Faculté d'architecture, d'ingénierie
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Towards *enlightened* students of architecture:

What lighting strategy is necessary for supporting the pedagogy of architectural design studios and the learning experience of students?

Auteure : Victoria Crevits
Promoteur : Sergio Altomonte
Assesseur : Marshal Maskarenj
Lecteur : André Stephan
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Abstract

Light is essential to human's rhythm. It is therefore necessary to adapt the lighting of a building to its occupants in order to support them during their specific activities. This thesis has been entirely centred on addressing the needs and requirements of students in architecture for their visual and non-visual responses, and to sustain at once, their learning experience, as much as their comfort, health and wellbeing.

To answer this problematic, it was needed to characterise the needs of the students, particularly in terms of the lighting that is demanded to support their *visual* task performance, and the specific *non-visual* requirements that are dictated by their working and living styles. To do so, this thesis was articulated on three fundamental research methodologies: surveys, measurements, and simulations. They were done in the actual studios. Based on the results obtained from the analysis of the actual design studios and its inhabitants, verification and recommendations can be provided for the design of the new building.

The lighting strategies for an architectural design studio should support the students and the pedagogy with great horizontal and vertical homogeneity, good colour rendering, and consistent luminous intensity. Moreover, daylight with a view would always be the preferred source of this light, but this has to be complemented by a spectrally-tunable and flexibly adaptable electric lighting system. Yet personal control is an element of major importance because all users of an architectural design studio should be able to choose, and adapt, the lighting they need at the time they want.

La lumière est essentielle pour le rythme de vie des humains, il est donc nécessaire d'adapter celle-ci aux occupants des bâtiments afin de les aider dans leurs activités spécifiques. Cette thèse a été entièrement axée sur les besoins et les exigences des étudiants en architecture pour leurs besoins visuels et non visuels, et pour soutenir à la fois leur expérience d'apprentissage, ainsi que leur confort, leur santé et leur bien-être.

Pour répondre à cette problématique, il était nécessaire de définir les besoins des étudiants, en particulier en termes d'éclairage requis pour soutenir leur performance visuelle, et les exigences non visuelles spécifiques qui sont dictées par leur méthode de travail et leur mode de vie. Pour ce faire, cette thèse s'articule autour de trois méthodes de recherche fondamentales : les enquêtes, les mesures et les simulations. Ces trois étapes ont été effectuées dans les ateliers actuels et, sur base des résultats obtenus à partir de l'analyse de ces ateliers et de leurs habitants, des vérifications et des recommandations peuvent être fournies pour la conception du nouveau bâtiment.

Les stratégies d'éclairage d'un atelier d'architecture doivent soutenir les étudiants et la pédagogie avec une grande homogénéité, horizontale et verticale, un bon rendu de couleurs et une intensité lumineuse constante. En outre, la lumière du jour avec une vue extérieure sera toujours la source de lumière à privilégier, mais elle doit être complétée par un système d'éclairage électrique à réglage spectral et adaptable de manière flexible. Le contrôle personnel est un élément d'une importance majeure, car tous les utilisateurs d'un atelier d'architecture devraient pouvoir choisir et adapter l'éclairage dont ils ont besoin au moment où ils le souhaitent.

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List of Abbreviations

ASE	Annual Sun Exposure
CBDM	Climate Based Daylight Modelling
cDA	Continuous Daylight Autonomy
CIE	Commission Internationale de l’Eclairage
CRI	Colour Rendering Index
CS	Circadian Stimulus
DA	Daylight Autonomy
DF	Daylight Factor
DGP	Daylight Glare Probability
HDR	High Dynamic Range
ipRGC	intrinsically photosensitive Retinal Ganglion Cell
LDR	Low Dynamic Range
LED	Light Emitting Diodes
MCTQ	Munich Chronotype Questionnaire
MSF_{SC}	Midpoint of Sleep during Free days Sleep Corrected
NAAB	National Architectural Accreditation Board
NIF	Non-image-forming
OWL	Occupant Well-being through Lighting
sDA	Spatial Daylight Autonomy
SDA	Seasonal Affective Disorder
UDI	Useful Daylight Illuminance
UGR	Unified Glare Rating

1. Introduction

Problem Statement

This thesis is based on a unique opportunity that was presented to the author this year: to contribute to the design of a new building to host the students of the Faculty of Architecture LOCI in Louvain-la-Neuve. As a matter of fact, the reflection on this project was in progress when the theme for this research was being chosen. The focus of this thesis was, therefore, oriented towards the analysis of the lighting strategies that can serve the specific needs of a population of students of architecture. The purpose of this work was not, of course, to challenge or modify the design or elaborate alternative proposals, but rather to test and validate the solutions proposed by the design team, and suggest complementary strategies that can be used for the benefit of the students and the pedagogy of architecture applied in this university.

