TÉCNICO
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THE IMPACT OF ARTIFICIAL LIGHT IN ARCHITECTURAL SPACES

FOR A METHODOLOGY OF INTEGRATED LIGHTING DESIGN IN ARCHITECTURAL CONCEPT

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EXTENDED ABSTRACT

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ABSTRACT

This work resulted from the lack of existing training in the practice of artificial lighting in architecture and the need to increase knowledge on the subject.

The lighting project is, currently, conducted by engineering firms, strictly according to legislation. However, the responsibility for the design aesthetic that influences the technical quality of light should be present from the beginning of the architectural concept.

Artificial lighting is an issue rarely addressed in architectural design. Due to the work complexity of the architect, and because lighting is generally seen as an attachment to the architectural design, it appears not only as a very specific technical matter, but also arises in the finalization of the project the choice of the light and the luminaries.

The main objective of this work is to contribute for a method to assist the architect in achieving the lighting project and its integration in the architectural concept. With such purpose, this work addresses the basic properties of light, working tools and examples of lighting project integration in the architectural concept. The development of study cases will allow highlighting the fundamental issues about the lighting design process.

Thus, this work, beyond presenting some theoretical aspects for comprehension of technical complexity existing in artificial lighting, it will focus on the subjectivity of the subject through examples that demonstrate the responsibility of the architect in lighting design with regard to compliance, the quality and aesthetic design of lighting, creating a unique lighting project supported by its integration into architectural concept [6].

1. THEORY OF ARTIFICIAL LIGHTING

THE LIGHT

To project lighting is necessary to understand what is light and its technical components. This theoretical lighting is the foundation that supports every lighting project.

There are two basic properties of light that are present in any lighting project: Colour Temperature and Chromatic Rendering Index (CRI). These two properties of light, create quality and mood, and can completely change the way we see an object. With the colour temperature we can change the colour saturation, and it creates an impact on the space environment that may cause feelings of greater or lesser proximity, or more or less pleasantness in space, due to the changing colour of light from warm to cold. This property of light can be seen in sunlight. During the day, the light has different colour temperatures, which changes the colour saturation of the landscape, and may appear more vivid or more vanished depending on the daytime [1] [2].

Figure 01
The sunlight in Lisbon at different stages of the day.

The same effect can be generated by artificial lighting, which, depending on the colour temperature can obtain different scenarios in the same space.

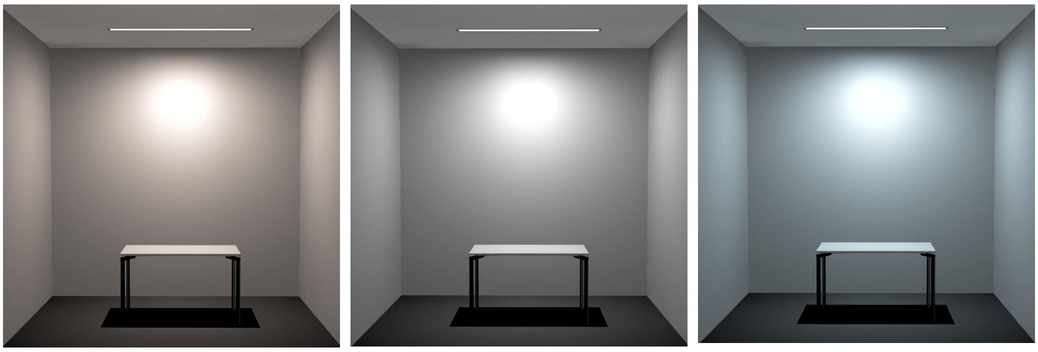

Figure 02
The different Colour Temperatures from warm white to cold white.

The colour temperature of a lamp can vary between 1800°K and 16000°K. It reaches from yellows to blues. It is common to give the name of Warm White to lamps with 3000°K, Warm White to 4000°K, and Cold White to 5000°K, which are the colour temperatures commonly used in most spaces [3] [13].

Figure 03
The range of the Colour Temperature.

The Chromatic Rendering Index gives us the value from 0 to 100, of greater or lesser refund colour reliable of an illuminated object. The CRI of a lamp is given through the spectral distribution of light graph.

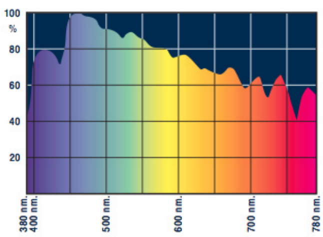

Figure 04
The spectral distribution of the sunlight in a sunny day.

