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Iluminação para espaços de trabalho sem janelas

Illumination for windowless workspace

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Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Enhenharia e design de produto, realizada sob a orientação científica do Doutor António Gil D'Orey de Andrade Campos, Professor Professor Auxiliar do Departamento de Engenharia Mecânica da Universidade de Aveiro, e sob co-orientação do Doutor Eduardo Jorge Henriques Noronha, Professor Professor Auxiliar Convidado do Departamento de Comunicação e Arte da Universidade de Aveiro.

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À minha família e namorado.

o júri

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palavras-chave

Design de produto; design de iluminação; sistema iluminação, biofilia; luz natural; sol; mimetização solar; espaço de trabalho; escritório.

resumo

Atualmente, o ser humano passa cerca de 90% do seu tempo em espaços interiores e, por isso, cada vez mais os espaços são projetados por forma a promover conforto e luz natural. A falta de um espaço interior de qualidade pode estar na origem de vários problemas de saúde, tais como a inibição de hormonas que afetam o ritmo cardíaco, humor e produtividade. Deste modo, os especialistas consideram o ser humano uma espécie biofólica, uma vez que é dependente da natureza. Ademais, a proximidade a grandes janelas, materiais naturais e plantas promovem a sua saúde e bem-estar.
Neste sentido, este projeto procura dar resposta a esta problemática ao desenvolver iluminação para um espaço sem janelas. O projeto foi concebido para um espaço de trabalho, tendo em conta que é onde um cidadão comum passa a maior parte do seu dia, assim como, onde o conforto e a produtividade são essenciais. Numa abordem inicial ao tema, a pesquisa por projetos de problemática idêntica demonstrou que existem já diversas propostas neste âmbito, indicadas para ambientes domésticos, evidenciando, assim, a oportunidade do espaço de trabalho. No entanto, este é um meio com necessidades e requisitos especiais, não podendo colocar em causa a saúde ocular dos seus utilizadores em função de uma luminária emocional.
O projeto culmina na proposta de um sistema de iluminação composto por dois tipos de iluminação que equilibram as necessidades do espaço de trabalho. Para tal, foi feita uma análise do espaço de trabalho e das suas necessidades, culminando no desenho de uma forma versátil e pragmática. O sistema é composto por uma estrutura de apoio e duas luminárias, concebidas para serem eficientes e inovadoras, equilibrando a vertente emocional e visual do utilizador. Uma das luminárias mimetiza o sol e a outra mantem o equilíbrio dos níveis de luminância do espaço.
Esta proposta surge depois de uma análise de mercado de luminárias de mimetização solar e a sua forma e propósito foram delineadas pela análise do publico e espaço alvo selecionado, o escritório. Após idealizado o funcionamento ideal do produto, procurou-se conhecer a forma e elementos que o podem materializar, desde a o desenho da forma á conceção do seu sistema elétrico. Ao longo do projeto abordaram-se as disciplinas do design e da engenharia na metodologia e procedimentos usados por via a realizar conceptualmente este projeto.

keywords

Product design; lighting design; lighting system, biophilia; natural light; sun; solar mimic; workspace; office.

abstract

Currently, a human spends about 90% of their time indoors, therefore, increasingly spaces are designed to promote comfort and natural light. The lack of a quality indoor space can be the cause of several health problems, such as the inhibition of hormones that affect heart rate, mood and performance. Thus, experts consider the human being a biophilic species, since it is dependent on nature. Besides, the proximity to large windows, natural materials and plants promote your health and well-being.

In this sense, this project seeks to answer this problem by developing lighting for a windowless space. The project was conceived for a workspace, taking into account that it is where an ordinary citizen spends most of their day, as well as, where comfort and productivity are essential. In an initial approach to the theme, the search for projects with the same problematic demonstrated that there are already several proposals in this area, indicated for domestic environments, thereby showing the opportunity of the workspace. However, this is a medium with special needs and requirements, and it cannot jeopardize the eye health of its users due to an emotional luminaire.

The projected peak in the proposal of a lighting system composed of two types of lighting that balance the needs of the workspace. To this end, an analysis of the workspace and its needs was made, culminating in the design in a versatile and pragmatic way. The system consists of a support structure and two luminaires, designed to be efficient and innovative, balancing the emotional and visual aspect of the user. One of the lamps mimics the sun and the other maintains the balance of the luminance levels of the space.

This draft comes after a market analysis of solar mimic lighting fixtures and, its shape and purpose were outlined by the analysis of the selected target audience and space, the office. After the ideal functioning of the product was idealized, we sought to know the shape and elements that can materialize it, from the design of the shape to the design of its electrical system. Throughout the project, the disciplines of design and engineering were addressed in the methodology and procedures used to carry out this project conceptually.

Illumination for windowless workspaces

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first chapter

Contextualization

01. Introduction

In general, people know that natural daylight has a big weight in our life day by day.

Lighting can be produced naturally by the sun, or artificially, by oil and gas flames and electric light sources. Natural light varies in magnitude, spectral content and distribution with different meteorological conditions at different times of the day and year and different latitudes. The artificial light has been developed for more than a century due to the fact that life conditions on earth are always improving. The light felt on the Earth's surface that is naturally produced can cover a large range, from 100,000 lx on a sunny summer's day to 1,000 lx on a heavily overcast day in winter (Boyce, 2004).

In general, people know that natural daylight has a big role in our daily life. However, sometimes it is felt and disregard or linked to other situation. Daylight is the people's natural clock and a huge part of their daily benchmark.

Nowadays, humans spend almost 90% of the time indoors, which is approximately 20 hours a day in closed rooms. That is why some architectural configurations of these spaces are not random and have been designed by someone guided by the conditions of their inhabitants (Boyce, 2004).

The growth of cities is leading to a lack of quality spaces and the need for improvisation. Consequently, several solutions emerge though they are not always the best or the healthiest ones, such as the creation of underground, underwater cities or even the reuse of spaces and buildings whose structure was not intended for later secondary use (Boyce, 2004).

Many studies (Begemann et al., 1997; Franco, 2019b; Kahn et al., 2009; Knoop et al., 2019; Küller et al., 2006; Veleva et al., 2018) state that several health problems are associated with an unhealthy space (poorly lit, poorly ventilated, noisy, excessively cold or hot), which results in very high expenses for people and, on a larger scale, for governments. Therefore, this issue is more complex than just adding windows. Its arrangement should not be random and the understanding of environmental conditions should be deeper, offering specific solutions following the architectural space and its functions (Begemann et al., 1997; Boyce, 2004). Moreover, some professionals in human behaviour describe mankind as biophilic which means that humans depend on nature, and it provides comfort and well-being (Kahn et al., 2009; Rogers, 2019; Stephen R. Kellert, 1993; Stevens et al., 2007; Stouhi, 2019; Studio, n.d.).

02. Sunlight as a natural clock

Earth rotates about itself from east to west every twenty-four hours. Consequently, creating day and night.

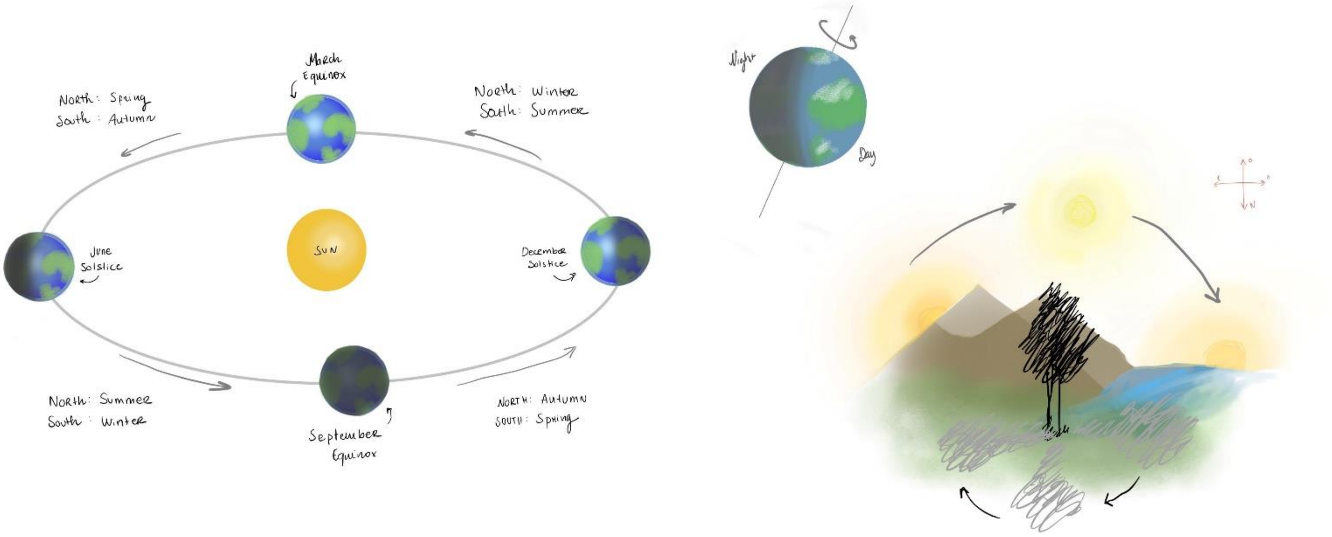


Figure 1 - Sketches of sun based in collected data.

However, these cycles are reflected in an apparent movement of the sun noticed in the variation of both the altitude of the sun throughout the day and the length and position of the shadow (figure1).

The variation of the position of the shadow can be used to build a sundial. The sun and the shadow allow us to orient ourselves during the day because they indicate the cardinal points. The variation in shadow length decreases from sunrise to midday and then increases until sunset.

The movement of the earth concerning the sun also defines the seasons and, consequently, the length of the day during the different months of the year. On the June solstice, the northern hemisphere is more illuminated, and the day is the longest of the year, which is precisely the contrary on the December solstice. In turn, at the equinoxes, both the northern and southern hemispheres are illuminated. Day and night last for 12 hours in all places on Earth.

03. Biophilia

"An evolutionary account of the human relation with nature"

(Stephen R. Kellert, 1993)

Since the earliest civilizations, nature served as humans' natural habitat. Fast forward to the present, the industrial and technological revolutions have reshaped the way humans interact with nature. "Biophilia" means "the love of living things" in ancient Greek, and it is gradually trending in the fields of architecture and interior design although it was first used in psychology (Stouhi, 2019).

The main principle to connect architecture and design behind biophilia is to try to connect humans with nature to improve well-being. They start to integrate nature in their projects bringing characteristics of the natural world into built spaces, such as water, greenery, natural light, elements like wood and stone. Even the most minimal connection with nature as looking to natural environments through a window can promote the healing of hospitalized patients, increase health in the workplace, and reduce the frequency of sickness in prisons (Stouhi, 2019).

Figure 2 - Examples of biophilic spaces:
(a) 1 hotel central park in New York;
(b) Biofit, Karolinska Institutet Gym in Stockholm;
(c) Biopholic Office of Art Medical in Tel Avivi, Israel by Roy David Studio.

Biophilia can be denoted even in simple things as ratings of preference for landscapes since people tend to choose natural environments more than built ones. Likewise, in a mere cultural convention, flowers are often sent to people who are in the hospital or who are passing through periods of mourning. In sum, the need and dependence to affiliate with nature provide great resulting benefits (Rogers, 2019; Stephen R. Kellert, 1993). Examples can be seen in figures 2(a), 2(b) and 2(c) (Michal, 2020).

Light is one of the requirements needed to build a biophilic space, as figure 2(a) (*1 Hotel Central Park*, n.d.) and 2(b) (*Biofit Natural Health & Fitness*, n.d.) depict. Natural shades and colours of daylight can be distinctive in human daily routine, proving the human dependence on light to be healthy.

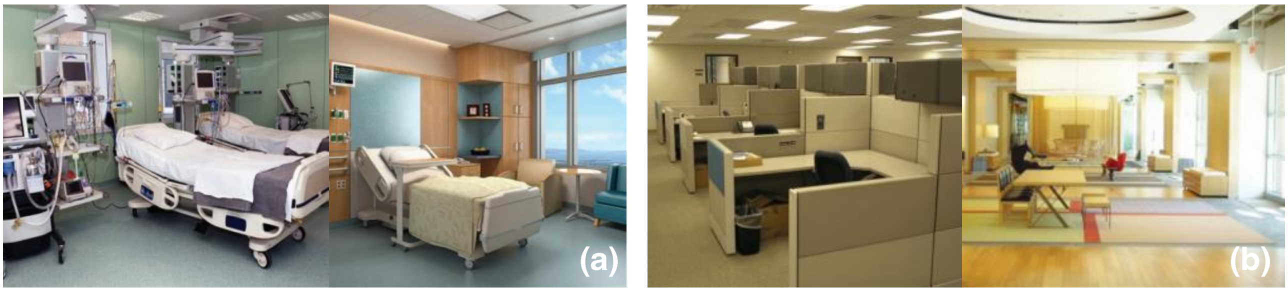


Figure 3 - Biophilic design examples: (a) Medical space; (b) Office Space.

Figure 4 - Night shift on Apple Iphone.

Figure 3 (Kellert & Calabrese, 2015) are two examples of how biophilic design can change a room. This rooms inspired in nature can improve the well-being and comfort of their users.

Moreover, when it comes specifically from lighting coupled to biophilic design, one should remit to other associated concept: "human-centric lighting" (Andrea Knust Licht, 2018; Claude MH Demers et al., 2019; Kellert & Calabrese, 2015). It is a lighting concept that offers a desired and appropriate light for the individual's working and living conditions at any time which means providing the right light for each hour of the day and year. This concept considers both the visual and non-visual effects of exposing humans to light and widens the range of possible effects from visual performance and comfort to the sleep quality, alertness, mood and behaviour with consequences for human health, learning and spending. These effects are also related to the biophilic concept. (Andrea Knust Licht, 2018).

An example of a technology developed in parallel with this concept is the *night shift* mode that is available on *iphones*, *ipads* and *ipods,* depicted in figure 4 (Husain, 2016). It uses the clock and the geolocation of the user's device to determine the time of sunset and then adjust the colours of the display to the warmer part of the spectrum. This technology is based on the rule of blue light during the day and red light in the evenings (Apple Inc., 2019; Sally Coulthard, 2020).

As demonstrated by the examples, biophilia is recurrently present in our daily lives and this is already a concern of several designers, architects and engineers because it is directed towards the quality of life of its consumers and the success of their creations.

04. Problem

“The people who design, operate and maintain our buildings have a bigger impact on our health than our doctors”

Joseph Allen, a teacher at Harvard University (Velux, n.d.)

The lack of daylight affects the whole world nowadays. For example, according to Küller & Wetterberg (1996), in Shanghai in the 1980s, two million square meters of underground space was developed for various uses, such as underground supermarkets, warehouses, garages, hospitals, markets, restaurants, theatres, hotels, entertainment centres, factories, cultural farms, plantations, subways and underwater tunnels. This underground space is just an example of a community that lives without natural light, but there are many people worldwide who live or work in the same condition. Sometimes these people are in the highest towers, so close to the sky and so far from natural light. One of the biggest causes of this is the massification of people in cities and the consecutive lack of quality spaces.

Küller & Wetterberg (1996) reports what happens to people who live in those spaces. Moreover, the authors list several potential negative psychological and physiological effects on people underground. Since the subterranean building does not provide a distinct image, spatial orientation may become difficult, and this sense of confusion may be enhanced by the lack of windows. The absence of windows also means losing daylight and sounds and other types of stimulation from the outside world (Küller & Wetterberg, 1996). In what concerns workspaces, hundreds of people who work in an office without a window, regardless of gender or age, tend to bring plant or photos of nature to make them more happy and productive (Bringslimark et al., 2011). Furthermore, it is estimated that the problem is more frequent in offices with employees with an inferior position in each company. Another situation happens in big offices where many people work. Here, even having windows, not everyone can be close to them and take the light that needs or bring their personal and natural objects to fill in the lack of nature (Bringslimark et al., 2011). This "windowless" problem begins in the buildings that sometimes, for a variety of reasons, cannot be rebuilt to open the necessary windows.

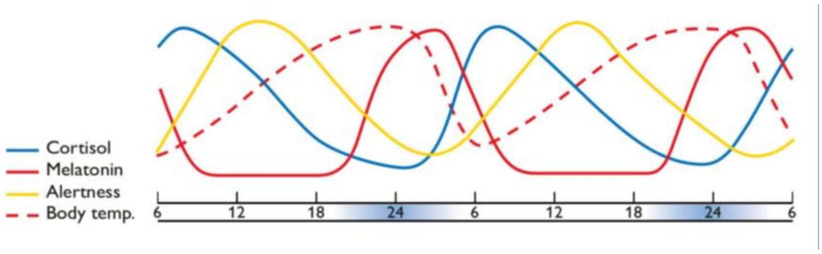


Figure 5 - Two days (2x24h)” graph of selected cardician rhythms. The diagram illustrates some typical rhythm in human beings. It shows only a few examples: body temperature, alertness, and the hormones cortisol and melatonin.” from Guide to human-centric lighting by Andrea Knust Licht.

Changes in daylight throughout the year is another common situation. Many papers state a problem called "seasonal depression" and prove that the absence of daylight during some periods of the year affects more than 10% of the population (Gysin et al., 1997). Furthermore, a couple of experts confirm physical and psychic alterations on the human body because of the lack of UV light and, consequently, the inhibition of some hormones who affects considerately the daily well-being performance. Those alterations can be denoted in levels of melatonin (sleepy hormone), cortisol (stress hormone), alertness and body temperature (figure 5 (Andrea Knust Licht, 2018)). These disorders can affect the humour and performance of each one. Consequently, it influences several issues such as cardiac rhythm, depression feeling, hypersomnia, carbohydrate appetite, until weight gain.

In brief, all these aspects evidence that light, productivity and well-being are interconnected. In practice, in a conventional office without natural light (for instance, Figure 6 (3Presupuestos, n.d.)), if 95% of all costs are represented by the salaries, any action devoted to increasing individual comfort is an investment that can be easily recovered, due to the reduction of sickness and absences situations. Furthermore, there is a study that says that the quality of workspace could reduce absenteeism by four days annually (View Inc. & Future Workplace LLC., 2019). It happens because vision is one of the most important sense, especially at work. Hence, good lighting quality is strictly connected to people's comfort and, consequently, to performance, even if it is impossible to find an objective law to describe the relationship between light and productivity, as many other factors are involved (De Giuli et al., 2008).

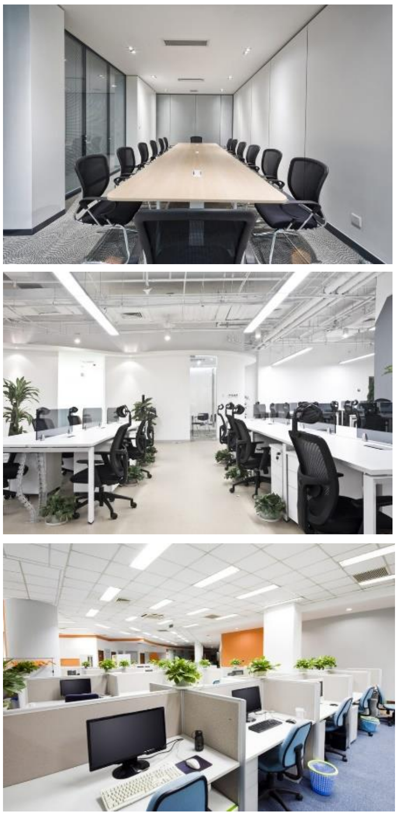


Figure 6 - Examples of windowless workspaces.

Workspaces without windows where is clear the "perfect" white light and some plants and wood which can represent it is a biopholic space.

A North American study asked thousands of employers what represents natural light to them, and answers are happiness and well-being (78%), work satisfaction (73%), work performance (70%) and organizational commitment (54%), which reinforces that comfort and good luminosity in the workspace are strong positive factors in employee experience. Also, 47% of employees admit that feel tired with the absence of windows and 43% report feeling gloomy due to this lack. In the middle of it, 73% said that using technology screens emphasizes the need of natural light (Meister, 2019). Lack of daylight and access to landscapes decreases the ability of the eye to relax and recover from fatigue. By prioritizing controlled daylight in their offices, companies can increase workers' ability to work comfortably for longer. Tested office workers report 63% fewer headaches, 56% less drowsiness and 51% reduced eyestrain when they have a balanced light (View Inc., 2019).

Furthermore, another article from the same above-mentioned brand shows that 7 out of 10 people feel encouraged to stay in a current job or to be more likely to accept a job offer if the workplace enhances health and well-being. In figure 6 (3Presupuestos, n.d.), it is possible to see which are the benefits that matter most to employees and it is clear that light is on the top three (View Inc. & Future Workplace LLC., 2019).

The company "View Inc." made some calculations and, assuming an annual salary of $50.000, if workers get 2% more productive, it can represent an additional $100.000 value for every 100 workers (View Inc., 2019).

05. Solutions to the problem and aim of this work

An obvious solution to the windowless problem would be remodelling the spaces and open big windows to receive the maximum possible daylight, because this is not always possible due to, for instance, legal issues. Other solutions could be combining artificial light with the necessary aspects of daylight for well-being and productivity (Bringslimark et al., 2011; Kahn et al., 2009).

Currently, the market already offers lights that change colour and intensity (Gearbest.com, n.d.; Ikea, n.d.; “Smart light,” n.d.; Worten.pt, n.d.), reproducing daylight. This is a solution that holds visual comfort for users but does not provide them neither the vitamins of the sun nor the sensation of being outside nor closer to nature. Another solution is the possibility to mimic light and sound of natural exterior environments with a device that capture the meteorological information. Combining this option with comfortable decoration and natural elements would be a good answer for the windowless problem. However, seasonal disturbs may jeopardize the feasibility of this proposal. Therefore, it is of utmost importance to analyze whether the solution should offer a mimic of a perfect day or the actual exterior environment even if it does not provide an appropriate light.

A third answer to the problem of the project may be related to phototherapy technology or "SAD Light". This technology consists of a medical light which provides the necessary hormones to human well-being. It has to be used for just a couple of minutes to accomplish the promised effect. Some studies show that this type of treatment is a worthy answer for winter and seasonal depression in more than 30-40% of the cases (Gysin et al., 1997).

However, the present work proposes to develop a luminaire that most of all respects the user well-being and brings a mimic of sunlight into the spaces where it is missing and would be a huge help in daily productivity and mental health. Thus, this project is intended to design a luminaire for closed spaces, without windows, where its essential presence is considered, as an example is an office given the emotional demand of the space and the high number of hours that users spend there. This luminaire must not only be efficient in terms of the light emitted, but also in its ratio with space and with the user and space. Aspects such as modularity, easy installation, and reconfiguration will be essential.

06. Reading guide

The approach in this project involves the study of sunlight and involves the study of sunlight and the associates with workspaces without natural light. Intending to develop a lamp that reduces the lack of sunlight in windowless spaces, this project increases the comfort and quality of life of its users. The final objective is to present a project in which Engineering and Design come together to answer questions such as eye balance, usability, versatility, well-being and modularity.

This document is divided into six main chapters that describe in an orderly way the development process of this project since the problem context to the final solution.

Firstly, the present chapter contextualizes the theme of the project, passing through the analysis of sunlight, its effects on humans and the problems associated with the lack of it. This initial analysis also supports the structuring and timing of the remaining future research.

The second chapter of theoretical contextualization presents the basic concepts of comfort associated with light and an analysis was made of what has already been done within this problem (criticisms of commercial and industrial property). Additionally, a potential user and space were defined and analysed.

In the third chapter, a conceptual basis about lighting and workspace was defined. Also, attached to this, a brainstorming was done, representing the way to discard pre-formed ideas and stereotypes, and exploring new ideas and possibilities.

The fourth chapter is dedicated to project development, where the elaboration and embodiment of the developed product are described. In this chapter, it is possible to know the immature sketches growing up and gaining propose and details on how it is adapted to production, functionality and usability.

Results appear in the fifth chapter, where the final solution, components and connections between them are presented. Also, this chapter depicts how the final solution works and integrates an architectural space.

