast to a specific problem, and different interpretations and calculations methods are possible. Contrast displayed on an image is an important factor in the assessment of light since it can become an indicator of the visual quality of space. This research does not explore the problem of contrast-sensitivity, but rather concentrates on an interpretation of luminance contrast on images. Contrast can be measured punctually, between two points on a surface when selecting pixels, or it can be interpreted through a small area consisting of a certain number of pixels. This research introduces a more global approach where contrast is interpreted on an entire plane.

The Evaluation of Contrast

Punctual method of analysis
Luminance contrast (C) usually depends on the luminance, between an objet and its background, and may be numerically defined in several ways [IES, 1984, p. 3-15]:

\[ C_1 = \frac{(L_d - L_b)}{L_b} \]

where \( L_d \) = luminance of detail
and \( L_b \) = luminance of background
The equation $C_1$ represents relative visibilities. It results in contrast values that range between 0 and 1 for objects that are darker than their backgrounds, and 0 and $\infty$ for objects that are brighter than their backgrounds.

$$C_2 = \frac{(L_g - L_l)}{L_g}$$

where $L_g$=greater luminance
and $L_l$=lesser luminance

The equation of contrast $C_2$ results in contrasts between 0 and 1 for all objects, whether brighter or darker than their backgrounds. The formula allows for the comparison of contrast between two different points of a surface, or even between two different surfaces. It is especially valuable in a situation such as a bipartite pattern, in which neither of the areas on the two sides of the border can be identified as object or background.

$$C_3 = \frac{(L_g - L_l)}{L_l}$$

where $L_g$=greater luminance
and $L_l$=lesser luminance

Equation $C_3$ is an alternative to equation $C_2$, and is commonly used when the object is brighter than the background [IES, 1984]. Since there are different aspects of measuring contrast, mentioning the definition is important. Different definitions of contrast have different applications because they relate to particular scales of analysis. Contrast may similarly be evaluated between pixels or small groups of pixels of the image [Demers, 1993]. This can easily be achieved within the context of image analysis. The exposure meter of the camera records the different brightnesses of the field of view of the camera. The notion of sensation and adaptability of the pose metre of the camera in function of the received light is not included in the measure of luminance [IES, 1984, ch.2, p.20]. Contrast could however be calculated in the relation between brightnesses, the exposure meter of the camera and the sensitivity of the film being the principal sources of error. It is possible to obtain a brightness for a selected point of a surface represented on an image. The equations of contrast for a group of pixels of the image become:

$$C_1^* = \frac{(B_d - B_b)}{B_b}$$

where $B_d$=brightness of detail
and $B_b$=brightness of background

$$C_2^* = \frac{(B_g - B_l)}{B_g}$$

$$C_3^* = \frac{(B_g - B_l)}{B_l}$$

where $B_g$=greater brightness
and $B_l$=lesser brightness
Some irrelevant pixels to the analysis could be misleading, as in the case of a black area of dust on a white wall, which would wrongly suggest high contrast. In that case, the assessment of contrast would be much less affected when using the general contrast calculation on an entire image. The punctual analysis may also consist in the insertion of a grid of squares where grey levels correspond to a mathematical average of brightnesses. Softwares of image analysis use the term mosaic for such an application. It is possible to regulate the level of detail needed for the establishment of the average of brightnesses for groups of pixels. This mode of subdivision into a grid can be adapted and modified according to dimensions of the object under analysis (figure 3.1). In principle, larger surfaces for which a brightness is needed correspond to larger dimensions of the squares that constitute the grid. An area of the original image may be subdivided into a mosaic pattern to study a specific character of light on a surface. In figure 3.1, the mosaic of 10 pixels squares (fig. 3.1c) is best adapted for the background and foreground inclined surfaces. For the smaller light zones, the 5 pixels square is more suitable (fig. 3.1b).

![Figure 3.1: Application of the mosaic function for a selected part of the image.](image)

**General Contrast Calculation**

This research proposes a method of contrast analysis for entire surfaces of space using the image as a support for brightness data. Image contrast relates to the range of grey levels on an image. The greater the range, the greater contrast, and vice versa. It is not always relevant to measure the contrast between an object and its background, especially in the case of a general assessment of contrast on an entire scene since visibility is not necessarily the issue. Instead, the evaluation of contrast on an entire image provides a more global interpretation of the visual quality of space. The lighting pattern enables the location of the zones of high contrast, whereas the histogram identifies the relative importance of contrast on the entire image.
This type of contrast may be numerically defined in several ways [Schowengerdt, 1983, p. 10]:

\[
C_4 = \frac{GL_{max}}{GL_{min}} \\
C_5 = GL_{max} - GL_{min} \\
C_6 = \sigma_{GL}
\]

where \(GL_{max}\) and \(GL_{min}\) are the maximum and minimum grey levels of the image, and \(\sigma_{GL}\) is the grey level standard deviation. Each of these definitions has advantages and disadvantages in particular applications. For example, one or two non representative pixels could result in extremely high values for \(C_4\) and \(C_5\), whereas \(C_6\) would be much less affected [Schowengerdt, 1983].

The Brightness Histogram

The histogram of an image is a useful source of information for the overall evaluation of contrast on a surface. It describes the statistical distribution of grey levels in terms of the number of pixels for each grey level. It does however not contain any information on the spatial distribution of brightnesses throughout the image [Schowengerdt, 1983, p. 58]. Figure 3.2 shows different types of grey level histograms in relation to contrast and brightness. The vertical axis represents the number of pixels and the horizontal axis refers to the grey level, or brightness. The brightness values range from 0% (black) to 100% (white). In computing terms, it corresponds to 0 to 255 grey values. The histogram provides the information on the brightness range and general values on an entire image. This information can be much useful in lighting research since it can afford a rapid evaluation of the type of lighting on a surface. In a low brightness scene (figure 3.2a)), most of the pixels are situated towards the 0% value and in the high brightness scene, they tend towards the maximum value at 100% (figure 3.2b)). The image of figure 3.2a) would thus be described as darker than the image of figure 3.2b). The horizontal dimension of the histogram is indicative of the contrast on an entire image. The more compact histogram (fig. 3.2c)) has a lower contrast level since most of its grey level values are situated within a restricted number of brightnesses. Figure 3.2d) suggests an image with higher contrast levels since it contains high and low, and even mid grey level values. The histogram is not indicative of contrast between specific points, but this information is available when directly pointing at pixels on the image. The area of the histogram remains constant whenever a transformation on the image occurs, since the total number of pixels is not affected. The distribution along the brightness scale may however change dramatically, depending on the nature of the modification.
The statistical data can be used in the comparison of images. The interquartile range, which consists in the difference between the maximal and minimal values, is perhaps the most important data since it measures the spread of the histogram [Aylsham, 1996]. The standard deviation may also become indicative of contrast [Schowengerdt, 1983], but its significance is only related to histograms with a normal distribution, as in figure 3.2, and therefore does not apply to all images.

However, the standard deviation may provide more accurate results since it omits the less numerous pixels located towards the extremities of the brightness scale [Aylsham, 1996]. In most cases, the histogram has a normal unimodal distribution, which implies only one peak (figure 3.2). The histogram may relate to no particular tendency, as in figure 3.2d). It can also have a tendency towards the low brightness level (figure 3.2a)) or to the high brightness level of the axis (figure 3.2b)). Some histograms may also present a bimodal (figure 3.3a)) or even a plurimodal distribution (figure 3.3b)), with two or more peaks. Images that have identifiable important peaks could be separated in relevant sections to enable a more representative contrast analysis [Demers, 1996].
The interquartile range acknowledges the highest and lowest data, which are not always relevant when they relate only to a small area of the image. But surely, the combined standard deviation and the interquartile range provide a fair sense of contrast on the entire image. The median could be an indicator of the brightness of a surface. It represents the value such that 50% of the data of observations fall below it. The lower median value associates with a low brightness image whereas the higher median relates to a higher brightness image. The mean is also indicative of the average brightness of a surface. These statistical functions assume the normality of the data distribution on the histogram. In more complex histograms, such interpretations need consideration.

Figure 3.4 compares different types of zenithal apertures and their histograms. The configuration consists in a cubic space with a variable zenithal aperture, where the 100% aperture corresponds to the absence of ceiling. The first column contains the visual representation of the different configurations. The second column describes the histogram and statistical data for the white vertical surface of analysis situated in front of the observer, which consists of the same number of pixels for each image. The third column represents the lighting pattern for the vertical surface of analysis, and also indicates the percentage of aperture area in relation to the surface of the ceiling. The histogram of the 15% opening configuration of figure 3.4a) has a wider distribution on the grey scale while the 100% opening is more compact and tends towards 100% brightness. This should indicate that the contrast on the white wall of figure 3.4a) is more important than on figure 3.4b). It is also possible to obtain the histogram for other specific parts of the image, or even for the entire image.
The mean value is obtained from the addition of the individual brightness values for each pixel, divided by the total number of pixels in the image. To obtain a corresponding brightness percentage the value has to be divided by 256, which is the number of grey levels in a bit mapped image. The mean value does not provide any information on the lighting distribution but it becomes an approximation that roughly classifies images of similar types of light according to their brightnesses. The table of figure 3.5 resumes the statistical data for different experimented conditions of aperture for the variables of area of the zenithal aperture, as resumed in figure 3.4.

<table>
<thead>
<tr>
<th>APERTURE</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Median</th>
<th>Interq. Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.25%</td>
<td>36%</td>
<td>24%</td>
<td>25%</td>
<td>80%</td>
</tr>
<tr>
<td>12.5%</td>
<td>44%</td>
<td>23%</td>
<td>41%</td>
<td>75%</td>
</tr>
<tr>
<td>25%</td>
<td>53%</td>
<td>19%</td>
<td>52%</td>
<td>63%</td>
</tr>
<tr>
<td>37.5%</td>
<td>53%</td>
<td>14%</td>
<td>54%</td>
<td>51%</td>
</tr>
<tr>
<td>50%</td>
<td>57%</td>
<td>15%</td>
<td>56%</td>
<td>50%</td>
</tr>
<tr>
<td>62.5%</td>
<td>59%</td>
<td>13%</td>
<td>60%</td>
<td>45%</td>
</tr>
<tr>
<td>75%</td>
<td>64%</td>
<td>10%</td>
<td>65%</td>
<td>39%</td>
</tr>
<tr>
<td>87.5%</td>
<td>66%</td>
<td>9%</td>
<td>66%</td>
<td>7%</td>
</tr>
<tr>
<td>100%</td>
<td>76%</td>
<td>6%</td>
<td>77%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Figure 3.5: Summary table of the statistical data for a vertical surface according to the variation of the area of a zenithal aperture (see figure 3.4).
The statistical data are presented in figure 3.6. It presents the statistical data in function of the aperture area. The graph shows that the most relevant data for the analysis of contrast on the vertical surface relate to the standard deviation and the interquartile range, as previously discussed. Both types of data are linear, lowering towards the largest zenithal apertures. This indicates lower contrast levels for larger apertures. The equation of their relationships are different, but in this case, it appears that the interquartile range offer the greatest difference between the maximal and minimal apertures. Since the equations are different, it becomes important to classify the images according to only a single type of data. The median and mean data are almost identical, both indicating an overall increased brightness on the surface of analysis as the aperture enlarges. The type of data that provides the most useful assessment of light relates to the type of images to analyse, and their statistical distribution on the histogram. Other statistical data for the variables could produce slightly different results, depending on the normality of the distribution.

![Graph of the statistical data according to the variation of aperture area.](image)

The impact of the modification of the mapping\(^1\) of an image, such as the brightness separation through posterisation or the mosaic filter do not have a considerable effect on quantitative statistical data and histograms of analysis. Figure 3.7 illustrates the variation of the histogram according to different mappings of a specific image. Figure 3.7a) represents the original image with a peak at 33%. The posterisation in 5 brightness levels creates five punctual groups of pixels on the axis (fig. 3.7b)) without altering the peak value. This distribution of the pixels into specific groups of similar brightnesses constitutes an approximation of the original histogram. It is less accurate since only five groups are considered, but it allows the lighting pattern to be seen and compared as

---

\(^1\)A mapping consists in the straight replication of an image, where the geometry of the original is unchanged, except for its size [March & Steadman, 1971, P. 13].
modifications of the space and aperture occur. The mosaic filter (figure 3.7c)) also alters the histogram, but the general statistical data are unchanged (fig. 3.7c) and d)), except for the interquartile range, which is mostly affected by such an oversimplification. The mosaic filter has no effect on the statistical variables of mean, standard deviation and median, but the pixel distribution on the histogram of figure 3.7d) is much less accurate for larger squares. The negative of the image creates an inversion of the histogram and its statistical variables (figure 3.7e)).

<table>
<thead>
<tr>
<th>IMAGE</th>
<th>HISTOGRAM</th>
<th>FUNCTION APPLIED TO THE IMAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="original image" /></td>
<td><img src="histogram" alt="original histogram" /></td>
<td><strong>a)</strong> <strong>original image</strong></td>
</tr>
<tr>
<td><img src="image" alt="posterisation" /></td>
<td><img src="histogram" alt="posterisation histogram" /></td>
<td><strong>b)</strong> <strong>posterisation</strong></td>
</tr>
<tr>
<td><img src="image" alt="mosaic" /></td>
<td><img src="histogram" alt="mosaic histogram" /></td>
<td><strong>c)</strong> <strong>mosaic</strong></td>
</tr>
<tr>
<td><img src="image" alt="mosaic" /></td>
<td><img src="histogram" alt="mosaic histogram" /></td>
<td><strong>d)</strong> <strong>mosaic</strong></td>
</tr>
<tr>
<td><img src="image" alt="invert" /></td>
<td><img src="histogram" alt="invert histogram" /></td>
<td><strong>e)</strong> <strong>invert</strong></td>
</tr>
</tbody>
</table>

Figure 3.7: Relation between histogram and the image mapping and filtering.
The Threshold or Contrast Index

The separation of the image in two brightness levels (fig. 3.8) could lead to a general comparison of contrast between images. A past research by Demers [1993] has established the comparison of different images in terms of general contrast on entire surfaces. An index of surface contrast was developed to complement the utilisation of the histogram and provide preliminary information for the design process, by the addition of the notion of the morphology of light. This index of surface contrast allows the evaluation and comparison of the behaviour of an entire surface under different lighting conditions. It is determined by the relative dimension of the different lighting zones of the pattern for two brightness levels: 0% and 100%. The software of image analysis allows the selection of an entire surface of a given brightness to determine its area in terms of pixels, within the histogram function. Contrast is expressed by the proportional relationship between the 0% and 100% brightness zones on the surface of analysis:

\[
\text{index of surface contrast: } \frac{\text{area of maximal brightnesses (100%)}}{\text{area of minimal brightnesses (0%)}}
\]

![Plan of Aperture](image)

**Figure 3.8**: Brightness separation for two zones.

The software of analysis separates the brightnesses at the 50% brightness level, consisting of the pixel threshold for the demarcation between the 0% and 100% zones. The *threshold* is a type of manipulation that is not meant to enhance contrast. Instead, it segments an image into two classes defined by a single grey level threshold [Schowengerdt, 1983]. In the threshold separation, small details of high contrast are not considered since their surface is not large enough to be part of the
calculation. The punctual method of analysis should be favoured, for instance, to measure the contrast between a very small object and its background and enable the comparison between specific points of surfaces.

![Low Brightness Image](image1)
![High Brightness Image](image2)

*Figure 3.9: Threshold separation for low and high brightness images.*

![Middle Brightness Image](image3)

*Figure 3.10: Threshold separation for a middle brightness image.*

![Contrast Index Variation](image4)

*Figure 3.11: Variation of contrast index according to the variable of area.*

The contrast index calculated with a 50% threshold separation provides a convincing classification of images of low brightness levels (figure 3.9a) for spaces photographed in a black box with a white surface of analysis [Demers, 1993]. Graphs of the contrast index according to the physical variation of the aperture indicate that the index could provide a preliminary information on the general aspect of an image. Figure 3.11 shows the results of the calculation of the contrast index for the variable of aperture, partly illustrated in figure 3.4. It indicates that the smaller aperture generates a higher contrast index than the larger aperture [Demers, 1993]. Moreover, the contrast level appears to stabilise as the area of the aperture enlarges. High brightness spaces should also be well represented with the 50% threshold separation (figure 3.9b) since there is no critical values located within the 50% threshold. The threshold at 50% does however not prove to be convincing in all cases. It appears that this simplification does not apply to a space with middle range brightnesses. The experiment shown in figure 4.18 (chapter 4) occurs in a grey space with surfaces
of 55% luminance. Figure 3.12 illustrates the sequence of images with a 50% threshold. It shows the brightness separation into 2 zones (0% and 100%) for the light on a vertical surface. From image 3.12a to 3.12i, a zenithal aperture is progressively enlarged. The grey surface of analysis produces mid-level reflectances and hence affects the histogram by concentration of the brightnesses on the mid-values of the brightness scale. A reflectance of about 10% for the surface of analysis reduces the extent of the variance of brightnesses found on the image. This indicates that at a maximum level of illumination, brightnesses of nearly 100% would be less likely to appear on the surface of analysis of a grey space of mid-reflectance than with a surface of analysis with a high reflectance. This would suggest the need to modify the threshold value of the brightness separation since the mid-scale brightness does not necessarily correspond to a 50% threshold. The threshold could vary according to the type of images when comparing the maximal and minimal reflectances of the internal surfaces of analysis. It is, for instance, more probable to measure lower brightnesses in a black space than in a white space. The problem is to determine whether the threshold value should consist in a variable that relates to the reflectances of a specific model, or if it should consist in a fixed value attributed to mid-values of reflectances. The definition of a fixed value implies an approximation and becomes an indication of a frequently employed combination of internal reflectances. It could therefore relate to the 18% reflectance employed in photography (refer to chapter 2) which corresponds to an average type of scene. This specified 18% value does however not respond to extreme cases that differ from average exposures, but it remains an important reference in most cases. In summary, the threshold value proves to impose a drastic separation in all mid-brightness spaces and its application to a classification of images needs further investigation. It could otherwise become a misleading factor of interpretation. The separation into 5 brightness levels offers more accuracy and sufficient approximation for most studies. It could be possible to create an interpretation factor of contrast from the mathematical relationship between the areas of the different brightness zones.

![Figure 3.12: Selected area with a 50% threshold.](image-url)
Physical Descriptors of the Lighting Pattern

The histogram was a descriptor of all the pixels of an image, but it does not contain any information on the distribution of brightnesses on the surface of analysis. The physical descriptors provide this complementary information relating to the morphology of the lighting pattern. They add a quantifiable aspect to the interpretation of the pattern. The utilisation of the pattern as a graphical representation instead of numerical values facilitates the integration to design, which consists in a visually oriented process. The disadvantages of this approach lay in the bidimensionality of the pattern and the need of a surface to materialise light. This section explores two descriptors of the lighting pattern: gradation and compactness.

Gradation

The gradation of light, can be interpreted from the pattern. Figure 3.13 shows the patterns on a vertical surface for a brightness separation into five zones for two identical longitudinal apertures under different sky conditions: the direct light of the sun (figure 3.13e)) and the diffuse light of an overcast sky (figure 3.13c)). The arrows indicate the main direction of the pattern and the relative measurements between the brightness zones on that axis are also included. The computer can calculate the vertical distance between the limits of different brightness zones for figure 3.13c), but the determination of the directionality of the pattern is not as easily definable in figure 3.13e). This can be done in pixel units, and even in metric or imperial measurements. In the last two types of units, the scale of the images must be identical, and in all cases, the resolution of different images should also be identical. The diffuse light condition (figure 3.13c)) shows a symmetrical pattern along the vertical axis. The main direction of the pattern is downwards, corresponding to the brightness distribution of an overcast sky with its highest value at the zenith. The direct light condition (figure 3.13e)) shows abrupt changes. Some lines of the pattern are so close that they even overlap. The pattern is asymmetrical according to the 45° angle of the sun. A coefficient of gradation could eventually be developed to provide a quantitative interpretation of the pattern. It should take into consideration the relative intervals between the brightness zones in a given direction, usually perpendicular to the main axis of the spreading.
a) Plan view of the aperture for spaces photographed in figures b) and d).

b) Longitudinal aperture under a diffuse overcast sky.

d) Longitudinal aperture under a direct sun light.

e) Lighting pattern of image d).