Light was selected as the central theme of this research since human life entirely depends on it. Light provides the necessary stimulus to carry visual tasks, but it is also necessary for our comfort, health, and wellbeing. Other than allowing us to see, light is an important trigger of our moods, alertness, hormonal regulation, and metabolic balance. Regular exposure to the 24h-cycle of light and dark, in fact, allows our body to follow this natural pattern and regulate its *circadian rhythm*, so that during the day we can be active outside, while at night we have rest. However, this is what should happen in theory as today, in our contemporary society, we spend most of our time inside buildings, disrupting our access to natural lighting stimuli. This problem is particularly evident for students of architecture, also due to the specific requirements of these studies. Architecture students often need to work on their design developments for many hours, at day and night, involving very stringent visual conditions (e.g., for acuity and detail resolution) and focusing on visual tasks of different nature (e.g., computer screens, drawings, 3D models). All these tasks are generally accomplished in dedicated spaces, *the design studios*, that most often were not designed to respond to these specific functions in the first place, hence entailing lighting strategies – both, daylight and electric lighting – that are completely unresponsive to the specific needs of the students and the patterns of their lives. For these reasons, this thesis aims to focus on the lighting needs of students of architecture to sustain their *visual* tasks but also their *non-visual* (e.g., circadian) requirements, hence encompassing issues of visual comfort and performance but also the importance of light exposure for health and wellbeing. The following research question will be the centre of this thesis:

> ***What type of lighting strategy – integrating daylight and electric lighting – is necessary to support the pedagogy of architectural design studios and the learning experience of students?***

1.2. Research Hypotheses

To address this question, the research hypotheses need to encompass consideration of both, the *visual* and the *non-visual* systems. Based on a broad review of the scientific literature, the following section of this thesis presents the theoretical grounding on which this work has been founded.

The first hypothesis is that lighting strategies, both daylight and electric lighting, can play a fundamental role to support the design and spatial distribution of the architectural design studios.

This concept is easy to observe in practice as for example, in the current studios, activities tend to be concentrated in the areas that are best illuminated (Baldwin et al., 2023). Students constantly strive to obtain a maximum amount of even lighting distribution when they are working, and often they change the position of their tables, or they select carefully the surfaces where to display their drawings. To support the student's learning experience, they need to have access to the *right light*, and at the *right time*.

The second hypothesis is that lighting strategies can be effective to sustain the subjective, psychophysical and physiological, needs of the students.

To better understand the meaning of this hypothesis, it is important to define these two words: psychophysical and physiological. According to the Collins dictionary, psychophysics is "*the branch of psychology concerned with the relationship between physical stimuli and the effects they produce in the mind*", and physiology is "*the scientific study of how people's and animals' bodies function*" (Collins, 2023). Indeed, student's needs are the centre of this research, and all the thesis focuses on these since they spend a lot of their academic time in the architectural design studios, and it is necessary that they are supported by appropriate lighting exposures.

This thesis is based on the assumption that lighting strategies can sustain the pedagogy of architectural design studios and the learning experience of students, offering conditions that can support their work but also enhance their health, mood, alertness, and circadian regulation. Yet, students (and buildings') subjective requirements might be different, as would the specific lighting characteristics needed for their work. Hence, the aim of this work is not to impose *restrictive* lighting solutions that need to be *enforced* in design studios, but rather to test and propose a range of opportunities and solutions that designers, managers, and building users might select to adopt based on their individual needs and preferences.

2. Literature Review

The aim of this section is to summarise the knowledge about the subject, specifically focusing on the lighting comfort and wellbeing for the students in their architectural design studios. We will focus first on the current scientific knowledge on light and its definition, and then on the pedagogy in the design studios. This section will also introduce the specific case of the studios at the Faculty LOCI in Louvain-la-Neuve, hence providing a basis of reference for the development of this research.

Light

2.1.1. What is Light?

The correct use of light in our buildings is essential for the comfort of the occupants, thus it is important to understand the interactions between light and people. To this aim, it is necessary to understand what light effectively is. The role of light can be separated into two categories: *visual* and *non-visual*. Visual effects focus on how light can enable us to see, while non-visual responses are concerned with how light changes our body, what we cannot see but what we can feel (in the short as in the long term).