In the final chapter is the conclusion of the project. Some future works are presented as well.

second chapter

Theoretical Context

07. What is a comfortable light?

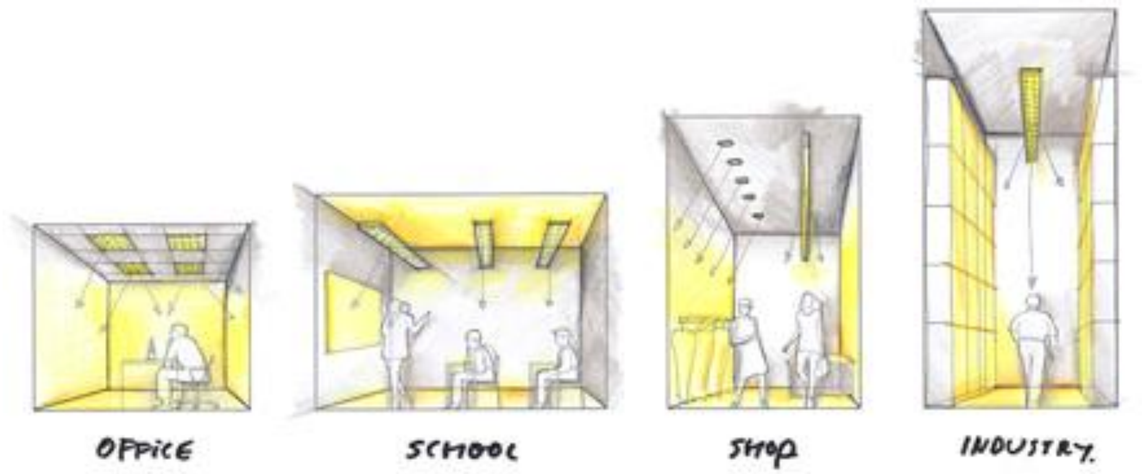


Figure 7 - Different levels of Light for each zone and activity.

Either too little or too much light can cause visual discomfort. Light quality can be defined for a variety of aspects as the rate of blinking, level of glare, and light blindness. Representations of colour, low reflection, and uniform distribution of light are other crucial aspects which help to determine environmental light quality in a room (Franco, 2019a).

In a building, people prefer having a clear view of the outside (Franco, 2019a). Therefore, daylight quality demands good control of light in terms of location and orientation. Shapes are a specific feature that defines daylight. During a day, it is possible to find different levels of light which eyes receive as glare. Light shades are crucial but if exaggerated can cause fatigue since the human eye is constantly adapting to different shapes or light levels with clear sharp contrast. Thus, everything in contact with eyes influences the health of our body and mind, affecting the human biological clock (sleep and wakefulness), heart rate function of organs, and state of mind. In sum, a good natural light dynamic has a good contribution to people well-being (Franco, 2019a; Juliëtte van Duijnhoven, 2020).

Prioritizing natural light is essential to guarantee visual comfort since human eyes are naturally prepared to adapt to the variation of the daylight. Natural light not only a huge contribution to saving energy but also improves awareness during the daytime, enhance sleep patterns, decrease depression risks, among many others advantages (Franco, 2019a; Juliëtte van Duijnhoven, 2020).

01. Illuminance vs luminance

Illuminance is expressed in lux. This represents luminous power that comes from all directions and reaches a given point where a specific task may be performed. For example, an office desk should have approximated 500 lux. In the specific case of offices, the light balance should respect the European standard daylight pattern (European standard for interior workspaces - EN12464-1; 2011) depending on the task being developed, ranging from 300 to 750 lux.

The Luminance, expressed in candela per square meter (cd/m2), corresponds to the different luminous intensities per unit area emitted or reflected by the light sources and the surfaces that surround us. It describes the brightness of the light from the point of view of visual perceptions and psychological sensations. One can also identify the contrasts of light and glare and understand if it comes from a specific source by measuring the luminance. In both cases, a photometer should be used. In contrast, the illuminance (lux) should be measure with a lux meter, which evaluates the quality of daylight (Innes, 2012; Whang et al., 2019).

02. Daylight autonomy

Another important concept is daylight autonomy. This represents the percentage of hours of the day with useful light. To define an approximated minimum requirement of spacial daylight autonomy designers and architects should consult the *European standard for daylighting - EN17037*. Although there is no universal quantity for the right light dose, people need a greater level of interior light than standard electric lighting provides. Daylight varies in intensity, colour and direction, and is more stimulating than artificial lighting. Therefore, daylight autonomy always depends on different aspects to achieve an effective balance of, for instance, location, orientation, windows shade and position, windows to floor ratio and visible light transmission of the glazing (Constructionmanagermagazine.com, 2019; Franco, 2019a; Paule & Flourentzou, 2019). Even because, as already mentioned, natural light balances a series of hormones essential for the human body, in addition to being considered a natural clock helping emotional balance. The lack of it can lead to serious consequences such as depression, changes in heart rate and mood (Gysin et al., 1997; Küller et al., 2006; Veleva et al., 2018).

08. Commercial Review

Figure 8 - Version HT25 from CoeLux®.

Figure 9 - “Blue Light” from Sad Solutions.

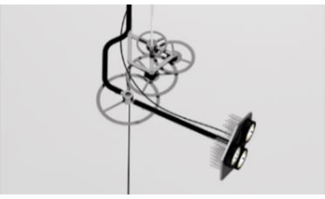


Figure 10 - “Luminarium” by Stefano Pertegato.

Figure 11 - “Lightcycle” By Dyson.

Figure 12 - “Cu-Beam” by Dyson.

Figure 13 - “Shade light” by The Orb.

Figure 14 - "Model F” By Luke Robert.

Regarding all the aspects that have been mentioned, it is possible to find in the market several examples of products that address the previously described problems.

Figure 8 depicts a Coelux product (Products, n.d.) version HT25. This is a LED panel that mimics a window with real sunlight. However, its major problem is the intervention needed on architecture to be installed. The panel works like a window and it should be previously planned on a building to avoid construction works later. It should be noted that the price of installing this product is higher than the basic product price. Therefore, it is too expensive for the majority of the companies, making it difficult to apply.

Figure 9 is “Blue Light”, an example of Sad Solutions products (*Soluções SAD BLUE Light*, n.d.). This company is specialized in medical light solutions to reduce the symptoms of seasonal affective disorder. This solution is affordable and can be used in just a couple of minutes to have the estimated effect. “Sad blue light” has several good impressions by users, however for windowless cases, it may not be the perfect solution because it does not follow up all day and does not assist the problems associated to claustrophobia.

A different project is depicted in figure 10, the “Luminarium” by Stefano Pertegato published in an online portfolio on the *Behance* platform (Pertegato, 2012). This project is visually different from the previous ones because of the mechanical aspect given by the visible cogs. With this device, Pertegato promises to mimic daylight shades and glare by doing the rotation of light. Nevertheless, it just works on small spaces because light shades and glare will be lost in bigger ones.

Figures 11 and 12, both from Dyson, are two of the most complete solutions in the market. Figure 11 shows Dyson Lightcycle (Dyson, n.d.), which is a table lamp with a variety of possibilities to the user, since the basic white focused light on different shades of colours and intensities. It also has a mobile phone application to control the light where you can add a timer to have, for example, a sunset light. Figure 12 is Dyson “Cu-Beam” which only changes light intensity. This product has been drawn to offices and has two light beams in opposite directions with functions that complete each other. One of the beams is like a normal lamp guided to the workspace and the other to the ceiling. This light that focuses on the ceiling was designed to create an ambience over and above the common useful light. The glare reflected in the ceiling and walls is like a way to clear the ambience without excessive uncomfortable bright light. In a nutshell, these two Dyson products have many advantages to consumers since they are useful, discreet, and intuitive.

Such as figure 11 and 12, figures 13 and 14 are similar in their shapes and utility. Figure 13 is called "Shade light" by The Orb (Slaatto, n.d.) and figure 14 is “Model F” by Luke Roberts (Roberts, n.d.). Those are ceiling lights which adapt colour and intensity regulated by a mobile application allowing users to choose which ambient they want to space. Both have a comfortable atmosphere, also suitable for home use.

Figure 15 - "The glow light" by Casper.

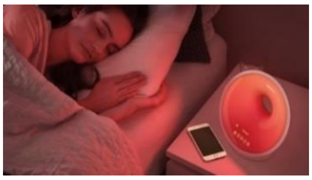


Figure 16 - "Somneo Sleep & Wake-up Light" by Philips.

Figure 17 - "Mycubic" by QCUBE.

The next two figures (figure 15, "The glow light" by Casper (Casper®, n.d.), and figure 16, "Somneo Sleep and wake up light" by Philips (Philips, n.d.)) are mostly for home use since they have been designed to be an alarm clock. These devices also have a connection to the mobile phone where users may decide when to wake up, and possibly listening to some relaxing morning sounds.

Finally, figure 17, "My cubic" by QCUBE (Qubic, n.d.), is the most simple idea from this roll of figures since it is a lamp. However, this lamp might be the base of the great majority of the examples above, since it offers the possibility to connect to smartphones and selecting intensity, colour, and glare.

The last five above-mentioned figures are cheaper than the majority while having an attractive appearance. However, the problems for which light may be the solution may require additional concerns, since solutions may not be enough to meet the complex human needs. Nevertheless, the above-mentioned options are a good help in correcting different individual problems, as they are examples of lamps that promote health and comfort.

09. Industrial property review

To complement the commercial review a research was made concerning to products adapted to windowless spaces.

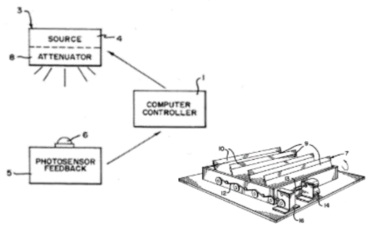


Figure 18 – US 5343121A -“Naturalistic illumination system”

“Apparatus for adjusting the circadian rhythm of a subject in a space by producing a variable light intensity level on a continuous basis…”

First, the “naturalistic illumination system” (Terman, Michael; Perlman, Bill; Fairhurst, 1994) depicted in figure 18, it is a photosensor which measures the actual daylight received and sends the empirical reading to the computer, in the way to fit the algorithm specifications and adjusting the illumination level. This system uses a light source, a computer controller, and a photosensor feedback loop. The light mechanism comprises a set of precision mechanical vanes which are closed and opened gradually by a silent motor drive. A reference generating algorithm specifies the expected momentary level of illumination on the earth's surface-from skylight, sunlight, and moonlight sources-across a twenty-four-hour day, at any day of the year and geographic latitude. Using precision motor-control, the algorithm drives the light attenuation mechanism, thereby producing simulated naturalistic illumination patterns.

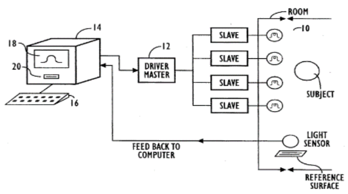


Figure 19 - US 20140117877A1 - “Natural daylight emulating light fixtures and systems”.

Next, represented by figure 19 -“natural daylight emulating light fixtures and systems” (Mapel, Jonathan King; Boehnlein, Albert John; Forbis & Cessionário, 2013) is a device with an interfacing a computer-operated system with software connected with calibrated lamp drivers. It is a method and system that provides to the user a selection of desired lighting parameters, with an on-line calculation of successive illumination levels, and digital mapping of illumination level for outputting to a specific lamp or lamp type. In alternative versions of the system, it can be used for example, as a stand-alone for home bedroom device to 24hour light cycles.

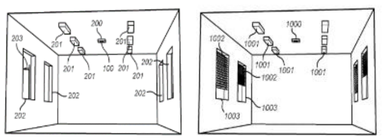


Figure 20 - EP 0739578B1 - “System to optimize artificial lighting levels with increasing daylight level”.

About figure 20, “System to optimize artificial lighting levels with increasing daylight level”(*System Comprising a Daylight Sensor for Sensing a Level of Daylight*, n.d.) is an artificial light system that matches a detector of daylight intensity and a controller of artificial light levels. This patent claims a set of things to work: the sensor to detect daylight; a daylight fount; an artificial light controller by daylight levels; and a daylight quantity controller. This last one transmits when daylight is excessive or insufficient (up or above the pretended limit) and regulates it.

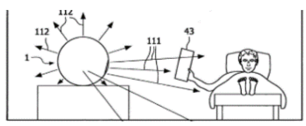


Figure 21 - BR PI0906849B1 - “Lighting device, and method for providing a stimulus for awakening through a lighting device”.

“Light raises cortisol levels in healthy people.” (Schlangen et al., 2009)

In figure 21, “Lighting device, and method for providing a stimulus for awakening through a lighting device” (Schlangen et al., 2009). This invention provides an enhancement of the device to generate a wake-up stimulus, regulating the user is levels of cortisol and binging to a good woke up humour to start to his day. The lighting device improves the light effectiveness on awake by colour spectral tuning and light timing, exhilarating the photoreceptor system in melatonin production. At the end of the sleep cycle, a human being can be awakened by the presence of light (Schlangen, Vinkenvleugel, & Hommes, 2009).

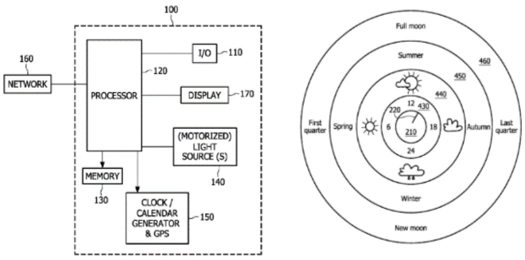


Figure 22 - US 2010.0084996A1 - “Natural daylight mimicking system and user interface”.

Figure 22 exhibits the “Natural daylight mimicking system and user interface” (Sluis, Bartel Marinus Van De ; Diederiks, Elmo Marcus Attila ; Bergman, Anthonie Hendrik ; Biggelaar, 2010), it represents an interactive system with a user interface for mimicking and controlling natural daylight. This device promises to mimic daylight with not only adapt the colour and intensity of light but also change the direction of light with constant or varying rates. Depending on the lighting possibilities in the horizontal direction, the system may also simulate the movement of an artificial sun throughout the day. All of it manipulated by the daylight knob in Such a system would give the user the feeling of manipulating the position and light of the artificial device.

10. Context, user, and space


Figure 23 - Three examples of offices without windows (Sarah Robinson, n.d.).

Figure 24 - MeUndies office in Los Angles (Michal, 2020).


Figure 25 - ZG Advogados office in Porto Alegre by Ambidestro architects (Ambidestro, 2018).

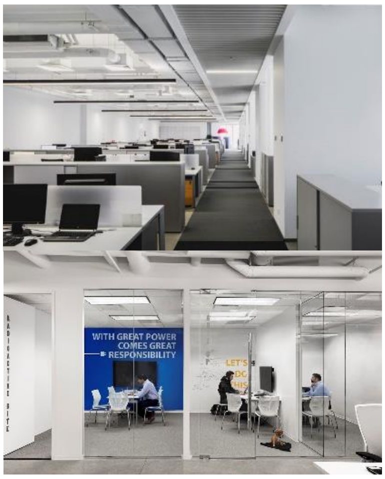


Figure 26 - 09 Solutions office in Dallas (Officelovin, 2017).

Users can take more advantage of an improved light mostly in workspaces. On the one hand, it happens because the workspace where they spent the great majority of their time, and, on the other hand, is where people need to be more productive. After all, companies are increasingly interested in health and productivity of their workers.

This project aims to adapt a space and make it comfortable for everyone during the day, and hence users should be people who work approximately eight daylight hours from morning to night. The main concern of the project is to create comfort which means health, productivity, interaction and better results.

I also highlight the importance of identifying the potential consumer of the consumption of the product. Designers, engineers and architects should decide which product in the market are adequate to their clients and company managers. Therefore, the product should be versatile, intuitive, easy to maintain, durable, have a fair price and be attractive.

Regarding this, figure 23 to 26 show some examples of workspaces where this project could make sense. Those are companies with offices, laboratories, workshops, or workstations.

This type of companies are growing day by day, and some of them invest more in pre-made spaces, dividers, and furniture with low weight and rollers (chairs, desks, even cupboards). Hence, the final product should be easy to adapt to these types of spaces. Additionally, in these spaces, the main light appliances are on the ceiling to illuminate the whole room and other appliances are on the desk and floor as a complementary tool. The main focus of the present work is on the ceiling appliances to improve the ambience of the workspace even to users that have an individual light. Also, ceiling light gives spaces a better organization and free space because it does not affect the circulation of workers on space, with electrical lead connectors and wires, allowing a possibility reset of space whenever necessary.

11. Workspaces market analysis

For a better understanding of office luminaires, it is important to analyse shapes, strategies and purposes of some of the most common ones in the market even if it does not satisfy what this work intends to achieve. What consumers usually choose their spaces should be understood.

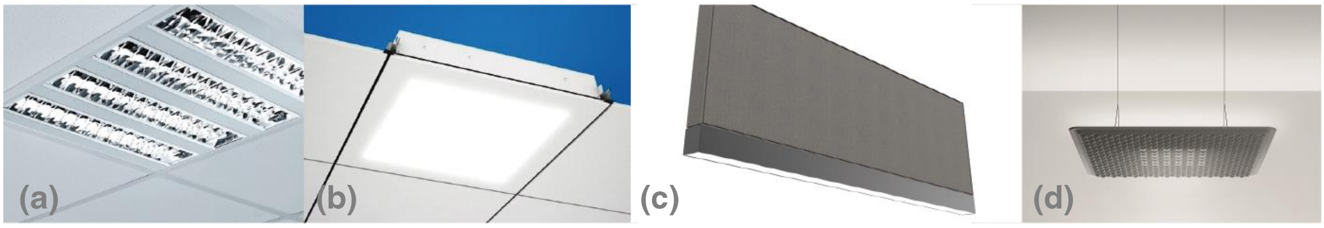


Figure 27 - Offices common lightening
(a) Ttriade-R by Plexiform;
(b) Ecophane square by Saint-Gobain Ecophon;
(c) Iyichì by Metalmek;
(d) Eggboard Matrix of Artemide by Roj, Massimo; Giacobone,Giovanni.

The first two figures (figure 27 (a) (Plexiform, n.d.) and figure 27 (b) (Saint-Gobain Ecophon, n.d.)) represents a type of solution, the architectural integrated one, that should be installed in conjunction with infrastructure works on ceilings. Both have a discreet aspect and do not interfere with anything about space design. In figure 27 (a), a sheet steel body is used and is equipped with pre-anodized aluminum optics for different brightness emissions.

Figure 27 (c) (Metalmek, n.d.) and figure 27 (d) (Roj et al., 2014) represent a completely different view of office room needs. Both are not only to illuminate but also to isolate sound. In contrast to the previous two pieces, these luminaires have a strong presence in space decoration. Figure 27 (c) is a vertical option with a face with an opal diffuser of light directed to the work zone. Figure 27 (d) is a panel with an eggs case shape that isolates sound and has some led lights within.

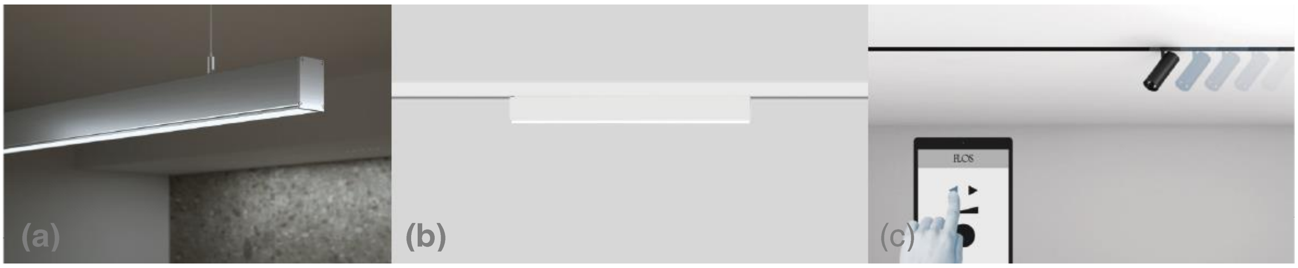


Figure 28 - Offices common lightening
(a) Claro of Lumines Lighting by Trzcieliński, Grzegorz and Starżyk, Krzysztof;
(b) Yori Linear by Reggiani;
(c) The Fast Track by Flos.

Figure 28 (a) (Trzcieliński et al., n.d.) and figure 29 (b) (Reggiani, n.d.) have similar shapes (usually designed to be cheap and match easily with any market lamp) and a similar way of illuminate but two different ways of installation.

Figure 28 (a) is a light product supported on two wires and the second is supported by a rail, as all next figures since figure 28 (c) to figure 29 (f). This railing method depicted in figure 28 (c) (Flos, 2018) allows reconfigurable spaces and adapt to different luminaires with direct or diffuse light.

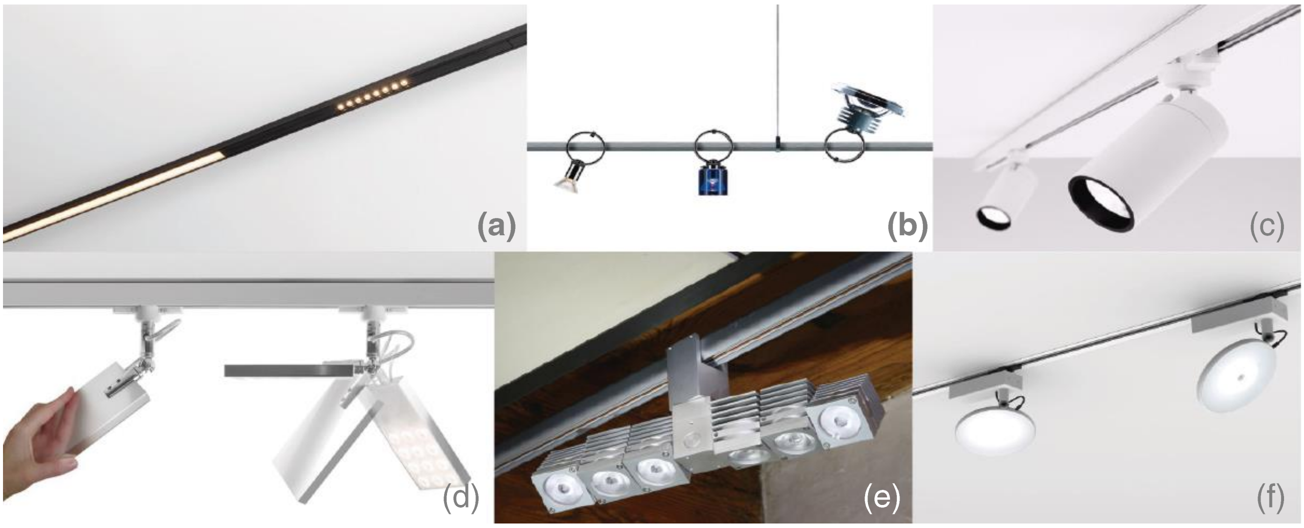


Figure 29 - Offices common lightening:
(a) Pista Track 48v Led Linear Spots by By Modular Lighting Instruments;
(b) Clip by Licht Im Raum;
(c) Dot Sistema by Davide Groppi and Omar Carraglia;
(d) Pad Square By Carlotta de Bevilacqua to Artemide;
(e) Gemini Plus Led by Umberto Tosi toTecnoilluminazione design;
(f) Avveni 3 Phase Track by Michael Schmidt and Ulrich Sattler to Sattler.

The next figures are different ways to combine rails illumination. Figure 29 (a) (Modular Lighting Instruments, 2019) is a simple rail that fits different types of single luminaires. Then, figure 29 (b) (Licht Im Raum, 1982) is a rail that can be matched with different types of lamps attached by metal arches with a clip system. Figure 29 (c) (Groppi & Carraglia, 2016) uses cylinders to attach the LEDs, allowing full rotation and movement. Figure 29 (d) (Bevilacqua & Artemide, 2012) moves identically to the previous one, but, instead of a lamp, a panel with several LEDs is used. Figure 29 (e) (Tosi & Tecnoilluminazione design, 2008) is similar to figure 28 (b), however individual lamps are used altogether, instead of a long lamp, with the advantage of being able to rotate and distribute the light at different angles. In figure 29 (f) (Schmidt et al., n.d.), the plug-in module of the luminaire can also be used for standing or table stands. It is also rotatable and can be adapted to space as in figure 29(d).

In sum, most of the analyzed ceiling lamps allow the reconfiguration of the light emission angle and are simple with very geometric shapes and low visual impact except for those that are concerned with the acoustic aspect of space. There is also a great concern with modularizing the light mostly using support rails. The light as a module allows the quantification and adaptation of light to space and the user.

third chapter
Concept and definitions

12. Conceptual development
13. Lighting brief
14. Workspace needs
15. Brainstorming

“The backbone represents the design process, starting with a market need, proceedingthrough the stages of concept generation the idea), (embodiment development the sketch) and detailed (design (the working drawings), finally ending in production. New design starts at the top and proceeds downwards. Re-design starts at the bottom and loops upwards before descending.”

(Ashby et al., n.d.)

12. Conceptual development

One of the fundamental premises of this project is comfort. Therefore, this project presents a solution for spaces without natural light that may cause discomfort at different levels.

In an ideal workspace, architects and users themselves seek for proximity from a window and natural light and demand for some lamps with the correct distribution scattered on the space to offset the hours in which the daylight is insufficient to get a productive mood (Bringslimark et al., 2011; Franco, 2019b; Kahn et al., 2009).