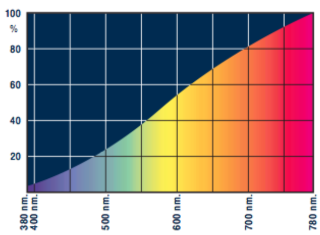

Figure 05
Spectral distribution of an incandescent bulb

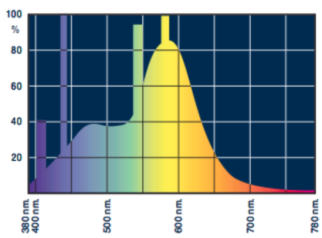

Figure 06
Spectral distribution of a fluorescent lamp

Thus, it is possible to note that depending on the luminous lamp under study, we may have different levels of CRI. The sun has the maximum level of CRI and it establishes the comparison with the other light sources. In the light bulbs, the incandescent bulbs have the same CRI level of the sun, while the low pressure sodium vapour lamps, which has a yellowish temperature colour, has the lowest CRI of all lamps. [1]

Both properties are referenced in the characteristics of the lamp and essential to understanding artificial lighting.

THE WORKING TOOLS

The working tools are the tools with which we can work with light. The various types and formats of existing lamps have different characteristics that allow us to do different lighting effects.

Figure 07
Incandescent lamp

Figure 08
Halogen Lamp

Figure 09
Compact Fluorescent Lamp

Figure 10
T5 Linear Fluorescent Lamp

Figure 11
Low pressure sodium vapor lamp

Figure 12
High pressure sodium vapor lamp

Figure 13
Induction Lamp

Figure 14
Led Lamp 6W

Figure 15
Led Tube

Each family of lamps have several types with different power, colour temperature and CRI.

Applying each type of lamp will depend on the intended use. Issues such as light intensity, lifetime of the lamp, location in space, maintenance, regulation of light and power consumption are important in deciding each type of lamp to use.

However, in order to be able to compare the results of different lamps, it is necessary to know the magnitudes that characterize light and allow light being calculated.

Thus, we can calculate the magnitudes of the Luminous Flux, Luminous Intensity, Luminance, or Level of Enlightenment (or illuminance) [1] [16].

These are the magnitudes lighting design that allow the mathematical study of light, which gives us the possibility of comparing the luminous flux of lamps, the income of the luminaries, and the lighting levels in the space.

However, each lamp does not work alone, and as such, the lamps are placed in the luminaries that are used to protect the lamp and projecting the light depending on the needs of the space.

Figure 16
Luminous Flux ø

Figure 17
Luminous Intensity (I)

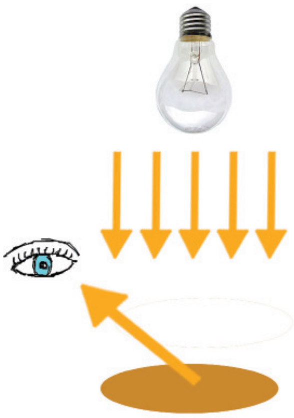

Figure 18
Luminance (L)

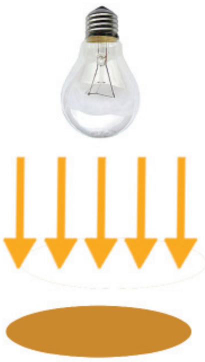

Figure 19
Illuminance(E)

Like the lamps, luminaries also have several characteristics which will vary depending on the objective of the lighting project. Thus, it is possible to create larger or smaller opening angles of a focus, as well as create solutions of more diffuse or more directed light.

Figure 20
Face modeling in diffuse light

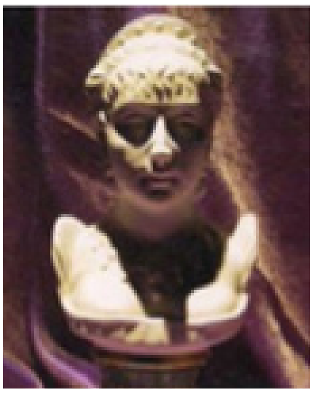

Figure 21
Modeling facial under light headed over.

Figure 22
Face Modeling in diffuse light and side light headed.

The different processes of modelling an object with light can create different kinds of contrast with light and shadow in order to accentuate the details of an object or homogenize the texture with diffuse light.

A similar effect can be achieved by putting the spotlight in different places. The more grazing the light is to an object, the greater will be accented the reliefs; on the contrary, the more frontwards the light is placed, the more homogeneous will the texture be.