Peter R. Boyce (2014) provides a context for these two requirements by stating:

- "*Physically, daylight is simply electromagnetic radiation in the wavelength range that is emitted by the sun, scattered in the atmosphere and absorbed by the photoreceptors of the human visual system*."
- "*Physiologically, the response of the human system to the light spectrum is determined by the spectral sensitivities of the different photoreceptors in the eye*." (Boyce, 2014)

Visual Requirements

Everyone knows what light is because we need it in order to be able see. Yet, for the development of this thesis, it is important to understand the effects that light generates and how it can be produced.

Daylight in the natural environment is "*the light from the sun filtered by the atmosphere, producing a broadband spectrum with characteristic 'dips' corresponding to absorption of light by molecules in the atmosphere*" (Webler, Spitschan, Foster, Andersen, & Peirson, 2019). Changes in the spectral composition and in the intensity of daylight happen regularly mainly due to the position of the sun with respect to the Earth, but they can also be determined by variations within the composition of the atmosphere. This is also, for example, why the quality and quantity of daylight changes with the different seasons.

Light is a form of electromagnetic radiation that supports visual perception: it is necessary for the human visual system to activate the visual experience of the surrounding environment. The visible spectrum of light corresponds to the wavelength region between 380 and 780 nm, as presented in Figure 1 (Boyce, 2014). The solar spectrum is divided into three different bands: the *visible* one represents almost 50% of the solar radiation's total energy; 45% corresponds to the *infra-red* region between 700 to 2500 nm; and, the last 5% correspond to *ultraviolet* rays included in the range between 280 to 380 nm (Architecture-et-Climat, 2014).

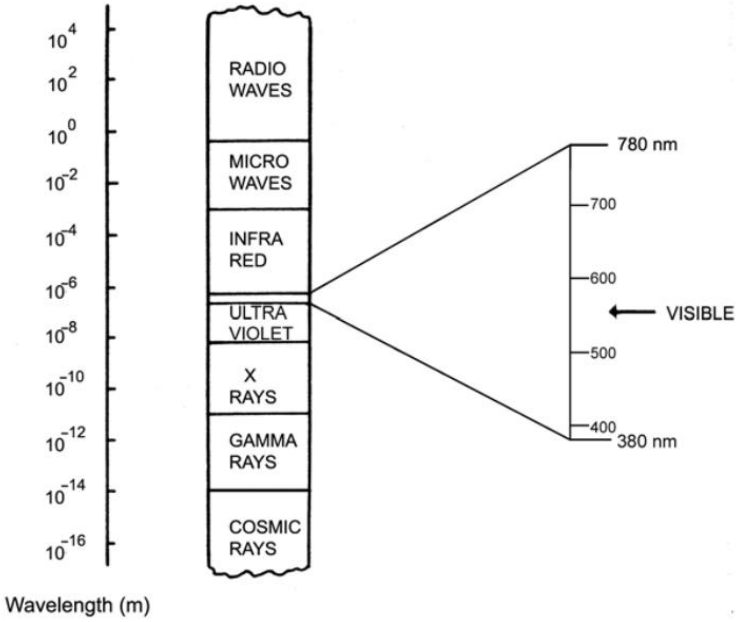

Figure 1 *- Schematic diagram of the electromagnetic radiation. Source: (Boyce, 2014)*

The visual range differs from the other wavelength bands due to the response from the human visual system, involving the eyes and the brain, which over evolutionary scales have adapted to convert these electromagnetic impulses into electric stimuli that can trigger visual perception. Among the forms of light, daylight is characterized by a continuous spectrum of radiation, featuring wavelengths that can vary over the times of day, the meteorological conditions, the latitude, and the seasons (Boyce, 2014).

From a perspective of ***photometry***, the branch of physics describing the various measures of light, based on how it is produced and transferred, it is important to distinguish between the following (Figure 2):

1. The light produced by a source is characterized by a **luminous flux**, "*the quantity of radiant flux which expresses its capacity to produce visual sensation*" (Boyce, 2014), which is expressed in *lumens*.
2. When light is moving in a certain direction, its **luminous intensity** can be measured in *candelas*, these representing "*the luminous flux emitted in a very narrow cone containing the given direction divided by the solid angle of the cone, that is, luminous flux/unit solid angle*" (Boyce, 2014).
3. When the light arrives on a surface, the process of illumination can be characterized by its **illuminance** measured in *lux* or *lumens/m²*, "*the luminous flux/unit area at a point on a surface*" (Boyce, 2014).
4. Finally, the part of light that is reflected (or transmitted) by a surface in a given direction is called **luminance**, and measured in *cd/m²*, that is "*the luminous flux emitted in a given direction divided by the product of the projected area of the source element perpendicular to the direction and the solid angle containing that direction, that is, luminous intensity/unit area*" (Boyce, 2014).