To make this possible, rather than thinking in only one luminaire that mimics the daylight, this project presents a light system (a coordinated composition of several lighting fixtures) to answer the multiple user needs.

The present work proposes to design a light system for workspaces that offer a solution for the necessity of having a comfortable light composition during the whole day. The conceptual idea of this project is to create a composition of lights that mimic the perfect workspace in terms of emotional and visual health and comfort. Therefore, to achieve these objectives, one should develop an artificial sunlight to make users emotionally balanced for long times and artificial lights with intensity adjusted to the previous one to spread the light over the space. The main objective is to provide a balance through the day according to the lighting European norm for interior workspaces (Norma EN 12464-1:2011), to guarantee that the daylight mimic does not make the space extremely relaxing and calming that makes the user less productive or, in contrast, the light is so artificial that provokes visual discomfort to users.

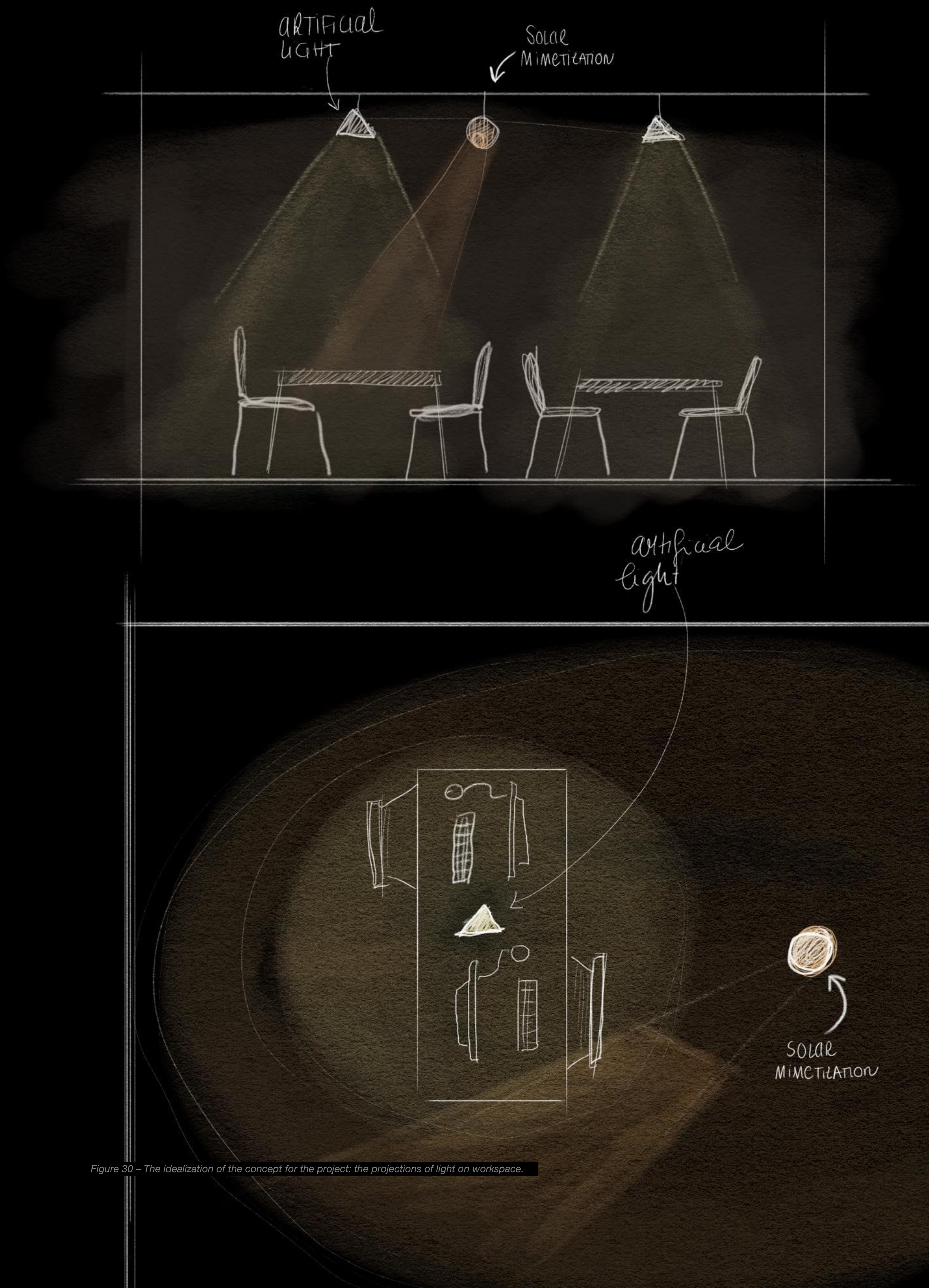


Figure 30 – The idealization of the concept for the project: the projections of light on workspace.

13. Lighting brief

Having the notion of time through daylight provides calm in the space.

The first challenge of this project was to design the light, to guarantee that it is efficient and works in harmony with all the other elements.

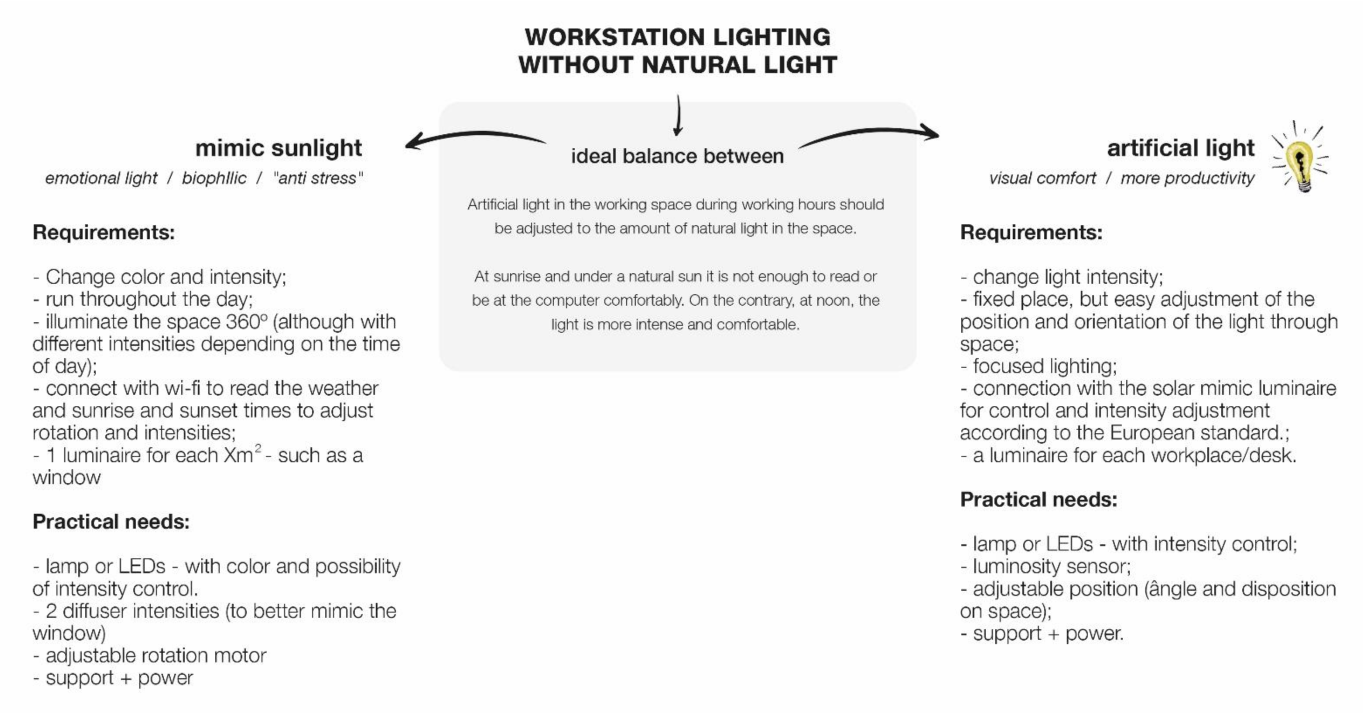


Figure 31 - Needs diagram.

All changes in intensity, colour and angle of natural light throughout the day mentioned above must be mimicked by the solar mimic lamp. However, even for spaces with windows, natural light could be not enough to meet the requirements of European lighting standards or to offer comfort to users throughout the whole day. For this reason, in this project, it was decided to develop not only a luminaire but a lighting system to ensure a balance between the ocular and emotional needs of the co-inhabitants of these offices. Therefore, this project proposes to overcome the problems associated with emotional and mood disorders caused by the lack of natural light and eye diseases caused by changes in daylight and insufficient light at certain times of the day.

Briefly, the lighting product should include an element of sunlight mimicry and another artificial and direct light. That way, to guarantee the balance of both emotional comfort and productive environment (figure 31).

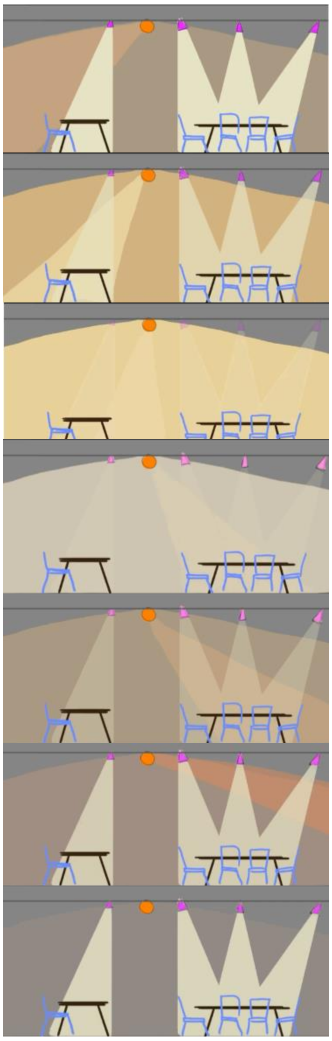


Figure 32 - Frames to illustrate the route of the light idealized in the workspace without windows.

To clarify and support the development of a shape, some sketches of how light should ideally result in space have been developed (figures 30 and 32).

To maintain the necessary natural - artificial balance, a composition of direct and indirect light with sun mimic lights and artificial light was created. Indirect light with solar theatre act should illuminate the space in an ambient and diffuse. This has part of the flow directed to the ceiling and walls it provides the office with a more pleasant light, with the disadvantage of being of low luminosity. The light spot should way and vary in colour and intensity throughout the day depending on the time and weather, season, and the area of the planet to be the closest to a real window. It is also important to highlight the hourly light issues by creating a rotation throughout the day so that the direction of the morning light is in the same direction as it would be if a window illuminated the space at sunrise and the opposite at the end of the day. For this, the luminaire should be connected to a mobile device connected to the wi-fi to obtain this information, thus coordinating the sunrise and sunset times, if the sun is bright or if it is cloudy, and the location of where the luminaire is installed to convey the feeling that a window is close.

The focal artificial or direct lighting that is focused in workspaces is necessary even in spaces with windows when sunlight is not enough given the time of day or the position in which the individual is concerning the window. This light with luminous flux emitted is directed on the surface to be illuminated is central to eye balance and worker productivity (Viva Decora PRO, 2018). This luminaire should be directed towards the workspace to avoid shadows in the work surface that disturb it and, throughout the day, it should regulate its intensity coordinating with the previous one. For example, at sunrise when the sunlight is less intense it should complete it, and, at noon when the light is usually clearer and more intense, it must adjust itself reducing its intensity so as not to cause discomfort in space by excess light. In short, this luminaire must ensure that the space it illuminates is constantly fit for the task that is developed there according to the European standard of lighting in workplaces (Standard EN 12464-1).

14. Workspace needs

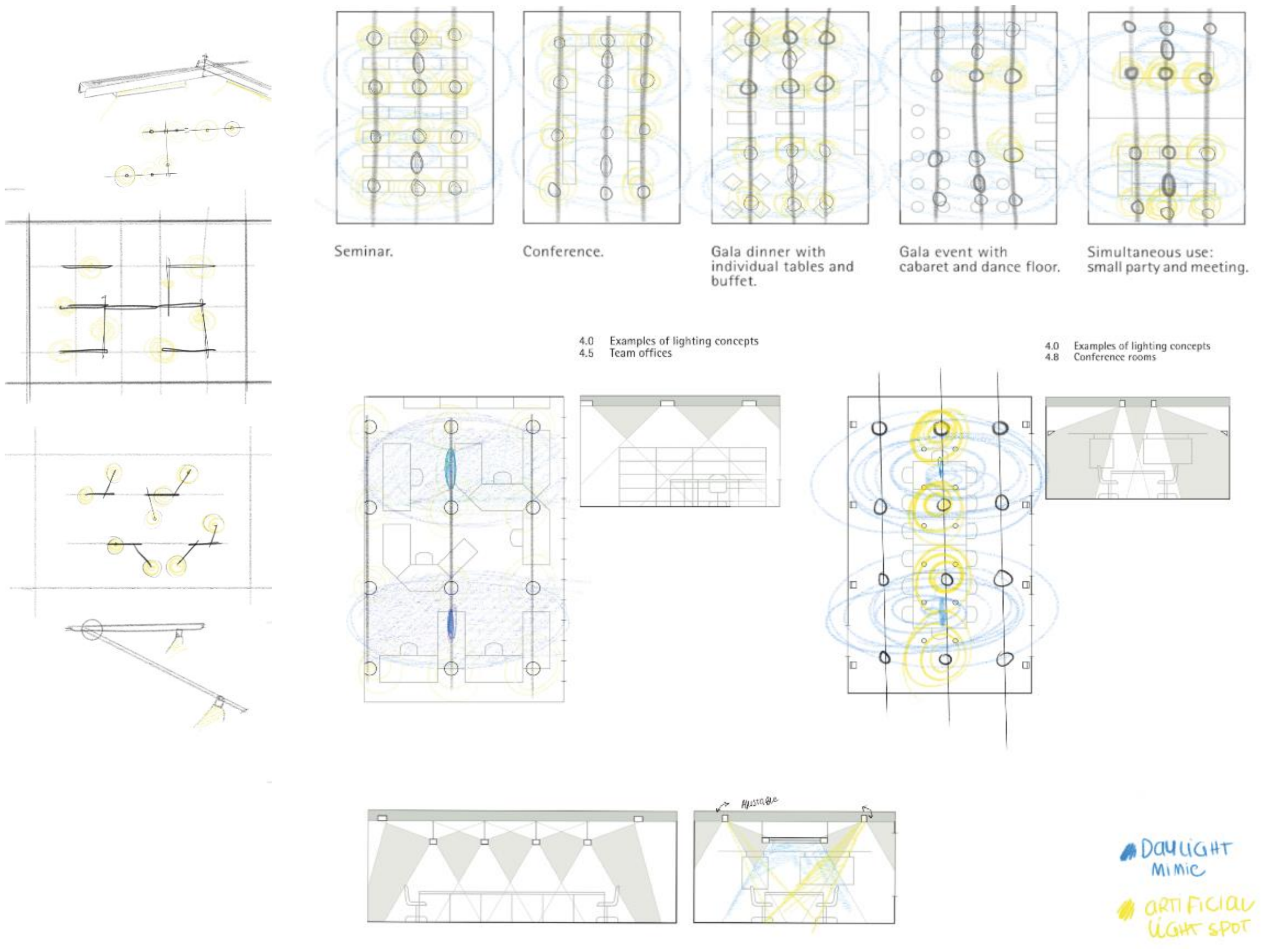


Figure 33 - A study of spaces in plan and light organization.

Several lighting systems are found organized in path structures distributed throughout the space that assembles the electrical material and couple the various luminaires. With this strategy, space designers do not need to fix the structures on the ceiling, allowing them to replace or reconfigure more easily those structures. Therefore, a wide variety of combinations and organizations may be achieved without the necessity of major work interventions in the space to add new luminaires because of the electrical components.

Thus, this project proposes a ceiling lamp to facilitate not only the configuration and planning of the space but also to guarantee the easy circulation of the users of the space and it is easy reconfiguration if necessary. In figure 33, it is possible to see some drawings made over plans of different workspaces (Hofmann & Ganslandt, 1992) to better understand the space and some of its possible configurations.

In sum, the ceiling light composition with a solar mimic will feign a skylight window through where natural sunlight enters. And the other will compensate for that same white light that varies according to the time of day. Creating a modular composition with two types of luminaires.

15. Brainstorming

"Brainstorming is an activity that will help you generate more innovative ideas. It's one of many methods of ideation—the process of coming up with new ideas—and it's core to the design thinking process."

IDEO U, 2020

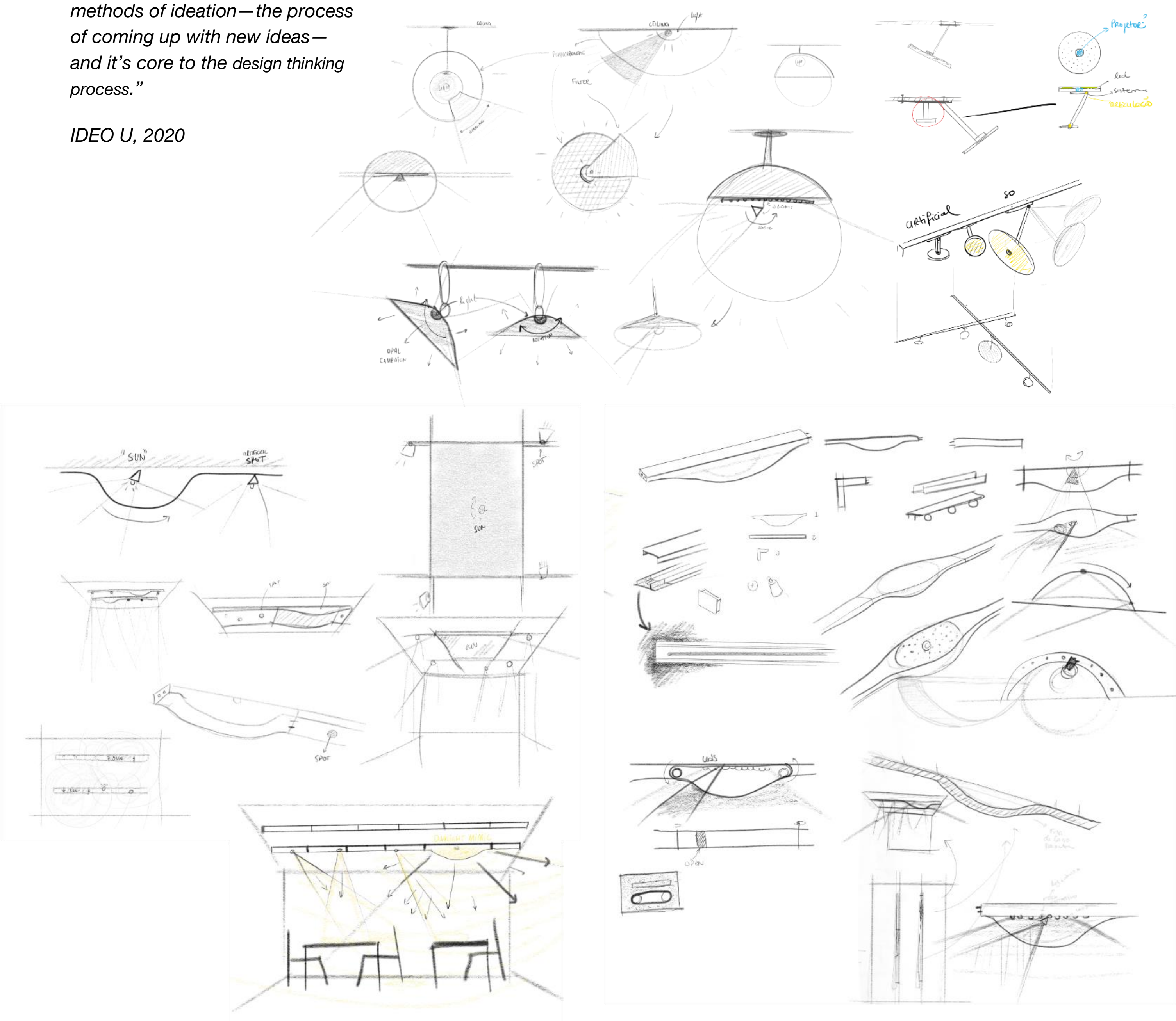
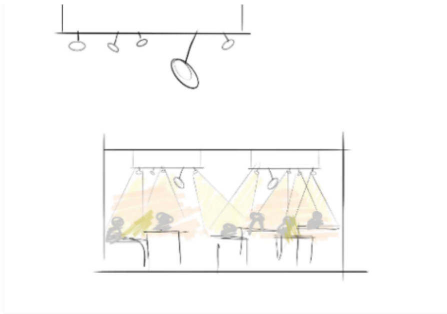


Figure 34 - Brainstorming.

“Brainstorming is a technique to stimulate the generation of a great number of ideas in a short time.(…) Criticism should not hinder the creative process and the generation of daring ideas. (...) New ideas or different angles of the same idea can generate innovative solutions. For this reason, it is positive to contribute with bold perspectives, without letting the critical sense hinder the debate and the development of the idea.”

Vianna, Mauricio; Vianna, Ysmar; Adler, Isabel K; Lucena, 2012



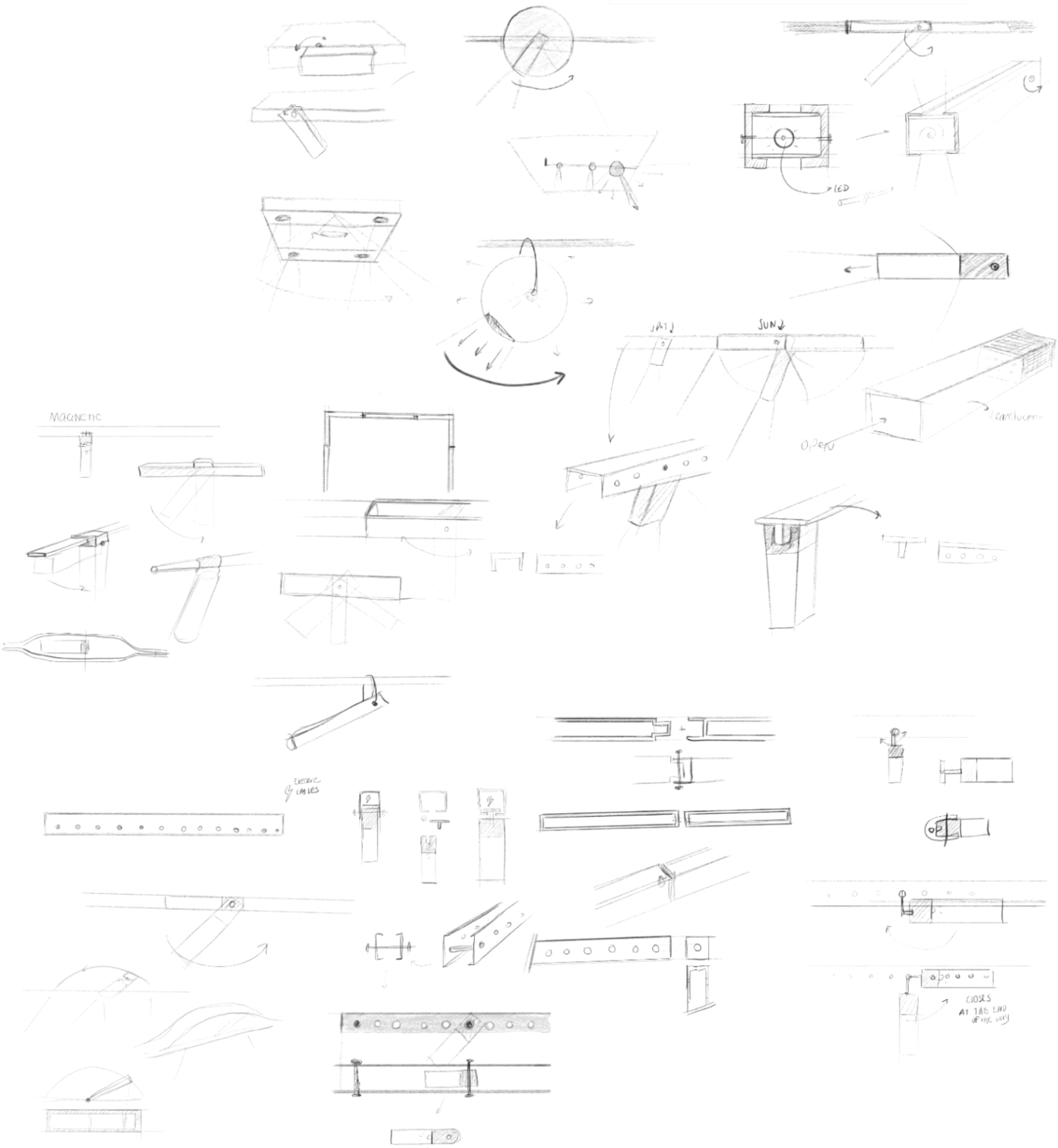


Figure 35 - Brainstorming: development and analysis of the drawn shapes.