Figure 23
Facade with oblique light

Figure 24
Facade with oblique light side

Figure 25
Facade with side light

Figure 26
Facade with front light

There are many different types of luminaries, and each may present several options. It is the complexity and variety of the existing work tools that gives the architect the ability to create unique project solutions. However, it is necessary to know the properties of light to be able to develop these same-solutions.

2. THE ARTIFICIAL LIGHTING IN ARCHITECTURE - STUDY CASES

EUROPEAN STANDARDS 12464-1

The lighting does not have strict legislation against its limits and applications. This is due to the difficult parameterization of the theoretical aspects of lighting. However there are standards that are used for technical workspaces that stabilize the minimum and maximum values for the basic properties of light and its magnitudes. With the standards, it is possible to create a framework that ensures the quality in lighting a space. However, the examples have shown that, although the standard is an important basic work, the subjective questions which depend on the sensitivity of the architect, and on the lighting characteristics of the space and the user, can change the quality of the lighting project. Those subjective questions can also change the welfare of the user through physical and psychological consequences from lighting space. Then will be present several examples of lighting a space so we can be able to make conclusions about some lighting aspects [12] [15].

EXAMPLE 1

Figure 27
Simulation of illuminance levels from study room

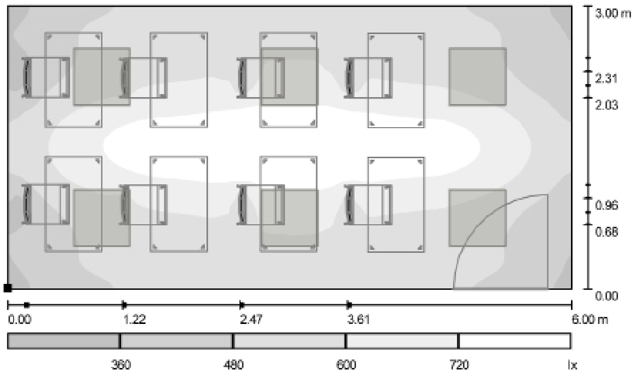

Figure 28
Grayscale map

In this example, six luminaries were place with four lamps of 14W each, arranged uniformly in space. The average illumination level of the study was 581lx. [17]

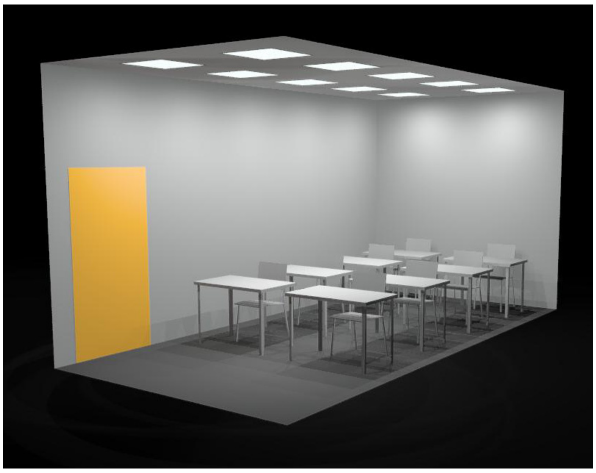

Figure 29
Simulation of illuminance levels from study room

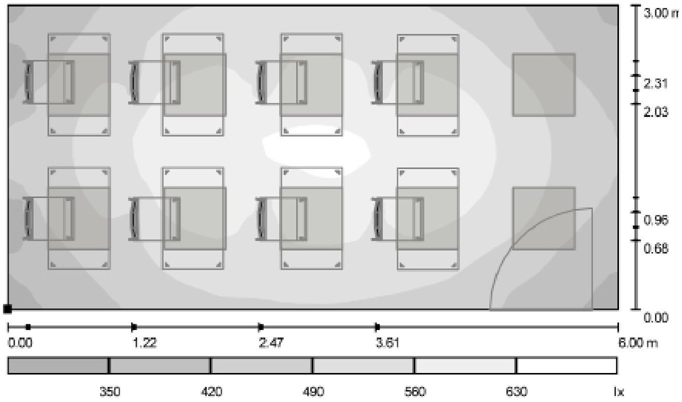

Figure 30
Grayscale map

In this example, were placed ten luminaries with four lamps of 14W each, arranged uniformly in space. However, in this example instead of reflecting optics, it was used opalescent diffusers. The average illumination level of the study was 508lx.