Figure 3.13: Image of a longitudinal aperture under overcast and direct light.

Compactness

The notion of compactness of the lighting pattern relates to the index of concentration of light, developed by Demers [1993]. It uses the pattern as an indication of contrast on an entire surface to enable a quantitative comparison of different types of lights. Figure 3.14 shows two different sizes of aperture under the diffuse light of an overcast sky. The pattern of the small aperture is described as compact (fig. 3.14a)) whereas the spread is less emphasised for the larger aperture, inducing less compactness (fig. 3.14b)). The compact pattern has a more abrupt gradation of light with brightness contours very close one to another, generating higher contrast levels. The larger
pattern possesses smoother transitions between brightness contours, producing a more uniform distribution on surfaces. The distance between the brightness curves indicates dominating directions of the spread. It is possible to compare, for instance, the vertical spread and the lateral spread of a lighting pattern, and ultimately, it should be possible to create a coefficient of compactness. The zenithal aperture under an overcast sky presents ideal conditions of calculation of the vertical spread since at the zenith, the light vectors are linear with a vertical orientation. Under an overcast sky, the linear spreading of the pattern is usually emphasised by the smaller aperture since most vectors of light originate from the zenith. The larger openings have a greater aperture onto the sky vault, which contributes to a more equilibrated combination of vertical and lateral spreading of the lighting pattern on the surface of analysis. The spreading could also be influenced by the luminance of the surrounding surfaces of the space. In figure 3.14a) and b), the interior space is entirely black, which minimises these internal reflections.

![Diagram of aperture](image)

**Figure 3.14: Compactness of a pattern.**

It may however appear that lighting patterns for a relatively uniform brightness distribution do not provide enough information to compare different images. For instance, figure 3.15 shows only two zones for a brightness separation into 5 levels. In that case, it is possible to use a greater number of zones to produce a more accurate evaluation of the gradation or compactness. Instead of the five zones of 0%, 25%, 50%, 75% and 100% brightness, it is possible to generate nine zones that
could produce the intermediate brightness values of: 13%, 37%, 62% and 87%. This does not affect the morphology of the pattern, but it simply adds some curves to the original lighting pattern.

Figure 3.15: Compactness of uniform brightness distribution pattern.

In summary, *gradation* is a linear measure in the main direction of the pattern while *compactness* is a measure of the bidimensional spreading, which refers to one or more directions of the lighting pattern. These concepts are not always separate since some situations would need an assessment of light on both levels of interpretation. Advanced mathematical research in fields of topology should provide the necessary information for the development of the *gradation* and *compactness* coefficients, which will be important in the classification of images according to physical descriptors of the lighting pattern.
Contrast and the Lighting Pattern

It was shown that the image can provide the quantitative information relating to contrast from the analysis of the histogram and the lighting pattern through the measure of compactness and gradation. The physical descriptors of the lighting pattern can be interpreted into a more qualitative vocabulary of lights by relating the quantitative measurements of compactness and gradation of the pattern to notions of high and low contrast, as these aspects are most important in the development of a qualitative assessment of light. The problem of relating quantitative and qualitative aspects consists in the definition of the limits of the categories or variables. Tests on visual appearance could be performed to verify the subjective interpretation of light in an entire space. The image of such space could then be quantitatively interpreted through the measures of compactness and gradation. It is however not within the scope of this thesis to establish such complex relationships. The aim of this chapter is rather to introduce a theoretical definition of the properties of the pattern. This may however provide the necessary information to establish a mathematical definition of contrast, which would allow a classification of images on a scale of contrast (figure 3.16). The following work is therefore highly speculative but tends towards a synthesis of light as art and science. The limit between the proposed categories do not necessarily need to be precisely defined since ultimately, the qualitative interpretation of the images belong to each individual architect.

The pattern corresponding to a high contrast situation typically contains greater variations and abrupt changes in brightness. It usually consists of a direct light (figure 3.13d)) creating specific patterns of light and shade that reinforce the visual information in a dynamic system [Lam, 1986]. The patterns for low contrast situations contain fewer brightness variations and smoother transitions between brightness zones, and are usually emphasised by a diffuse type of light (figure 3.13b)). There is a close relationship between contrast and most qualitative and quantitative aspects of light as discussed in chapter 1, and for this reason, contrast becomes a global integrator for the interpretation of images. Figure 3.16 shows the variables relating to contrast that affect physical and perceptual aspects of light. This table summarises the information provided from the different classifications of light described in chapter 1. The physical aspects of light directly relate to the morphology of the pattern, whereas the perceptual aspects relate to impressions which may be

![Figure 3.16: Theoretical scale of classification of images according to contrast.](image-url)
Contrast as a Global Integrator

suggested by the pattern. The interpretation of perceptual aspects is much more complex than the physical ones, although only the variables relating to the morphology of the pattern are considered. Figure 3.17 presents some aspects of contrast that relate to contrast analysis. The main categories of variables are the physical and the perceptual aspects. The variables have been selected from previous classifications of light (chapter 1). The following sections explore the possible relationship between the character of an image and each of the variables presented in figure 3.17.

<table>
<thead>
<tr>
<th>VARIABLES</th>
<th>HIGH contrast</th>
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<tbody>
<tr>
<td><strong>PHYSICAL ASPECTS</strong></td>
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<tr>
<td>Quality of the source</td>
<td>Direct</td>
<td>Diffuse</td>
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<td>Brightness distribution</td>
<td>Non Uniformity of light</td>
<td>Uniformity of light</td>
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<td>Dominance of the pattern</td>
<td>Concentration of light</td>
<td>Dispersion of light</td>
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<tr>
<td><strong>PERCEPTUAL ASPECTS</strong></td>
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<tr>
<td>Perception of space</td>
<td>Fragmentation</td>
<td>Unity</td>
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<tr>
<td>Perception of objects and surfaces, and perception of the shade</td>
<td>Materiality</td>
<td>Immateriality</td>
</tr>
<tr>
<td>Concentration</td>
<td>Attention</td>
<td>Distraction</td>
</tr>
</tbody>
</table>

Figure 3.17: Variables related to contrast.

The Physical Aspects

Three categories of physical aspects can be evaluated through the analysis of the lighting pattern (fig. 3.17): quality of the source, brightness distribution, and dominance of the pattern. Each category is roughly subdivided into two main components relating to the evaluation of contrast of an image. The descriptions are not exhaustive and they may even constitute hypothesis for further researches.

Quality Of The Source

The source is the primary component affecting light. It influences modelling and the revealing of textures, but more directly, the quality of the source affects the entire experience of space. The two distinct types of sources are direct and diffuse. The effects of the quality of the source upon contrast were already discussed at the beginning of chapter 1. The following paragraphs therefore simply illustrate the effects of the source upon the lighting pattern and the resulting brightness.
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### The Physical Aspects

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### Quality Of The Source

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Contrast as a Global Integrator

histogram. Lam [1986] mentions that the apertures may sometimes be considered as sources since they influence the type of lighting within a space.

Direct and diffuse types of lights usually produce antagonistic effects. Direct light has a directional emphasis that usually induces strong shadows and sharp edges whereas the overcast sky does not emphasise a sense of direction (fig. 3.13d)). The lighting pattern usually has abrupt gradients from high to low brightness. The typical pattern of a surface under a diffuse light has smoother transitions between brightness zones than the direct light (fig. 3.13b)). The shape of the pattern is also rounder since sharp edges are tempered by the multidirectionality of light. Diffuse light has a capacity to flatten forms, often producing patterned shapes and silhouettes that become grey and ghostly in rain, snow, or dense fog [Hogarth, 1981]. It thus diminishes the tridimensional perception of forms, and generally corresponds to a mood of solemnity, melancholy, despair, sadness, alienation, anguish, or desolation [Hogarth]. These qualifications appear overstated, but Larson's quantitative research [1964] also acknowledges that diffuse light relates to melancholy. Direct light produces sculptural effects with sharp corners and usually generates ambiences of cheerfulness and gaiety. The direct light sun light has the added characteristic of being the most variable, which confers different ambiences throughout a certain period of time.

Direct light associates with patterns of shade because of the presence of strong shadows and effects of chiaroscuro [Hogarth, 1981]. The poetic animation has been related to the composition of light and shade in rhythms [Michel, 1996, p. 5]. Direct light corresponds to the light-space in Von Meiss' classification [1990] and describes a theatrical light that introduces strong patterns of light and dark. Directional light also helps to articulate spaces and objects, clarifying forms and textures [Hopkinson & Kay, 1969, p. 29].

Diffuse light corresponds to low contrast and brightness uniformity whereas direct light has high contrast associated with non uniformity. De Bruyne associates the Renaissance temple with fullness of light. The conditions of diffuse light are apparent when "the light sources are spread out regularly with precise speculative intention. It implies that all architectural elements are illuminated with equal intensity where the space as a whole volume prevails, not the separate accentuation [De Bruyne, 1991, p. 321]." Artists and photographers generally describe diffused illumination as flat [Gibson, 1966, p. 212]. Edges and curvatures become less insistent on a cloudy day than on a sunny day. When edges and corners vanish, Tanizaki [1991] mentions that the world also vanishes, and the diffuse illumination enfeebles contrasts. Diffuse conditions of light not only occur on cloudy days, but also when the aperture is large and the reflectances of surfaces are high, creating uniformity of distribution. Tanizaki reflects on diffuse light:

"... so dilute is the light there that no matter what the season, on fair days or cloudy, morning, midday, or evening, the pale, white glow scarcely varies. And the shadows at the interstices of the ribs seem strangely immobile, as if dust collected in the"
corners had become a part of the paper itself. I blink in uncertainty at this dreamlike luminescence, feeling as though some misty film were blunting my vision.”
[Jun’ichiro Tanizaki, 1991, p. 35]

This illustrates the intemporal and static impression relating the unevenness conditions of diffuse light throughout the day. The image of the dust and paper suggests immobility, and creates a visual confusion of the edge definition, a sense of uniformity. Rasmussen [1959, p. 196] describes the light coming from an open ceiling as a skylight of free influx of natural light that produces a shadowless interior. He adds that under that light, forms are not quite plastic and textural effects are generally poor. In a later example, he also adds that diffuse light relates to dull and lifeless spaces.

In his classification of lights, Von Meiss [1990, pp. 121-124] introduces the light from a series of objects and light from surfaces associated with diffuse light. The series of sources tend to establish a sense of balance and a possible inversion between the figure character of luminous objects and the background character of the spatial envelope that they illuminate. This contributes to the delineation of spatial limits, the extension of space. He emphasises that the arrangement of the light sources requires understanding of the principles of balance since they should help to clarify the reading of spatial geometry. Von Meiss’ classification does not imply the need for particular spatial functions.

Brightness Distribution

There are two main categories of brightness distributions. Flynn [1977] refers to the non-uniformity and the uniformity of light. These categories can be identified through the brightness pattern of the image. The histogram, as previously mentioned, does not allow to identify the brightness distribution, but it provides the information about the brightness levels on the image.

More arousing behaviourally than uniform light, non-uniform light strengthens the user’s impression and thus requires specific design intentions. This notion presupposes that light affects the user’s selective attention or alters the information content of the visual field [Flynn et al., 1992, pp. 14-15]. These patterns influence user orientation and space comprehension, as well as impressions of activity, setting, or mood. An inherently dull environment can only be made more interesting by the addition of colour, more relevant and appropriate foci for the visual attention, shadows from directional light emphasising the nature of its three-dimensional forms (figure 29), or dramatic luminance gradients [Lam, 1992]. A bright space may however appear dull and uninteresting if intended or desirable objects are dominated by inherently uniform or unintelligible elements, such as a luminous ceiling. Light is perhaps the most effective method of achieving visual diversity, which relates to non-uniform lighting patterns.
Uniform light is a neutral system in the sense that it does not usually establish a reinforcing and guiding influence on user impression or behaviour. The lighting pattern contains fewer brightness variations, whose increments are minimal. It offers advantages in space utility, flexibility and general clarity. Because the human organism is not adapted to unvarying stimuli, uniformity of stimulus is undesirable [Birren, 1982, p. 24]. For some types of activities, the diffuse uniform light distribution is rather deficient because of the lack of stimulating psychological effects [Flynn et al., 1992, p. 13].

Ciriani introduces the term *hygiene lighting* to describe the uniform light from the North inducing low contrast. He maintains that such light represents a state of balance between interior and exterior and therefore creates a tendency to find the same light conditions inside and outside. He qualifies it as the light that is everywhere, originating from the disappearance of the opaque frame, the window-wall. Functional light often associates with diffuse light. Hogarth’s description of diffuse light [1981] confirms that the uniformity of light may lead to a diffusion of space. He adds that such diffuse light may originate from haze, mist, fog, smoke, dust and incipient rain or snow, reducing contrast between light and shadow. Shadows create pale, vague, and ill-defined patterns that question the direction of the light source.

Unfavourable adaptation to light may create the sensation of melancholy. Looking out of a window provokes the eye to adapt to the bright scene to ensure clear perception of details. The darker shadows of the interior however appear devoid of detail and the space becomes gloomy until the eye has properly re-adapted to the interior conditions [Hopkinson & Kay, 1969, p. 48]. The eye rapidly adjusts itself to brightness but the adjusting to dimness is slow. Contrast between interior and exterior is an important factor in determining the atmosphere of space. The succession of different lighting patterns should create a succession of atmospheres that would differ depending on the direction of the spatial transition created by the process of adaptation.

**Dominance Of The Pattern**

Concentration and dispersion of light constitute the main variables affecting the dominance of the pattern, which partly relates to the brightness distribution of the pattern. It specifically describes the relationship between the area of high brightnesses compared to the area of lower brightnesses. Images with similar histograms can relate to different variables of dominance of the pattern. For instance, the pattern that reveals a larger area of pixels of higher brightnesses will correspond to a concentration of light (figure 3.14a)) whereas the pattern with smaller, evenly distributed pixel area of high brightnesses will correspond to dispersion (figure 3.14b)).
Concentration and dispersion of light are antagonistic descriptors of the lighting pattern. The concentration of light can be measured in terms of the lighting pattern in the interpretation of gradation of brightness zones. It is an indication of the focalisation of light and provides some information on the "visibility" of a brighter light zone. Concentration of light also appears when the demarcation of the pattern is clearly defined on a surface, which relates to gradients of light and contrast. Dispersion of light corresponds to a disappearance of the pattern involving fewer brightness levels. It relates to low contrast and may be detected through the lighting pattern. Brightness contours that correspond to concentration associate with high contrast.

Concentration of light is generally best achieved with only one source of light because contrast tends to be higher, whereas dispersion of light associates with large sources of series of sources uniformly distributed. A concentration of light also emphasises details when falling in a certain direction. Concentration often relates to direct light, which heightens the appreciation of space and materials whilst diffuse or multidirectional light diminishes it.

The Perceptual Aspects
Three categories of perceptual aspects can be evaluated through the analysis of the lighting pattern (figure 3.17): perception of space, perception of objects and surfaces, and concentration. Each category is roughly subdivided into two main components relating to the evaluation of contrast on the image.

Perception of Space
Two aspects of space perception are taken into consideration: fragmentation and unity. Flynn [1992, p. 3] indicates that lighting patterns affect the definition of visual boundaries and hierarchy of space, which relates to perceptual aspects. The pattern therefore becomes an indication of the perception of space. This concept may be illustrated in the following example. Kalff [1971, pp. 33-36] proposes an application of the interpretation of lighting patterns when comparing two identical space morphologies with different lights: the first possesses three apertures and the second has only two. Figures 3.18 and 3.19 respectively represent the projection of the lighting pattern on the floor of a space with respectively three and two identical apertures, accompanied by their corresponding lighting patterns. Vertical surfaces are generally the focus of this thesis, but in this application, the location of the camera within the ceiling of the space is more representative of Kalff's example. The composition with three apertures establishes a geometrical and visual centre of attention, accentuated by the high illumination in the middle of space [Kalff, 1971]. The composition with only two apertures situated at each end is characterised by a dark central area that
emphasises the spatial extremities. The space is therefore clearly divided in two zones, which can be identified in the representation of the lighting patterns. It is possible to refer to figure 3.17 to establish the basis of Kalff's conclusions. For identical types of sources, the variables of the physical aspects indicate that the brightness distribution of figure 3.19 should produce a pattern characterised as non-uniform, therefore producing higher concentrations of light at each end of the space. The variables of the perceptual aspects indicate that the space would then be perceived as fragmented. The high contrast should produce impressions of materiality of objects. This would produce a dual concentration of attention for each of the aperture since they would be perceived as two equal entities producing light, instead of one single source.

![Figure 3.18: Horizontal projection of a space with three apertures.](image1)

![Figure 3.19: Horizontal projection of a space with two apertures.](image2)

The fragmented space therefore appears divided in sub-spaces. This is usually emphasised by high brightness zones at different and distant locations from each other in the space, or by a high brightness zone surrounded with low brightness zones and abrupt gradients from high to low brightness. Unity refers to the impression of being enveloped by space and corresponds to the uniformity of brightness [Bloomer, 1990]. A space where all the brightnesses of its surfaces are equal should induce an impression of continuity between the planes. The brightness pattern is usually uniform with soft gradations from high to low brightness. The plane that visually detaches itself from space indicates a rupture from the brightness pattern of other surfaces. Moreover, the edge definition accentuates this impression.
Perception Of Objects And Surfaces

Contrast rhythms space in an alternation of chiaroscuro to create a variety of patterns. Hogarth’s description of chiaroscuro [1981] relates to the description of materiality where bright lights generate strong shadows and high contrast. Such strong light often originates from a single source. This focuses attention and induces concentration. Hogarth suggests that it associates with powerful emotions, passionate moods and sometimes tragic plots. He adds that material light generally produces dramatic luminous effects.

The appearance of a space may correspond to specific characteristics of the lighting pattern such as the representation of the transitions from light to shadow that affect the visual appearance of surfaces, and the perceived morphology of space. For instance, it appears that gradual transitions from light to shadow may lead to the curvedness perception of a surface, whereas sudden changes from light to dark are experienced as a change in plane, such as occurs with an edge or a corner [Bloomer, 1990, p. 129]. Figure 3.20 illustrates the curvy surface whereas figure 3.21 illustrates the surface with folds and strong edges. The lighting pattern of the curvy surface (figure 3.20) is more gradual while the lighting pattern of the surfaces with folds (figure 3.21) indicates an abrupt change in brightness along the edges. Gradients of light and dark also produce illusions of depth where dark surfaces appear to recede whilst light ones appear to project towards the observer [Bloomer, 1990, p. 130].

Figure 3.20: Curvy surface.  
Figure 3.21: Surface with abrupt changes.
The round lighting pattern could induce an impression of roundness or an impression of being wrapped by space. Figures 3.22 and 3.23 represent identical spaces with different apertures, accompanied by their corresponding lighting patterns. The impression of being wrapped is stronger in figure 14, and the corners of space vanish. Perception is directed on the light falling on the wall, whereas in figure 3.23, all the surfaces and corners of the space are revealed. The effect is reinforced by a greater number of brightness levels contained in the pattern (figure 3.22) and consequently, higher contrast levels. Brightness variations are more abrupt and the pattern is therefore compact when the brightness contours of the pattern are close one to another.