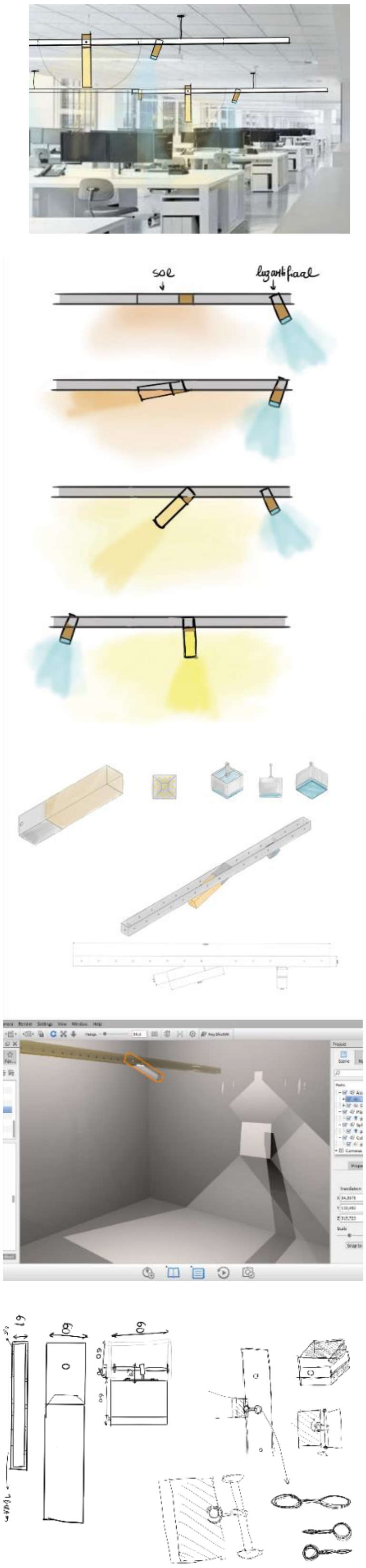


Figure 36 - Test drawings and 3D models made using a modular ruler, a pioneer for this project.

In this stage of the project, a brainstorming of several formal possibilities is presented, as figures 35 and 36 shows.

First, it was sketched plans or large spaces in order to promote modularity and flexibility of the product, regarding potential dimensions and configurations that could be possible. This process helped to improve the composition of lights and its dynamics so that any space can be organized with this system (figures 34 and 35).

After evaluating possible plans of the space for the luminaires, two options are available. On the one hand, one may use fixed structures such as rails on the ceiling to optimise the space and ensure that the whole space is supplied easily with lighting. On the other hand, it is also possible to design the luminaires so that they are the structures themselves and create the necessary luminous composition to each space.

At figure 35, some shape possibilities may be observed, in which a sphere allows a 360º illumination and a filter or opening moves throughout the day to create the hourly illusion in space. At this point, it was considered that this filter could be made through a tear in a diffusing polycarbonate. Also, figure 36 shows other possibilities based on the development of continuous modular structures. It is presented options using panels or even small rails that could be integrated as several luminaires creating visual compositions in the space.

After sketching several possible shapes, the ceiling structure was the most promising solution since it allows the desired dynamism in what regards the versatility of an office combined with the requirements of the solar mimic lamp already mentioned.

Various compositions of structures and lamps were considered until reaching a shape that is similar to a perforated ruler (see figure 36) whose objective is to organize all the electrical components of the composition of lamps. This ruler rail can be modular and fitted and can adapt to different dimensions of the room. The fact of being perforated allows the luminaires to hang on the ruler and to be connected to, as well as easily adjust to the needs of each space by choosing the number of luminaires.

Regarding the shapes of the luminaires, it was considered that the solar mimic lamp and its clockwise rotation can be compared to the hand of a clock, rotating throughout the day, and directing the light to the east or west. With this ruler structure, and in order to create less visual impact when it is not in operation, at the end of the day the solar lamp retracts inside the structure, leaving all the attention on the artificial lighting spots during the hours without sunlight.

fourth chapter

Project Development

16. Support structure for fixtures
17. Product development
18. Luminaires
19. Materials
20. Proportion analysis

16. Support structure for fixtures

At this stage of the project, it was considered necessary to further develop the structure that will support the composition of luminaires. This development was contained by the needs of space, lighting and consumers already identified throughout the project, such as:

- space with different configurations;
- the possibility of growth or alteration of space or number of space users;
- irregular ceilings;
- different right feet;
- ensures that the light is at the correct distance from the work surface, regardless of the height of the surface or the ceiling;
- more possibilities for compositions of luminaires (flexibility and versatility);
- reduced visual impact - adapts easily to any space and "style".

Figure 37 - Modular Aluminium Cable Tray "APIS" by Valeman.


(a)

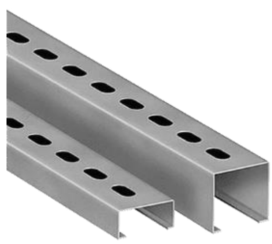

(b)

Figure 38 - Cable trays: (a) Pemsa brand profile variety; (b) Aluminium profile by Elecon.

The design of the structure is a fundamental part of the product and, therefore, it is important to further explore what already exists in the market for rails in addition to the common cable trays (like is depicted in *Valeman* spaces of figure 37 (Valeman, n.d.) and the example of the product of figures 38 (Elecon, n.d.; Pemsa, n.d.)), spaces where these are integrated, as well as understanding their technologies.

In this way, further research was done to clarify how electrical connections work, in general, on these types of rails and to ascertain that it will be easy to install and use, and not jeopardise the versatility and practicality of the project.

Initially, simple paths were imagined, influenced by the optimal requirements for space and inspired by some images such as, for instance, figure 37 (Valeman, n.d.). The cable trays found in most spaces are simple (in the sense that they are extruded profiles) (figures 38 (Elecon, n.d.; Pemsa, n.d.)) and have several functions in addition to lighting.

However, given the importance of creating a complete and versatile lighting network in this project, several formats and possibilities of structures were analysed.

Figure 39 - (a) Skeninge from IKEA; (b) "The running magnet" by Flos; (c) "Clip" by Licht Im Raum.

In addition to these type of cable organizing paths, other solutions were considered that are more focused on lighting and has common characteristics to those that are sought for this project such as those in the figures 39.

Square rails with electrical conductive circuits are a suitable solution (figure 39 (a) (Ikea, n.d.)). It can be used as a floating structure. All luminaires have a separate power supply, enabling an individual connection and can be easily repositioned anywhere on the rail. Therefore, it is possible to create a multifunctional rail system for several situations and uses.

Another solution is the magnetic tracks, such as, for example, "The running magnet", by Flos (figure 39 (b) (Flos, 2017)). Like the previous ones, these rails have electrified circuits, but instead using the mechanical fitting, the luminaires are connected through magnetism. Moreover, these structures can be moved while they are still on, achieving enormous flexibility and adaptability in the configuration of the lighting project at any time.

The "Clip" by Licht Im Raum (figure 39 (c) (Licht Im Raum, 1982)) also stands out. This solution is visually different from the previous ones because, on the one hand, luminaires are connected through their exterior and, on the other hand, it allows to reposition the luminaire and adjust the direction of the light.

17. Product development

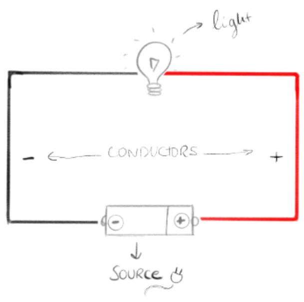


Figure 40 - Sketches of electrical connections and components.

It is essential to understand the bases of the electrical circuit, a path that allows the passage of electrical current.

Electrical circuits are closed sections, which start and end at the same point. These are formed by several interconnected elements and by a conducting wire, which allows the passage of the electric current. They are used to connect electrical and electronic devices according to their operating specifications. Also, they are used for electricity distribution (Santos, n.d.).

The electrical circuits are composed of 3 basic elements: the source, the load and the conductor (figure 40).

All gutters are connected to a source and have a metallic material along with their structure, wich grantees electrical conductivity. In the case of figures 39 (a) and (b) (Flos, 2017; Ikea, n.d.), it is made through micro copper cables inside the structure where, when the luminaire is fitted, connected. As an example of figure 39 (c) (Licht Im Raum;, 1982), the metallic structure that supports the luminaires is powered by connecting to the luminaires by contact.

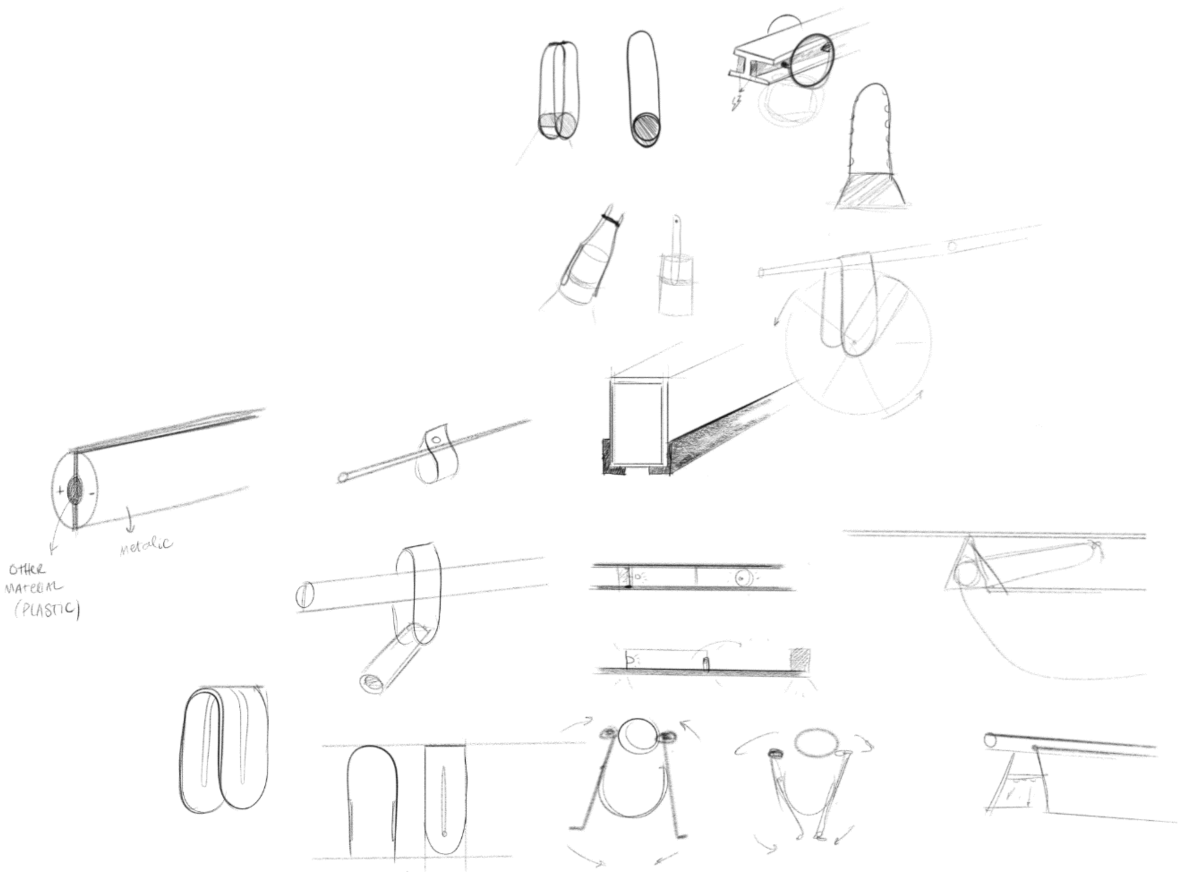


Figure 41 - Sketches of shapes.

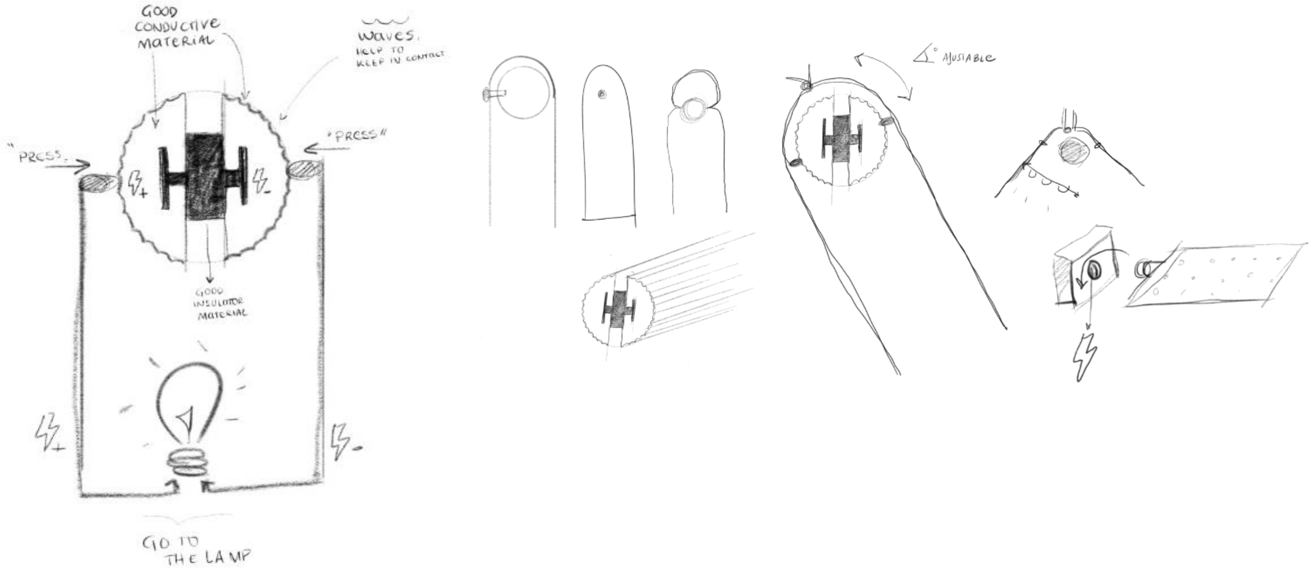


Figure 42 - Outline of the luminary relationship with the profile.

Although some formal possibilities of electrical tracks (see figure 41) were studied, a circular profile track (figure 42) was proposed to guarantee that the lighting could be automatically adjusted. When arranged at different angles, the luminaires allow directing the light to the desired work area avoiding unpleasant shadows.

With this type of profile, solar and artificial mimic lamps may have identical physical aspects, maintaining a continuous language throughout the space with no excessive emphasis of the solar mimic lamp. This aspect is important to guarantee from the beginning of the project and to maintain formal simplicity. It is considered that the visual impact of the solar mimic lighting fixture may fill a gap of the space and so it is intended to offer a feeling of ideal space.

To complete the luminaire in practical terms, the circular aluminium profiles that will be electrified are not regular and have slight ondulations to guarantee mechanical security for fitting the luminaires. Moreover, instead of a complete circular profile, two halves of the circle are considered to transmit respectively the positive and negative current of the device. These two faces are kept close together but separated by another non-conductive profile that supports the structure.

Using a circular electric profile provides a lot of practicality to the lighting system, through the reconfigurability, repositioning and direction of the luminaires. Besides, it brings irreverence and exclusivity, accompanying the unusual nature of a solar mimic luminaire associated with a technical lighting system for workspaces.

The non-conductive profile that supports the structure separates the phase from the neutral side. At an early stage, a profile was designed with a shape that could maintain the stability of the structure. However, since this element has a reduced visual impact, was searched a shape that is already on the market that can also satisfy the requirements. Consequently, the product can be more accessible, avoiding the development of a new mould.

18. Luminaires

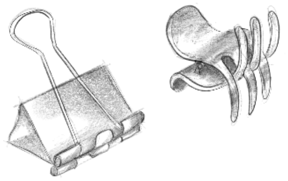
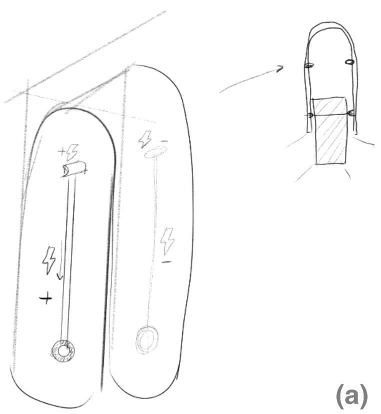


Figure 43 - Illustration of a spring, paper and hair clip, objects used as inspiration.

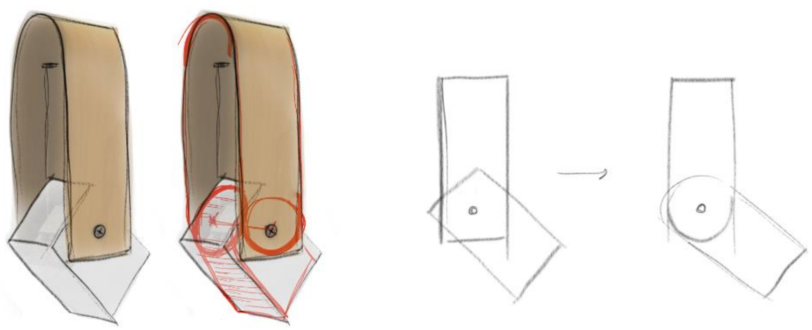
The luminaires were developed in parallel to the profile and were initially hypothesised with a similar shape to a hair or paper clip (figure 43) to make it easy to attach to the profile where they are supported. These must have a positive and negative conductor that brings the energy to the system of each luminaire. Hence, the association of the luminaire with a spring is essential to keep the luminaire in constant pressure on the profile, both on the positive and negative sides. This system also allows easy fitting and displacement or repositioning of the luminaires through the profile, which is a characteristic that has been pursued since the beginning of the development of the project. Furthermore, the above-mentioned formal example of the springs served as a practical inspiration considering that it was necessary to find a way to control the stability of the contact between the same profile and the luminaire, to guarantee the smooth functioning of them. Also, it allows making it easier to fit and unplug the luminaires so that users can reconfigure the system and reposition the luminaires.

Initially, it was thought to use a spring in the literary sense to carry out this task but, as the design progresses, it was considered the use of a slightly elastic material to make the required effect. At this stage of the design of the product, one should study the suitable material that may satisfy the design in this aspect. Use polymeric material is the first possible solution. Polymers are a group of materials that offer an elastic material in the right proportion. However, picturing the piece in the space, it was considered that it would be a better option to use moulded plywood. Since it is an organic material and can easily acquire different finishes. Moreover, in the vast majority of spaces that are considered as a target of the project, the use of wood in the furniture is considerable. Furthermore, this is a visual aspect that brings nature element and comfort to a biophilic space, and this is one of the fundamental principles of these project. Therefore, wood is considered an ideal material for this piece because it is natural, but above all, it is a bad electrical conductor and allows different finishes, shapes and properties according to the way it is crafted.

In terms of shapes, these were gradually improved over the course of the project, depending on the technical and visual needs.



(a)



(b)

Figure 44 - (a) Sketch of the support and connection of the luminaires; (b) - Formal progress of the luminaire throughout the development of the project.

Figure 46 - Final option of the screw embedded in the plywood "U".

Figure 45 - 3D tests about the visual presence of the screw in the luminaire.

In figures 44 and 45 can bee seen some drawings made in a more advanced design phase. In this case, the shapes of the luminaires were rounded, both in the polycarbonate box and in the wooden part. It was considered that the use of a rounded and concentrated shape in the various pieces evidences the rotation of the luminaires (figure 44 (b)). To further accentuate this issue, the screw size was also adjusted. Initially, it was thought to use a standardized screw, but with the progress of the project, it was concluded that visually its design could show the function and give an aspect of a less technical lighting object if it changed its shape (figure 46). Therefore, was selected a standard metric thread and a top designed built into the "U" part, as depicted in figure 45.

19. Materials

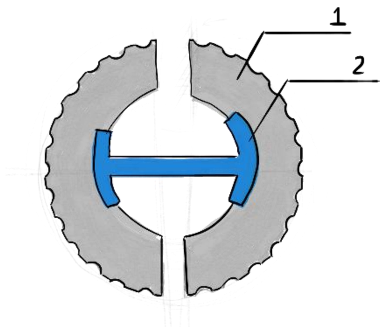


Figure 47 - Simulation of profiles: Zone 1 - conductive aluminium profile; Zone 2 - core, non-conductive support profile.

Material	Conductivity $(\Omega m)^{-1}$
Silver	$6{,}17 \times 10^{-9}$
Copper	$5{,}91 \times 10^{-9}$
Gold	$4{,}25 \times 10^{-9}$
Aluminium	$3{,}63 \times 10^{-9}$
Tungsten	$1{,}90 \times 10^{-9}$
Iron	$1{,}03 \times 10^{-9}$
Platinum	$0{,}94 \times 10^{-9}$

Figure 48 - Table electrical conductors : (Melhores Condutores Eletricos – Eletronica Industrial, n.d.).

In the next stage of the project, decisions were made to bring maturity to the project, such as its materialization and production.

Starting with the materialization of the luminaires, the support is made of plywood, as previously mentioned, and the body of the luminaire is in translucent polycarbonate to diffuse the light, as is modelled in figure 45. The used wooden plywood must be easy to bend and resistant to bending so that it can be easily fitted without deforming or undermine. For that, the *Laminar Lamiply Flex* from the company *Laminar* (Laminar - Indústria de Madeiras e Derivados, 2018) was used, whose thickness is between 5 and 7 mm and is suitable for indoor use.

Regarding the support profile of the luminaires that is divided into two parts: the support core (figure 47 – highlighted as zone 2) and the exterior that conducts electricity to the luminaires (figure 47 – highlighted as zone 1). For zone 1 in figure 47, a metallic material was considered in one phase as these can conduct electricity 10 to 100 times faster than other substances. However, at this stage of the project, it is important to define it taking into account that the brief is now defined by its function.

The greatest feature of this material is that it must be a good electrical conductor and that is why the best metals for this function have been analyzed (metal table). And from there arose the hypothesis of aluminium alloy, which is one of the most conductive metals (figure 48 (*Melhores Condutores Eletricos*, n.d.)), but which also has several other characteristics than the other equally conductive metals such as its acceptability and weight. Aluminium alloy can present itself as one of the most used metals, but also more abundant on earth, it is light and easy to machine and recyclable (iMetais.com Ltda, n.d.; Poly Lanema, 2020a). Given that a profile is intended, one aluminium alloy profile must be extruded (only an extrusion nozzle is necessary taking into account the symmetry of the piece), which will then be assembled by the other support profile (figure 47, zone 2). The ideal aluminium alloy would be 5005 for its strength and for being one of the best in terms of electrical conductivity in aluminium alloys. Also, this alloy is easy to polish and will have a nice surface finish over and above the extruded aluminium alloy 5000, and it is commonly used in architecture and decoration products. Additionally, this alloy is a favourable combination of mechanical and corrosion resistance, and ductility (Poly Lanema, 2020b, 2020a; Scgeid, 2010).

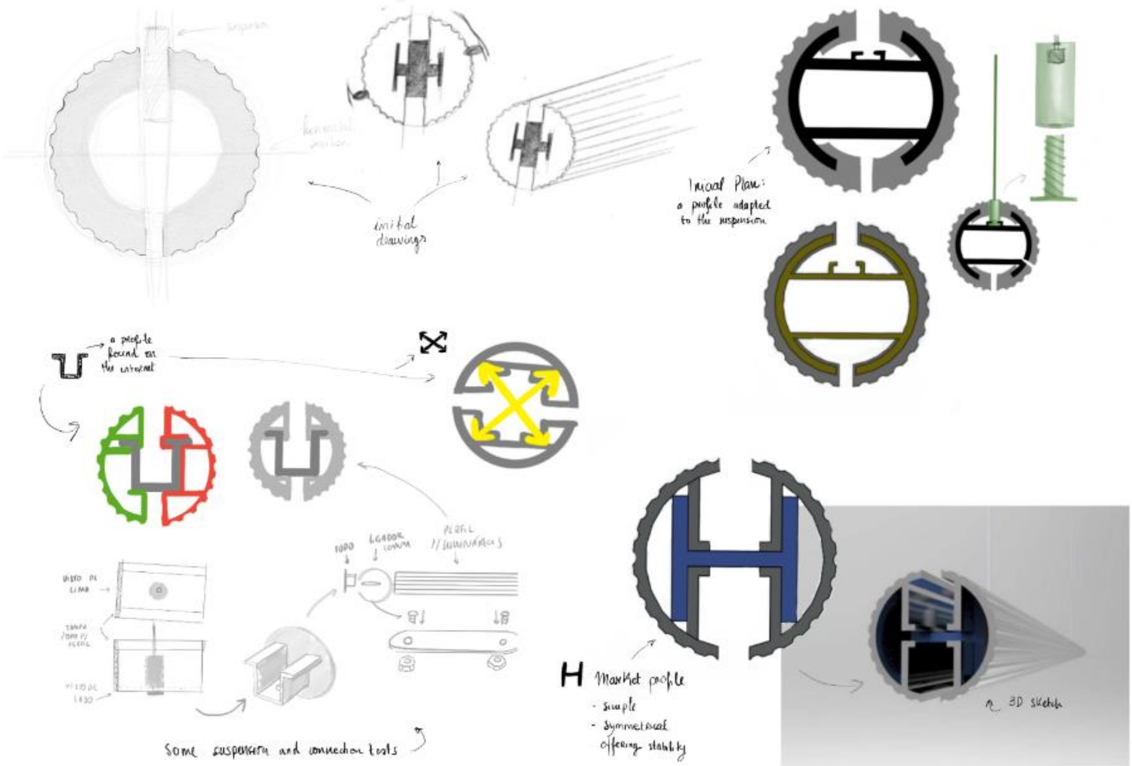


Figure 49 - Formal sketches on the proper form for the

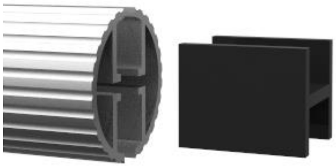


Figure 50 - The final shape of profiles.