EXAMPLE 3

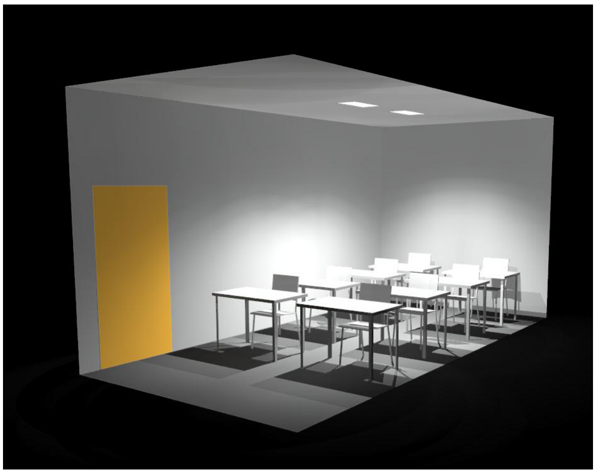

Figure 31
Simulation of illuminance levels from study room

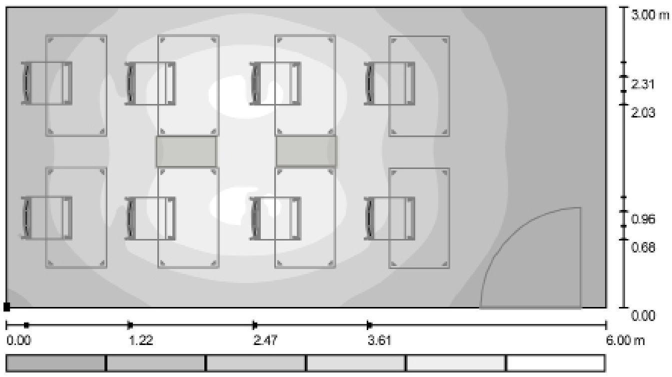

Figure 32
Grayscale map

In example 3 we used two luminaries with two lamps of 80W each, arranged on top of desks. The average light level in the space is 594lx.

For the standard, it is required that a workspace as shown in examples should present a minimum level of illumination of 500 lx. However we cannot always prove that the fact of obtaining the 500lx level means that it is the best solution for the space.

Comparing the example 1 to example 3, it can be shown that depending on the finishes of the light, we can get totally different energy expenditures. Therefore, if we use a reflector in a luminary, the income will be optimized. The opposite happens when you put diffusers, which typically derive 30% to 60% of the income of the luminary. In this solution despite the 500lx necessary to ensure the project, it is strongly increasing energy expenditure.

In the third example, the fixtures are concentrated in the centre of the space above the desks. Thus, we also ensure the 500LX in working areas. However, the space will present a harsh environment due to the sharp contrasts of light and shade in the space. This solution may create a glare and eyestrain due to sharp intensity upon the workplace, which will reflect the light in the furniture directly to the eye. [4]

EXAMPLE 4

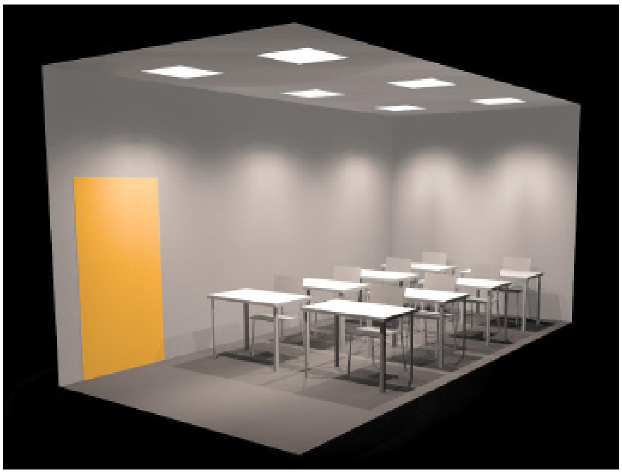

Figure 33
Simulation of illuminance levels from study room

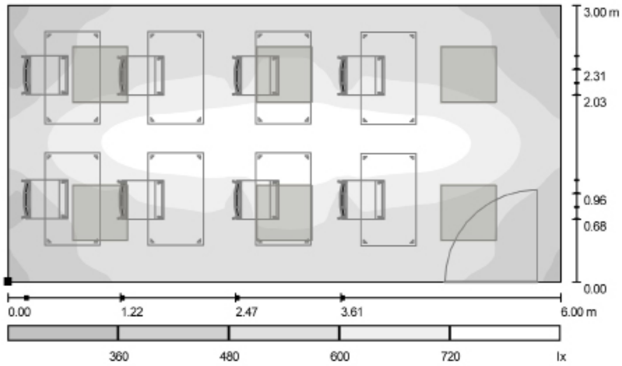

Figure 34
Grayscale map

In this example it were used the same lamps as in example 1. However, it was altered the colour temperature from 4000ºK to 2700°K. This example serves to demonstrate that the colour temperature does not change the lighting levels of space, however creates a different environment that may or may not be conducive to the functional objective of the space.