Contrast can relate to concepts of materiality and immateriality. Materiality is the state or quality of being physical or material. It is a physical consequence of a strong light that reveals textures and the nature of materials (figure 3.24). There are two types of materiality: the materiality of light and the materiality of opacities. The materiality of opacities should associate with strong light and high contrast in space. A light that materialises opacities emphasises details and edges of surfaces to produce strong contours of shapes. Immateriality is antagonistic to materiality. Details and edges disappear and the shapes of objects are difficult to discern. Materiality occurs when light rays parallel to the receiving surface reveal the textures of matter. Light shows its presence, and in becoming material, it discloses its nature. It is not material in the tactile sense, but it feels material when it reaches a surface because its pattern is clearly visible. The more it is visible, the more light feels...
material. This condition associates with contrast. Other elements such as smoke (figure 3.24), dust, and water can materialise light. When light comes through such elements, ideally with a dark background, it appears almost material.

![Figure 3.24: Light that emphasises textures and the materiality of a surface (with corresponding pattern).](image)

A material light indeed becomes a component of space like all other building materials. In a sense, it can be felt almost physically and hence relates to quantitative components. The immateriality of a surface, by opposition to its materiality, involves more perceptive aspects. High concentration of light relates to the notion of *materiality*. Light as a matter becomes more tangible and appears palpable, hence material. Pieter de Bruyne [1993, p. 321] uses the example of the rotunda to comment the Roman period of architecture where architects have applied the principles of concentration of light to raise tensions between masses with maximum expressive force. Such concentration is more likely to be emphasised when the oculus is directly lit with sunlight, as the stream of sunlight defines time and surfaces. Ciriani argues that concentration of light reveals the matter itself in variations of density and forces that construct space. Light works on opacities and contributes to their materiality. It relates to concentration on the interior and concentration of attention since the more its presence is felt, the more it excludes the exterior, physically and emotionally [Ciriani, 1991]. The lighting pattern has a well-marked contour created by much higher illumination levels than the actual illumination on which surface it falls upon. Light acts as a material,
but it also discloses the nature of the material on which it interacts. It defines surfaces and their
textures by creating gradients of light on curves, unevenness, and textures.

The location of the viewer is another important aspect. Von Meiss's light box, where its limits cease
to exist when standing in it, demonstrates the dematerialisation and materialisation of light and
space. From the exterior, the light box seems palpable because of the high concentration of light.
From the interior, the limits are much more difficult to identify. A material, such as any building
component, can also give impressions of materiality or immateriality. This impression may vary
between individuals, but it generally associates with visual qualities of an object under a certain
light.

Tadao Ando uses a dialogue with materials as the main support to fix in actuality the spaces he
creates. Each material imbues the intent of the whole. Ando's utilisation of concrete does not
reinforce sculpturesque solidity and weight, but instead, it expresses fragility and lightness.
Concrete produces light on its homogeneous surfaces defined by sharp edges:

"When light is drawn into it (concrete), cool, tranquil space surrounded by a clearly
finished architectural element is liberated to become a soft, transparent area
transcending materials. It becomes a living space that is one with the people
inhabiting it. The actual walls cease to exist, and the body of the beholder is aware
only of the surrounding space."

[Tadao Ando, 1990, p. 55]

This notion of non existence corresponds to the Zen Buddhist thought where space comes into
being at the boundary where material things vanish. Ando mentions that "a person sitting silent and
contemplative in such a space has the feeling of experiencing limitless size within the interplay of
light and dark" [1990, p. 53].

Concentration

This section examines the perceptual aspect of concentration. It refers to attention and distraction,
which are not sensations. Hopkinson [1963, p. 261] mentions that good lighting demands not only
the provision of sufficient light to enable work to be done efficiently and in comfort, but also that the
distribution of light in the visual field should make the work the natural focus of attention.
Concentration of light and concentration of attention have some common characteristics because,
as Hopkinson argues, people are inclined to phototropism [1963, p. 261]. Hopkinson adds that the
tendency is well recognised but does not appear to have been investigated quantitatively. It can be
assumed that, to a certain extent, an observer's focus of attention would often correspond to zones
where higher illumination levels are found.
The eye is naturally drawn to things that are particularly bright, or things that are markedly different from the general view of objects of the visual field [Hopkinson, 1963, p. 21]. The attention is increased when the essential part of the visual field has the greatest brightness [Kalff, 1971, p. 74]. Bright colours as well as bright lights attract the attention [Hopkinson, 1963]. Concentration on a particular visual element is consequently best achieved when the focus of attention is bright, colourful, or both. Some lighting patterns affect personal orientation and understanding of space, emphasising the inner character of space. Interesting or pleasurable stimulus often become the focus of visual attention whereas uninteresting or irrelevant stimuli may be passed over and stored immediately in the visual memory. The environment that appears and behaves as expected produces a positive emotional response to the observer since associative links established by prior experience are confirmed [Lam, 1992, p. 34]. Attention is stressed by the lighting pattern since the brighter parts of space attract more attention than the darker areas. Concentration depends upon the brightness difference between the point of interest and its surroundings. Alexander [1977] refers to it as the phototropic nature of the human eye. An object will command attention to itself by virtue of its brightness alone if its luminance is at least three times superior to its surroundings [Hopkinson & Kay, 1969, p. 49]. Figure 3.26 shows the importance of brightness ratios on visual perception of a particular element in space. In spaces where brightness ratios are high, intensity contrast is important and concentration of attention becomes more probable. The distribution of higher brightnesses on surfaces could therefore correspond to a pattern of vision. The lighting pattern would thus determine the zones where concentration of attention is most likely to happen. In concentration on space, the interior becomes the focus of perception.

<table>
<thead>
<tr>
<th>VISUAL IMPACT</th>
<th>FOCUS-TO BACKGROUND BRIGHTNESS RATIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barely recognisable contrast; negligence power as a focal point.</td>
<td>2 : 1</td>
</tr>
<tr>
<td>Minimum meaningful contrast as a focal point; marginal attraction power.</td>
<td>10 : 1</td>
</tr>
<tr>
<td>Dominating contrast as a focal point; strong attraction power.</td>
<td>~ 100 : 1</td>
</tr>
</tbody>
</table>

Figure 3.26: Visual impact and brightness ratios. [From Flynn, 1977].

Concentration on the interior often relates to spaces deprived of a direct view towards the exterior. Concentration on space describes this powerful influence that light possesses on capturing attention. It defines a relation between a space and the exterior or other adjacent spaces. Zevi
[1991, p. 58] mentions that interior space exists in Roman architecture, statically and in isolation. Light remains an entity, creating a concentration with little contact with the exterior. The light source may be hidden or even absent from the visual field of the observer, creating an ambience of secrecy or mystery. Concentration of light enables the observer standing in the illuminated area to isolate himself and concentrate better. In museum environments, concentration of attention is desirable whereas concentration of light may not be. Concentration on interior space exists because of the absence of apertures in the visual field.

When distraction is caused by an extremely bright source or luminance dominance, the eye responds by constricting the iris, reducing the amount of light that falls on the retina. This simultaneously restrains the visibility of other objects in the visual field. Unexpected bright elements, particularly if distorted, demand the attention of the focus selector that often causes distraction. Sparkle is described as an attractive brilliance, a desirable focus for space. Even though its brightness may interfere with the perception of other elements of the visual environment, the source itself is attractive because it does not cause an annoying distraction. The same source can cause glare if it distracts without satisfying biological needs for visual information. The effect of glare in the luminous environment is similar to noise in the acoustical world [Flynn, 1992]. Visual noise is particularly significant when intensive visual attention is required.

Although inherently phototropic, the focus selector is profoundly influenced by the relevance assigned to incoming stimuli, which Lam describes as the experience filter. Irrelevant or undesirable signals are rejected, but possible centres of visual attention are favoured by signals related to the need for information [Lam, 1992, p. 37]. Judgement of brightness relates to the ability to perceive the information required for satisfaction of activity or biological needs. When light competes with the subject of perception, it becomes unpleasant. Distraction happens when concentration on a focal point of interest is disturbed by attraction to other directions of the visual field [Lam, 1992, p. 52]. The focus selector interrupts the normal sequence of consciously directed eye movement, and the new stimulus is processed through the experience filter [Lam, 1992, p. 37].

Strong patterns of visual information can also dominate the visual field, demanding the attention of the focus selector. The problem of visual noise can be traced directly through the lighting pattern since brightness ratios between surfaces establish or modify the sense of visual limits or enclosure [Flynn et al., 1992, p. 17].
Three Ambiences

This section explores three ambiences often cited by architects and artists. The following discussions are therefore more exploratory than the earlier described physical and perceptual aspects, but they illustrate the interrelations between different components of ambiences.

Melancholy

Melancholy may be experienced when the perceived brightness does not meet expectations, regardless of the actual ambient light levels. Inappropriate focal points in the luminous environment may also cause the impression of melancholy by drawing attention away from the centre of interest. A uniformly overcast sky is always the brightest element in the visual field, but since the centre of interest on the ground is visually more interesting and relevant. Moreover, the entire scene appears gloomy despite the high ambient light levels induced by the sky. An environment in which all the surfaces tend to be uniformly lit also produces the effect of an overcast sky. The lack of shadow and modelling may result in an equally depressing atmosphere. The absence of a focus when its need or expectation is obvious, generates equally strong negative feelings about a design, as can inappropriate focus [Lam, 1992]. The visual environment that shows no variation of light reflectivity is perceived as featureless. In the featureless visual field, objects and depth fade, and disorientation or anxiety may be experienced [Bloomer, 1990, p. 129]. This sensation is usually caused by the lack of some expected and desirable quality in the luminous environment, usually accompanied by a lack of information or appropriate focal points, and aggravated by the awareness of a more satisfactory alternative. It often associates with low contrast environments. Melancholy often appears when light does not fulfil biological needs for environmental information, regardless of the actual ambient light levels [Lam, 1991, p. 54].

Mysticism

"The light from the pale white paper, powerless to dispel the heavy darkness of the alcove, is instead repelled by the darkness, creating a world of confusion where dark and light are indistinguishable."

[Jun'ichiro Tanizaki, 1991, p. 17]

This description of mystical light is essentially physical, relating to the notion that diffuse light could create such an atmosphere. The indistinguishable light and dark emphasise the apparent immateriality of space and matter. Light transforms matter to generate other perceptions than reality. Mystical light refers to pictorial light whereas space becomes an abstraction. Franco Purini [1991, p.115] explicitly affirms that the identification of the spiritual and the immaterial corresponds to the
absence of light. Hogarth describes mystic light as a “not vivid nor strong or bright light that would be associated with an aerial or atmospheric quality of space”. Under such light, linear elements disappear, and firm, hard-edged forms give way to pliable, fluent or vapour forms. The tones are airy, powdery, like gases of varying densities in a dusty atmosphere. An extremely diffuse atmosphere may therefore associate with mystery when all sharp corners disappear and space vanishes. For Tanizaki, it is the space of light where forms appear and disappear in a lost and found fashion.

In his description of the Faaborg Art Museum in Denmark, Rasmussen [1959] suggests that the succession of spaces may amplify the lighting effect in the hall, by contrast. It agrees with Ciriani’s idea of contrast between the interior and the exterior, mentioned in the lighting-light and radiant types of light where contrast is minimal for the first type, but maximal in the second. In Rasmussen’s description, this would also imply that from the hall, the first room of the museum would appear “radiant” because of the excessive brightness that would then occur from the different observation point. Rasmussen’s mentioning of the presence of colour, with the quasi-absence of light might induce an impression of mystery and mysticism:

“A climax is created by letting a small dimly lighted room follow a brilliantly lighted one. In the museum the first room, with its large skylight, is as bright as day. Seen from it the octagonal domed hall is like a mystic sanctuary. A dim light sifts down from the small opening in the dome over the black stone statue of the founder, Mads Rasmussen. The impressive figure turns towards the observer and the light is just enough to reveal the great form from which the sculptor, Kai Nielsen, has smoothed away all but the essential. The statue is seen against a cobalt blue wall, the colour of which strangely intensified in the half-light. If the hall were lighter the effect would be much less dramatic”

[Rasmussen, 1959, p. 194]

Light may be very dimmed, almost absent. Through darkness, objects and spaces slowly emerge and are deformed, appearing differently from time to time. An excess of light would destroy this abstraction. Physical variables that could create such an ambience include the use of small apertures, translucent skins, and low reflectance surfaces. Mystical light offers the possibility to create an illusion, not unlike Ciriani’s pictorial light. Scott Fitzgerald refers to the audible presence of a particular music that helps to enhance the effect of atmospheric light. The element of water modifies the dimmed light, where it may create confusion and deformation through vibrations:

“As they passed through the principal salon they saw ahead of them figures that seemed to dance in the half light of the circular stern. This was an illusion made by the enchantment of the music, the unfamiliar lighting, and the surrounding presence of water.”

[Fitzgerald, 1934, Part 3, Chapter 5]
A mysterious ambience seldom corresponds to a practical function, except in the expression of the sacred. In the interior of the Great Pyramid at Gize, the experience of mystical light emanates from the fire of lanterns. Light is dimmed, filtered by the roughness of the surrounded walls (figure 3.27). The eye slowly discovers space and surfaces as it adapts to different brightness levels. The reduction of visual stimulus also emphasises the impression of mystery.

**Radiant Light**

Radiant light usually refers to a very bright source located within the field of view. Ciriani [1991] introduces the notion of a radiant space. This section therefore explores these two aspects of radiant light:

- The object as a source
- The space as a source

**The object as a Source**

When looked at directly, the source-object simultaneously fascinates and dazzles, as in Ando's architecture (figure 3.29). This effect is however conditional to its relatively small size in relation to the space. When turning away from the source, spatial perception is completely altered because the walls, floor, and ceiling become weak light reflections whose surfaces are immense and enveloping. This light may induce glare or simply sparkle, depending upon the centre of attention in space and the distance to the source. The radiant source-object emerges from a brightness difference between the source and its surrounding space (figure 3.28). It establishes a relation of dependence between source and space. The reflectance of the surfaces should be low, especially
Contrast as a Global Integrator

when the source has a low intensity such as a candle. When the source has a low intensity or a small size, the illuminance of the background surfaces should be accordingly low to maximise contrast between source and space and induce a radiant light. Hogarth [1981] describes radiant light as a light in emanation of energy, far more powerful than the light of the chiaroscuro, because it is an assault to the eye. He states that it usually characterises an ambience of health, intense joy and happiness. It is never screened nor reflected from a secondary surface so that the eye is in direct contact with the source itself, usually producing glare. The essence of radiant light is that it originates from a difference between two spaces. Ciriani implies that the interior is full of brightness but in Hogarth's view, the source could also consist of a candle in a dark surrounded space where the flame would become the radiant source of light. The object as source, as well as the space as source, can therefore create radiant light.

![Figure 3.28: Radiant light: the object as source.](image)

The Space as a Source

Ciriani [1991] states that radiant light is an excess of light. The interior is filled with more light than necessary, even more than outside (figure 3.31). White, which became the colour of modernity, justifies the radiation of light, generating maximum internal intensity. Ciriani's vision of radiant light is established between two spaces. It can consist of adjacent spaces such as an interior and an exterior, where the interior can be considered as a source. In that case, the interior weakens the strength of the exterior shedding light like the sun. If the exterior and interior illuminances are equal, it creates a balance which smoothers contrast. The translucent wall appears more luminous than a transparent wall for that reason. It decreases the external contrast and produces a highly luminous material. Ciriani mentions that radiant light modifies space by dilatation and fluidity. Richard Meier disagrees with Ciriani's statement on radiant light and argues that there is never too much light. Ciriani's description of radiant light refers to glare, which usually relates to negative aspects of perception, whereas in Meier's architecture, glare becomes the sparkle that positively reinforces
the focus of attention and concentration. Meier's approach to diffuse light also differs from Kahn's approach. Kahn uses light to reveal the nature of opacity, the matter that structures space, whilst Meier dematerialises the opacity (figure 3.30), inducing a feeling of lightness of the material, not unlike Ando. These different utilisations reaffirm that perceptive factors vary from one designer to another.

The experience of space as a source may occur at night, when the interior is illuminated and the exterior remains dark. The impression of radiation is greater when standing from the dark space. This infers that certain spaces could be radiant only at night but during the day they would relate to another type of light. The presence of snow in certain climates also modifies the balance between interior and exterior. The interior space appears dimmer than the bright exterior, redirecting concentration towards the exterior. Space as source could also be experienced from inside. Hagia Sofia comprises a series of peripheral apses that dilate the void to draw proportions of the dome from inside out, competing with the light that attempts to enter:

"In fact, the light wins, hits the mosaic surfaces, is incorporated and reflected by them in such a way that it seems as though the light would emanate from inside out. The walls are radiant, more so than their apertures".

[Zevi, 1991, p. 58]

The entire space of the dome becomes the radiating source. This indicates that radiant light is not a result of modernity, as implied by Ciriani, but existed in the Early Medieval period with the exploration of new structures and configurations of apertures. The high reflectivity of mosaics contributed to the weightless impression of the structure.
Radiant light is produced by an excessive brightness and may cause either a negative or a positive glare. Dematerialisation of objects and surfaces largely depends on the visual sensation that can be illustrated as an overexposure, in photographic terminology. In Meier's architecture, the interior radiates night and day. White, the colour of demateriality optimises the effect. Meier mentions that:

"The fact that white doesn't absorb but reflects it (light) with almost no loss enables me to experiment with light at full intensity. This is what makes the radiant feeling expressed by the building. White intensifies the perception of light and makes it easier to read architectural intentions. White also intensifies the perception of colour, of the colour variations of natural light. Some people have used the term "immateriality" in describing my architecture. The idea of using white is indeed to dematerialise the surface, the place. The truth is I'm not very concerned with the material so long as it ends up being made with light. My prime material is light itself."

[Richard Meier, 1991]

Lam [1992] states the importance of expectation in the evaluation of space. Judgement is based on satisfaction of the need for visual information and the expectation for such needs. Relevance and appropriateness are concepts that relate to expectations, true determinants of visual comfort in the luminous environment:

"Relevance and interest, not the measured surface brightness, are the critical factors; yet these factors, being very difficult to quantify, are almost always omitted from experimental research on glare and from conventional lighting criteria. Such omission effectively invalidates the results of such research as useful criteria for the design of the luminous environment."

[Lam, 1992, p. 53]
Conclusions

This section has presented the lighting pattern as a mean of analysis, and contrast as a global integrator for quantitative and qualitative assessments of light. Existing theories about the lighting pattern were discussed and a method of obtaining instantaneously the lighting pattern on a digitised image was proposed. This method consists in the division of the image into a certain number of brightnesses with the application of a posterisation function of the computer software. The brightness recorded on the image does not refer to the perceived brightness of the eye, but to the interpretation of brightnesses through the posemeter of the camera. The term luminance would not correctly describe this attribution since the luminance meter measures, with only a small degree of apertures, the light reflected from a surface (preferably 1° maximum [Schiler, 1992]), whereas the camera proceeds with a much wider angle.