For the purpose of this thesis, particularly in terms of the description of the spectral composition of light (that is, its composition based on the distribution of its wavelengths), it is also essential to introduce a further metric, that is the **correlated colour temperature**, measured in *Kelvin*, physically described as the "*equivalent temperature of a black body emitting within a defined wavelength range*" (Boyce, 2014).

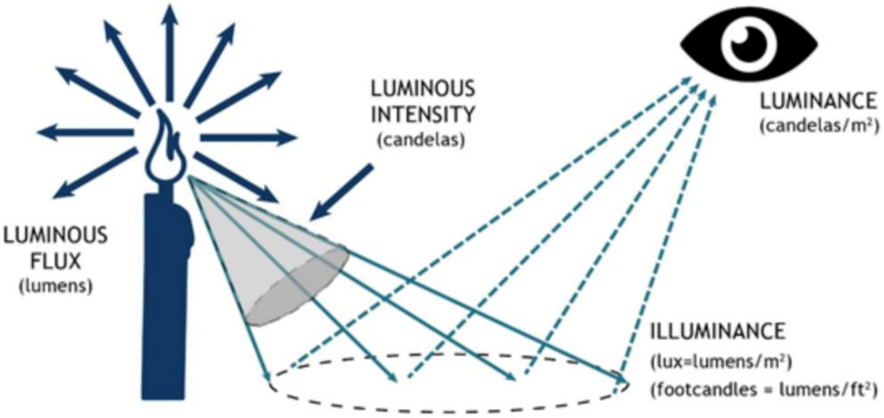

Figure 2 *- Schematic diagram of lighting measures.*
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Good light for vision is characterized by a high level of illuminance and a balanced composition of its spectrum to enhance colour discrimination with respect to the colour rendering that is produced by daylight. Other than these parameters, luminance is also an important factor that affects the quality of the luminous environment, particularly in terms of visual comfort. In fact, increasing the luminance of a source may lead to strain and fatigue within the visual system, this resulting in a decline of visual efficiency. An excessive luminance can also lead to discomfort glare which can distract or annoy people, also irrespective of their capacity to perform a visual tasks (Liu, Zhang, Wu, & Yang, 2021).

To complement daylight, electric lighting (often referred to as *artificial lighting*) can come in many variants, among which, currently, the most common are incandescent and fluorescent lighting fixtures and the light emitting diodes (LED). Each of these lighting technologies is characterized by a different spectrum. Light in an indoor environment should preferably favour a correct blending between artificial and natural lighting, unless in a windowless space. Conversely, the illuminance in a room is often the mixture of transmission and reflection of artificial and natural illumination (Webler et al., 2019).

Other than characterising physically the luminous stimulus, it is also important to understand how visual perception is triggered: the eye that captures the light and the brain that interprets it. Peter R. Boyce (2014) explains that the functioning process of the visual system includes two parts (Boyce, 2014):

- an optical system that produces an image on the eye's retina.
- an image-processing system that extracts different aspects of that image at various stages of its progress from the retina to the visual cortex, while preserving the location of the information.

To better understand how this process operates, it is essential to understand how the eye and the retina operate. Light enters the eye by the pupil, an optical aperture that regulates the amount of light that can reach the photoreceptors located on the retina (Figure 3): an average of 125 million rods and 5 million cones. These photoreceptor types are responsive to different characteristics of light such as its intensity, spectrum, position, size, and temporal resolution (Barrionuevo, Issolio, & Tripolone, 2023). These biological photoreceptors are not equally sensitive to all wavelengths of light, with cones assuring a tri-chromatic vision (red, green, blue) in bright light, and rods offering monochromatic vision under dim lighting conditions (Enezi et al., 2011).

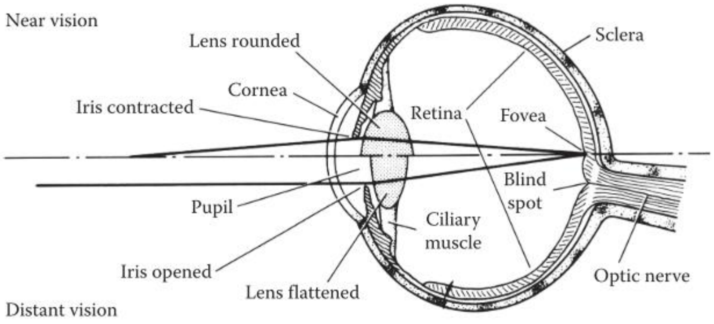


Figure 3 *- The human eye. Source: (Boyce, 2014)*

The information triggered by the luminous stimuli is transmitted from the retina, through the optic nerve, to the visual cortex, which is located at the back of the cerebral hemisphere (Boyce, 2014).