In this case, due it is a working space, the ideal colour temperature would be close to 4000 º K, because a colder colour temperature stimulates and helps with concentration. The lower temperatures are more used in situations of more relaxation.

These issues covering human psychological factors are not present in the standards of lighting, however are crucial to consider in the lighting project. [10]

INTEGRATION OF LIGHTING PROJECT IN THE ARCHITECTURE CONCEPT

The integration of artificial lighting in architecture concept is a subject, usually, absent in the architectural project. The fact that artificial lighting is a subject of little practice in architectural development is notorious by the observation of several examples where the lack of integration in architectural concept, and the lack of education lighting, makes it an underdeveloped theme despite the responsibility of architect in the lighting project.

Thus, it is then possible to present as examples, the differences between a project where there is an integration of the lighting project in the architectural concept and a project where this integration does not exist.

ROVISCO PAIS HOSPITAL - TOCHA

Figure 35
Lighting of circulation areas in Rovisco Pais Hospital in Tocha.

HIGHER SCHOOL OF EDUCATION - SETÚBAL

Figure 36
Lighting of Higher School Education classrooms in Setubal.

Figure 37
Lighting of Higher School Education cafeteria in Setubal.

STREET TRADING - SETÚBAL

Figure 38
Lighting store with downlights.

Figure 39
Storefront shop Lighting

Figure 40
Store lighting.

The examples presented above shown some of the commonly situations found in architectural spaces. The careless disposal of the lamps (Figure 35), the inappropriate choice of luminaries according to the spaces to be projected (Figure 36), the lack of maintenance of the lamps which leads to improper change of the colour temperature (Figure 37), the too homogenous or too directed light which makes the products not being detached (Figure 38 and 39), or the too many points of attraction in the same space (Figure 40). Situations such as those above may jeopardize the welfare and productivity of the user, and unconsciously remove the user to attend the space.

The aim of the architect being responsible for the lighting design makes the light acquires an essential role in the architectural design, creating unique lighting solutions, built on the concept of the architecture itself. When we can unite these two projects into one concept, the space becomes praised and lighting starts to be felt as an inseparable part of the space, as the following examples illustrated (Figures 41 to 46).

VODAFONE HEADQUARTERS - OPORTO

Figure 41
Lighting circulation areas and cafeteria of Vodafone Headquarters in Oporto. Example of integrated lighting in architectural concept.

RESIDENTIAL SPACES

Figure 42
Single Family Residence - Detail of stairway lighting

Figure 43
Residential lighting

Figure 44
Lighting of living / dining space

Figure 45
Changsha Culture and Arts Center - Arq. Zaha Hadid

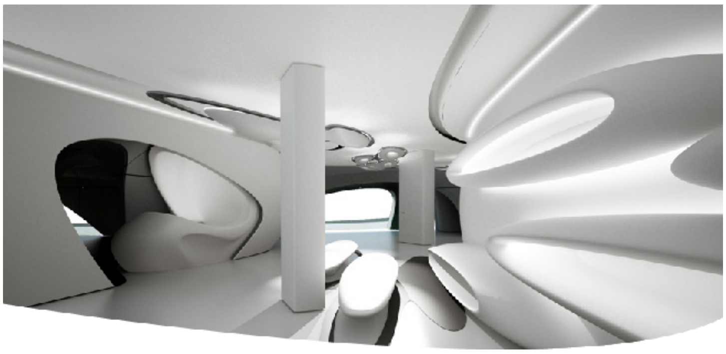

Figure 46
Rocca London Gallery - Arq. Zaha Hadid

"I think it would be ideal if the light were, in the entire project, treated as a design element (...). (,,,), the final work must be unique. And this is more than integrating the light to the project: it is to be."

Fernanda Carvalho, Arquitect and Light Designer [9]

STUDY CASES - OFFICE AND STORE

In order to aid understanding of the practical implementation of lighting we created two case studies that present two functional space types common in daily life: office and store.

OFFICE

When performing a lighting project for a workspace as an office, it is necessary to note the colour temperature used, the lighting levels in the space, and the glare due to the location of luminaries, for example, depending on the location of the luminarie from the user, it may undergo the welfare. Glare causes eyestrain and drowsiness which affects worker productivity.