Correspondence between image data and elements in lighting theory are tackled throughout a discussion on physical and perceptive aspects. Contrast constitutes the most important parameter of light analysis, and is therefore the global integrator of physical and perceptual aspects since it influences most visual aspects and is easily quantifiable through the analysis of the lighting pattern. Two methods of measuring contrast are proposed: the punctual and the general methods. There is however not one single measure of contrast that can be applied to all images. The punctual method relates to the commonly employed formula comparing luminance differences, by pointing pixels of a specific brightness on an object. The general method is explored since it could provide a more global assessment of contrast on an entire image, and therefore also provide an idea of an ambience in a specific space. It mainly consists in the analysis of the histogram and statistical distribution of the pixels of different grey levels of the image. The combined interpretation of the interquartile range and the standard deviation provides a conclusive appreciation of contrast on the entire image. The number of brightness levels in the lighting pattern also complete the general assessment of contrast. The notions of gradation and compactness of the pattern are also explored, but would need more investigation, especially to establish a coefficient of the spreading of patterns.

This chapter has demonstrated the quantitative information that can be extracted from the lighting pattern, which in turn can correspond to some physical and perceptual aspects of light. Finally, a table of the variables affecting contrast (figure 3.17), based on a previous discussion on classifications of lights, is proposed. It relates some physical and perceptual variables of light to contrast. An exploration of the use of the information provided through the pattern establishes criteria for the classification of ambiences. These aspects constitute an exploration of the possibilities offered by the pattern, and therefore, there would be a need to verify these hypothesis.
Composition with Images of Light

Chapter 4

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The previous chapter has demonstrated the use of the image in providing a support for the quantitative analysis of light on surfaces, and has proposed a possible extension towards its qualitative or perceptual analysis. The approach introduces the combined use of the lighting pattern as the main source of information with other quantitative attributes such as the histogram. The photographic method of evaluating light has some limitations, but in a global approach to architectural design, the advantages outweigh these disadvantages. The image can therefore initially provide a framework for suggesting ambiances, or more realistically, propose an accurate visual representation of a space to build. This chapter identifies the possibilities offered by the use of the image in the design process, and establishes a methodological approach to spatial composition with light. The methodology suggests two complementary approaches to the utilisation of images in lighting design:

- The interaction approach based on the simultaneous use of the video and physical models.
- The typological approach based on a library of images.

The first utilisation of the image is closely linked to the artistic creative process with all meanings inferred, within a spatial framework not so defined. The second, more realistic approach, provides immediate design solutions, and originally needs lighting representations of real spaces or physical models. The library of images acts as a beginning of the design process, allowing a more formal and realistic approach.

Maholy-Nagy had foreseen the interdependence of the two approaches when he suggested that composition and construction are aspects of the same problem [Moholy-Nagy, 1932, p. 59]. He...
argues that composition constitutes the highest level of intellectual evaluation of elements in their relationships between each others, whereas construction must ideally be pre-determined at every point of its technical and intellectual relations. Construction therefore demands an increased quantity of knowledge, especially technically, which should not necessarily imply the non-existence of any intuitive inspiration [Moholy-Nagy, 1932]. In architecture, composition needs to preserve its constructive realism to remain in the realm of the possible. The first approach therefore refers to the inspiration stage of a composition which remains rather suggestive, while the second proposes a context of acute, more constructive realism. These two aspects are complementary, but necessitate different methodological and technical operations.

Le Corbusier [1923] presents surfaces and apertures as the potential elements of composition of light that can be transformed into a *symphony*. He also evokes the importance of light and the elements of its composition as generators of emotions. His omission of the horizontal surface in the elements of composition asserts the significance of verticality in the generation of emotions. As discussed in the introduction, the horizontal surfaces are the focus of most current quantitative studies whereas light on vertical surfaces is barely considered in lighting science. This research therefore introduces a framework of design and analysis that relates to the visual field and proposes a quantification of light on vertical surfaces. The main components of space are the vertical and horizontal surfaces, and the system of apertures. The transposition of such architectural components through the photographic medium implies the knowledge of a further level of abstraction: the abstraction of an image that represents a space, or suggests an idea of a space. In the photographic approach, the elements of architectural composition with light remain, but there are composition rules that need to be defined according to the physics of light and the possibilities offered by the computerised image processing. This definition of the use of images could lead to the creation of a library of images that would constitute a basis for composition. Determined variables establish the basis of the library of images to enable the creation of other combinations and variations which can occur within the addition of filters and modifications of the mathematical grid. This chapter focuses on the diffuse light of the overcast sky since this condition predominates under northern latitudes. It also offers more possibilities for the composition with images because the position of the sun has fewer implications on the directionality of the lighting pattern. This implies that a single image offers more flexibility of utilisation and more design possibilities. Moreover, direct sunlight presents optimal conditions of design while diffuse light is more problematic, especially when low contrast levels are critical for visual appearance [Lam, 1992, pp. 25-28]. The diffuse light of the overcast sky is also more constant throughout the day than the direct sun light which continuously changes in intensity and position. Images issued from conditions of direct sun light would only represent a single moment in an entire day, ignoring the translation of the lighting pattern in space, whereas images of diffuse light are much more versatile. It therefore appears that the utilisation of fixed images corresponds more realistically to an overcast sky condition than images taken under the direct sun light. Such images would necessitate a more
The Composition With Images

dynamic approach, taking into consideration time and orientation. The video camera could again provide a solution in future research under direct sun light.

The interactive approach:

Vernon [1971, p. 35] notes that the image may be utilised for purposes of recollection and identification, but also for its intrinsic value in rendering the whole creative experience more vivid and enjoyable. The perception of pictures may be accompanied by a search on form and colour in conjunction with the imagery of other pictures. Vernon adds that a variety of feelings and emotions may enter into this perceptual experience. The designer has an intuitive interaction with the image that should support a creative environment. The camera and computer provide the quantitative analysis of contrast (refer to chapter 3) but these tools can also be used in a creative manner. This section explores the creative application of the image in lighting design.

The Camera

The camera has a privileged relationship with reality that tends to create a belief of its strong capacity to report, identify and document functions. The representation is not always objective since the operator may alter a photograph in such a way that it transforms reality into other interpretations. Prendeville [1996, p. 10] notes that the pictorial perception of space and the instantaneous and simultaneous perception of objects that occur in photography do not happen in everyday reality. Familiarity with the camera has however encouraged an unconscious instrumental attitude to perception. In its habitual exploitation, the camera functions as a means of appropriation, and thus has perhaps reinforced a seemingly ingrained assumption that the world is arrayed, ready composed and itemised [Prendeville, 1996]. Photography is part of science and part of recording history. A photograph may promise reality, truth, and scientific precision, but it also belongs to the domain of art as it often holds magic and mystery. Evidence and art are conventionally considered the two central foci. Photography requires a mechanistic basis which confers an antithetical character to art, but yet it is an art form, crucially shaped by ideas, influenced by behavioural attitudes, and defined by certain beliefs about the community [Beloff, 1985, p.22]. Photography could allow designated faulty photographs to introduce new visions of the world. Maholy-Nagy [1967, p. 28] mentions that the secret of the photographic effect rests on the camera that reproduces the purely optical image, therefore showing the optically true distortions, deformations, and foreshortening, whereas the combination of the eye and intellect supplements the perceived optical phenomena by means of associations, formally and spatially creating a conceptual image. This conceptual image therefore becomes the generator of ideas in the design process and enhances creativity. Moholy-Nagy argues that the camera provides the most reliable support for the commencement of an objective vision. He adds that everyone is compelled to recognise that the optical truth is objective and explicable in its own terms, before the attainment of any possible
subjective position. Moholy-Nagy also believes that photography and the moving image are at the origin of a new perception of the world [1967, p. 29].

Lessard [1988] maintains that the linear continuity of events in a logical sequence is no longer an appropriate model for describing relationships with the world and culture. He mentions that nowadays, the adequate expression of this relationship is throughout the arrangement and combination of elements in space. The introduction of *collage* and related spatial techniques in the early twentieth century contributed to rebel artists from established concepts of painting and sculpture, offering unpredictability and limiting easy explanations [Lessard, 1988]. The medium of photography, because of its technical possibilities, becomes part of an interactive process of retouching and photomontage. The acts of cutting or juxtaposing, which consist in the careful arrangement of photographs, is a more advanced art form than the early glued photographic compositions of the Dadaists [Maholy-Nagy, 1967, p. 37]. Such alterations have been undertaken by photographers in darkrooms, as in the example of an elongated horse (figure 4.1). The achievement of visual effects, unknown to traditional photography, depends on the redefinition of accepted notions of framing and focusing [Lessard, 1988, p. 79]. In 1927, Maholy-Nagy was emphasising that wonderful potentialities, inherent to photography and film, will only be realised when mechanical improvements and technical developments will boldly be carried forward. Noll [in Youngblood, 1970, p. 192] mentions that the computer nowadays provides an advanced tool for image retouching and allows various manipulations of pictures and film. It is however an electronic device only capable of performing explicitly instructed operations, leading to the portrayal of the computer as a powerful tool incapable of any true creativity. Noll mentions that if creativity is restricted to the production of the unconventional or the unpredictable, the computer should instead be portrayed as a creative medium, an active collaborator with the artist. He maintains that the computer’s great speed, freedom from error, and vast abilities for assessment and subsequent modifications of programs allow the impression that it acts unpredictably and produces the unexpected. In this sense the computer may suggest a synthesis that is not always acceptable, although possessing some of the external attributes of creativity [Noll, in Youngblood, 1970].

![Figure 4.1: Elongated horse (from Maholy-Nagy, 1967).](image-url)
The Video as a Data Collector

The prevalent use of the video consists in documenting conditions, but this research proposes a generative application for architectural design: the composition with images. The possibility to obtain immediate results of qualitative and quantitative analysis is a significant advantage of the video camera as a tool of data acquisition. It would particularly be suited to the initial design stages since the image data are available for an immediate processing within the computer. The video is also an ideal mean for the documentation of the evolution of the manipulations of a model throughout the creative process. Figure 4.2 shows the continuous video recording of the manipulations of paper under a light source. It displays the complexity of the lighting pattern on a banal crumpling sheet of paper, as the creative act occurs (figure 4.3). Although a sheet of paper is a familiar object, the camera has a potential to emulate it, proposing new assessment prospects offered with the reframing and manipulations of the image. An image therefore gains potential when it is detached and abstracted from the continuum [Hewitt et al., 1995]. A sequence of transformations, similar to a parametric study, enables a basis for the comparison of images in a more systematic and scientific manner. The video camera has the capacity to capture a moving object and to freeze it in a particular position. The image may not always be at its best definition and quality, but the frozen instant becomes persuasive in terms of imagery and suggestion. The photograph reinterprets a familiar object and emulates it to an art form to allow further interpretations.

Figure 4.2: Sequence of paper manipulations.
Images from figure 4.4 are issued from a video sequence of a bottle under direct sunlight. In figure 4.4a), a hand is propelling the bottle, inducing a rolling movement on a horizontal surface. The image can capture a fraction of this gesture, which operation is not possible for the eye. In the other images, the bottle is static, but filmed from different angles. The recording of several modifications over a short period of time provides a documentation of the sequential development of an idea. This allows for the possibility to freeze images and to reconstitute an idea that had been lost during the development of a project, dissecting the creative act that occurred in motion [Hewitt et al., 1995].
Szarkowski [1980] mentions that there is no such thing as instantaneous photography since there is always the implication of time exposures of shorter or longer durations, each describing a discrete parcel of time which is always the present. Szarkowski adds that in the days of slow films and lenses, photographs were describing a time segment of several seconds or more. If the subject moved, images resulted in a way that had never been seen before. There would be dogs with two heads and a sheaf of tails, faces without features, or transparent men spreading their diluted substance half across the plate. Chamboredon [1990, p.134] mentions that the diversity and the heterogeneity of representations of the creative act introduce a fragmentary perception of the photographic act. Perceived as a discontinuous succession of different operations, photography cannot be conceived as a creative act occurring over a homogeneous period of time and constantly inspired by identical intentions. The moment of inspiration is difficult to reconcile with the succession of moments of the making of the product. Chamboredon argues that the artistic creation must be located within a period of time whose successive moments are interpenetrant to reconcile the instantaneous character of inspiration with the length of the operations necessary for its manifestation. For the painter, the sequence of gestures appears as the simple development of an intention that provokes and inspires while itself remaining constant. For the photographer, the technical process requires the successive execution of distinct and discontinuous operations which necessarily imply a certain type of temporal sequence that may disrupt the evolution of the act of creation [Chamboredon, 1990, p. 134]. The artist and the photographer therefore have distinct approaches to creativity. The discontinuity and disruption of the temporal sequence of gestures in photography is however minimised with the combined utilisation of the video and computer since the processing of the film is eliminated. Images are therefore available for an immediate utilisation, even simultaneously as the camera operates.

This research proposes an interactive design studio allowing simultaneous activities of creation and lighting analysis. The use of an artificial sky is ideal, but it is also possible to improvise a temporary design studio. The proximity to a window can provide a satisfactorily environment for initial studies, allowing the rough assessment of an idea (figure 4.5). This immediate accessibility of the model
studio is important since it favours spontaneity and corresponds to the urge of the creative act. The simplicity of the method allows a freedom of movement and the necessary artistic impulse. If the activities of modelling and filming were burdensome, the computer processing and analysis would rarely occur for initial assessments. It is however recommended to use an artificial sky for more accuracy when the comparison between solutions becomes critical, especially during later developments of the design.

Figure 4.6: Sequence of model construction from modular units.

The video is a valuable source of information to record the continuous evolution of the construction of a physical model. The additive process of scale building can be read retrospectively to provide new insights from the earlier developments of an idea (figure 4.6). This produces a video sketchbook, which constitutes a record of the creative activity. It allows for instance the experimentation of different viewpoints that constitute a more global evaluation of the model. The viewpoint of the camera affects the perceptivity of the idea, and when it differs from the creator's viewing angle, it offers other interpretations of the design. It is also possible to use the camera as an observer for the visualisation of an architectural promenade. The kinetic of the moving image can bring new perceptions of the project at the scale of the observer, conferring even higher levels of interpretation of the images in the video sketchbook.
MANIPULATION OF AN IMAGE

"In this glum desert, suddenly a specific photograph reaches me; it animates me, and I animate it. So that is how I must name the attraction which makes it exist: an animation. The photograph itself is in no way animated, but it animates me: this is what creates every adventure."

[Barthes, 1993, p. 20]

The image retains a capacity to animate and suggest ideas in the creative process. All images contain the potential for an adventure through an imaginary world. The image may literally represent space or, more abstractly, suggest a physical context. Such contemporary painters like Bacon were seeking their inspiration in photographs, but reinterpreted the atmosphere according to their own personality and history. Lessard [1988] mentions that poetry invades and shatters images that appear to escape from their original format, creating the impression that the alteration of images becomes imperative, as compelling as a brute force of nature. The creative potential of the image can be enhanced by various manipulations of transformation. With the interaction of the computer, the image offers even more possibilities to the creator as it becomes entirely transformed, scaled, reversed, stretched, cut, and pasted to others, until it becomes a new reference, an abstract representation of an ambience that is visually desirable. This process approaches the method of collages made especially popular with the development of image reproduction techniques. The new transformed image is a basis for the composition of space, an ideal representation of an ambience that is not necessarily issued from its literal interpretation. The transformed image merely contributes to the necessary animation, as Barthes puts it, to suggest and even dictate a space and aperture morphology. The transformed image therefore supports and enriches the research of the spatial concept to create an atmosphere. Lessard [1988, p.90] argues that if a photograph represents a frozen moment in the existence of a space subjected to the inexorable wear and tear of time, the alteration of the photograph compresses the duration of this arrested moment and accelerates it to other levels of interpretation. The manipulated photograph imposes a release of emotions and energy, forcing an acceptance of the present and the ignorance of the omitted [Lessard, 1988]. Vestiges of the various stages of reworking may be apparent but the only genuine connection that remains between the final and the initial images is the alchemy of creativity. Most artists that are already working with photographic manipulations seem motivated by a desire to break through definitional boundaries and technical constraints by appropriating the image. They are motivated by a need to shape and reshape, fragmenting the image to surpass the confines of the initial photograph [Lessard]. Barthes [1993] describes this attraction of the observer to a photograph as an animation. The architect, as an observer of an image, can also become active in its manipulation and transformation, as the artist. The animation is converted through the physical act
of modifying the image to create a new spatial representation. This approach is illustrated in this extract from Lise Bégin, artist:

"Quick, take photos of these photos. Use these pictures by your procedures of the heart, of the spirit. Precedent... "For the Road." For the album. In colour... Installed on the veranda behind the hills of sand, I did paint all of that trembling in the breaths of wind, Escaping this palette on the grass. Everything leans to the left, to the blue side, to the heart side, causing this image to pitch."

[Lise Bégin, 1988]

The manipulation of the image may be solicited by an *adventure*, a passion. The gestural act of transformation is however more controlled and confined with the use of the computer because it lacks the direct touch with the working surface and the alternative media. The decoupage can mainly serve as a mean to suggest an ambience, in which case further developments are necessary (figures 4.7 and 4.8). The same original image can be duplicated and modified as many times as necessary. For later design stages, the manipulation of the image could realistically represent a final space condition. More precision is involved towards the end of a project where the computer eases the transformation and evolution of an idea. The differences between traditional and computerised photography become even more meaningful in the manipulation process. The virtually limitless options and possibilities offered by computerised photography are not theoretical, but tangible.

The work on an image does not preclude the pursuing of other variations of that image. Each new idea that emerges can be integrated with an older one, and yet the older can be preserved in its original form. Digital photography is appealing because of its flexibility in manipulating images and the speed at which it can generate them [Breslow, 1991].

![Figure 4.7: Original image.](image1.png)  ![Figure 4.8: Decoupage and collage of parts of the original image (fig. 4.7).](image2.png)
Filter Addition

The software of image analysis allows modifications of an image by the addition of filters, similarly to the possibilities offered by the photographic darkroom. Some filters correspond to photographic filters or developing techniques for the darkroom, but others are specifically related to mathematical applications on digital images. The computer has the advantage to facilitate the use of filters since the technique provides immediate results. Moreover, many different effects may be achieved in a relatively short time. In computer imaging, filters are mathematical matrixes that modify the initial matrix of an image. It is possible to use a pre-set filter, or invent a new filter for specific purposes. Most filters are not specifically designed to deal with light but they contribute to the expression of an idea that could eventually be translated into a lighting application. They may be employed to enhance some of the qualities of light or, as previously demonstrated, to quantify some of its aspects. The introduction of filters may be part of the transformation process, or relate to the analysis to simplify the image and provide a common basis for comparison [Demers, 1993]. Figure 4.9 illustrates some of the possibilities offered by the application of filters over an original bit-mapped image (figure 4.9a)). Each filter can be adjusted to allow different degrees of transformations, sometimes leading to a modification of the mapping and the complete deformation of the spatial representation, such as in images h) to o). None of these filters produce an accurate modelling of light, but their suggestive powers confer them as important design tools and generators of ideas.

Figure 4.9: Effect of filter addition on a bit mapped image. (continue on next page)
Threshold

The threshold function was previously presented in the method of contrast quantification (chapter 3), but it can also be part of a more qualitative study of light for its abstractive potential. The threshold allows the transformation of a grey-scale image with multiple grey levels into an image with only two levels: black and white. It is interesting in creating different perceptions of a single object, but it however remains a function that is highly abstract since the luminous and visual properties of the image are affected. From the white to the almost completely black frame appears the subject of the image, with limited visual information. This restrained vision allows for the imagination to create other interpretations and suggestions of images and spaces. It also has the capacity to represent with reduced information, and even to demonstrate the zones where a highlighting pattern is most likely to appear.
The threshold converts to a white value (100%) all the pixels that are lighter than the threshold value, and to black (0%) all the pixels that are darker than the threshold value. Figure 4.10 shows a series of images representing a bottle. The photograph of figure 4.4c) has been modified, allowing a brightness separation in black and white at specific thresholds. At 10% threshold value, most pixels of the image appear as white and the bottle is scarcely perceptible. Different interpretations of a single image can occur within this simple manipulation of grey level separations. The brightness histogram (figure 4.11) illustrates the emplacement of pixels in relation to the grey level percentage, for the threshold separation. It indicates that most pixels are located between 10% and 70% brightness levels. A threshold of 75% or higher would, for instance, result in a completely black image. At the mean brightness value, there would be as many white as black pixels in the threshold image.