The profile that joins the aluminium profiles (figure 47(1)), although essential for the project, is not an element with large formal restrictions and therefore, for its materialization, a profile that already exists in the market was sought, abandoning the design that had been initially proposed and adapting it to the shape of the aluminium profiles (figure 47 (1)). Figure 49 shows some studies carried out for this purpose.

To select a profile format, three important aspects were taken into account: stability; the amount of material needed for fitting the aluminium profile and the suspension of the profile. The "H" profile was selected (represented in the lower right corner of figure 50, found in the *Fibrolux* catalogue (Fibrolux GmbH, 2020b)) because, besides what has already been mentioned above, also has the appropriate proportions for the project. *Fibrolux* is a company that produces profiles used for high weight and even for buildings. The material in which the particular "H" profile selected for this project is a polymer reinforced with glass fibre, which besides being great for supporting the structure due to its high resistance is also a good electrical insulator which is essential for this component (Fibrolux GmbH, 2020a).

01. Static calculations

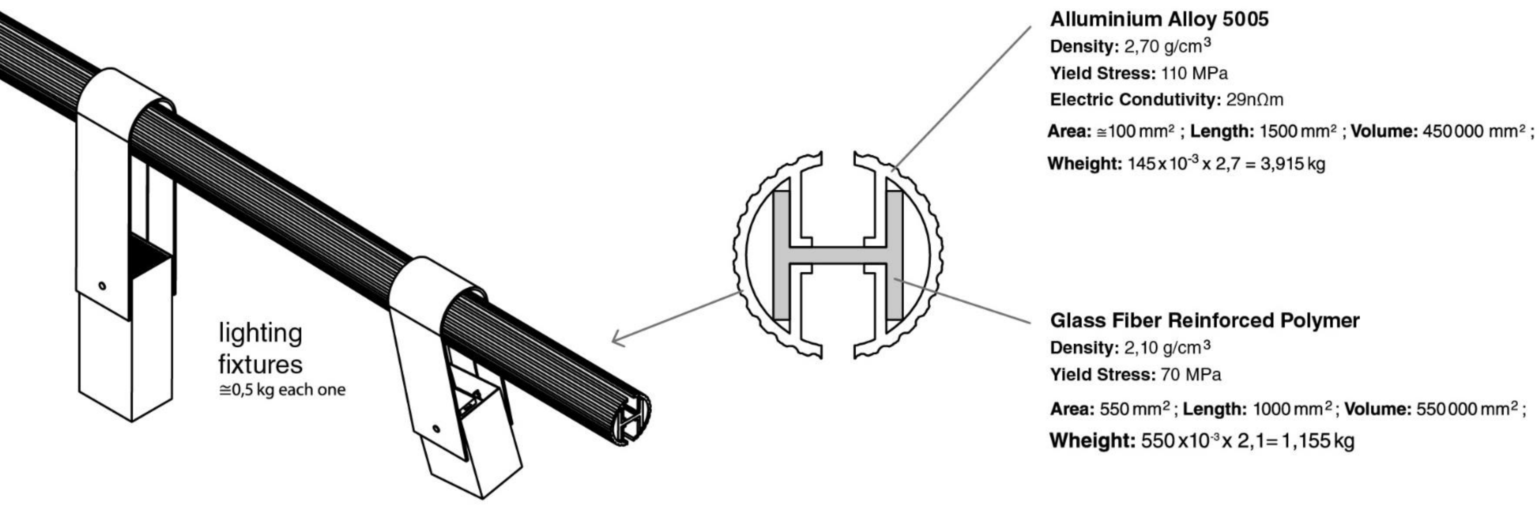
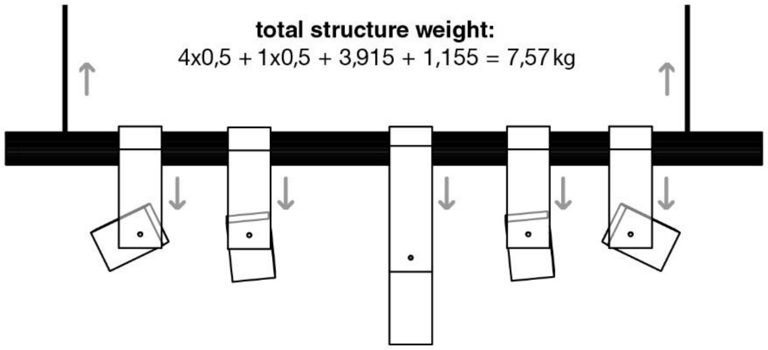


Figure 51 - Illustration of components and technical datasheet.



Z_{Max} : point of greatest effort in cutting

$$Z_{Max} = \frac{\text{weight x acceleration of gravity}}{\text{area where force is applied}}$$

$$Z_{Max} = \frac{7{,}57 \times 9{,}81}{1 \times 10^{-4}} \; (=) \; Z_{Max} = 7{,}2826 \text{ MPa} << \frac{T_{ced}}{2} = \frac{110}{2} \text{ MPa}$$

Figure 52 - Calculation of structure resistance.

However, in a subsequent phase, tests were carried out on the strength of the materials to make sure that this structure will not deform in the long term (figures 51 and 52).

For this calculation, a 1500 mm polymer profile and a 1000 mm glass fibre reinforced polymer inside were used. The average value of 500 g was also used for each luminaire. It was concluded that the structure designed is very far from the material limit that can be applied to the structure (figure 52).

20. Proportion analysis

The data collected in this operation also made rethink the proportion of the profiles. When calculating the weight of the polymeric structure, a length of 1000 mm was considered (figure 51 and 52). However, taking into account the high resistance shown, it was considered to decrease the length of this structure, avoiding the use of unnecessary material.

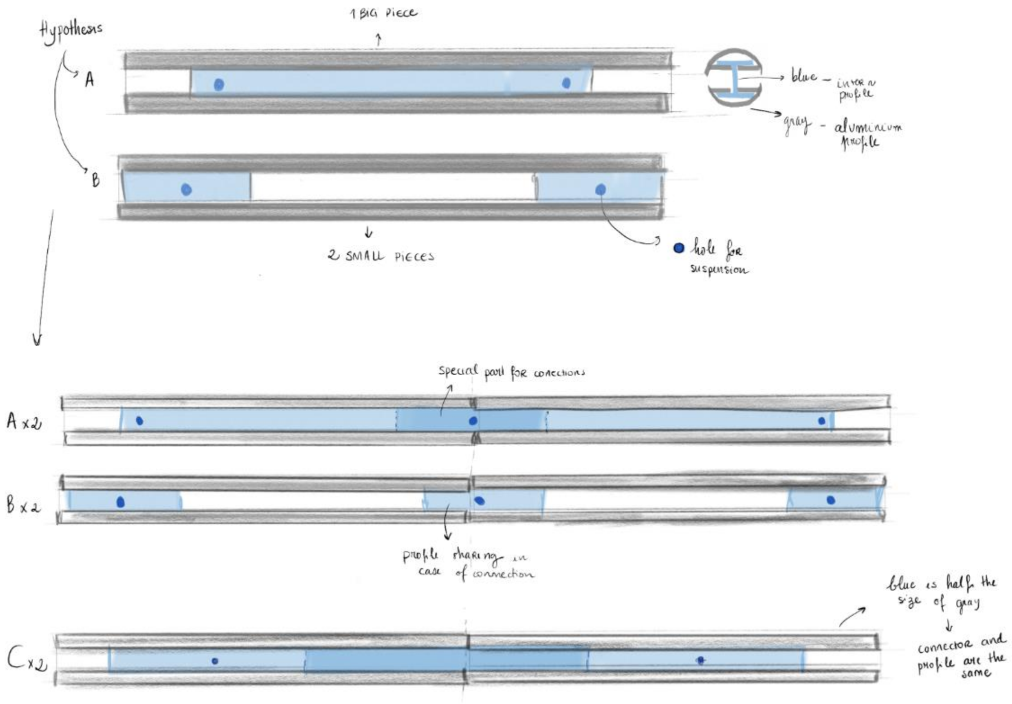


Figure 53 - Experimental drawings of the proportion of the profiles. The blue outline shows the "H" polymeric profile and the grey aluminium profile.

In figure 53, it is possible to see an outline of the studies carried out. The reduction in the length of the polymeric profile (the blue colour in figure 53) may not only make the structure lighter and more sustainable but also more agile when it comes to the sequencing of aluminium profiles. Initially, it was considered to use a one-meter profile, leaving twenty-five centimetres on each side for a connector, if necessary. In this phase, the use of a single piece of one size is considered only to support and connect the aluminium profile.

It is important to remember that this profile is responsible for the stability of aluminium profiles, for sequencing structures and for suspending them.

Figure 54 - Exploded view of how multiple profiles connect and suspend.

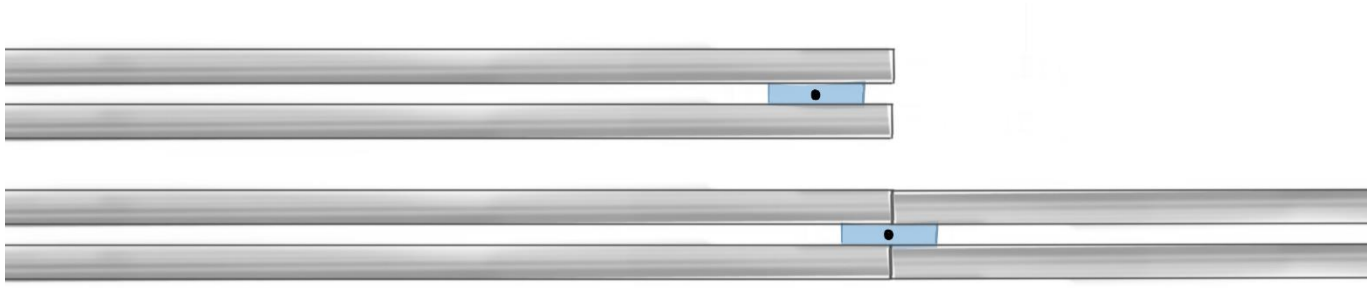


Figure 55 - Top view of how the "H" profile should be positioned in relation to the aluminium profiles. First, how it would position itself if there were no connections to add and, second, in connection of two profiles.

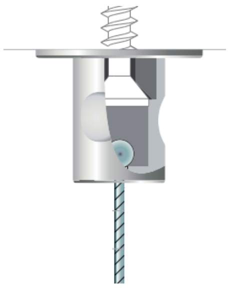


Figure 56 - Suspension kit.

Figures 54 and 55 illustrate the solutions found for the relationship between the profiles. In figure 54, it is exemplified how the assembly of the various parts should be made, even if with more than one aluminium profile. Also, in figure 55, the positioning of the polymer profile in "H" concerning the profile and aluminium is illustrated, both in the case of suspending only one profile and in the case of a sequence of profiles.

Figures 54 and 55 also show the suspension of the entire structure. For this, an existing suspension kit identical to that of figure 56 (SLV Germany, 2020) was used, which must support the structure through polymeric profiles. It should be noted that the wire that suspended this profile must be rigid, avoiding imbalances when changing the structure's center of gravity with the luminaires.

fifth chapter

Results

21. Lighting output

"... the best energy-efficient and innovative lighting solutions use the quality of light to create scenarios that not only stimulate the senses, but also increase productivity and help create moods or atmospheres that simply contribute to improving the feeling of people's well-being. "

Andrea Knust Licht, 2018

For a lighting project to be implemented efficiently and to ensure a long-term effect on human health, well-being and productivity, it should provide integrated and holistic lighting and space planning, as well as appropriate installation and implementation.

Currently, the workspace is considered as a living environment for working, communication and recreation. Therefore, the lighting should meet the requirements for good visual performance on flexible space concepts with suited light features and high-quality lighting.

The light should be regulated when necessary, according to the task of each person and each day. The light should be adjusted to the visual task, required degree of concentration, communication, device that each person uses (e.g. a computer), user ergonomics and health. In this way, it was concluded that it is necessary a system that offers two types of lights: (i) activating and visual, and (ii) a biological and ambient one.

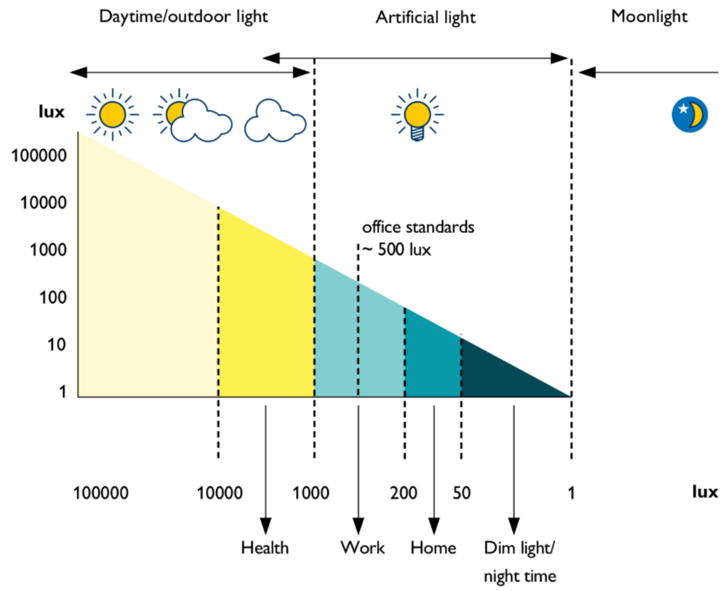


Figure 577 - The typical range of light levels encountered in daily life. Current office standards lay down a horizontal luminance of 500 lux.

Figure 588 - Colour temperature of light on the Kelvin scale (K).

First, the visual light is directed to the work areas and are used to guarantee the requirements for luminance according to *DIN EN 12464-1*. This light should improve performance and concentration and requires higher illuminance levels, achieving very quickly illuminance levels between *1,000 to 2.000 lux* (figure 62 (Andrea Knust Licht, 2018)). However, such illuminance levels compromise a reasonable use of energy. As shown in figure 57, the offices lighting standard is *500 lux* on average, even though in standard EN 12464-1 task such as technical drawing and CAD, *750 lux* is recommended. Therefore, the lamp should be able to keep up with those needs as well. When it comes to colour warm, white light and colour temperature between *2,700K and 3,000K* (represented in figure 58) provide a good arrangement with high-quality vision.

The second light intends to create artificial daylight with an emotional approach. This should have spectral proportions at specific times in the user's eye to support the biological rhythm in the best possible way. This biological illuminance throughout the day enhances the activity and productivity of its users.

Since the colour temperature of sunlight varies throughout the day and day by day, the solar mimic lamp should be coordinated with it, and for this reason, it should be connected to a device (like a smartphone) that provides this information.

The figure 59 depicts illumination levels on a typical Fall day. Daylight properties were set for September 21st (Equinox). In the middle of the day, in the south side, the daylight has achieved comfort level to a standard office. But, in the rest of the day and in all day in the north side had light levels below 200 Lux at the beginning and end of the workday.

Furthermore, the figure illustrates the lighting levels at three different times on a typical summer day. The simulation shows that, on average, the 250lux list was reached in all zones. Therefore, natural light was sufficient for some tasks throughout the day.

(Philip Luo, 2009)

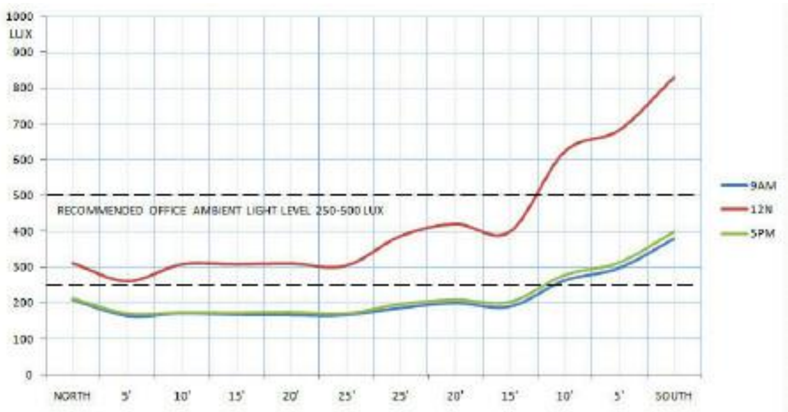


Figure 59 - Daylight simulation of a 60 'wide rectangular building in San Francisco: Illuminance (lux) along the north-south axis (fall), (Philip Luo, 2009).

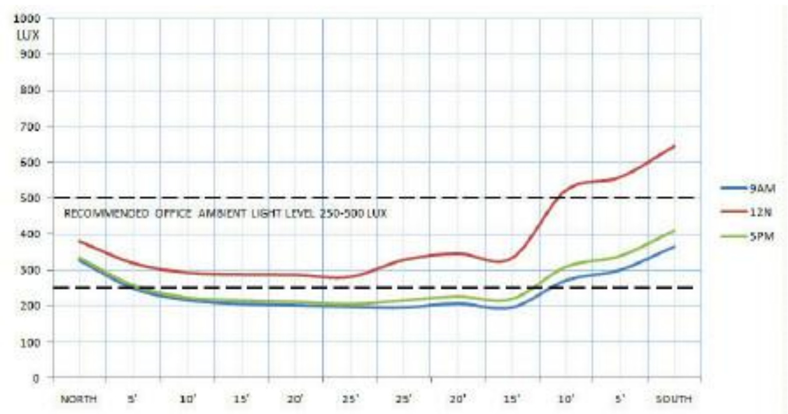


Figure 60 - Daylight simulation of a 60 'wide rectangular building in San Francisco: illuminance (lux) along the north-south axis (summer), (Philip Luo, 2009).

As is possible to see in figure 60, the sunlight can reach up to *10000 lux,* however, as is possible in the curves of the graphs in figures 64 and 65 (Philip Luo, 2009) when it is reflected in an interior it decreases considerably, hardly reaches *1000lux.*

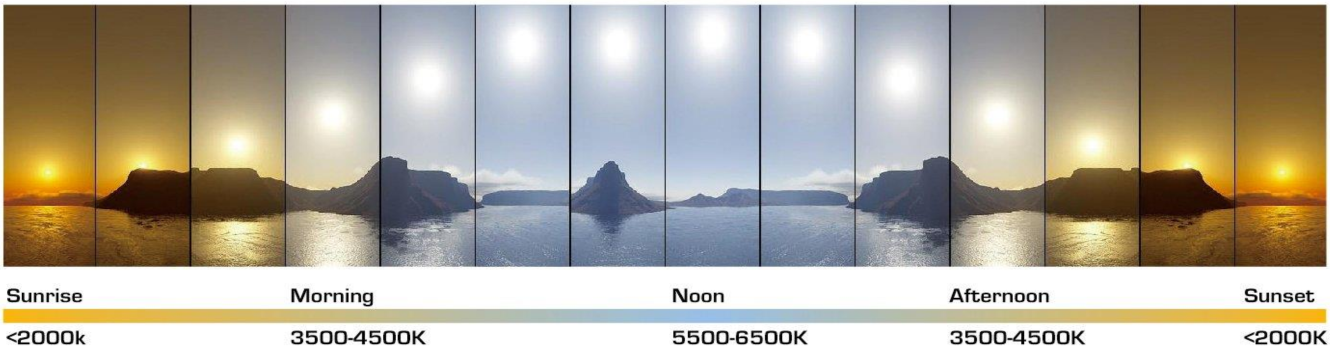


Figure 61 - Daylight colours during a day.

Different colour temperatures throughout the day	Light colour temperature in Kelvin (K)
Daylight	5000K - 5800K
Daylight (clear sky and sun)	5800K - 6500K
Overcast sky	6000K - 6900K
Sunset	2000K

Figure 62 - Colour temperature depending on sky and mereology.

Figure 63 - Example of lens and reflector to be used in luminaires.

In terms of the colour of the light, it varies a lot depending on the time and the weather, ranging from *2000 to 7000 Kelvin* as is represented both in figure 61 (LEDRISE.limited, 2019) and figure 62 (Thomas Van Erp; Bianca Van Der Zande; Marine Knoop; Luc Schlangen, n.d.).

Taking into account the facts previously analyzed, the components responsible for lighting the luminaire can be better described. Taking into account the light sketches developed, it is estimated that the structure of the luminaires is placed up to 2 meters away from the work surfaces to be illuminated. Therefore, in the case of the first eye balancing luminaire, it has a smaller ash tree, leading to a workplace. For this lamp to cover a working area of 2 meters at a distance of 2 meters, the use of an optical system of 60º of opening will be ideal, requiring from the lighting device a luminous efficacy of 2 600lm to obtain the 750 lux necessary for the comfort of users (Banner Brasil, 2017).

In the solar mimic luminaire to obtain a maximum of 1000 lux, with an optical system of 120º the luminaire will be reflected in an area of up to 7 meters requiring the lighting device 12700 lm (Banner Brasil, 2017).

The choice of Led PCB for the luminaires should be restricted to the listed features. The number of LEDs placed on the PCB depends on its number of Watts. Concerning the optical system, a set of reflectors and lenses should be used in both the luminaires that will assist the direction of the luminaires. In figure 63 (Higher Together Store, n.d.), it is possible to see an example of an optical system equal to that required for this project.

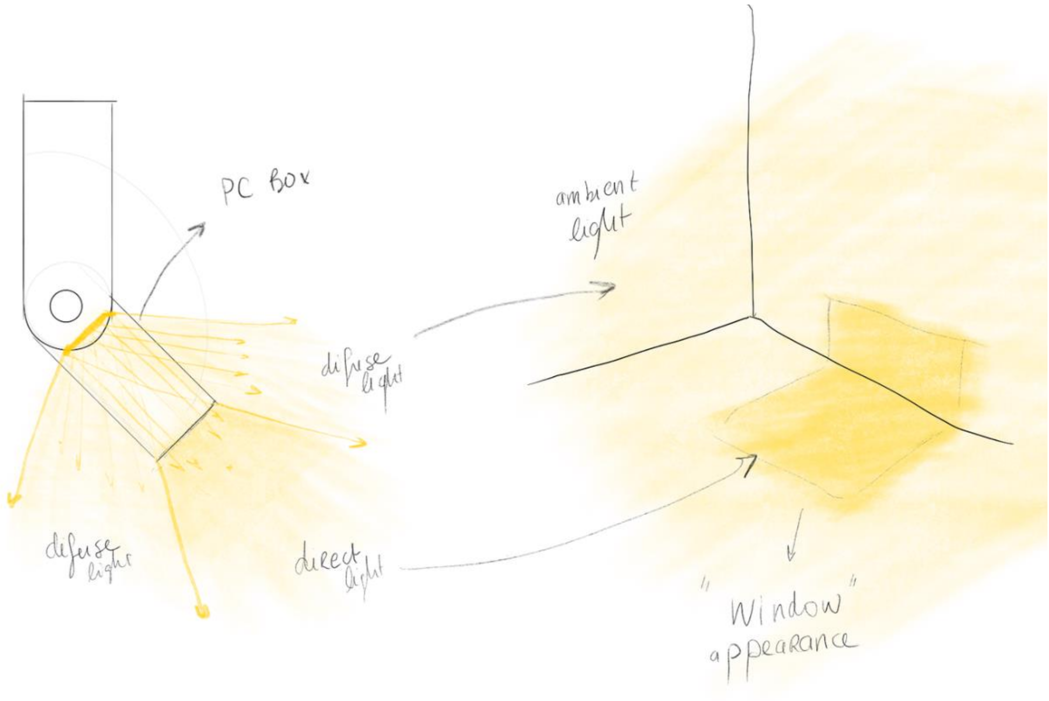


Figure 64 - How the shape of the luminaire helps to mimic the artificial window in space.