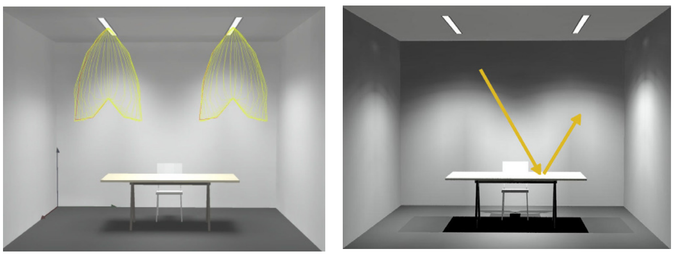

Figure 47
Scheme (A) of light reflection on the work plan placed in the transverse axis of the luminaires.

Figure 48
Scheme (B) light reflection on the work plan placed on the longitudinal axis of the luminaires

When performing a lighting project for a workspace as an office, it is necessary to note the colour temperature used, the lighting levels in the space, and the glare due to the location of luminaries. For example, depending on the location of the luminary from the user, it may undergo the welfare. Glare causes eyestrain and drowsiness which affect worker productivity. There are many ways of designing the light in an office, however to optimize the lighting project, instead of massive light flooding of the space, the light can be concentrated at the work place.

Simulation A: 20 luminaries of 4x24W

Average Illuminance = 542lx

Watts - 1920W

Figure 49
Simulation of illuminance levels from office

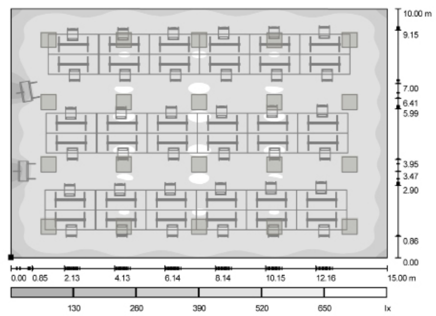

Figure 51
Grayscale map

Simulation B: 21 luminaries of 49W

Average Illuminance = 395lx (more than 500lx on the tables surface)

Watts - 1029W

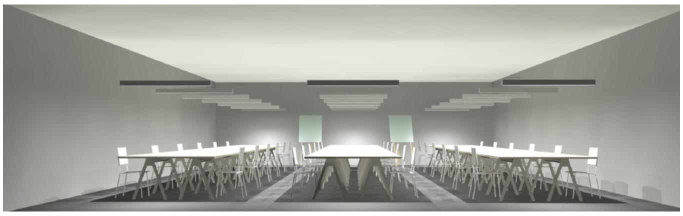

Figure 50
Simulation of illuminance levels from office.

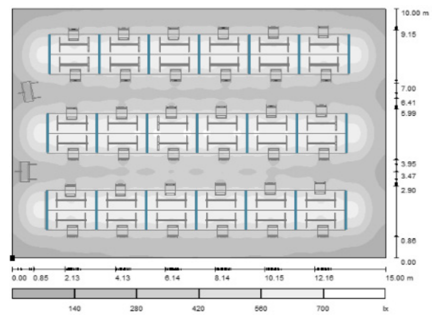

Figure 52
Grayscale map

Through the examples it is shown that it's possible to locate the lighting just in work areas, and get the same results with less energy expenditure. When performing a lighting project of an office building, this aspect can have a huge impact. However, the ideal situation for offices lighting design it is to have a balanced space with low contrasts. Thus, it would be advantageous for the welfare of the user having points of interest in space. This way the user can rest the vision as well as balance the lighting levels. The eye do not need to be in constant adaptation because of the light contrasts between light and dark environments. Thus, to create these points of interest two boundary walls should be illuminated. Thereby, the room will be light balanced and with lower energy costs [4] [5].

Simulation C: 21 luminaries of 49W + 14 luminaries of 26W

Average Illuminance = 456lx (more than 500lx on the tables surface)