Figure 4.11: Histogram of the original image of a bottle (figure 4.4c)
Manipulations of a Model

In architecture, the purpose of images is to suggest space. The introduction of a physical model to act as a basis for composition provides a source of imagery and constitutes a beginning for a new adventure. The video allows the continuous recording of the modifications of spatial components to constitute a library of images obtained during the development of a project (figure 4.12). In that context, the video bears some analogy with a designer’s sketch book, except that it also offers the possibility to capture a fragment of time during the elaboration of a sketch or alteration of the model. This way of working induces solutions that would probably never have been envisaged unless by accident. Artists themselves claim their share of the ineffable, a range of the unknown that never rise to the surface [Lessard, 1988 p.90].

![Figure 4.12: The hand continuously alters the model.](image)

The method proposes the use of physical models and images in the quantitative analysis of different spaces and aperture configurations. The exact simulation of the complex organ of vision is not intended, but the quantification and organisation of certain design parameters can create a sense of order. In such an analysis, the interpretation organ of the brain is absent, and only the optical aspect of vision is considered. Architects are however responsible for their own qualitative interpretation of the images, which could however rely on quantitative variables relating to contrast (refer to chapter 3). The video camera interacts at the different phases of conception. It generally involves a more intuitive and qualitative relation with the architect at the early design stage, favouring manipulations and transformations from the video sketchbook. Figure 4.13 proposes an integration of the video into the design process by using computer image analysis. It identifies two stages: the early design stage that uses the video recording as a sketch book, and a later stage involving a more precise tridimensional simulation. The graph does not suggest the existence of well defined stages, but it rather implies the different uses of the video throughout the evolution of a project. The early design stage involves more modifications of the model and therefore, a rougher construction can be more rapidly assembled, allowing reasonably precise assessments of light. This has the advantage of liberating the creator from technicalities since accuracy is not yet of paramount importance. A preliminary model usually allows more versatility than a model used for final assessments. The physical model and the video recording become important sketching tools. The
manipulation of the image within the computer provides the quantitative analysis that induces an additional interactive level with the physical model and the video sketchbook. Diagram 500 also suggests the construction of a more accurate physical model allowing minimal adjustments for a final assessment. The rougher model relates to creativity, whereas the accurate model involves less alteration to offer more realism.

Series of transformations may be recorded for further comparison and analysis of certain variations of apertures or space morphology. The sequence of images can allow some freedom in the manipulation of the variables of aperture and space. For instance figure 4.14 shows a sequence of images where the lateral walls are mobile, and where the zenithal aperture is consequently altered. Most of these spaces would not be modelled within the rigorous experimental setting of traditional photometry of light, and would probably not be acknowledged as part of a lighting concept at the design stages of a project. This example illustrates that the photographic method of lighting analysis has this advantage to offer more flexibility and allow more explorations of light and space.
Figure 4.15 illustrates the lighting patterns for each image of the sequence, and figure 4.16 shows the corresponding brightness histograms of analysis for the entire image. The simultaneous study of the different lighting patterns and histograms informs the architects on several aspects of light and contrast, as discussed in chapter 3. For instance, in images where the lighting pattern of the different surfaces appear to melt into each others such as in figure 4.15k), the space appear more uniformly lit and the physical distinction between the surfaces is not marked. In figure 4.15h), the edges of the surfaces are well defined through the pattern and the surfaces appear to be more distinct from each others.
The Composition With Images

Figure 4.15: Brightness separation into five zones for the sequence of images (from fig. 4.14)

The histograms of analysis were calculated for the entire image for a more global assessment of the combined effect of light on all the surfaces of the image, but it is also possible to isolate a unique surface such as the vertical wall situated in front of the observer. The histograms indicate similarities between the images. The histogram of image j) is, for instance, the least similar of the group, and this is also apparent through the graph of histogram data (figure 4.17).
Figure 4.16: Histograms for entire image of sequence (from fig. 4.15).

Figure 4.17: Evolution of histogram variables for the entire image (from fig. 4.15).
Figure 4.18 shows images obtained from a model filmed under an artificial overcast sky. The model consists in a rectilinear space lit by a longitudinal aperture on which slides an opaque mask. This therefore simulates different dimensions of a zenithal aperture where the space, initially dark, fills with light as the aperture progressively enlarges. This sequence of images facilitates the comparison of different design alternatives which have occurred within a matter of seconds.

Figure 4.18: Moving sequence with variations of the zenithal aperture.

The lighting pattern enables the comparison of a series of images within the computer analysis. Figure 4.19 shows the corresponding lighting patterns for the sequence illustrated in figure 4.18. The patterns are created from a brightness separation of 5 levels: 100%, 75%, 50%, 25% and 0%. There is therefore the possibility to locate those 5 brightness levels on each image, but it appears that images g), h) and i) contain only 4 levels. This absence of the 100% brightness level was expected. Indeed, the brightness histograms of the vertical surface (figure 4.21) confirm the disappearance of pixels with a brightness value higher than 87.5% for those images, thus eliminating the 100% brightness zone. The surfaces of spaces g), h) and i) have therefore lower contrast values since they lack one brightness level. The simplified brightness representation (fig.
4.19) allows possible classifications of images according to contrast and other characteristics of light obtained from the morphology of the lighting pattern, as previously defined in chapter 3. The comparison of the quantitative results is possible when the camera is in a fixed position, which eliminates variables such as the framing of the image and the emplacement of the viewpoint of the camera. The light source should also remain constant.

The following brightness histograms (figure 4.21) are restricted to the vertical square surface of analysis, located directly in front of the observer. The photographic results provide a reasonable accuracy since the image distortion is minimal at the centre of the image. As already mentioned in
chapter 2, the automatic light meter of the camera is more precise towards the centre of the image. Moreover, the absence of apertures within the zone of analysis mitigates most problems of light exposure. These factors are particularly important for an accurate assessment of light, but practically, it may not always be possible to gather ideal physical conditions for all spatial configurations.

Figure 4.21: Histograms of analysis of square walls of figure 4.15.

Figure 4.22 summarises the percentage values of the four statistical data of figure 4.21 according to the sequence of modification of the model. The interquartile range and the standard deviation data are most relevant for the analysis of contrast since they indicate the horizontal spread of the brightness histogram (refer to chapter 3). It is difficult to identify the number of brightness levels on image A because the area of the different zones are very small, but the data suggest that this configuration has the lowest contrast value, which is possible since the space is almost entirely dark. Contrast attains a maximal value at images b), c), d) and e), after which it gradually decreases as the aperture enlarges (image 4.21 i). The mean and median data indicate that the peak of the histogram progressively moves from the dark values (2% to 3%) to the mid-grey values (35% to 40%) as the aperture enlarges. This indicates that the average brightness value on the surface of analysis reaches a plateau from images d) and e).
This analysis of a sequence of images can be relevant for the choice of a system of apertures. It allows the interpretations of a series of variables within a limited time. The graph has the advantage to provide the quantitative information for designs possibilities that were not necessarily simulated.

Summary

The interactive approach to the composition with images provides the necessary creative freedom combined with quantitative results of lighting analysis to initiate the design process. The computer becomes a design tool that interacts with models and other media to generate ideas based on the image. The methodology introduces the concept of the video sketchbook which takes part of the development of the design, similarly to the sketchbook that the architect fills with drawings and esquisses. The suggestive power of the image is an essential aspect of the methodology as it provides inspiration and visualisation of light in creating ambiances. The image is also a promising tool in its capacity to be transformed and manipulated in such ways that it can be abstracted to define different interpretations. The introduction of filters provides even more advanced possibilities of abstraction of an image. Even though these abstractions are not always compatible with the representativity of light, they remain important generators of ideas. The method proposes two types of interactions of the video camera with the design process: early and late design stages. The first interaction corresponds to the use of the video as a sketch book, and the second consists in a more accurate correct simulation of light with a physical model. Two sequences of images are analysed to illustrate some of the possibilities offered by the quantitative analysis offered by the software of image processing.

The following section proposes a systematic approach to the composition with images, introducing notions of representativity of light and the advantages of a library of images.
The Typological Approach:
a library of images

Images have a potential to suggest ambiences. Because of this suggestive power, images inspire and enable different reflections in the design process [Mitchell & McCullough, 1991]. Spatial creation from the nature of light is possible with the use of images. This section explores the visual capacity of multimedia technology to suggest and generate different lighting ambiances through computer manipulations such as collage, scaling, and duplication. Designers are already familiar with these activities, but not necessarily within the computer medium. Editing an image with the computer facilitates and accelerates the process of alteration and transformation. Initial images may originate from a real environment but, for a more abstract and systematic classification, the use of a physical model produces more accurate results. A library of images may constitute a starting point to initiate the design process to avoid any physical modelling. A library consists of basic photographs that initially inspire the architect, allowing to sketch spaces with existing images of light. It constitutes a premise to the actual building of physical scale models. These initial images compose a basic resource for space creation. The combination of images generates numerous design possibilities, and enables explorations of space and light. A physical model may however be used at a later design stage to assess the behaviour of light in intricate spatial organisations with more precision. The introduction of a physical model responds more appropriately to a complex problem and verifies the hypothesis offered by the interaction between images (figure 4.13). The extensive use of computer space generation contributes to an exploration of numerous design alternatives within a limited period of time. There are some limitations that need to be applied to the components and the use of a library of images. For instance, some types of images provide more latitude for explorations and offer more transformational possibilities than others. The library of images consists of basic space-aperture configurations but it could also evolve to include the most extensively used configurations throughout a project. Figure 4.23 illustrates the interaction of a library of images in the design process. It identifies two stages: the early design stage that uses bidimensional simulations, and the late design stage which includes the tridimensional aspect. The library contributes to a considerable reduction of the involvement of the video camera and physical models, because of the availability of basic images with known quantitative and qualitative attributes. The early design stage can therefore produce reasonable results of analysis without the use of the video camera or physical model. The images that compose the library are modelled in an artificial sky to allow an accurate final analysis at the early design stage. Figure 4.23 also implies that a final analysis could also occur with the sole bidimensional simulation. A more accurate analysis should result from a tridimensional simulation to verify the interpretation of the image obtained after subsequent transformations. This could allow some final modifications of the model and refinement of the design.
Components of a Library of Images

This section describes the methodology to elaborate of a library of images. The bank consists of basic configurations of spaces and apertures photographed under the controlled conditions of an artificial sky. The library uses the diffuse light of an overcast sky since it is most critical in design, especially under northern latitudes where it produces lower illumination and contrast levels. Indeed, as previously noticed, the pattern created by the direct light of the sun continuously varies throughout the day, making it difficult to assess all possible configurations. The images of a library are ideally photographed with a 35mm camera, and the negatives are scanned with a slide scanner. This method provides a highly accurate visual representation because of the great quality of the negatives, and it therefore allows an excellent quality print out. The commonly available video camera does not provide such precision (refer to chapter 2) but it has the advantage to produce images for an immediate use. Since the library of images can be compiled in advance, the 35mm camera should be privileged for accuracy and visual rendering. Configurations of spaces and apertures should be simple enough to allow a certain flexibility, and to optimise the possibilities of transformations and combinations of images during the design process. Libraries of images will most probably be different for each architect due to personal preferences and spatial vocabulary. There are also some designs that need to produce certain ambiances related to specific contrast
levels, therefore influencing the initial choice of images. Richard Meier and Tadao Ando would surely create distinct libraries of images since they use different types of apertures, and usually prefer opposite ambiences relating to quite specific contrast levels (refer to chapter 3).

**Surface Reflectance**

The choice of materials and reflectances have a marked effect upon the brightness pattern of a surface. The library of images that contains surfaces of different reflectances is usually specific to a project since a more restrictive number of combinations and modifications are allowed. Reflectances affect the brightness of surfaces, but they also modify the proportion of indirect or reflected light by altering the appearance of objects. A space with generally high reflectances, will generate soft contrasts and gentle modelling. An interior with dark surfaces will have a greater proportion of direct light, producing a harsh, dramatic character with strong contrasts of light and shade [Hopkinson & Kay, 1969, p. 27]. The nature of the design process often involves tridimensional transformations that will affect the ambience of a space. Minor planar modifications that affect the luminance of a surface can produce a great impact on the perception of space.

Figures 4.24 and 4.25 a show two identical spaces where the surface located in front of the observer has different luminances. The lighting patterns vary accordingly in figure 4.24b) and 4.25b). The lighting pattern on the rear wall in figure 4.25 is larger than in figure 4.24. The pattern on the right lateral wall is also affected by the transformation, especially near the rear surface. The histograms of analysis for the rear wall are very different (figures 4.24c) and 4.25c)). Most of the pixels are located towards the 0% brightness value for the black rear wall whereas there is a peak at the 25% and 100% brightness values for the white rear wall. The histogram for the lateral wall in both examples (figures 4.24d) and 4.25d)) are quite similar, except for the interquartile range, which appears to be greater for image 4.24 than 4.25. Both lateral walls have the same reflectance, except that they are adjacent to a rear wall that has a different reflectance. This shows the importance to model different situations involving different surface luminances. Other configurations and combinations of surface luminances would produce other lighting patterns. The direct alteration of a surface luminance on the image through the computer processing would therefore not acknowledge the variation of the lighting pattern and would involve specific physical modelling. Other examples of a space and aperture configuration with different surface reflectances are illustrated in Appendix C.
Figure 4.24: Analysis of a space with an internal reflectances of 0%.

Figure 4.25: Analysis of a space with mixed internal reflectances of 0% and 100%.
This section examines the simulation of a library of images with generally low reflectances. The black box with a nearly 0% surface reflectance, has the advantage of minimising the visualisation of spatial limits and the interreflection of surfaces. Other reflectances could also be assessed since all spaces do not have these internal reflectances. It therefore appears that it is hardly possible to establish a universal library of images that would respond to the need of every architect since it would consist of an infinite number of images. As a first rule, it is clear that the more abstract and basic representations generally allow more design possibilities and computer transformations.

**Position of an Aperture**

The darken edge of an image of the space with black surfaces facilitates this abstraction because the lighting pattern is primarily affected by the aperture and its adjacent surfaces. The lighting pattern of a small aperture positioned at the centre of such a space would only be affected by the perimeter of the aperture and the receiving wall or surface of analysis because the interreflections are minimised by the low reflecting properties of adjacent surfaces (figure 4.26a). The relative position of the aperture has an influence on the flexibility of utilisation of an image. For instance, an aperture adjacent to many surfaces is more restrictive in terms of manipulations and representativity (figure 4.26b) because the adjacent surfaces define a specific condition of light and space. In cases where obstructions of light from the horizon are important, a library of images may not be an appropriate solution since it would become too specific to allow design explorations. The library of images needs to provide the flexibility for initial sketches, with the added possibility to employ physical models in the simulation of the correct environmental obstructions for a more accurate representation and analysis. The centre location of an aperture (figure 4.26a) produces a relatively comparable lighting pattern than the corner location (figure 4.26b). The proximity to the nearly 0% reflectance surface does not affect the reflecting component of light in this example.

![Figure 4.26 Punctured apertures, zenithal location.](image)
The vertical location of lateral apertures also affects the lighting pattern. The absence of an axis of symmetry signifies the need to experiment at least three positions to constitute the library of images: high, central and low positions. The central position (figure 4.27a) is the least exposed from any reflecting component of interior surfaces. Even with its low reflectance, the black ceiling affects the lighting pattern by enlarging it along the surface of contact with the aperture (figure 4.27b). The 10% ground reflectance of the artificial sky may also create a reflection on the ceiling and consequently enlarge the pattern. The low vertical position accounts for the smallest pattern since it only relies on the horizontal sky components (figure 4.27c). Even the horizontal spread is less emphasised than in the centred location because the lower illumination level of the sky on the horizon creates a more compact pattern, shorter on the horizontal axis. This situation occurs even with nearly 0% internal surfaces of space.

Figure 4.27: Punctured apertures, lateral location.
The library of images may initially consist of a limited number of images, as illustrated in figure 4.29, which would evolve with other typologies of apertures as required by the development of a particular design. Distinction should be made between zenithal and lateral orientations of apertures because even under diffuse conditions of an overcast sky, light has a directionality (figure 4.28). Even though it is possible to combine series of punctured apertures to visualise a linear aperture, it may be relevant to experiment the linear type individually for a more accurate representation.

![Figure 4.28: Longitudinal apertures for an overcast sky condition.](image)

<table>
<thead>
<tr>
<th>ORIENTATION</th>
<th>TYPES OF APERTURES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZENITHAL</td>
<td>LINEAR</td>
</tr>
<tr>
<td></td>
<td>PUNCTURED</td>
</tr>
<tr>
<td></td>
<td>centred</td>
</tr>
<tr>
<td></td>
<td>corner</td>
</tr>
<tr>
<td>LATERAL</td>
<td>LINEAR</td>
</tr>
<tr>
<td></td>
<td>PUNCTURED</td>
</tr>
<tr>
<td></td>
<td>centred</td>
</tr>
<tr>
<td></td>
<td>corner</td>
</tr>
</tbody>
</table>

![Figure 4.29: A library of images for overcast sky conditions.](image)
Transforming Images

The software of image analysis provides tools that facilitate the modification of images and enable actions that would normally need great preparation with most conventional design tools. The computer transforms images by performing several mathematical operations. Some transformations are mathematically correct but not always acceptable to lighting physics. Other transformations are slightly inconsistent with lighting physics, but they can illustrate a design solution for a preliminary study. It is therefore important to identify the transformations that provide accurate results of lighting analysis from the transformations that only approximate reality (refer to table 4). It is however recommended to validate the final configuration with physical modelling when using transformations that only provide approximations. The following section explores the possibilities offered by the computer to modify images. The chosen images from the library have a limited number of variables to facilitate the comparison of the effects obtained from modifications. A transformation can appear on the entire surface of an image, or in a selected area. There are transformations which only affect the brightness value of pixels, and others which modify the entire mapping of the image, deforming the original grid of space.

The directional quality of the diffuse light is due to the high illumination of the overcast sky at the zenith, which is approximately three times stronger than on the horizon [Robbins, 1986]. Different orientations of apertures, for instance located zenithally or laterally in space, create variations of the lighting pattern. This directional aspect of light is at the origin of the diverse applicabilities of the image in the composition of space. Marsh and Steadman [1971, pp. 18-25] define six mapping conditions familiar to architectural composition. Figure 4.30 shows those mapping conditions according to invariants that are commonly used in architectural design. Among the properties described in the table, the identity is the only physically accurate transformation for image mapping. Most of these mapping transformations are incompatible with the pattern theory since whenever a space is reshaped or mapped, the lighting pattern varies, depending on the morphology of the aperture.
Figure 4.30: Mapping conditions according to invariant [adapted from Marsh and Steadman, 1971, p. 25].