In addition to the features already mentioned, the shape of the luminaires was also developed to help to mimic solar space. As shown in figure 64, the elongated polycarbonate box of the solar mimic lamp will absorb some of the light emitted, creating an emotional illusion of window reflection in space.

22. Shapes and components

Figure 65 - System in workspace.

The lighting system developed in this work can be used to conceal the lack of windows (natural light). The shapes and materials were carefully chosen taking into account the proper functioning and harmony of the workspace. Aluminium and wood are already common materials in workspace furniture. In addition, wood is the key finish of the design of the luminaires. Connecting it with nature and detaching the lighting element as a prominent element of the space break the industrial and business aspect of the workspace.

The suspension structure of luminaires has also a design that provides usability and sophistication by providing easy adjustment of the luminaires and having an unusual system and shape. These characteristics accompany the rarity of a solar mimic system in a workspace. Therefore, not relinquishing functionality, the combination of this structure with the luminaires provides flexibility and versatility to space, providing easy changes in spaces configuration. Users can easily add or to reduce the number of luminaires, or simply adjust this position or angle in space.

The shape of the luminaires shows a rotation through the rounded and prominent shapes, representing the hands of a watch. Therefore, it highlights the time associated with light and the biophilic need of the presence of a natural sun clock in everyday life.

This project is developed to emphasise the role of light in the health of its users. For this reason, it was developed so that users can digitally interact with the luminaire. Thus, through an interface, users can add their tasks to their profile so that the light adapts to them.

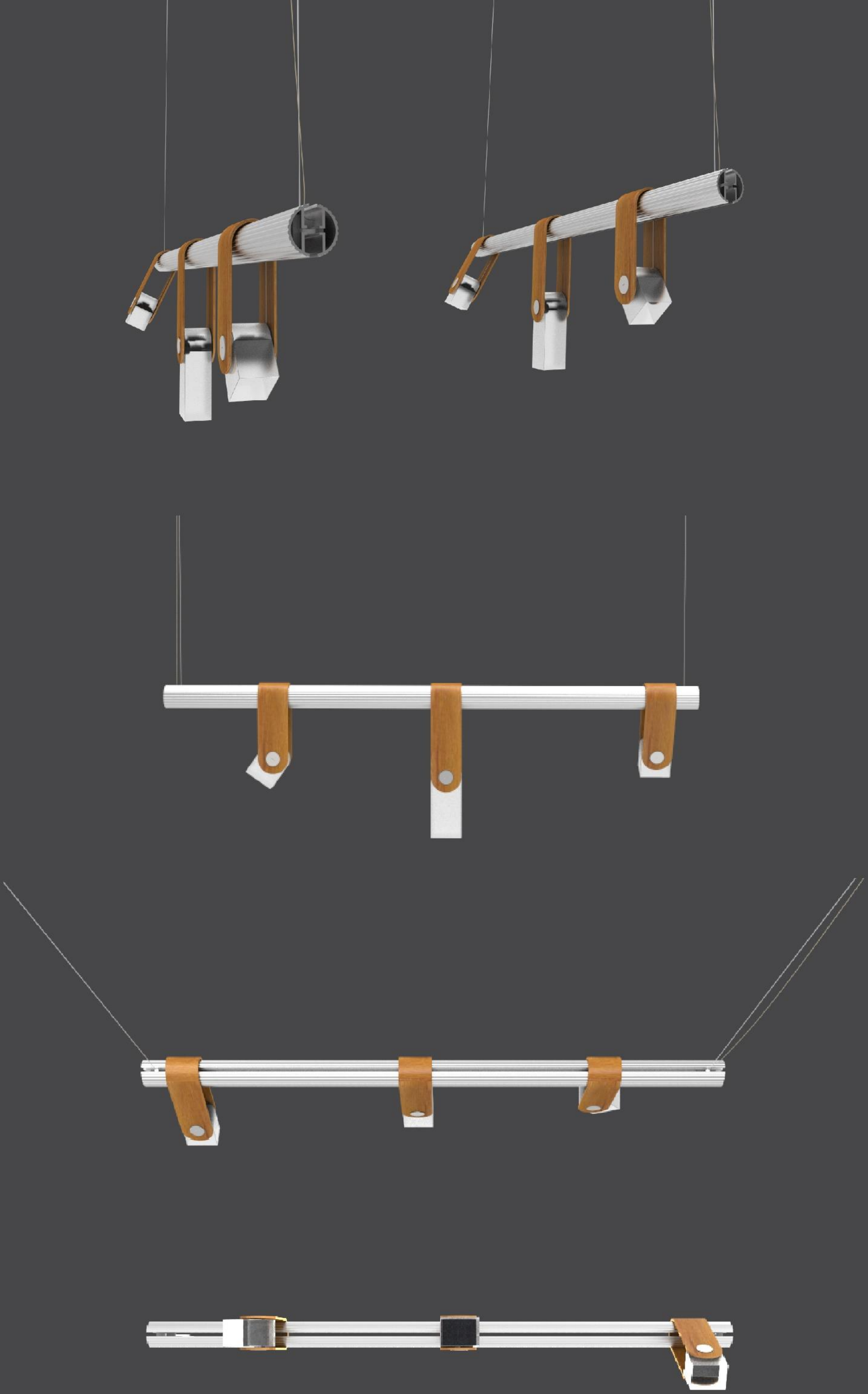


Figure 66 - All the components of the developed system.

In figure 65, it is possible to check the developed product integrated into a workspace for which it was designed. The final product of this project is a modular lighting system for offices that consists of 3 main components (figure 66): structure, solar mimic luminaire, and a working fixture and light balance.

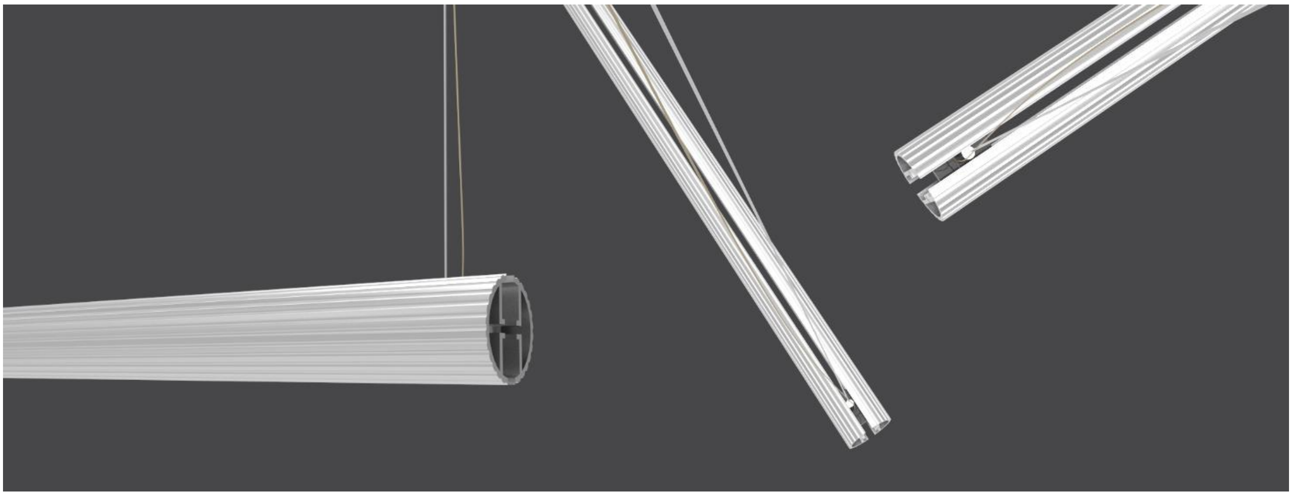


Figure 67 - Several suspension structure views of fixtures.

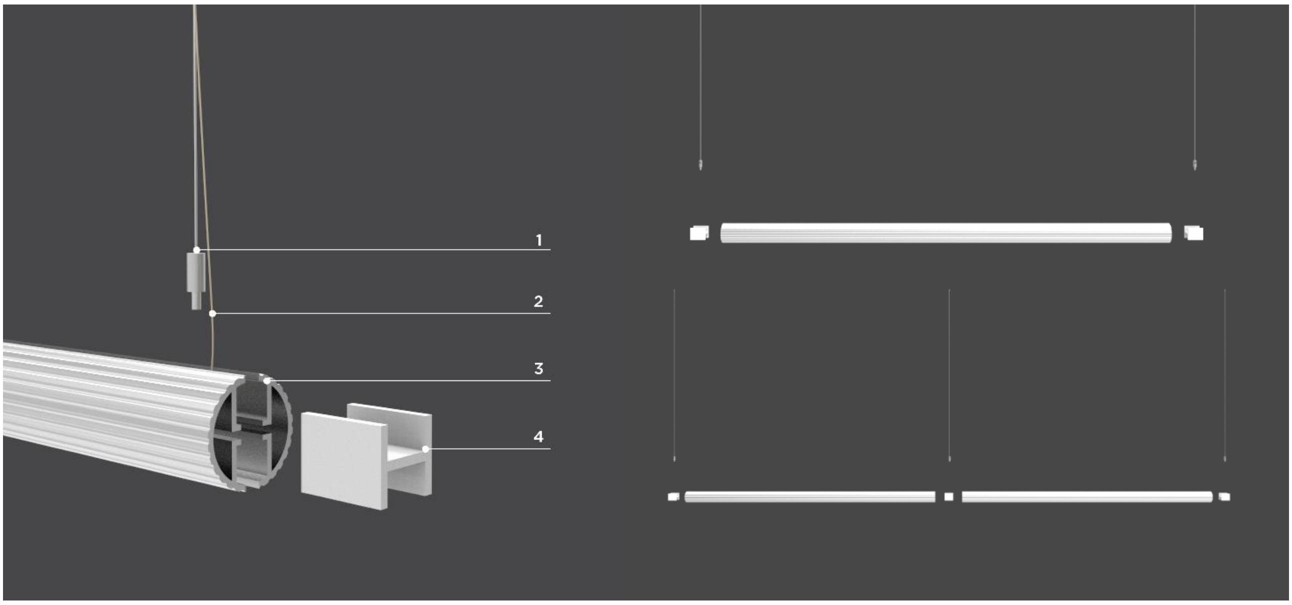


Figure 68 - Exploded view of the suspension system of the luminaires: (1) suspension kit; (2) Electric power cable; (3) Aluminium alloy profiles; (4) "H" glass fibre reinforced polymer profile.

Figure 67 shows the structure which is responsible for several functions that are essential to the system, such as the support, power, and repositioning and direction of the luminaires.

It is an extruded 5005 aluminium alloy structure with a tubular shape (figure 68 – component 3). However, there are two semi-circles whose outer face contains smooth waves that allow the lighting and regulation of the fixtures in the structure. Inside the aluminium semi-circle, there is a structure that supports the polymeric *"H"* profile (figure 68 – component 4) that joins the two symmetrical semi-circular faces, making them look like just one piece. These semi-circular faces are responsible for supporting and powering the luminaires and, hence, need to be separated by a non-conductive material. For this purpose, the *"H"*-shaped polymer profile reinforced with glass fibre, found in the company Fibrolux catalogue (Fibrolux GmbH, 2020b), is used to keep a distance between the metal faces that conduct energy to the luminaires. Moreover, the bar must be powered through a power wire discreetly revited to the structure (figure 68 – component 2). For the aluminium alloy profile, it was chosen a length of 1500 mm, considering that it is ideal for a minimum space of 3 m^2 with the possibility of adding profiles according to the need of the space. For the polymer profiles reinforced with glass fibre, a 50 mm long dimension was chosen. These components are assembled by sliding the *"H"* profile into the aluminium alloy profile. When assembled, it must be ensured that the aluminium profile is stiff and in tension to avoid slide inside and guarantee stability of the structure. The modularity of the product is guaranteed by these profiles that can be obtained in sequence. In these cases, the profiles can be electrified in sequence as well. through a male-female harness inside the structure, with only one connecting directly to the building's energy.

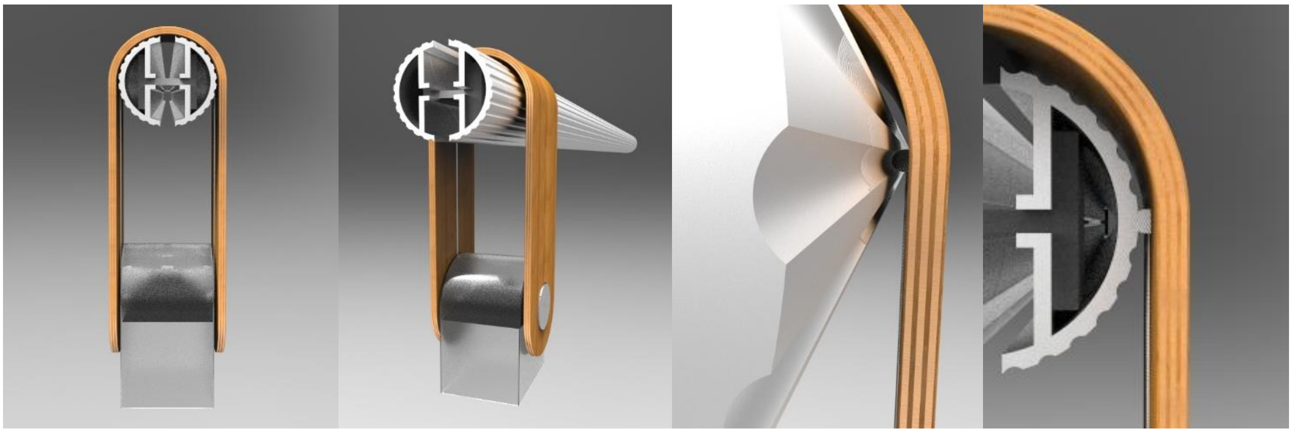


Figure 70 - Tubular structure and light fixture and fittings.

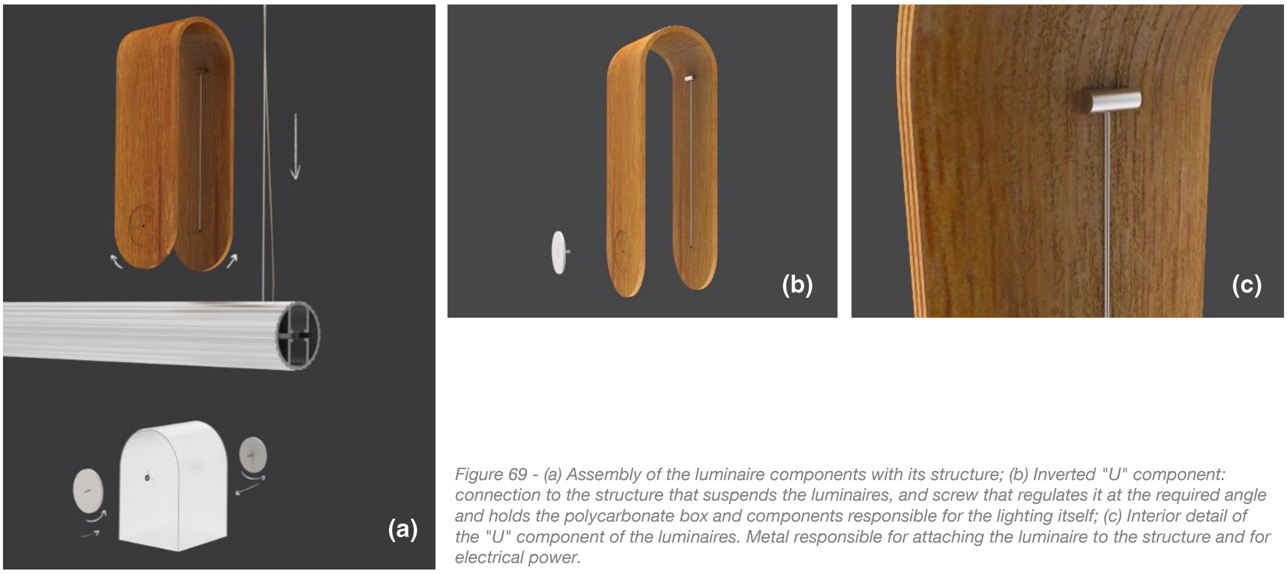


Figure 69 - (a) Assembly of the luminaire components with its structure; (b) Inverted "U" component: connection to the structure that suspends the luminaires, and screw that regulates it at the required angle and holds the polycarbonate box and components responsible for the lighting itself; (c) Interior detail of the "U" component of the luminaires. Metal responsible for attaching the luminaire to the structure and for electrical power.

Figure 69 depicts the relationship between the structure and lighting fixture, and how it can be fixed and powered. The inverted “U” in plywood is used to support the fixtures and fix them to the structure. It can acquire different finishes depending on the wood sheet that is used. Figure 70 (c) shows the system inside de plywood that fits in the aluminium alloy profile. The necessary power for the luminaire is fed through the metal contact.

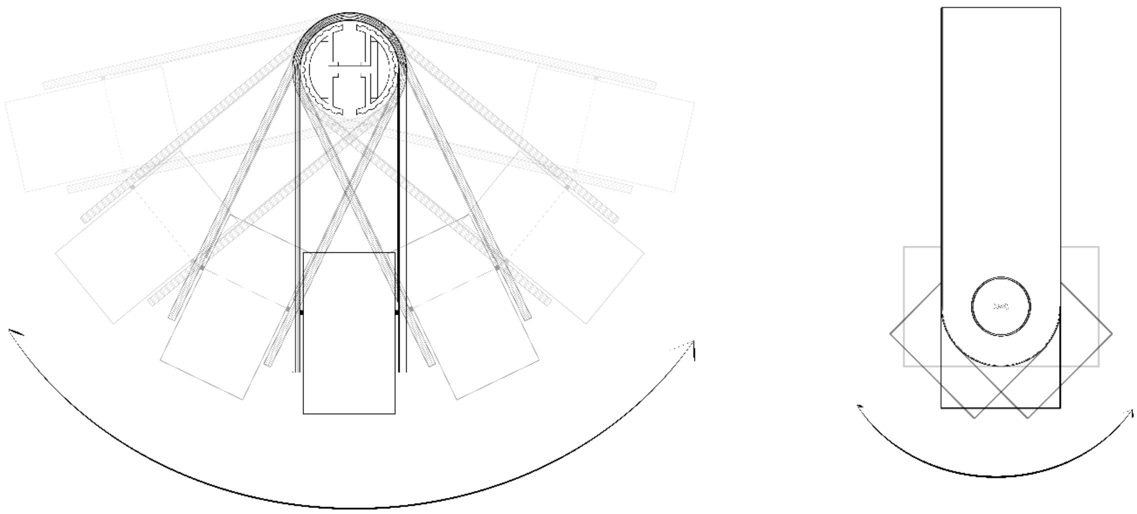


Figure 71 - Sketches of how the adjustment of the lighting fixtures should be done.

In the inferior part of the piece, there is a round cavity where the screw enters, holding the polycarbonate box that contains the electronic components of each luminaire. This screw is also part of the repositioning of the luminaire, allowing it to be tilted at an angle. In the case of the solar mimic luminaire, it must be placed vertically and closed (the right position to be activated). In the case of the remaining luminaires, these should be pointed out to the workplace. The direction of these can be done by adjusting the angle in the two zones of the luminaire already mentioned: the suspended bar and the screw, as shown in figure 71. The angle adjustment is constrained to 26 positions, taking into account that each face of the aluminium profile has 13 position notches, allowing to tilt the luminaire every 14 degrees, approximately.

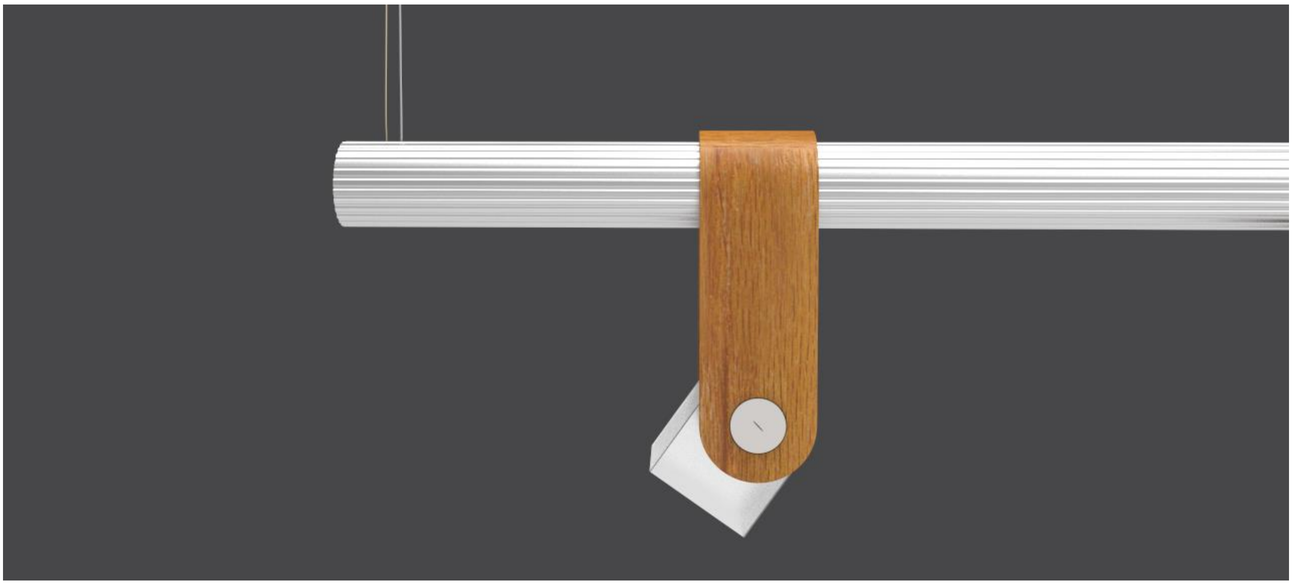


Figure 72 - Workspace luminance regulation: lighting fixture hanging on aluminium alloy structure.

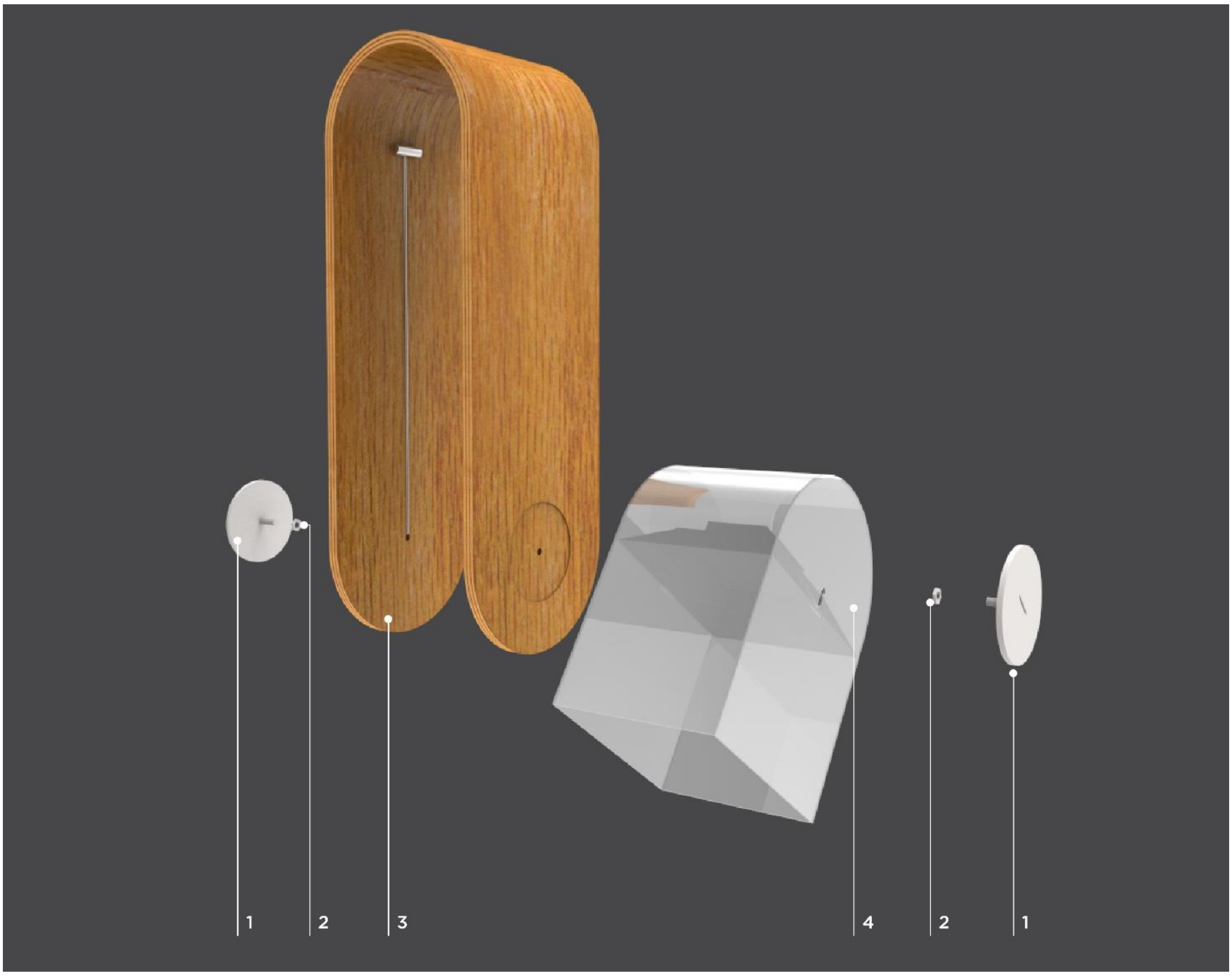


Figure 74 - Workspace luminance regulation: lighting fixture exploded view: (1) screw; (2) nut; (3) polycarbonate box; (4) "U" in plywood.