Watts - 1393W

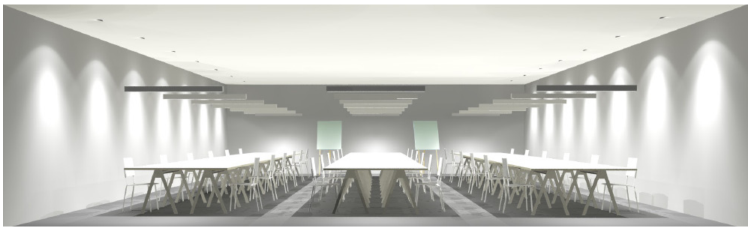

Figure 53
Simulation of illuminance levels from office

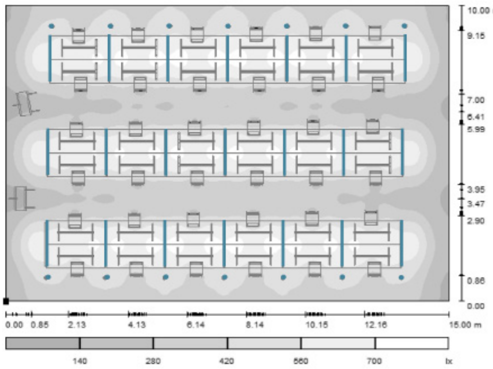

Figure 54
Grayscale map

THE STORE

In a store, light plays a key role, as can create proximity between the customer and the store. There are several concepts of illumination that can be applied to different types of store. The greater uniformity of light in a shop, the lesser impact on the display products. This type of lighting is widely used on large surfaces, not only because of the large amount of products but also because they have large areas, making it easier and cheaper to use luminaries with greater incomes and high dispersion of light. In other examples, we can see that the lighting is more directed to the products exposed and the customer's attention will be directed to the exhibitors or for some highlighted products. [7]

Figure 55
Virtual image of the store with uniform diffuse lighting

Figure 56
Virtual image of the store with direct spot lighting to highlight the products.

Figure 57
Stores with homogeneous illumination.

Figure 58
Stores with spot lighting to the product.

In a store is also necessary to create points of interest in order to encourage the customer to enter. These points of interest are created with light, either by highlighting some product, or through decorative lamps. These points are usually located near the entrance and / or the place of payment, in order to approach the client to the shop [8] [11].

Figure 59
Simulation of attraction point in the store..

Figure 60
Examples of attraction point in the store.

Depending on the needs of the store, this can be modelled with lighting in order to improve the negative constructive elements in space. Thus, by illuminating only the interior of the store, leaving the walls limit in darkness, it creates a feeling of continuous space. The opposite happens to brighten the limit walls. It creates a feeling of closeness to the walls decreasing the space area [3] [14].

Figure 61
Lighting centred on products. Feeling of continuity in space.

Figure 62
Lighting walls limit. Feeling of decreasing area.

Figure 63
Store example with continuity of space effect.

Figure 64
Example store with the space reduction effect.

The same happens in situations of high or low ceiling. With the right type of lighting it can be created the illusion of having a higher or lower ceiling depending on the intended purpose. Therefore, to lower the ceiling, molding should be created in order to achieve the sensation of continuity in the walls. Thus, the space seems less enclosed. In the opposite situation, for example, in the presence of high ceilings, we can create a contrary sensation by suspending luminaries. Thus it creates the illusion of a lower second ceiling. [3]

Figure 65
Lighting with molding: the ceilling seems higher.

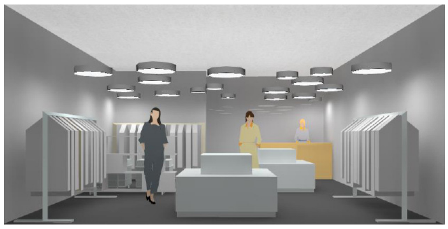

Figure 66
Lighting with suspensions: the ceilling seems lower.

Figure 67
Example store with lighting moldings.

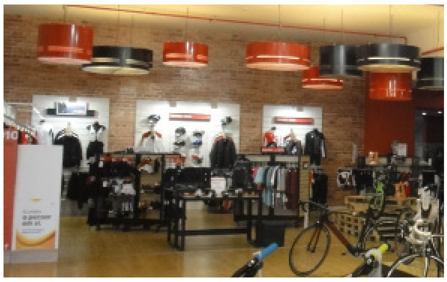

Figure 68
Example store with lighting suspensions.

FOR A LIGHTING METHODOLOGY

It is through practical exemplification that becomes possible to develop lighting design skills, and through observation and comparison of the examples given it becomes possible to understand the different phases of a lighting project.

The scheme (Figure ?) summarize the four main stages of a lighting project: 1) the space; 2) the light, 3) the integration and 4) the studies, which can be used as methodological support in creating a lighting project integrated in architectural concept.

The development of the methodology, covers essential aspects such as: 1) the achievement of enlightenment according to the space, 2) the definition of the different areas existing in space and their need for modelling, 3) the light spots that project the desired environment, 4) the creation of a unique lighting system for the surrounding area obtaining a unique concept for the two projects, architectural and lighting, 5) the knowledge of existing standards and their application, as well as, about the working tools available with attention to the issue of energy sustainability.