Figure 4.31 resumes the transformations that can be performed on images with limited alteration of the lighting pattern. The transformations that have the least effect upon quantitative attributes are located at the beginning of the table, whereas the most critical mapping transformations are listed towards the end. As previously mentioned, most transformations have a certain effect upon the representativity of light, mainly in quantitative terms. For qualitative purposes, transformations which affect this representativity become desirable since the visualisation of light remains somewhat realistic. Morphological properties of the pattern such as proportions, angle ratios, and parallelism must however be preserved to maximise the representativity of realistic conditions of light.
### CHARACTERISTICS OF THE IMAGE

<table>
<thead>
<tr>
<th>MAPPING</th>
<th>DEFINITION</th>
<th>length</th>
<th>proportions</th>
<th>angle ratio</th>
<th>parallelism</th>
<th>LIMITATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Basic Transformations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>bidirectional scale</td>
<td>Proportional enlargement or diminishing of an entire pattern.</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>No limitation.</td>
</tr>
<tr>
<td>rotation</td>
<td>Simultaneous rotation of all the pixels of an image.</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>Even with 90° increments, does generally not correspond to the direction of the pattern.</td>
</tr>
<tr>
<td>reflection (mirror)</td>
<td>Inversion of the mapping of the pattern according to an axis.</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td></td>
<td>Vertical axis only. Other types of reflections may not represent reality.</td>
</tr>
<tr>
<td>duplication (identity)</td>
<td>Repetition of the pattern.</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>√</td>
<td>For different locations, the interreflections may not correspond to reality.</td>
</tr>
<tr>
<td>variation of the frame (cropping)</td>
<td>Cropping of the image and the pattern.</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
<td>Affects mainly the pattern where the rupture appears in small brightness zones. Interreflections may not correspond to reality.</td>
</tr>
<tr>
<td><strong>Complex Transformations</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>decoupage collage</td>
<td>Cutting and pasting of an image.</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
<td>Does not always produce an accurate representation.</td>
</tr>
<tr>
<td>unidirectional scale</td>
<td>Directional dispersion of the pixels of an image.</td>
<td></td>
<td></td>
<td></td>
<td>√</td>
<td>Does not always produce an accurate representation.</td>
</tr>
</tbody>
</table>

Figure 4.31: Mapping conditions for image transformations according to invariants.

### Basic Transformations

This section explores the basic transformations of an image. They are more precise than the complex transformations, and are therefore recommended for more accurate representations of light.
Bidirectional Scale

The scale of the physical models employed for photometric analysis has theoretically no significance on the accuracy of the simulation of light [Hopkinson et al., 1966, p. 378], but it has to submit to the size limitation of the equipment of data acquisition. In the methodology (chapter 2), the focal length of the camera lens and the size of the artificial sky are the main factors affecting the dimension of the model. With the real sky, the camera remains the only restrictive element in determining the scale of the models. Similarly, the bidirectional scale of an image does not affect the visual representation of light (figure 4.32), nor the lighting pattern or the histogram (figure 4.33), provided that the proportions of the image are respected. The scale of the image needs to vary proportionally in both “x” and “y” axis to maintain the morphology of the lighting pattern. The unidirectional variation of the scale, which transformation corresponds to the linear deformation later described in this chapter, may not always provide a correct modelling of light. The number of pixels remains constant but affects the image resolution at different scales. It is therefore possible to simulate a space at different scales and to combine the resulting images to visualise a new interpretation of that space. Figure 4.32 shows scale factors applied to an initial image. The nature of light allows scale changes, which are of great advantage in the composition with images since they allow different insights of the same lighting pattern. Variations of the scale of an image is also accurate for direct light applications.

Figure 4.32: Scale factors applied to an image.

mean: (31) 12%
std dev: (46) 18%
median: (12) 5%
interquartile range: (92) 36%

Figure 4.33: Histogram of images (from figure 4.32a), b), and c).
Rotation
This section investigates the implications of the rotation of an image upon the lighting pattern. The internal reflectances of the model are nearly 0%, to ensure a correct comparison of patterns. Zenithal apertures under a diffuse light generally produce a larger lighting pattern than lateral apertures because the illumination from the overcast sky is greater from the zenith than from the horizon. Figures 4.34 to 4.36 illustrate three examples of image rotations. The first image of each series (a) represents a space photographed under a zenithal light, while the second image (b) consists in a counter clockwise rotation of that original image, simulating a lateral light. The third image of the series (c) reveals the actual lighting pattern of the rotated aperture photographed under a lateral light. The zenithal condition produces a downward symmetrical pattern whereas the lateral condition has no axis of symmetry, but the main directional axis of the pattern is horizontal. Refer to images 4.26, 4.27, and 4.28 at the beginning of the section on the components of a library of images for a more detailed analysis of the lighting patterns. The histograms for the rear surface of analysis (refer to Appendix A) are much different for zenithal and lateral conditions. These important variations indicate that a rotation of the pattern does not provide an accurate modelling of light. Zenithal and lateral apertures therefore need independent experimentations to represent the directionality of light.

Figure 4.34: Rotation of a longitudinal aperture (photograph and lighting pattern).

a) Original longitudinal aperture under a zenithal light (refer to fig. 4.28a).

b) Rotation of image 4.34a) under a zenithal light (refer to fig. 4.28b)).

c) Experimentation of a longitudinal aperture under a lateral light (refer to fig. 4.28b)).
The Composition with Images

Figure 4.35: Rotation of a punctured aperture, centre location (photograph and lighting pattern).

Figure 4.36: Rotation of a punctured aperture, corner location (photograph and lighting pattern).
Reflection (mirror image)

Mirror images show an accurate modelling of light when performed along a vertical axis. The symmetry on the vertical axis is allowed for the study of vertical surfaces because of the downward directionality of the lighting pattern. Figure 4.37 shows an original image a) and its reflected images from the vertical (image b) and the horizontal axis (image c). The mirror image on the horizontal axis is not accurate since light has a directionality. However, it can be interesting for exploratory design stages (figure 4.40). The histogram of the images (fig. 4.37d)) remains constant for all directions of rotations since the image is preserved.

![Image a) Original image. b) Mirror on vertical axis. c) Mirror on horizontal axis. d) Histogram of image 4.37a.]

<table>
<thead>
<tr>
<th>Values</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>49%</td>
</tr>
<tr>
<td>Std Dev</td>
<td>19%</td>
</tr>
<tr>
<td>Median</td>
<td>30%</td>
</tr>
<tr>
<td>Interquartile range</td>
<td>86%</td>
</tr>
</tbody>
</table>

Figure 4.37 Reflection of a zenithal aperture, diffuse light:

The combination of the original image with a reflected image can create a new space (figure 4.38). Figure 4.38b) shows the lighting pattern of the new combination of images. The cutting of the pattern has occurred within the lowest brightness zone of the image, which also occupies a larger proportion of the image. This minimises the error related to the overlapping of the patterns. The final histogram for the combined images (figure 4.38c)) is almost identical to the histogram of the original image (figure 4.37). This indicates that contrast values are preserved.

![Image a) Reflection on the vertical axis. b) Lighting pattern for image with mirror on the vertical axis.]

Figure 4.38: Combination of lights by reflection for a zenithal aperture (continues on next page).
It is also possible to cut an image within the lighting pattern (figure 4.39a), but the resulting image (figure 4.39b) indicates a darken line towards the centre, at the junction of the images. The lighting pattern clearly shows this rupture. The correct location of the cutting line of the image is therefore essential to avoid any distortion or deformation in the representativity of the combination of images. The histograms of the collage of the original and reflected images remain identical (figure 4.39c), as in the previous example (figure 4.38).

Figure 4.38: Combination of lights by reflection for a zenithal aperture.

Figure 4.39: Cutting and reflection of an image on its vertical axis.
An image can therefore generally be cut without any major deformation when the variation of the image occurs in the largest brightness zone of the pattern, or within a single zone. This larger zone, shown in black on the following images, is where the gradation of luminances varies the least on the surface of analysis.

Figure 4.40 shows the combination of the original image (figure 4.37a) with its reflection image on the horizontal axis. Although the reflected image should not produce such a large and upward pattern (shown on figure 4.40b), the image can suggest other types of situations where the light coming from the floor would be reflected from a specular surface such as water.

**Duplication (identity)**

The duplication of a lighting pattern enables the simulation of a space configuration with multiple light sources. Collages of adjacent lights create overlapping of patterns with undesirable dark zones, such as in figure 4.41, when using transparency modes of selection, which should not appear in reality. This effect is minimised with the application of the 100% transparency mode of the computer software of image processing. Consideration on the location of the cutting line of the original image also applies, as previously discussed. The duplication function is very useful to the elaboration on an initial screen sketch. The final proposition would need proper modelling under an artificial sky as the overall increase in light sources affects the interreflecting component of light from adjacent surfaces. As in the reflection of an image, the duplication preserves the histogram of analysis when a single portion of an image is simply reproduced without any other change.
Variation of the Frame (cropping)

The photograph is the result of a selection, by opposition to the painting which is a creation. Szarkowski [1980] mentions that the central act of photography consists in choosing and eliminating, to force a concentration on the picture edge and on the shapes that are captured by the camera lens. The edge constitutes the limit between the image and the other world. The sense of the picture's edges as a cropping device is hence important to the signification of the image [Szarkowski, 1980]. Photography introduces this possibility to alter the frame of an image, which constitutes a major aspect of the definition of space. The partial selection of an image creates a context for new interpretations, suggesting other spatial configurations and redefining an ambience. The modification of the frame or decoupage of an image can abstract or subtract a part of its initial context to allow a new vision of space (figure 4.42). The images of figure 4 illustrate the perception of a certain character of the bottle, which was voluntarily identified and selected by the designer. The image with well-defined space edges restricts the interpretation to its existing representation, omitting the original context.
Figure 4.42: Reframing of an image (from figure 4.4b).

<table>
<thead>
<tr>
<th>IMAGE</th>
<th>HISTOGRAM</th>
<th>LIGHTING PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td><img src="image1.png" alt="Histogram" /></td>
<td><img src="image2.png" alt="Lighting Pattern" /></td>
</tr>
<tr>
<td>b)</td>
<td><img src="image3.png" alt="Histogram" /></td>
<td><img src="image4.png" alt="Lighting Pattern" /></td>
</tr>
<tr>
<td>c)</td>
<td><img src="image5.png" alt="Histogram" /></td>
<td><img src="image6.png" alt="Lighting Pattern" /></td>
</tr>
<tr>
<td>d)</td>
<td><img src="image7.png" alt="Histogram" /></td>
<td><img src="image8.png" alt="Lighting Pattern" /></td>
</tr>
</tbody>
</table>

Figure 4.43: Cropping of an image (from figure 4.41).
The variation of the frame of an image can therefore produce new spaces by creating the impression that the enclosing surfaces of the initial spaces have moved. Figure 4.43 shows different elevations into hypothetical spaces issued from the square rear wall of an initial image (figure 4.35). The newly reframed images suggest different relationships between an aperture and a vertical plane, which could initiate the exploration and the composition of a new space. The reframing of an image without any alteration to the lighting pattern implies that reflectances of adjacent surfaces should be of nearly 0% (black) to ensure an exact representation of light and avoid further modelling. As previously stated, even low reflectance surfaces create a slight variation of the pattern, but these can be considered unimportant in earlier design stages. Higher reflectance surfaces would clearly affect the lighting pattern and representation of the new image. The reframing of an image is a generative medium to space creation that offers many possibilities. The approach also allows further qualitative and quantitative analysis with physical modelling, simultaneously as the design progresses, minimising the error related to spaces with higher reflectances than 0%. The approach assumes that the image provides inspiration for the beginning of a project, but further experimentation would ensure a correct final representation.

**Complex Transformations**

The image allows modifications of the width and height of a space through mapping transformations such as decoupage, collage, and linear deformations. This section examines a real case study before tackling these complex mapping transformations. The different spaces were filmed under an overcast sky condition and processed through the computer software of image processing. The internal surfaces have a reflectance of 55%.

Three spaces were filmed with different lengths of apertures corresponding to the varying widths. Figures 4.44, 4.45, and 4.46 illustrate the different conditions, showing the image, the lighting patterns, and the histogram. The histograms remain relatively unchanged, suggesting the constancy of contrast. The vertical distribution of the brightness zones of 100%, 75%, 50%, and 25% slightly varies. A 0% brightness zone also appears on the lighting pattern of the space represented in figure 4.46. Figure 4.45 has the pattern that possesses the greater vertical spread (image d) whereas the space of figure 4.46 has the smallest. These small variations may be caused by the different interpretations of the lighting levels through the posemeter of the camera. Also, the calculation of the vertical spread of the pattern would be more precise if the patterns were larger. It can however be assessed that the variation of spatial width does not significantly affect the vertical spread of the lighting pattern, nor the histogram of brightness distributions on the surface of analysis, except for the appearance of the fifth brightness zone in the wider space.
The Composition with Images

Figure 4.44: Space with square surface of analysis (x.x).

Figure 4.45: Space with rectangular surface of analysis (x.4/3x).
Two spaces with different heights and identical sizes of apertures were filmed under an overcast sky. The histograms for the vertical surface of analysis are relatively constant, and the vertical spread of the lighting pattern of the higher space (figure 4.48) is slightly greater than for the lower space (figure 4.47), but not significantly. Because of the higher location of the aperture, the 100% brightness zone appears larger in the higher space. The brightness distribution between the two spaces is however much different on the lateral surfaces, but it is difficult to assess the effect of the posemeter of the camera at this stage. The most interesting aspect is that the lighting pattern remains almost identical for the two spaces when only considering the higher part of the pattern of the higher space.
The Composition with Images

Figure 4.47: Space with square surface of analysis (x.x).

Figure 4.48: Space with rectangular surface of analysis (x.3/2x).
Initial design stages involving the composition of space allow the variation of the spatial width and height of space to produce qualitative and quantitative results of analysis without the need for any experimentation. There are slight variations that can influence the brightness distributions in the final image. These could eventually be experimentally verified for later design stages. The following sections explore the mapping transformations that allow the modification of the spatial width and height.

Decoupage and Collage

The *decoupage and collage* is the most representative method of doing a unidirectional scale of the pattern. Figure 4.49 shows a linear aperture and its symmetrical lighting pattern, photographed under an artificial overcast sky. The internal reflectances of the space are nearly 0% (black), except for the surface of analysis which is about 80% (white). The corresponding histograms and lighting patterns are also presented in Appendix C.

![Image of a linear aperture along a wall.](image)

In figure 4.50, an area of the image of figure 4.49 is cut, copied, flipped and pasted to the original image to simulate a narrower space. The resulting image is visually convincing, and the lighting pattern shows a slight rupture where the collage occurred. The initial and resulting histograms are almost identical, as expected. The final image does however not account for the reflective effect of the vertical wall upon other surfaces. The black box with its surface reflectances of nearly 0%, minimizes this effect. The aperture of the resulting space is much smaller than in the original space and the side walls are closer. The receiving wall should theoretically not receive as much light from the sky and the resulting lighting pattern on its surface should therefore be affected. The vertical spread is preserved because of the technique of decoupage. The lighting pattern on the side walls should also appear slightly smaller since it would have a more restricted view of the sky, and hence...
receive less sky light. For initial design stages, this confirms that the image remains a representation of an ambience and would need further experimentation before proceeding to a final assessment of light in the **collage** representation. The collage however allows a preliminary visualisation of a narrower space, and although the transformation of the original image is slightly inaccurate, it can still become part of a research on the design of space for the early design stage.

![Decoupage](image1.png)

![Resulting image of a narrow space](image2.png)

![Lighting pattern for a brightness separation into five levels](image3.png)

**Figure 4.50: Decoupage and collage of an image (small portion).**

A larger portion of the image may be copied (figure 4.51a)), mirrored and pasted to the original image to create a wider space (fig. 4.51b)). In that case, a darker area may appear in the centre of the new image, because the duplication did not occur from the centre of the pattern. The lighting pattern shows the effect of the collage at the centre of the image. Although the histograms of the initial images are similar (figure 4.50d)), they do not inform on this aspect of the qualitative representation of the lighting pattern.
The variation of width using the collage method remains a rough approximation of reality. The resulting lighting pattern demonstrates that a variation of width could lead to an erroneous qualitative and even quantitative representation of light. This emphasises the importance of the selection frame on the representativity of the final lighting pattern. Therefore, such manipulations should mainly use the centre line to cut the initial image and minimise this important source of error. However, collage techniques enable other types of combinations to vary the width of space. The error caused by the side wall could considerably diminish by duplicating the central section, until the obtaining of the desired width. Figure 4.52a) shows different sections obtained from the original image (figure 4.49). The central section is copied and pasted until the image reaches the desired width of space (fig. 4.52d)). The lighting pattern of the new image (fig. 4.52e) is visually more convincing. The variation of the spatial width also affects the visual representation in perspective. The emplacement of the vanishing point of the original image does not correspond to reality. Such factor could prove to be important in a final assessment, but have less significance in the early design stages.

Figure 4.51: Decoupage an collage of an image (large portion).
The Composition with Images

a) Sections of the original surface of analysis of the image (from figure 4.49).

mean: (119) 46%
std dev: (61) 24%
median: (103) 40%
interq range: (185) 72%

b) Histogram for the left and right sections of wall.

c) Histogram for the central section of wall.

mean: (124) 48%
std dev: (59) 23%
median: (110) 43%
interq range: (176) 69%

resulting histogram for rear wall
mean: (121) 47%
std dev: (59) 23%
median: (106) 41%
interq range: (186) 73%

d) Wider space with reproduction of the central section of figure a).

e) Lighting pattern for 5 brightness zones.

f) Resulting histogram of figure d).

Figure 4.52: Decoupage and collage of multiple section of an image.
The collage enables variations of width with a relatively accurate representation. The important aspect is to ensure the correct cutting of the pattern to avoid any rupture or discontinuity in the final pattern. The operations of collage and decoupage however do not produce a correct modelling of light through the variation of the height of a space. It was earlier demonstrated that the higher space has a lower brightness zone towards the floor of the space than the lower space. The following section studies the potential of linear deformations to simulate variations in width and height.

**Unidirectional Scaling**

The software of image processing allows the transformation of a space by repositioning the corners of an image. This can also be described as a unidirectional scaling or stretching of the image. The modification of the image starts from a point of origin specified by the designer. The computer uses an interpolation method to calculate the brightness values of the pixels that are added or deleted as a result of the transformation. Figure 4.53a) shows an original lighting pattern and the grid represents the mapping of the pixels of the image. Figure 4.53b) shows the possible horizontal compression of the mapping and the final lighting pattern.

![Figure 4.53a) Initial image of a linear aperture along a wall (fig. 4.49).](image)

![Figure 4.53b) Mapping transformation for the narrowing of space by horizontal stretching of the image a).](image)

![Figure 4.53c) Narrowing of space by horizontal stretching of the image.](image)

![Figure 4.53d) Corresponding brightness pattern.](image)

![Figure 4.53e) Resulting histogram of analysis for rear wall.](image)

*Figure 4.53: Unidirectional scaling of an image (horizontal compression).*
Figure 4.53c) shows the horizontal compression of the mapping of the image of figure 4.49. The lighting pattern does not show any rupture, which is an advantage in qualitative assessments. However, the histogram for the surface of analysis is much different than it is for the initial image, which does not seem to appear in the case study earlier presented.

Figure 4.54 illustrates the horizontal elongation of the mapping of image figure 4.49. The histogram for the surface of analysis is much different, but the pattern appears realistic.

a) Horizontally stretched image.

b) Brightness pattern of the stretched image.

c) Resulting histogram for rear wall.

*Figure 4.54: Unidirectional scaling of an image (horizontal elongation).*
Figure 4.55 shows the vertical deformation of the lighting pattern. Although appearing realistic, the lighting pattern is also vertically stretched, which does not happen in reality. The vertical stretch does however not constitute a correct representation of light.