Figure 73 - Luminance regulation lamp for work: three points of view.

Figure 75 - Design for Assembly (from right to left): luminaire components, from right to left, nut, translucent polycarbonate box, plywood structural "U" and screw.

The luminaires that compose this system are visually identical, however, their system, functions and dimensions are different.

The smaller luminaires are essential to the project. Their function is to regulate the brightness of the space, guaranteeing eye comfort and productivity for its user (figures 72 and 75). In figure 73, it is possible to check their various components. The small luminaires are made with a "U" shape in plywood, as already mentioned, through which the energy is transferred into a polycarbonate box. Inside the box, there are the electronic components necessary for the operation of this luminaire. To support the union of the pieces, there is an screw with a standard thread (though with a design head for this piece). The head is embedded in the wood and has a large dimension that accompanies the round of the wood, emphasizing the rotativity of the piece. Figure 75 show the details of the piece designed to assist the assembly of several components.

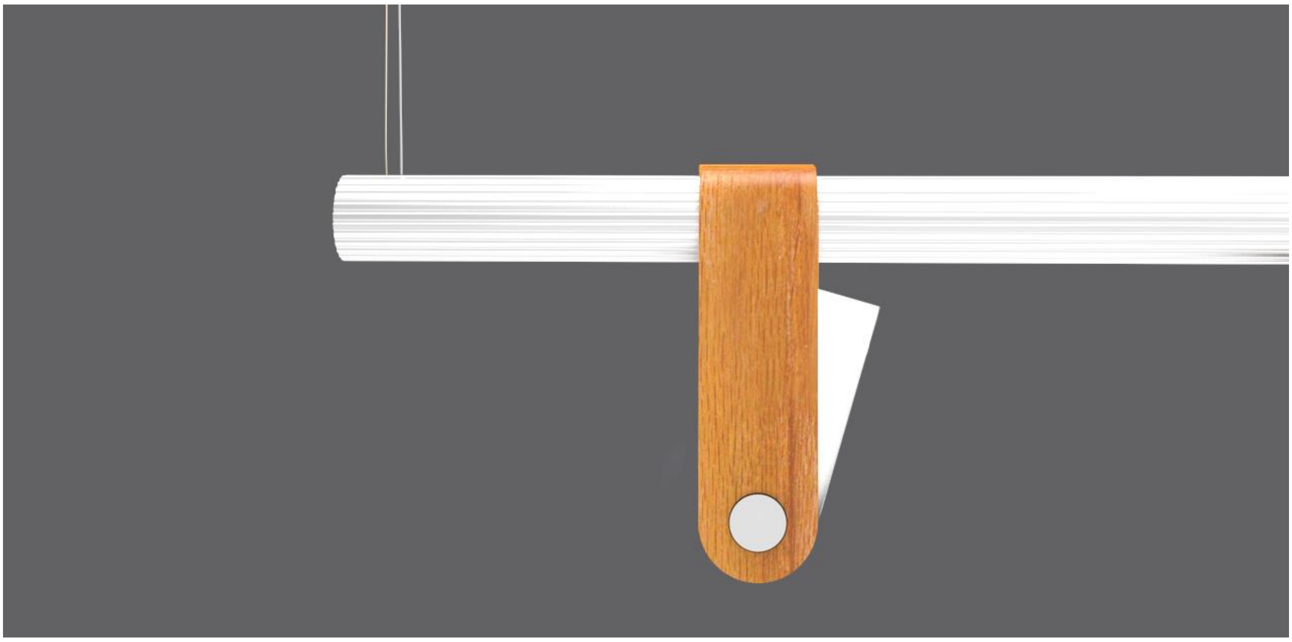


Figure 76 - Daylight mimic luminaire hanging on aluminium alloy structure.

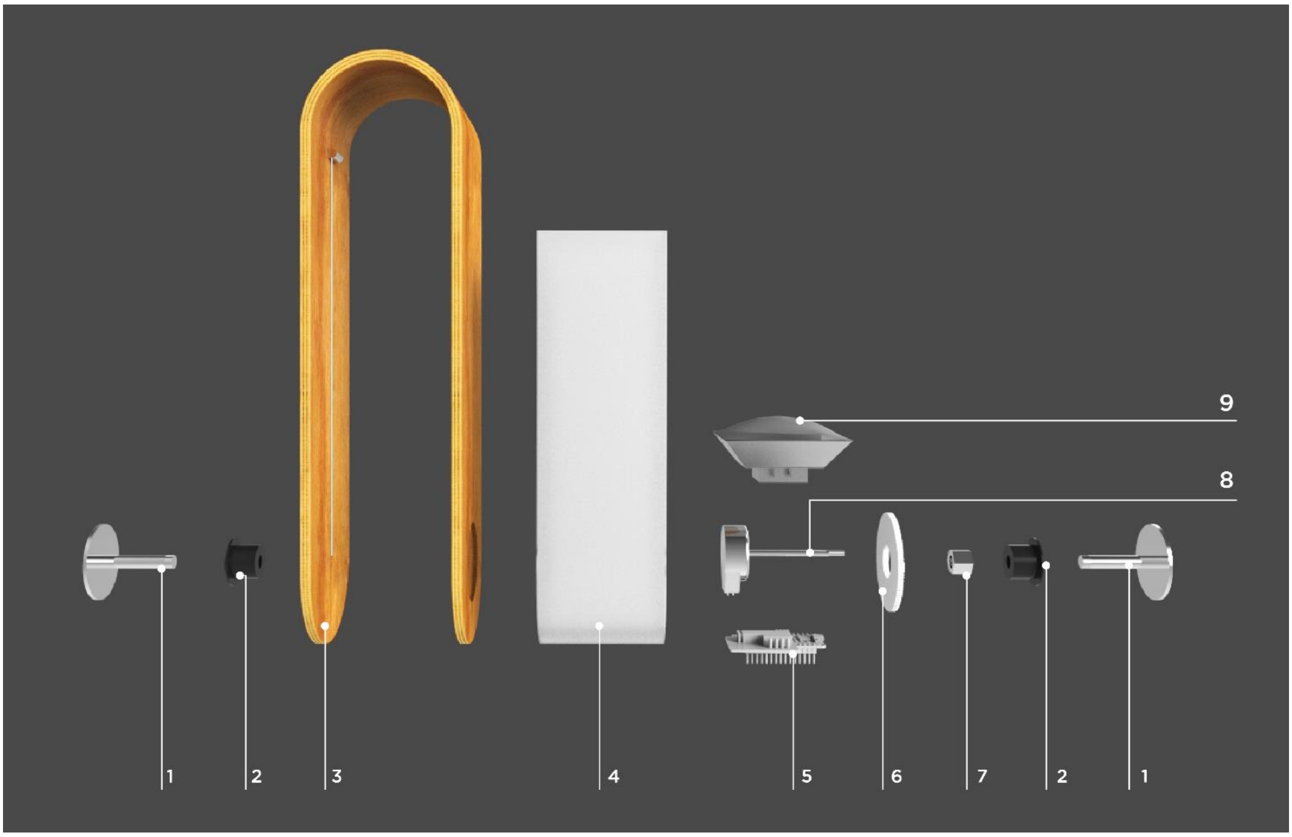


Figure 77 - Exploded view of daylight mimic luminaire: (1) screw; (2) rotating electrical connector; (3) plywood “U” support; (4) translucent polycarbonate housing; (5) Arduino IoT and stepper motor driver; (6) gear; (7) double nut; (8) motor rotation; (9) optical system: reflector and lens.

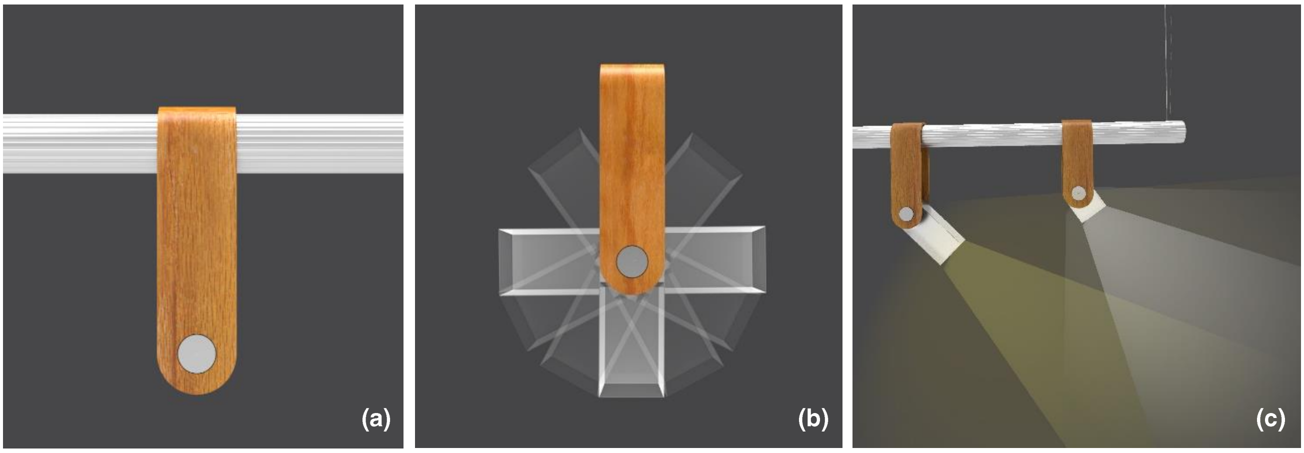


Figure 78 - (a) Daylight mimic fixture off/closed; (b) Movement of daylight mimic fixture during a day; (c) Simulation of operating luminaires.

The other already-mentioned luminaire (figures 76 to 78) is an emotional illumination that mimics the light of the day outdoors providing a sense of time for windowless spaces. This luminaire is visually identical to the previous one. It is also suspended in a “U” plywood with visible outer screws that support a polycarbonate box that contains the electronic components of the luminaire. In this case, the polycarbonate box is more elongated because, in this case, it has an additional function attached to the fact that it is an emotional light. As can be seen in figure 78 (c)), the main difference is in the proximity of the light source to the end of the polycarbonate box. In the solar mimic luminaire, the polycarbonate box helps to diffuse part of the light, appearing that there is a rectangle projected on the light (figure 65). This rectangle of light mimics the window, usually rectangular, which is more noticeable in space at times of high light intensity.

23. Functional embodiment

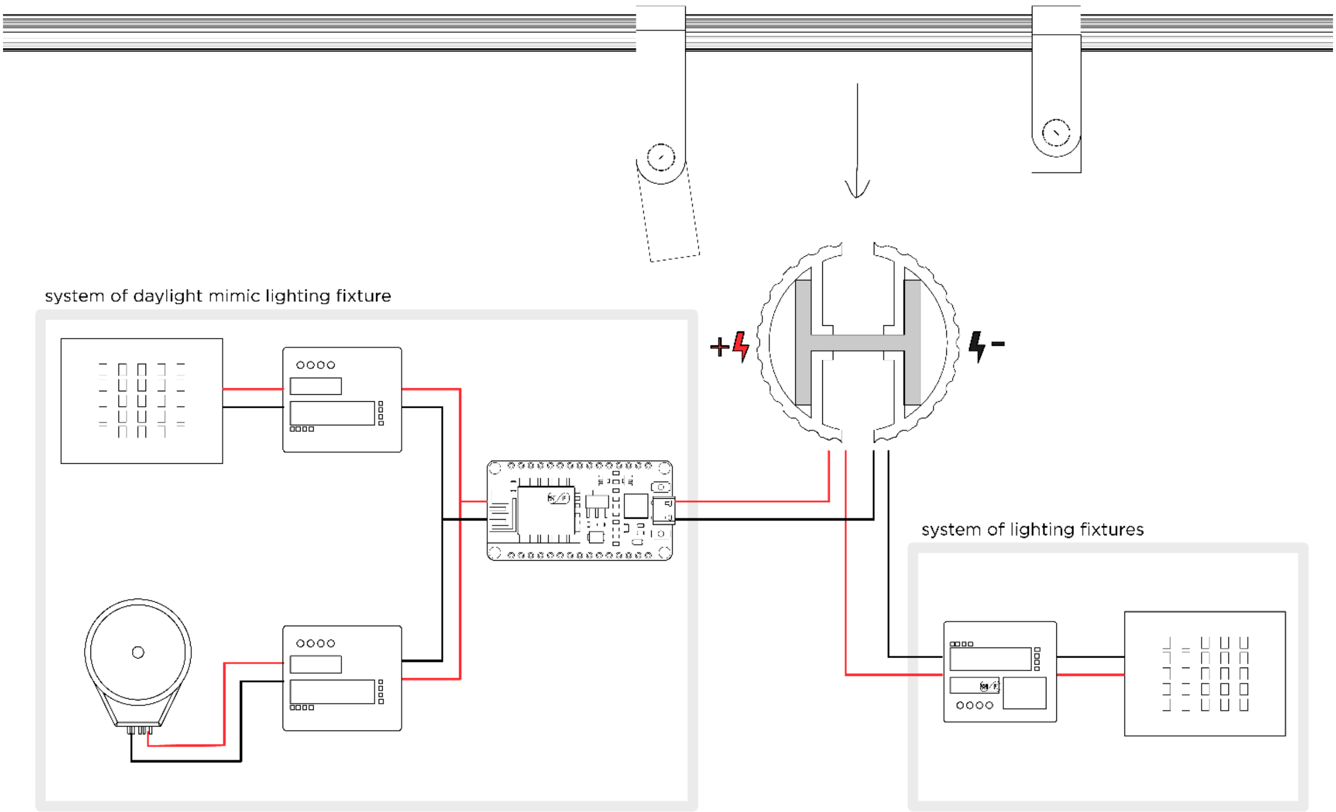
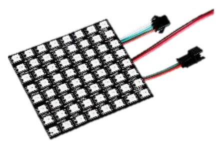


Figure 79 - Outline of the connections of the luminaire components.

The electronic components also distinguish and give life to this project (see figure 79). As such, it was necessary to understand which basic components are necessary for their functions and dimensions, not least because these can be a constraint in the form previously planned.

Component (figure suggestive of products with properties and dimensions identical to the intended one)	Where is going to be applied	Function
DIMMABLE LED BOARD		
 ***Figure 80 - LEDs (presentation suggestion)*** (Gleco Home Lighting Store, 2020).	DIMMABLE LED BOARD WITH AJUSTABLE COLOUR	
	Daylight mimic fixture	Responsible for the light emitted in the solar mimic luminaire. It is a set of colour dimmable LEDs.
	DIMMABLE LED 3000K	
	Lighting fixtures	Responsible for the light emitted in the luminaires. It is a set of *3000K* colour dimmable LEDs.

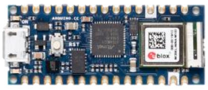
LED DRIVER		
 *Figure 81 - Example of a LED driver* (KPG Electronics, 2020).	All light fixtures	Used in the luminaires to transmit colour and intensity information to the LEDs
ARDUINO IOT		
 *Figure 82 - Arduino IoT* (Arduino, 2020).	Daylight mimic fixture	Arduino is the brain of the system and, it is responsible for making the connection between the smartphone and the luminaires, transmitting the necessary information.
STEPPER MOTOR		
 *Figure 83 - Stepper Motor* (Solectroshop™, 2020).	Daylight mimic fixture	Responsible for the rotation of the solar mimic luminaire.
MOTOR DRIVER		
 *Figure 84 - Driver for stepper motor* (electro fun, 2020).	Daylight mimic fixture	Transmits information regarding the Arduino's luminous position to the motor.
POWER CONNECTOR FOR ROTARY ENGINES		
 *Figure 85 - Conector de energia para motores rotativos* (Mux, 2019).	Daylight mimic fixture	Responsible for transmitting energy to the interior of the solar mimic lamp. The luminaire rotates when it is turned on and the connectors guarantee the passage of energy without twisting or threading cables.

Table 1 - Electrical Components.

Table 1 shows the various components that compose the system and its functions.

Figure 79 and table1 depicts the necessary base components and how they connect to the power supply. The components are powered by their suspension structure. Each luminaire removes the negative-positive electric current through contact with the respective profile face. In the case of light spots, a driver with Wi-Fi connection is used (to coordinate with the solar mimic light and keep the necessary cleaning in the workspace) that transmit the light intensity information to the domes of 3000 Kelvin. An Arduino IoT is placed in the solar mimic lighting fixture, which will connect to the network and transmit the time information to the motor driver and respective motor. The position of the light depends on time (coordinated with the positioning real sun). The Arduino, as in the other luminaire, is also responsible for transmitting information to the LEDs driver and respective LEDs so that the colour and intensity of the light is adjusted.

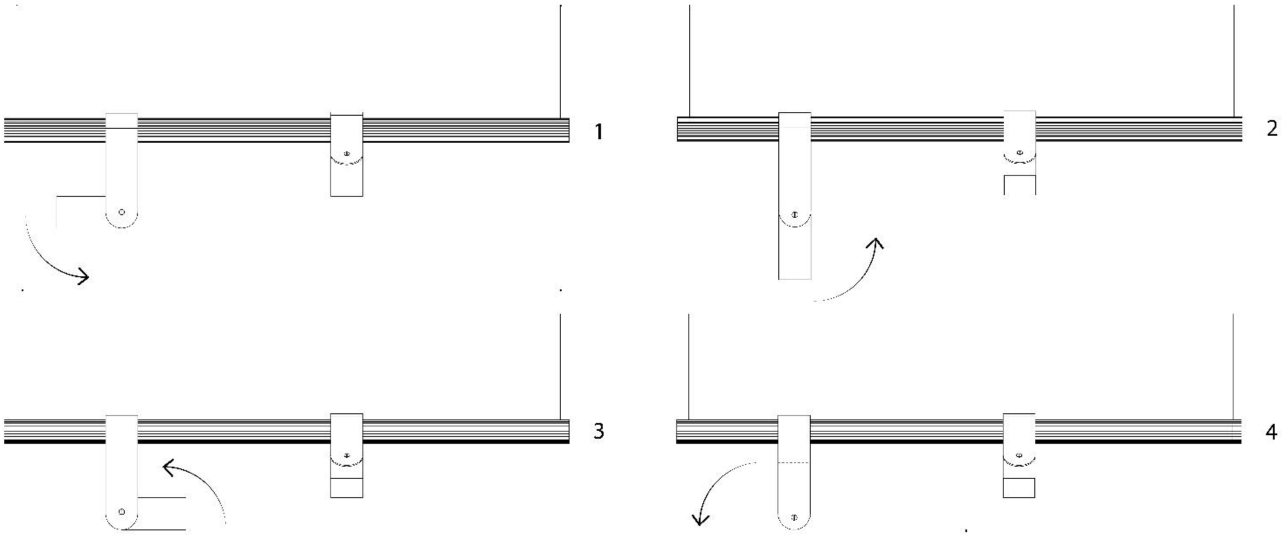


Figure 86 - Daylight mimic fixture rotation through the day (example of positions throughout the day).

The stepper motor is responsible for the angle of light projection into space. To do this, it adapts its speed of rotation to the time of daylight. Over Wi-Fi, the Arduino transmits the sunrise and sunset information to the engine so that its speed is defined (taking into account the available daylight time).

The following is an example of a day:

ω = 180º/(T sunrise – T sunset) where ω is the angular velocity [º/min]

Sunrise at 9h – fixture position on 0 degrees;
Sunset at 18h - fixture position in 180º degrees;

ω =180º/ 9h= 20 º/h
= *1/3* º/min

Conclusion: on this day when the sun rises at 9 am and sets at 6 pm the movement of the luminaire will be one degree every three minutes.

The rotation of the piece during the day is 180 degrees, placing it in position 1 (illustrated in figure 86) at sunrise and position 3 at sunset (see figure 86 as well). The light motor system collects more quickly at the end of the day for the inside the wooden capsule (position 4 of figure 86). Just as at sunset when the luminaire is switched on at sunrise, it quickly rotates from position 4 to 1.

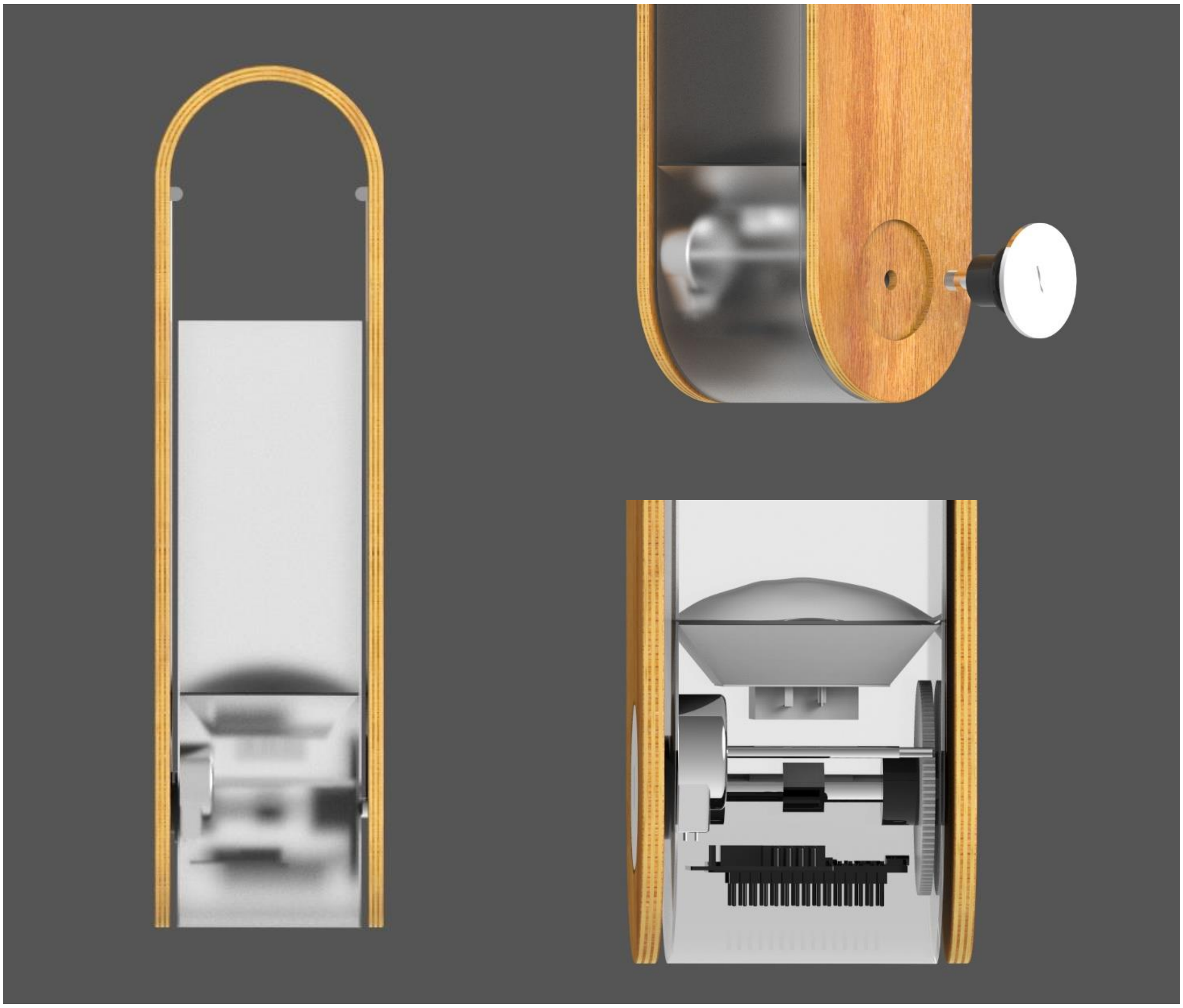


Figure 87 - Luminaire of daylight mimic in the "off" position: components and assembly.