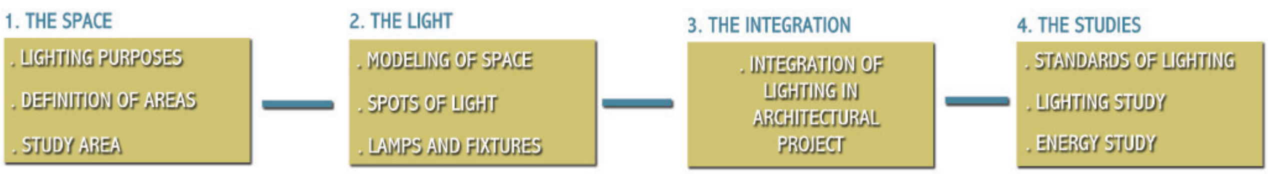

Figure 69
Schematic summary of the steps to achieve the lighting project

3. CONCLUSIONS AND FUTURE DEVELOPMENTS

This work aimed to contribute towards a methodology for integrate lighting in architectural design. It is intended to define the fields of responsibility of the architect on the subject of lighting, and approaching this area to the development of conceptual architectural design. This thesis argues that Is necessary to give to lighting design an equal weight of a constructive element in the design process, in opposition to the existing role as a technical annex to the architectural project. This work also aims to support architects in the identification of the working tools, knowledge of the lighting concepts, and understanding of the difference between integrated and non- integrated lighting project in the architectural concept.

During this work arises some themes for future development such as: 1) deepen modelling types such as classroom, office, exhibition space, among others according to their specific needs and spatial characteristics; 2) develop methods for assessing user satisfaction with regard to different lighting environments, using several approaches: test cells, real spaces with different possible scenarios of light, immersive virtual environments, among others, 3) develop software better suited for the integration of lighting architectural design, creating the possibility for achieving real photometric calculation (which currently takes place in programs such as Dialux) in 3D modeling tools used in architectural design (e.g. Autocad, Revit, Sketchup, 3D Studio Max).

BIBLIOGRAPHY

BOOKS

[1] Ganslandt, R.; Hofmann, H., 1992 – Handbook of Lighting Design, ERCO Edition.

[2] Major, M.; Speirs, J.; Tischhauser, A., 2005 - Made of Light, The Art of Light and Architecture, Birkhauser - Publishers for Architecture - Basel . Boston . Berlin

[3] Brandston, H., 2008 - Learning to see, A Matter of Light. IESNA.

MAGAZINES

[4] Sá, C., 2008. Iluminação Corporativa - A trajectória e os efeitos da luz nos ambientes de trabalho, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao24.html

[5] Godoy, P., 2005. Iluminação de Escritórios: Uma nova abordagem, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao13.html

[6] Gonçalves, G., 2005. O Light Designer e as suas diferentes áreas de atuação, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao13.html

[7] Chou, I., 2008. Iluminação de espaços comerciais: Luz adequada pode determinar o sucesso de supermercados, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao24.html

[8] Maio, M., 2008. Julio Takano: Sobre luz, merchandising e arquitectura, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao24.html

[9] Carvalho, F., 2007. A luz como elemento construtivo: Lições da exposição por Clarice Lispector, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao27.html

[10] Castellan, E., 2007. Normas de aplicação em iluminação: O quê, por quê e para quê?, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao26.html

[11] (Redacção), 2004. Loja Bayard: Jogo de luz envolve e conquista o consumidor, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao10.html

[12] Cunha, M., 2003. Verdades e Versões: Em iluminação cada caso é um caso, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao4.html

[13] Cavallo, C., 2003. Lâmpadas Fluorescentes: Temperatura de Cor e Índice de Reprodução de Cores, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao1.html

[14] Cassol, V., 2004. A luz empresarial: A iluminação como ferramenta nas estratégias de venda, *Lume Arquitetura* [online] Available at: http://www.lumearquitetura.com.br/edicao9.html

LEGAL DOCUMENTATION

[15] Norma Europeia 12464-1, Light and lighting – Lighting of work places Part 1: Indoor work places, Edição 2003

COURSES

[16] Vajão, V. ; Brás, A. ; Telhado, P. ; Maneira, L., 2011. Curso de Iluminação - Nível Profissional. Centro Português de Iluminação, unpublished.

LIGHTING INFORMATIC PROGRAMS

[17] DIALUX. Available at: http://www.dial.de/DIAL/en/dialux-international-download.html