Figure 4.55: Unidirectional scaling of an image (vertical elongation).
Figure 4.56 shows the combined vertical and horizontal deformation of the mapping of image 4.49. Although it obviously does not correspond to an accurate representation of a lower and wider space, it remains interesting for investigations of initial design stages.

![Horizontal and vertically stretched image.](image)

**Figure 4.56:** Non-proportional bidimensional scaling of an image.

Stretching space is conceivable, but stretching the lighting pattern might result in an inaccurate representation of light, especially for a vertical deformation. When stretching the entire image, the pattern also stretches, which does not appear in reality unless the attribution of a bidimensional scale of identical values for vertical and horizontal axis. For instance, the lighting pattern should not be stretched when the aperture remains intact. Other commands enable the deformation of a surface by using `perspective` and `distortion` functions. All the mapping transformations relocate pixels of an image and fills the gap with new pixels to create sometimes unusual shapes or distortions. These ways of transforming images are also stretching the lighting pattern, sometimes affecting the realism of the representation. Mapping transformations should mostly be employed for a visual estimation.
Adding Lights

Perhaps the most versatile and realistic application of computer image processing of a library of images consists in the addition of lights. It offers a dynamic approach to the composition of space. It also has the capacity to visualise and even quantify almost instantaneously the results of the combination of apertures for a certain space, provided that the proposed apertures are available in the library of images. This enables the observer to concentrate on the elaboration of the ambience of a space and to obtain simultaneous quantitative and qualitative assessments. There are however some limits to the possibilities of combining images, all of which could not possibly be resolved within the scope of this research, but in most situations, these limits are not crucial to early design stages.

Superimposition of images with different lighting patterns is possible within the software of image processing and analysis. It allows the creation of new spatial ambiances by combination of lights. An essential condition for accurate results is that the photography of the different aperture configurations needs to operate from a similar viewpoint, within identical spatial configurations. The addition of lights, in this manner, allows the comparison of several lighting concepts without having to model all possible combinations. Additions and subtractions of bit mapped images are arithmetically accurate. Two photographs or more may be combined by adding different image matrixes. The designer chooses an image, and through the software of image analysis, creates a new matrix which in turn defines the new image. In lighting analysis the data may be processed in black and white to minimise computing and storage memory (refer to chapter 2). It is possible to combine a second image with the original image, which would consist of a new configuration of aperture in the same space as the original image for instance. When the addition calculation is applied to the image, the computer adds the difference of grey value for each corresponding pixel of the image matrixes, which explains the need to preserve the type of space and the location of the viewpoint between the images. This operation creates another matrix where only the new pixels corresponding to the new lights are added to the original image. Figures 4.57a) and b) show two images of different space-aperture configurations photographed separately in the same space under an artificial sky. Figure 4.57a) represents a lateral aperture, and 4.57b) is a zenithal aperture. The combination of the two apertures was also photographed under an artificial sky (figure 4.57c). The mathematical combination of images 4.57a) and 4.57b) through the computer produces a new image (fig. 4.57d). The result is physically plausible since the addition of apertures of different lights is vectorial. The histograms are comparable and the statistical data also indicate that the resulting image (fig. 4.57d) approaches the experimental condition (fig. 4.57c). In terms of isolux curves, additions of lights are possible when using the lighting pattern to quantitatively predict new configurations and combinations of apertures.
<table>
<thead>
<tr>
<th>IMAGE</th>
<th>HISTOGRAM</th>
<th>LIGHTING PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Lateral aperture.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
- mean: (13) 4%  
- std dev: (17) 7%  
- median: (10) 4%  
- interq range: (77) 30% |  |
| b) Zenithal aperture. |  
- mean: (21) 8%  
- std dev: (20) 8%  
- median: (16) 6%  
- interq range: (85) 33% |  |
| c) Combination of apertures. Photograph from a physical model |  
- mean: (30) 12%  
- std dev: (25) 10%  
- median: (23) 9%  
- interq range: (108) 42% |  |
| d) Combination of apertures. Theoretical, from computing. |  
- mean: (34) 13%  
- std dev: (26) 10%  
- median: (28) 11%  
- interq range: (101) 39% |  |

Figure 4.57: Combination of lateral and zenithal apertures.

Figure 4.58 illustrates the additive process of apertures from a library of images. The initial images a), b), c), and d) are progressively added to result in image abcde, combining the four types of apertures. The example demonstrates the potential of the typological approach to lighting design in generating new atmospheres in a defined space, without the need of physical modelling during the design stage.
<table>
<thead>
<tr>
<th>IMAGE</th>
<th>HISTOGRAM</th>
<th>LIGHTING PATTERN</th>
</tr>
</thead>
<tbody>
<tr>
<td>a)</td>
<td></td>
<td></td>
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<tr>
<td>b)</td>
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<tr>
<td>ab</td>
<td></td>
<td></td>
</tr>
<tr>
<td>c)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>abc</td>
<td></td>
<td></td>
</tr>
<tr>
<td>d)</td>
<td></td>
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</tbody>
</table>

**Figure 4.58:** Combination of apertures through computer processing (continues on next page).
There are rules for building a library of images allowing applications of addition and subtraction. The types of surfaces need to remain identical for all the configurations that will be used to perform the addition of images. The addition through different image matrixes involves consistency of the spatial configuration, and the viewpoint of the camera must remain static since the calculation relies on the differences between pixel values on the different images. The library of images for surfaces of low reflectances is more flexible since more combinations are possible to create different space configurations. It allows, for instance, the modification of the frame of an image without affecting the lighting pattern of the final image.

**Conclusions**

Photography has the capacity to report and provide a reliable support for an objective vision. The evocative and suggestive character of photography allows the formation of a creative approach to light through the development of conceptual images. The computer enables manipulations and transformations of images to enhance their content according to the architect's intentions related to a specific ambience or lighting concept. The composition with images, although well established in disciplines of art and photography, is still in its early developments in architectural design. Architects are about to discover the advantages of using the technology of image processing in an artistic manner. The suggestive power of images is inestimable to the architect's work, and the possible transformations of images furthermore provide elements of new and perhaps unexpected light compositions.

This chapter has explored some of the readily available tools of computer image processing. Many transformations could also be performed by conventional photographic processing, but it would take much more time to obtain significant results. The computer also offers the possibility to modify the mapping of images which is virtually impossible with conventional photographic processing.
Some manipulations are considered as correct in the sense that they correspond to the physical behaviour of light. The addition of images is perhaps the most interesting manipulation since it has a certain correspondence with the vectorial character of light. A summary table has proposed a classification of the most useful manipulations of images in order of accuracy of the lighting representation. These transformations have been described through examples and compared to experimental case studies. Many manipulations proved not to be accurate enough for a realistic representation of light. This does however not forbid their utilisation when it becomes imperative to suggest an idea at the early design stages. More research should be invested on the limits of the transformation of images through the comparative investigation of theoretical and experimental case studies.
The Sanctuary of Art:
Between the measurable and the unmeasurable

Chapter 5

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The Sanctuary of Art: Between the measurable and the unmeasurable

The balance between art and science, between the unmeasurable and the measurable, corresponds to Kahn's notion of the Sanctuary of Art. The main objective of the research was to establish a basis on which architecture and light could attain the Sanctuary of Art. This research was based on Kahn's assumption that "the measurable is only a servant of the unmeasurable" [1969], and that the attainment of the Sanctuary is only possible through an intuitive design process, as expressed by Le Corbusier. The measure of qualitative aspects of light is not the prime intention of the research since, as it was demonstrated, it is not possible to measure everything, especially when emotions are at stake. The architect must continue to develop its own intuitive vocabulary of space and light to become a more knowledgeable assessor of its qualities. The architect should also consider light as if it were another material. This materialistic approach involves the establishment of a design method that enables a more coherent and global approach to the creation of spaces with light, considering the present fragmented practice whereas art and science are much separated. It appeared essential to develop a design approach to the generation of spaces from lights that could allow the expression of the architect's emotions and sensibility, in Le Corbusier's sense that "it cannot be measured" [1924], and which he also refers as intuition. The method had to simultaneously offer the possibility to obtain effortless and immediate quantitative assessments of light when needed to support the creative design process (figure 5.1).
The qualitative aspects of light have always been fascinating for architects and artists. Light as art or "Light as a tool of expression" as Louis I. Kahn puts it, is perhaps the most important but yet unmeasurable aspect of space. The architect, in opposition to the artist, has to be conscious about quantitative aspects of light to achieve the desired result in the constructed project. There is therefore the need to include quantitative as well as qualitative aspects of light in architecture. The new technological developments that have introduced the liberation of the façade from constructive matters and opacity has recently deprived architects of a theory of light. This liberation of space from the load-bearing structure is responsible for the new complexity involved with light. The introduction of many new design possibilities have created a state of ineffectiveness in the elaboration of lighting concepts because of the rupture with tradition and intuition, which Le Corbusier also expresses as "the sum of acquired knowledge" [1924]. It is important for architects to take advantage of the present technological era. The need to rediscover light as a constructive matter of space is imminent and the development of design tools and theory should be privileged in the future to take advantage of these new technological possibilities and therefore extend the range of design solutions that were available in the past. Research on quantitative aspects has mostly developed from a systematic approach to the luminous environment, leaving the qualitative aspects virtually unexplored. The visualisation of the resulting ambience is rarely possible before the final design stages. Studies on qualitative aspects have contributed to the quantification of perceptual aspects of light, but it is still argued that the results of these researches are much cruder than the real perception, and that they lack in the involved complexity of seeing and living with light. Scientific precepts and rules do not appear to be effectively adapted to the architectural practice and are virtually not employed in early design stages. Such aspects have instigated this reflection on the development of a design method which would correspond to the applied nature of the architect's design practice.

**Contribution to Light as Art**

This research proposes an original means of assessing light that enables architects to develop a more global approach to the luminous environment, and in some respect incites them to enquire more about its quantitative aspects. The methodology favours a convivial relation between the architect and light by introducing a technique which develops an intuitive thinking and a visual approach to light. It also explores the possibilities of using the image as a design tool. The image is an abstraction of reality, but its realistic and convincing character propels the design activities to higher levels of interpretation. The image constitutes a stimulating design tool because of its capacity to represent the immaterial qualities of light. There are however certain limits to the validity of the photographic representation, but they can easily be abstracted by most architects at the early design stage. An advantage of using images is to obtain quantitative and qualitative assessments of
light in space. Quantitatively, the image represents more than its usual attributes. The familiarity with the design tool eventually encourages a more global comprehension of the luminous environment. The architect will progressively gain more confidence about the visualisation of light and ultimately become less dependant on the tool as, in Le Corbusier's terms, the sum of acquired knowledge increases. In that respect, the pedagogic significance of the method cannot be underestimated.

The method integrates the traditional tools of the architects to the computer image analysis to promote a continuity with existing design methods. The composition of spaces with physical modelling and computer image processing enables immediate qualitative and quantitative results (figures 5.2 and 5.3). The method corresponds to the urge of creation, allowing impulsion and intuition to interact, within a framework allowing an understanding of the physical nature of light. The computer enables an analysis of the brightness distributions on the image and the method explores further processing of image data to provide an assessment of light. The generation of spaces from light ultimately leads to the composition with typologies of light. This aspects of the methodology introduces a further level of abstraction, allowing different activities within the design process. The manipulation of an image taken from the typological library furthermore accelerates the design process and the generation of ideas by providing qualitative and quantitative assessments of light without the need for any physical model nor simulation.

This research has proposed:

- A design method enabling the quantification of the information available through the image for an architectural assessment of light (chapter 2).

- An investigation of contrast as a global integrator of quantitative and qualitative aspects of light (chapter 3).

- An approach to the composition of space with lights (chapter 4).
Despite the fact that the qualitative aspects of space and light are mostly revealed within the field of view of the observer, most quantitative researches deal with the horizontal working plane. The quantitative analysis of this research were therefore limited to vertical surfaces. However, it could have also been applied to horizontal surfaces. A quantification of light on vertical surfaces does not need to obey to lighting criteria established for the working plane such as the daylight factor. This functional freedom allowed for the exploration of more appropriate means to visualise light on vertical surfaces. Such an approach to light also introduced a more convivial and visually oriented method of analysis than current design tools, providing quantitative information when required, while remaining essentially connected to the design process.

Most qualitative aspects of light are not measurable, but this research introduces the use of contrast as a global integrator. Contrast has the advantage to relate to quantitative aspects of light since it can be measured. It also relates to qualitative aspects because it constitutes an essential component of the perceptual description of an ambience. Indeed, contrast has always been an important descriptor of the quality of photographic images. It appears that contrast is perhaps the most versatile variable that can establish a common basis for the qualitative and quantitative comparison between design solutions. The conventional calculation of contrast consists in the comparison between the luminances of an object and its background. This approach is rather limiting for the evaluation of an entire space, and therefore, this research has explored other means to evaluate contrast on an entire image. The lighting pattern obtained from the brightness separation of the pixel units of the image offers a morphological assessment of light in space (figure 5.4). The number of levels in the pattern and the distance between the curves are indicative of contrast. The research proposes two physical descriptors of the lighting pattern: the gradation of light and the compactness of the pattern. These descriptors add a quantifiable aspect to the interpretation of the morphology of the pattern. The histogram of analysis for the brightness distribution of the pixels of the image also provides additional quantitative information that is relevant for the classification of spaces. The statistical data are used in the comparison between images. The standard deviation and the interquartile range are particularly significant in the overall evaluation of contrast as they are indicative of the variance between highest and lowest brightness values.

This research has shown the use of images as a tool for light analysis and composition. There are presently new techniques for movie making that involve sequences of images or even drawings that could be combined to create a moving sequence. The concept of creating a moving sequence from transformed images and original drawings produces a virtual space and enables the expression of the translation of an observer in space. This form of composition could contribute to an assessment of the visual aspects involved in transitions between spaces. Another interesting aspect of the video is the possibility to establish, for instance, a moving sequence of a sun pattern throughout the day. Reflections on water or the movement of a curtain under shadows of light are
not always frozen as in photography but are much more alive through the use of the video. The moving image has this possibility to render the kinetic of light in space. The possibility to create a moving sequence between different images that blend one into the other through the use of a specially designed software of image processing can create an impression of translation in space. The process of the moving image is still involving much time and even though it appears as an interesting tool for architectural representations, it will perhaps need extensive developments to ensure its valuable use in daily architectural practice. The more simple aspect of the image which simply uses fixed image is a more abstract approach, but it is presently more suitable for an assessment of light at the initial design stages. It is however limited to an abstraction of reality, even more importantly than for the moving image.

**Contribution to Light as Science**

More than making a scientific contribution, this research allows an *artistic* insight into the world of science, and affords a scientific insight into the world of art, opening new areas of research on the photographic representation of light for an architectural use. It proposes verticality as the main artistic canvas of light creating ambiances, even in spaces where specific tasks are accomplished. The study of light on vertical surfaces therefore introduces a promising direction that science might explore to integrate qualitative aspects of light to the current well-developed quantitative knowledge.

The composition of spaces from images is an aspect that should provide the basis of interesting developments in computer imaging technology. The photographic image has a certain quality that is still unattainable through mathematical modelling, and therefore provides the highest standard of visualisation of light. Although the fastest and easiest way to create and generate ideas for the early design stages, the use of images in computer processing and analysis still remains in its early developments. Some limitations in the composition of spaces from images, which could not be resolved within the scope of this research, were identified. Some combinations and transformations of images do not correspond to reality, particularly those involving the direct sun light since it is the most critical condition because of the directionality of its pattern. Although some resulting transformations and combinations of images only approximate experimental conditions, they remain valid for the representation of a speculative ambience. The relevance of images in the design process is seldom acknowledged by scientists who praise the accuracy of mathematical models, which provide an absolute recognised basis of assessment. But it appears that for architects, the visual aspects are more closely related to their design approach, and that their use of recognised scales, such as the daylight factor and illuminance levels, are not the best mean to assess the ambience of a space. The proposed methodology encourages the use of the suggestive power of
the image since it is often much more important for the architect than the quantitative assessment of light. This aspect is not fundamental to lighting science, but the recognition of its validity and the exploration of design possibilities with the image will ensure that scientists will become more aware of the preoccupation of the architect.

Figure 5.4: Brightness separation of image 5.x into 5 levels.

In such a visual approach, the image becomes a bi-dimentional array of numbers where each represents the brightness of a small area in the digital image. The relation with brightness and the characterisation of the lighting pattern encompasses qualities extended to visual aspects of light and relates them to perception (figure 5.4). The numerical representation of images allows the application of a variety of computer processing and analysis techniques (figure 5.5). The resulting transformation of the mathematical grid of brightness data consists of a new array of numbers creating new images of spaces. Mathematical applications are rapidly evolving, especially in the case of advanced image manipulations and computer programming. This will contribute to even more advanced possibilities to interact with light and the image and afford even more creativity in the design process. Softwares for lighting analysis have been developed using such mathematical knowledge, but the quantitative and qualitative results approximate roughly the real situation. The correspondence between the photographic and the photometric methods is an aspect of the research that should eventually be part of more extended studies. The correlation described in chapter 2 is encouraging, but the limits of the correspondence have not yet been explored.
Towards a Classification of Lights

Further developments in interactive design methods involving simultaneous qualitative and quantitative assessments of light should contribute to the elaboration of a basis for criticism. This should in turn enable the initiation of an architectural discourse on light, adapted to the present technological context. This discourse will certainly provide a more solid qualitative analysis of historic design solutions and favour the comparison with present and future projects. The relation with past, present and future design solutions can be established through a classification of lights from precedents, or typology. This aspect is still in its early development and the following discussion proposes a framework to create such a classification. Although generalisations may take place, qualitative aspects of light should remain somehow unmeasurable, since their systematic quantification would probably diminish their mystical properties. A general classification of lights according to basic design variables should provide some order in the complexity of the lighting environment and constitutes a basis for composition. The typology imposes an order and an understanding of light and space. Architects are familiar with the use of precedents, and the classification into types and categories simplifies the organisation of design solutions according to visual qualities of spaces. The classification of the images of the library is also an essential part of the methodology since the great amount of material available through the processing of images could become problematic and eventually useless.

The classification is composed of two scales: the scale of contrast and the scale of focalisation. Frandsen [1987] had recognised the importance of contrast and detail in the visual field but he never proposed a unification of these variables. These two aspects are quantifiable. They furthermore closely refer to the qualitative aspects of light and define the character of space.

A Scale of Contrast

The research proposes the use of contrast as a global integrator of qualitative and quantitative variables of light (chapter 3). A scale of contrast provides an indication of physical aspects and also suggests perceptual aspects of light on surfaces. It also acknowledges associations with principles of concentration of light and the general visual appearance of space. The comparison between the compactness of different lighting patterns can lead to the classification of aperture and space morphologies. Technically, the scale of contrast can be produced by the classification of image histograms according to their interquartile range and standard variation. The association of the lighting patterns with physical and perceptual aspects is possible. Figure 5.6 consists in the schematic representation of the scale of contrast. The four contrast levels are only suggesting a progression from low to high contrast, and are therefore not prescriptive. These impressions (discussed in chapter 3) constitute a basis in the definition of ambience and the establishment of the typology.
A Scale of Focalisation

The scale of focalisation relates to perceptual aspects of light since it defines the vision of space and objects at different scales. The light that emphasises details and textures has specific proprieties, different than the typical lighting of an entire space. Frandsen’s scale of shadows [1987] differentiates levels of perception according to levels of detail. This aspect is relevant to the classification of images since it recognises the importance of two different types of stimuli produced by the eye. Visual acuity is highest in a very small area of the retina, called the fovea [Robbins, 1986]. Under normal conditions, lighting patterns reaching the fovea are reported to the brain in much finer details than the visual information obtained from other parts of the retina (figure 5.7; chapter 2 figures 2.32 and 2.33). This innate differentiation of the visual receptor produces a functional differentiation between central and peripheral vision. The central vision scrutinises the luminous environment, gathering detailed information about elements of the visual field to which it is directed by the focus selector. Simultaneously, the peripheral vision monitors the remainder of the environment for changes that might be of sufficient biological significance to warrant the attention of the central vision [Lam, 1992, p. 36]. The central stimulus is associated with the perception of detail, and the peripheral stimuli relates to the entire space.