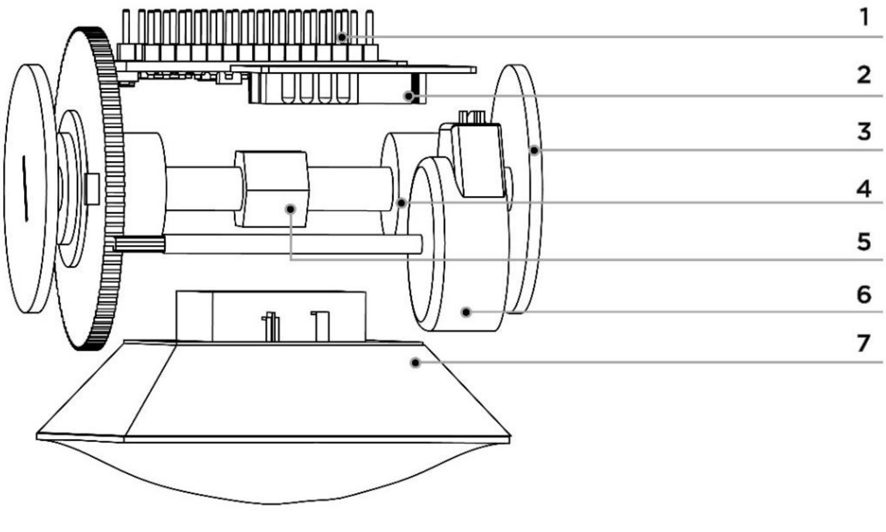


Figure 88 - Simulation of the incorporated system in the daylight mimic luminaire: (1) Arduino IoT; (2) Motor driver; (3) Screw; (4) Power connector for rotary engines; (5) Double nut; (6) Stepper motor; (7) Led and light optics.

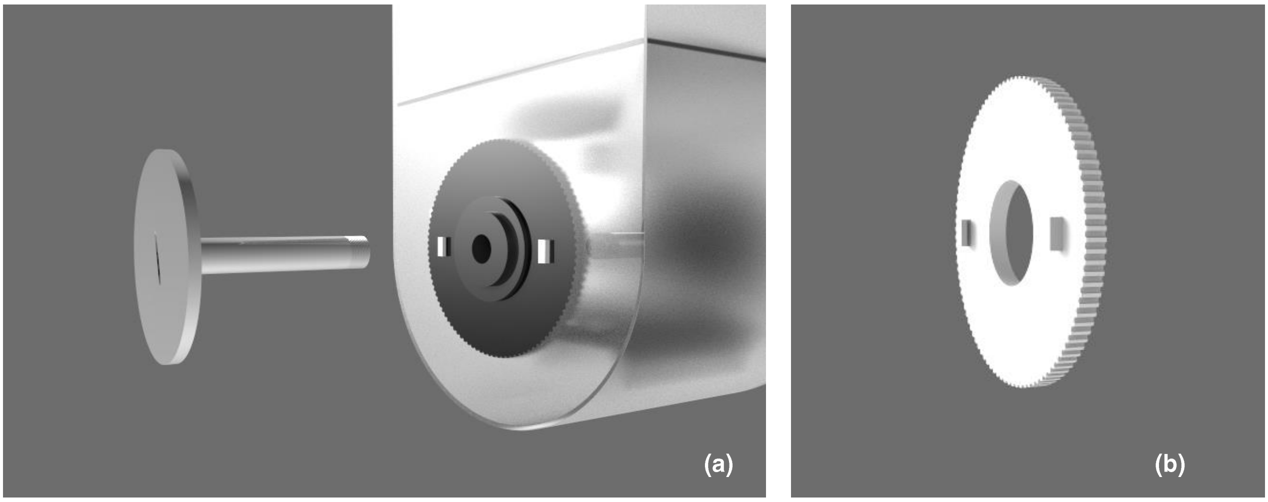


Figure 89 - Details of the system components: (a) screw and gear fitting; (b) gear.

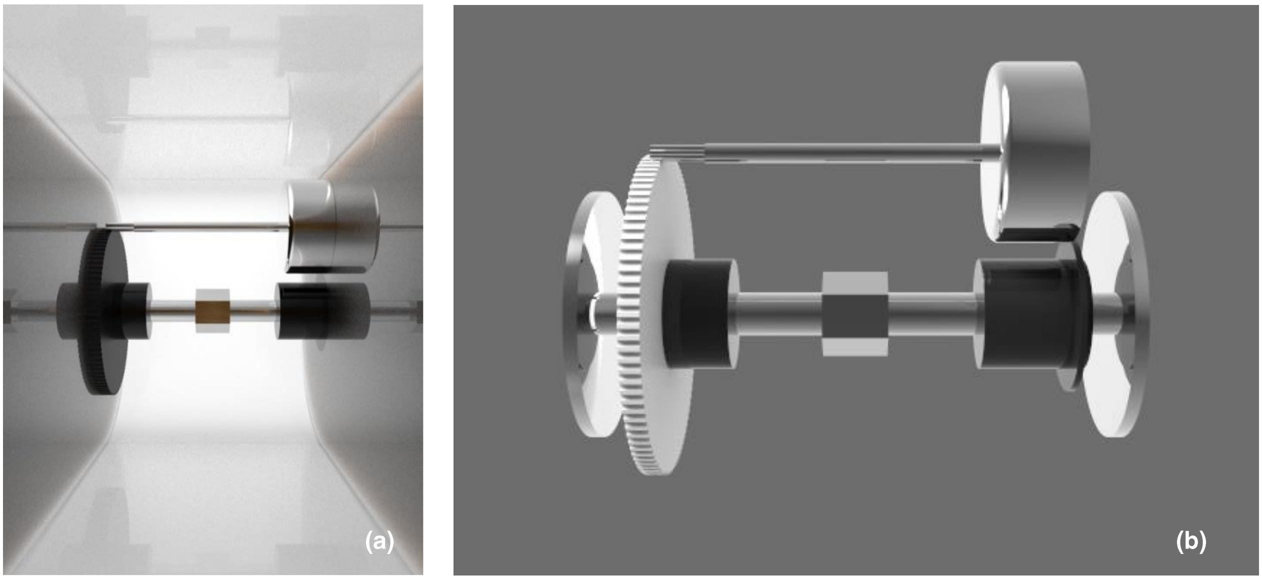


Figure 90 - Components responsible for the movement of the solar mimic luminaire.

However, taking into account that the axis of rotation of the motor is not centred, a gear was used as a motor transmission. Therefore, following the previous example day in which the angular speed of the luminaire is 1 º of rotation every 3 minutes, the speed of rotation of the motor will be larger, taking into account that it is multiplied by the gear. To calculate the rotation speed of the motor, it is necessary to point out that the gear radius is 26 millimetres and the radius of the motor shaft is 1,5 millimetres.

Angular gear velocity = $\omega gear$ =1/3 º/min

Angular motor velocity = $\omega\ motor$

Linear velocity *= 1/3 º/min x 26 mm =8,67mm/min*

$\omega\ motor = \frac{8{,}87}{1{,}5}$ = 5,78 º/min

It is concluded that for the luminaire to rotate by one degree every three minutes, the motor axis must rotate 5.78º per minute considering sunlight of nine hours during the day. However, this value is variable through the programming of the Arduino that updates the speed every day, using the sunrise and sunset information obtained through wi-fi.

Also, figures 87 to 90 illustrate the components of the daylight mimic fixture assembled to fit into the luminaire exterior structure. In figures 88, the rotating connector is shown, which allows the electric current to enter the polycarbonate box without damaging its conductors. In the centre of this box is the examinee that gathers all the components and where is the centre of rotation of the piece. Symmetrically, on the other side of the structure is another screw that fits in the opposite side of the same double nut. Also highlighted in figure 88 (b) the gear increases the speed of the rotating motor and connects the motor to the polycarbonate box using the fittings in gear. In figures 89, it is possible to see separately the part of the system responsible for the rotation and its assembly. Figure 89 (a) also exhibits a view of the interior of the polycarbonate body with the mentioned elements.

24. Mockup

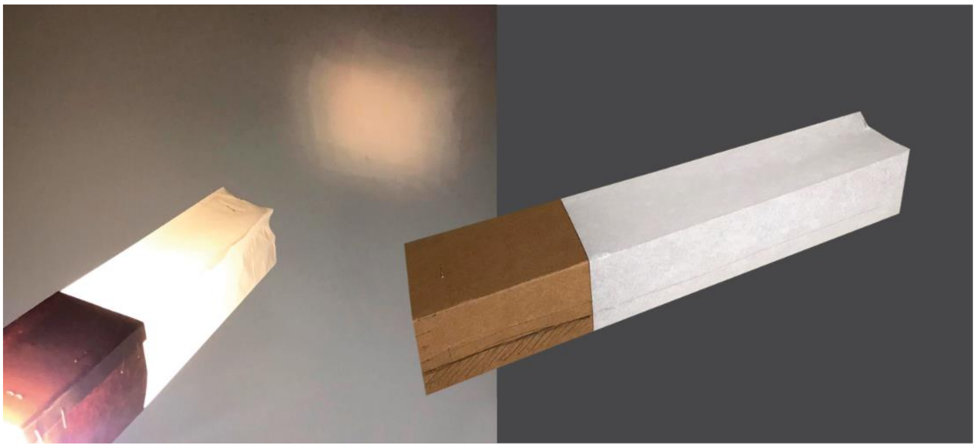


Figure 91 - First mockup on cardboard and parchment paper. Essential in the form development process.

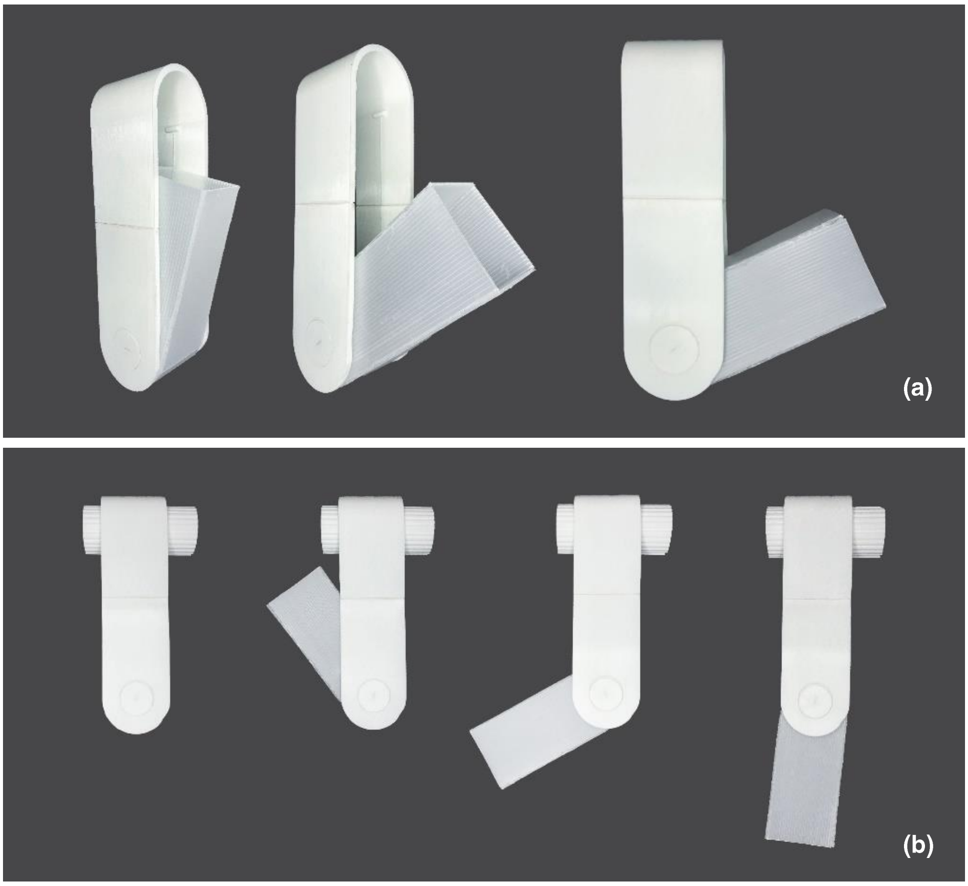


Figure 92 - Physical model of the solar mimic luminaire, performed in 3d printing on opaque components and neutral plastonda polypropylene on translucent components: assembly.

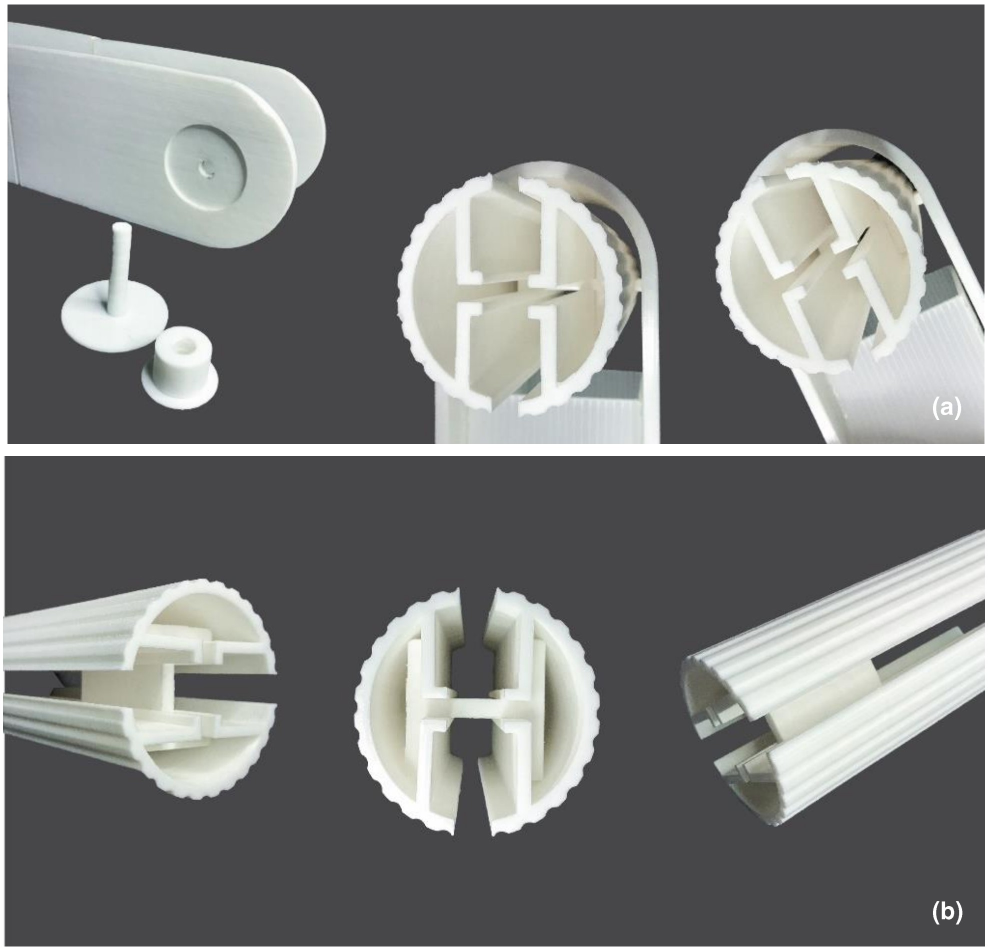


Figure 93 - Physical model of the solar mimic luminaire, performed in 3d printing on opaque components and neutral plastonda polypropylene on translucent components: details.

The model is considered the "primitive form, which for many people represents, the thing that is done before starting to make millions of them"(Relvas, 2017). Therefore, since the beginning of the development of the form, this method was used to make simple three-dimensional shapes that approximate what is being studied (figure 91). Therefore, to complete the development of the form, a physical model of the product was developed so that it can better verify its scale, shapes, fittings and mechanisms. For this, the opaque components of the structure were printed in 3D and, using neutral plastonda polypropylene on translucent components (figure 92 and 93).

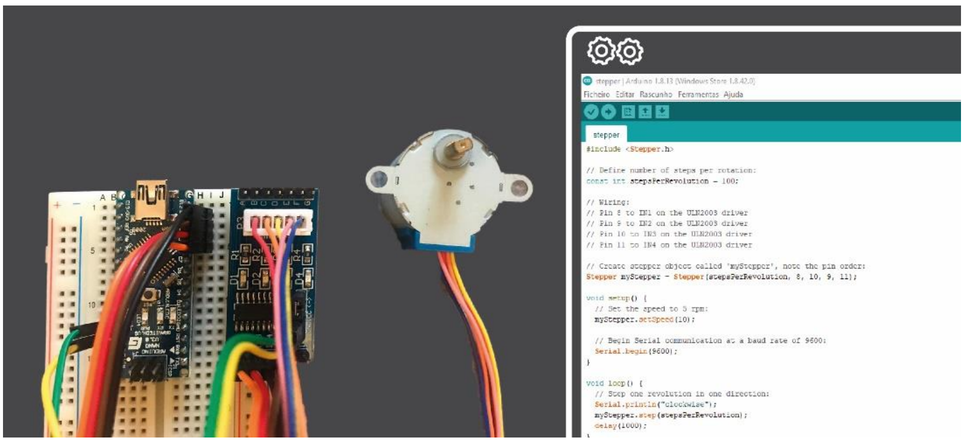


Figure 94 - Arduino, engine and engine driver.

Figure 95 - Mockup with led tape inside.

To better understand how the product works, some electronic components have been added to the model. The motor, respective driver and arduino that allowed to make a simulation of the stepper motor rotation programming (figure 94). And a led strip was used inside the translucent body (figure 95) of the piece so that one could simulate the light imitated by the working solar mimic lamp.

25. Interaction and system operation

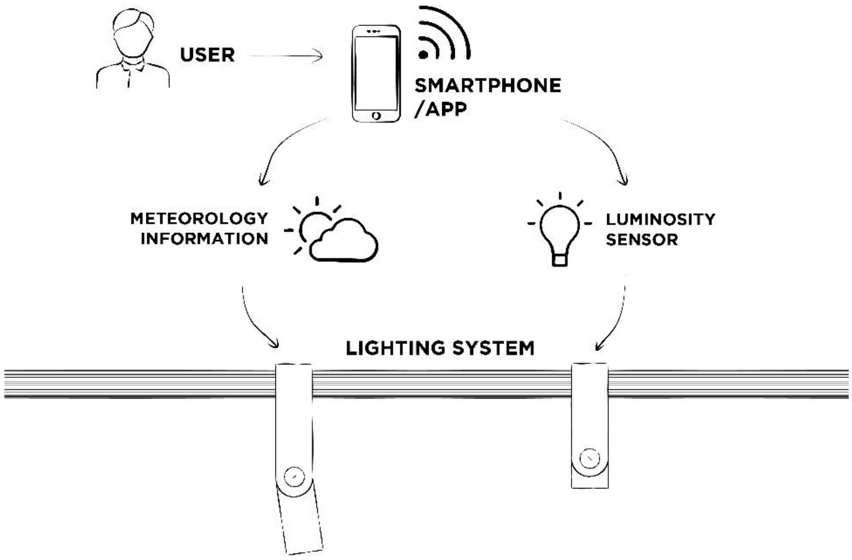


Figure 96 - Relationship of the application with the developed product.

For the proper functioning of this product, it is provided with an application for smartphones and tablets (figure 96). Ideally, users connect via wi-fi to the luminaire located at their workplace and, through this connection, system accesses the location and weather so that the solar mimic luminaire can accompany it, and to the luminance sensor of users smartphone, getting spaces luminosity information. Thus, the luminaire can ensure that the illuminance present in the user's space is adequate.

The application also interacts and with the user, and the user can create a profile to choose which task to perform so that the lighting in their workspace can also be adapted. For example, if the user is in a meeting or presentation, the luminance levels can drop to 300 lm. In opposition, when working on a computer, the application can adjust the luminance level to 700 lm. In this way, it is possible to prioritize the user's comfort and health and also excessive energy consumption as well, making this product more sustainable.

In a nutshell, the daily dynamic of light depends on the year season and geographic site. So, users can select individual light moods actively or run automatically according to space pre-definition. In areas that are used by several people, automatic sequences are most effective. When the system is instaled the definition should be pre-defined by a light expert, coordinating lights to spaces network and defining the lighting necessities of space. However, individually light management can make an important contribution towards minimizing consumed energy.

In the digital platform, the management of the luminaires must be done through the extension of the luminaires and the users so that they can easily access their luminaire. This can be accessed in floor plan mode (figure 97).

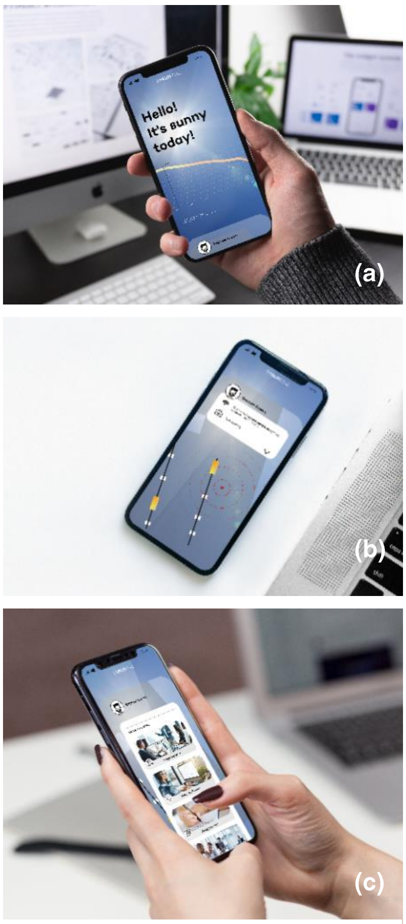


Figure 97 - Mockup of the app: (a) welcome screen where it shows the chart of light intensity expected for the day; (b) floor plan with lamps in space; (c) selection of user activity.

sixth chapter
Conclusions

26. Conclusion

This project proposes a solution for the problematic of the lack of natural light in indoor spaces. This gap is felt by human biophilic side and can speak up in health disorders and or in simple acts like bring plants and natural elements to these interiors to feel comfortable. Therefore, the lighting system was designed to return the emotional presence of natural light in the space without discarding the quality of the light. For this purpose, the workspace was considered as space where the device with the described characteristics may be more advantageous, due to the larger number of hours spent daily and the need for light quality. For the product to be efficient in any workspace, a support structure was developed in parallel with the luminaires that supports and electrically feeds the luminaires. This structure combined with the luminaires resulted in a versatile modular system that allows composition of luminaires combined with the mimicking of sunlight through a window as the light indicated for greater productivity and eye quality in the workspace. Therefore, it allows reconfiguring spaces and personalizing the composition according to the users' taste and needs. The easy repositioning of the luminaires defined the shape allowing the consumer to control it. To improve the interaction a smartphone application was proposed interacting with the users so that the light mimic by the slide can also be better applied, improving its smooth functioning.

In the development of the project, the light was also designed, and the way these are projected in space. To this end, the behaviour of the sun and the European standard for office lighting were analyzed. In this way, two types of luminaires are proposed, (i) a solar mimic with a more elongated body, which distributes an emotional light over a larger area of space, and that turns on at sunrise and turns off at sunset, varying in intensity and colour throughout the day to be as close as possible to the present day. And, another (ii) luminaire focused on the workspace with a smaller opening angle, illuminating the workplace more concentratedly and which connects to the previous one, ensuring the necessary balance in the space for a productive workday without causing excessive lighting and fatigue eyepiece. To control both luminaires a wi-fi app was masterminded.

The project culminates in the development of a concept, form and virtual prototyping of the same. So, 3D modelling was used to design, assemble and test the various components of the project.

To the present work, a lighting product was developed for windowless spaces, resulting from a dependence on nature that experts call biophilia. Therefore, the developed luminaire responds with a mimic of the sun, inside that emotionally satisfies the user's needs. Apart from mimic current daylight, such as the analyzed in the market, also has spots that adjust the necessary brightness in the workspace to maintain eye health and productivity throughout the day.

The definition of the workspace as the target space for this project was an opportunity to innovate in relation to the analyzed market, and in this sense, it is considered that the completed project was successful. However, it will still be necessary to develop some works in the future that aim to improve and confirm what has been achieved so far.

01. Future Works

In future, it is intended to prototype these products and develop the app previously outlined.

Prototyping and experimenting can highlight possible design errors or defects that the product developed may have. After prototyping, it is convenient to communicate the project by presenting it to potential consumers and users, using the creation of a brand that should be transversal to the entire product, i.e., from the product packaging to the smartphone application.

When the product is considered to be prototyped and its possible faults corrected, it is intended to register it.

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