### Table: Scale of Contrast

<table>
<thead>
<tr>
<th>Physical Aspects</th>
<th>Low Contrast</th>
<th>High Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quality of the source</td>
<td>diffuse</td>
<td>direct</td>
</tr>
<tr>
<td>Brightness distribution</td>
<td>uniformity</td>
<td>non uniformity</td>
</tr>
<tr>
<td>Dominance of the pattern</td>
<td>dispersion</td>
<td>concentration</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Perceptual Aspects</th>
<th>Low Contrast</th>
<th>High Contrast</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perception of space</td>
<td>unity</td>
<td>fragmentation</td>
</tr>
<tr>
<td>Perception of objects</td>
<td>immateriality</td>
<td>materiality</td>
</tr>
<tr>
<td>Concentration</td>
<td>distraction</td>
<td>attention</td>
</tr>
</tbody>
</table>

**Figure 5.6. Scale of contrast.**

**Figure 5.7: The human eye** [from Flynn, 1992, p.5].
Specific classifications of lights could relate to the type of visual stimuli induced by different sources and apertures. Frandsen [1987] has recorded different light modelling to establish a relationship between light and the scale of the lit objects. Four main categories are defined according to their scale:

- **A** The scale of space
- **B** The scale of the human body
- **C** The scale of the hand
- **D** The scale of textures

The light of the entire space (A), and at the scale of the human body (B) occur when light is relatively weak and dominated by reflections from surfaces of space. The small shadows of the scale of the hand (C) and textures (D) occur when light is strong, often originating from a single source. The smaller shadows need a higher contrast to ensure their visibility since the gradation from bright to dark appears at a decreasing viewing angle [Frandsen, 1991]. The categories differ from each other in size, position in space, illumination levels, and precision or level of detail. The perceptual characteristics of space are generally associated with a softer light for the larger objects, whereas the smallest details need higher contrast to be seen. This thesis proposes a scale of focalisation that relates to the degree of attention in space (figure 5.8). The light of the entire space relates to the peripheral vision whereas the light of the texture and small details relates to central vision. The scale refers to the concentration of light on objects. It for instance suggests that when the entire space is uniformly lit, textures and details disappear and that, when light is focalised on objects, the rest of the space may disappear since it does not become the central focus of attention.

The focalisation can be detected on an image by calculation of the size of details with the software of image analysis. The determination of the size of objects that have some relevance of interest remains to be judged by the architect. The classification of images becomes possible by comparison of the level of detail. The scale of focalisation refers to the focus of vision and therefore also relates to the notion of attention. It may be part of the early design stages where the architect decides on the desirable foci of attention.
The Classification of Lights

The classification of lights should preferably be established with objective and quantifiable variables. Only morphological and physical aspects of light should therefore constitute the basis of the classification to ensure objectivity. The interpretation of qualitative results should not be quantified but extrapolated through architectural precedents. The scales of contrast and focalisation are represented in a table where the combined scales situate the types of light in a bidimensional grid (figure 5.9). The contrast level relates to the concentration of light and constitutes the vertical axis. The horizontal axis relates to the concentration on different scales of space, which represents to the degree of focalisation.

![Figure 5.9: A scale of concentrations.](image)

The two extremes of the scale represent the highest and lowest degrees of attention (figure 5.10). The highest degree of attention defines the strong light that produces high contrast levels and focalises on details, while the lowest degree of attention defines the light that is generously diffused in space and where details are barely perceived. It is assumed that these extremes constitute two different types of lights. There are obviously intermediate variations of lights between the extremes and other categories may eventually emerge with the application of the classification to a library of images.
Figure 5.10: Extreme degree of attention.

Figure 5.11 defines other general types of lights in the grid. This graphical representation of types is advantageous since it combines perceptual and physical lighting patterns. Further research could lead to the integration of qualitative aspects relating to the emotive response to light that would constitute a further level of interpretation.

Figure 5.11: The four lights.
Several typologies could emerge from such a classification of lights since many variables can be considered to affect the relative position on the scale. Simplified representations and theoretical configurations of single apertures could be established but in reality, architecture is much more complex and the validity of such a typology could be argued. As there is not a unique library of images that responds to the need of all architects, there should also exist many systems of visualisation based on the proposed scales of classification of lights (figure 5.12). The images of a library could therefore be classified into the combined scale to constitute the visualisation, and particularly, to provide order and reference.

Figure 5.12: A library of lights for the composition of space with images.
As the library of images develops, numerical values mainly provided by the analysis of the histogram such as the interquartile range and the standard deviation, and by the physical attributes of the pattern such as gradation and compactness, will allow a more discrete classification of lights. The classification constitutes a guide for the ordering of the images of the library. It allows a rapid visualisation of images that may inspire and arouse creativity. The utilisation of the notions of contrast and focalisation allows a quantification of variables, but most importantly, they are essential in the objective assessment of space and light.

**Light as a Generator of Space**

The classification of lights, although presented in a schematic manner, enables the ordering of design solutions that relate to the visual character of light and space. It provides a basis for comparison and nourishes the imagination of the architect, providing architectural references and creating an ordered library of lights that correspond to certain ambiances. It also contributes to fix in images what is impregnated in the architect’s mind, providing a more systematic way of looking at the future. As the application of the classification finds its way amongst architects, a clearer theory of light could evolve and offer design orientations adapted to specific contexts. Further evolution of the scientific aspect of the method should always tend towards an easier approach to the luminous environment, asserting light as a major generator of space. Future developments in architectural lighting should favour the emergence of a poetry of light, enabling the designer’s emotions and intuition to be transposed in ambiances and atmospheres.

The methodology developed in this research could also become a valuable didactic tool that would favour the development of an interest for light as art and science amongst architects to be. Future investigations in an academic environment will allow the assessment of the feasibility of the integration of the method into early design stages. This should provide a framework to stimulate architectural criticism and open the debate on the essence of light in architectural design.

*Figure 5.13: The composition of a theoretical space with images of the library.*
Bibliography

ADOBE SYSTEMS INCORPORATED, (1991), Adobe Photoshop user guide & program version 2, Mountain View, California.

AIA (American Institute of Architects), (1982), Daylighting, New York, AIA.


AMBASZ, Emilio, (1976), The Architecture of Luis Barragan, New York Graphic Society, Boston.,


BIRREN, Faber, (1982), Light, color and environment, New York, Van Nostrand Reinhold Co.


Bibliography


DEMERS, Claude M.H., (1993), L’influence du design des ouvertures sur le contraste d’intensité dans les espaces intérieurs éclairés naturellement, Master’s Degree Thesis, School of Architecture, Faculty of Architecture, Laval University, Quebec, July.


DEMERS, Diane, (1996), M. Mathematics, University of Montreal, Quebec, Canada, private communication, August.


KOZLOFF, MAX, (1979), *Photography and fascination*.


LIBBEY-OWENS-FORD, Predicting daylight as interior illumination, Toledo, Ohio, Libbey-Owens-Ford Glass Company.


LUCKIESH, M., (1916), Light and shade and their applications, New York, Van Nostrand Co.


MEIER, Richard, (1991), propos recueillis par Jean Mas: "Aux américaines, il n'est jamais assez de lumière" in L'Architecture d'Aujourd'hui, n° 274, April, pp. 84-89.


MILLET, Marietta S., (1992), Poetry in Light, Graduate seminar, report session four: making place: material, culture and light, Department of Architecture, University of Washington, Seattle, Washington.


SCHILDER, Marc, (editor), (1987), Simulating daylight with architectural models, Los Angeles, DNNA (Daylighting Network of North America) and the University of Southern California, San Diego.


ZEVI, Bruno, (1990), International Conference of the UIA (Union Internationale des Architectectes), Séminaire des Critiques en architecture, Montréal, Canada, July.

Appendix A

Practical Considerations

The Selection Of A Moving Image
The selection of a specific image may become problematic when it is part of a continuous moving sequence, but the non moving scene does not affect the image analysis in such ways. The use of a function such as pause fixes the right image but causes some noise with most available cameras, as shown in figure I. The capture of an image viewed without interruption of the video eliminates this problem of distortion. It might however create some difficulties in selecting an exact configuration of space when conditions vary rapidly. The selection of the image is easier and more precise when long sequences are filmed to represent different space conditions. In a moving sequence, such as shown in chapter 3, lighting conditions between the first and last images vary greatly within a few seconds. It therefore becomes difficult to reselect a specific image during the reviewing of the video recording. In many cases, this may not be a necessity, but when a specific aperture dimension needs to be assessed, it is preferable to avoid any changes within spatial lighting conditions.

Consistency Of The Results For A Series Of Images
The consistency of the quantitative results of analysis between identical images is important to ensure the validity of the method. The following example consists in the verification of the similarity between images taken through a sequence of a static environment. It illustrates the similarity of quantitative results emerging from the information taken from eleven frames of a non moving scene filmed under an artificial sky. Six images are represented in figure II. The spatial configuration was chosen for its moderate contrast and brightness distribution, but other types of spaces could also be analysed. Quantitative data obtained from histograms of grey scale gradients show that the average mean varies approximately of 1,5%, the standard deviation of 0,88%, the interquartile range of 1,5%, but the median has the highest difference with 2,4% (figure III). Figure IV shows the relative distribution of the statistical analysis of the images. These slight variations are due to the non linearity of the video signal recorded through the camera.
Figure II: Images from a Non Moving Sequence.

<table>
<thead>
<tr>
<th>Image</th>
<th>Average</th>
<th>Mean</th>
<th>Standard Deviation</th>
<th>Median</th>
<th>Interquartile Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>image A</td>
<td>61.28</td>
<td>Δ=1.37</td>
<td>Δ=0.95</td>
<td>29</td>
<td>59</td>
</tr>
<tr>
<td>image B</td>
<td>62.93</td>
<td>Δ=0.28</td>
<td>Δ=0.01</td>
<td>30</td>
<td>62</td>
</tr>
<tr>
<td>image C</td>
<td>64.08</td>
<td>Δ=1.43</td>
<td>Δ=0.81</td>
<td>31</td>
<td>60</td>
</tr>
<tr>
<td>image D</td>
<td>62.77</td>
<td>Δ=0.12</td>
<td>Δ=0.06</td>
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<td>60</td>
</tr>
<tr>
<td>image E</td>
<td>61.95</td>
<td>Δ=0.70</td>
<td>Δ=0.38</td>
<td>29</td>
<td>61</td>
</tr>
<tr>
<td>image F</td>
<td>60.97</td>
<td>Δ=1.68</td>
<td>Δ=1.01</td>
<td>29</td>
<td>60</td>
</tr>
<tr>
<td>image G</td>
<td>62.52</td>
<td>Δ=0.13</td>
<td>Δ=0.21</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>image H</td>
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<td>Δ=1.07</td>
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<td>59</td>
</tr>
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<td>61</td>
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<tr>
<td>image J</td>
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<td>60</td>
</tr>
<tr>
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<td>60</td>
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<tr>
<td>Average</td>
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<td>Δ=0.97</td>
<td>Δ=0.59</td>
<td>30</td>
<td>60.36</td>
</tr>
</tbody>
</table>

Figure III: Table of Comparison of Identical Images Obtained from a Video Sequence.

The graph (figure IV) shows that images of a sequence produce relatively constant quantitative results. These results are satisfactory for a correct evaluation of contrast and brightness on surfaces. The advantages of using a longer video sequence and a static simulation are the simplification and facility of data acquisition of a specific image. It also enables the analysis of two or more identical images to ensure more accurate results. The advantage of a shorter video sequence resides in the more intuitive and rapid manipulations of a model. This also enables an immediate quantification of images.
Appendix B

Image Analysis

Figure I

1 unit

1.5% aperture

mean: (54) 21%
standard deviation: (49) 19%
median: (31) 12%
interquartile range: (216) 84%

Figure II

2 units

3.1% aperture

mean: (68) 27%
standard deviation: (57) 22%
median: (41) 16%
interquartile range: (215) 84%
Figure III

3 units

4,7% aperture

mean: (87) 23%
standard deviation: (60) 23%
médian: (60) 23%
interquartile range: (212) 83%

Figure IV

4 units

6% aperture

mean: (89) 35%
standard deviation: (61) 24%
médian: (61) 24%
interquartile range: (208) 81%
Figure V

5 units

7,8% aperture

mean: (98) 38%
standard deviation: (59) 23%
median: (72) 26%
interquartile range: (207) 81%

Figure VI

6 units

9,4% aperture

mean: (115) 45%
standard deviation: (60) 23%
median: (90) 36%
interquartile range: (194) 76%
Figure VII

- 7 units
- 10.9% aperture
- Mean: (126) 49%
- Standard deviation: (57) 22%
- Median: (114) 45%
- Interquartile range: (180) 70%

Figure VIII

- 8 units
- 12.5% aperture
- Mean: (119) 46%
- Standard deviation: (59) 23%
- Median: (104) 41%
- Interquartile range: (185) 73%
### Statistical Data

<table>
<thead>
<tr>
<th>Aperture (%)</th>
<th>Mean (%)</th>
<th>Std. Deviation (%)</th>
<th>Median (%)</th>
<th>Interq. Range (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5%</td>
<td>21%</td>
<td>19%</td>
<td>12%</td>
<td>84%</td>
</tr>
<tr>
<td>3.1%</td>
<td>27%</td>
<td>22%</td>
<td>16%</td>
<td>84%</td>
</tr>
<tr>
<td>4.7%</td>
<td>23%</td>
<td>23%</td>
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<td>83%</td>
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<td>24%</td>
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<td>81%</td>
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<td>49%</td>
<td>22%</td>
<td>45%</td>
<td>70%</td>
</tr>
<tr>
<td>12.5%</td>
<td>46%</td>
<td>23%</td>
<td>41%</td>
<td>73%</td>
</tr>
</tbody>
</table>

Statistical data (for vertical surface) according to variation of aperture area.

Statistical data of the histograms of the variables.
(refer to figure VIII)

16 units

mean: (136) 53%
standard deviation: (49) 19%
median: (134) 52%
interquartile range: (157) 61%

Figure IX
24 units
25% 0,21x
75% 0,42x
100%

37,5% aperture
mean: (163) 64%
standard deviation: (36) 14%
median: (164) 64%
interquartile range: (123) 48%

32 units
25% 0,49x
50% 0,37x
75%

50% aperture
mean: (145) 57%
standard deviation: (38) 15%
median: (145) 57%
interquartile range: (126) 49%

Figure X

Figure XI
Figure XII

40 units

- 75% aperture
- 0.54x
- 50%
- 0.46x
- 0.25%

mean: (152) 59%
standard deviation: (33) 13%
median: (155) 61%
interquartile range: (112) 44%

Figure XIII

48 units

- 75% aperture
- 0.69x
- 50%

mean: (164) 64%
standard deviation: (26) 10%
median: (168) 66%
interquartile range: (94) 37%
Figure XIV

56 units

87.5% aperture

mean: (171) 67%
standard deviation: (23) 9%
median: (174) 68%
interquartile range: (84) 33%

Figure XV

64 units

100% aperture

mean: (195) 76%
standard deviation: (15) 6%
median: (197) 77%
interquartile range: (58) 23%
### Statistical Data

<table>
<thead>
<tr>
<th>Aperture</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>Median</th>
<th>Interq. Range</th>
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<tr>
<td>12.5%</td>
<td>46%</td>
<td>23%</td>
<td>41%</td>
<td>73%</td>
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<td>6%</td>
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</table>

Statistical data (for vertical surface) according to variation of aperture area.

#### Statistical Data of the Histogram of the Variables

**Equation:**

- Mean: \( y = 0.68571 - 0.44571x \)
- Std. Dev: \( y = 0.23429 - 0.17429x \)
- Median: \( y = 0.68571 - 0.44571x \)
- Interq. Range: \( y = 0.23429 - 0.17429x \)
(refer to figure VIII)

Figure XVI

mean: (136) 53%
standard deviation: (41) 16%
median: (140) 55%
interquartile range: (166) 65%
Figure XVII

- Mean: (163) 64%
- Standard deviation: (29) 11%
- Median: (166) 11%
- Interquartile range: (109) 43%

Figure XVIII

- Mean: (145) 57%
- Standard deviation: (29) 11%
- Median: (145) 57%
- Interquartile range: (109) 43%
Figure XIX

- Mean: 155, 61%
- Standard deviation: 32, 13%
- Median: 162, 63%
- Interquartile range: 74, 29%

Figure XX

- Mean: 177, 69%
- Standard deviation: 26, 10%
- Median: 186, 73%
- Interquartile range: 62, 24%
Figure XXI

- Mean: (117) 46%
- Standard deviation: (49) 19%
- Median: (103) 40%
- Interquartile range: (155) 61%

Figure XXII

- Mean: (159) 62%
- Standard deviation: (31) 12%
- Median: (173) 68%
- Interquartile range: (109) 43%
## Statistical Data

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<thead>
<tr>
<th>DISTANCE</th>
<th>MEAN</th>
<th>STD. DEVIATION</th>
<th>MEDIAN</th>
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<td>7 units</td>
<td>66%</td>
<td>19%</td>
<td>68%</td>
<td>43%</td>
</tr>
</tbody>
</table>

Statistical data (for vertical surface) according to variation of the distance of the aperture to the surface of analysis.

**Statistical data of the histogram of the variables.**

![Graph showing statistical data](image)
Figure XXI

- mean: (125) 49%
- standard deviation: (54) 21%
- median: (128) 50%
- interquartile range: (234) 91%

Figure XXII

- mean: (136)
- standard deviation: (54)
- median: (142)
- interquartile range: (226)
mean: (148) 58%  
standard deviation: (49) 19%  
median: (154) 60%  
interquartile range: (232) 91%

mean: (157) 61%  
standard deviation: (38) 15%  
median: (156) 61%  
interquartile range: (215) 84%
Figure XXV

- Mean: (120) 47%
- Standard deviation: (44) 17%
- Median: (112) 44%
- Interquartile range: (203) 79%

Figure XXVI

- Mean: (105) 41%
- Standard deviation: (52) 20%
- Median: (87) 34%
- Interquartile range: (204) 80%
Figure XXVII

mean: (119) 46%  
standard deviation: (46) 18%  
median: (109) 43%  
interquartile range: (200) 78%

Figure XXVIII

mean: (108) 42%  
standard deviation: (51) 20%  
median: (93) 36%  
interquartile range: (212) 83%
Figure XXIX

- Mean: (113) 44%
- Standard deviation: (50) 20%
- Median: (99) 39%
- Interquartile range: (205) 80%

Figure XXX

- Mean: (96) 38%
- Standard deviation: (72) 28%
- Median: (70) 27%
- Interquartile range: (233) 91%
Figure XXXI

mean: (39) 15%
standard deviation: (55) 21%
median: (13) 5%
interquartile range: (243) 96%

Figure XXXII

mean: (48) 19%
standard deviation: (56) 22%
median: (23) 9%
interquartile range: (242) 95%
Figure XXXIII

mean: (39) 15%
standard deviation: (52) 20%
median: (13) 5%
interquartile range: (242) 95%

Figure XXXIV

mean: (15) 6%
standard deviation: (36) 14%
median: (6) 2%
interquartile range: (239) 93%