Non-Visual Effects

Other than allowing us to see, light exposure has many other effects on our body, influencing our health, human physiology, and behaviours, as well as contributing to regulate our circadian rhythm, sleep, alertness, mood, and several neuroendocrine and cognitive functions (Brown et al., 2022). These responses are known as *non-image-forming* (NIF) or, more generally, *non-visual* effects (Boyce, 2014), and their consideration is essential to promote physical, physiological and mental health, other than visual performance (Brown et al., 2022). Discoveries about the non-visual system are relatively recent, and its processes are better known since a new form of photoreceptors was identified at the end of the last century, the *intrinsically photosensitive retinal ganglion cells* (ipRGCs) (Boyce, 2014). Situated in a different layer of the retina than the cones and rods, the ipRGCs have different characteristics and responses than the known photoreceptors, yet still active within the mesopic range (that is, they can be stimulated also at the presence of very dim lighting conditions) (Barrionuevo et al., 2023). They contribute to control the size of the pupil and have a fundamental role in entraining the circadian rhythm to the natural 24h cycle.

The ipRGCs can convert the electromagnetic luminous signal into a neurochemical signal through the expression of *melanopsin*, a photopigment whose spectral sensitivity differs radically from those of cones and rods and which shows peak in the short-wavelength (blue) region at around 480 nm (Boyce, 2014) (Brown et al., 2022). This is represented by the blue curve (melanopic) in Figure 4. Conversely, the green curve (photopic) illustrates the combined spectral sensitivity of the three types of cones in the retina, with a peak corresponding to around 555 nm. The differences between these two spectral sensitivity curves clearly illustrates the need for lighting strategies to take into account, at once, the melanopic function corresponding to the non-visual effects and the photopic luminous efficiency function related to the functioning of the visual system (Houser, Boyce, Zeitzer, & Herf, 2020).

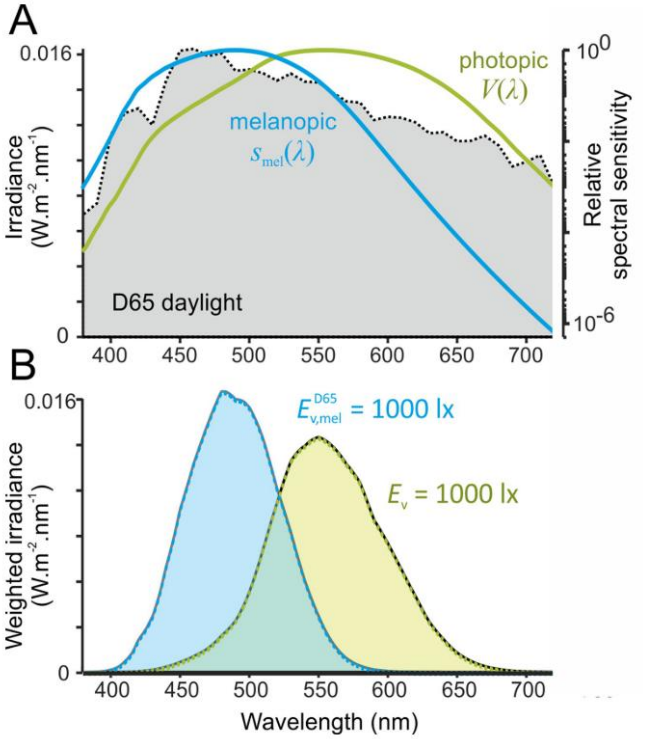


Figure 4 *– Differences in photopic and melanopic spectral sensitivity formalized in the SI-compliant for quantify ipRGC-influenced responses to light. Source: (Brown et al., 2022)*

There are at least three different subtypes of ipRGCs in the human body, each with a different response to light (Houser et al., 2020), and all contribute to regulate our body's biological functions. Among these, the *circadian rhythm* represents the cyclic sequence of a series of daily events, including – as already mentioned – the regulation of sleep, alertness, mood, neuroendocrine and cognitive functions, etc. (Houser et al., 2020). The internal metabolic cycles controlling the occurrence of sleep/wake and fasting/feeding times are an important output of the circadian clock (Marcheva et al., 2013). Sleep is regulated by the principle of *homeostatic pressure* (Figure 5) that controls a series of physiological parameters (Cannon, 1929). The term homeostasis can be explained as: "*the maintenance of metabolic equilibrium within an animal by a tendency to compensate for disrupting changes*" (Collins, 2023).

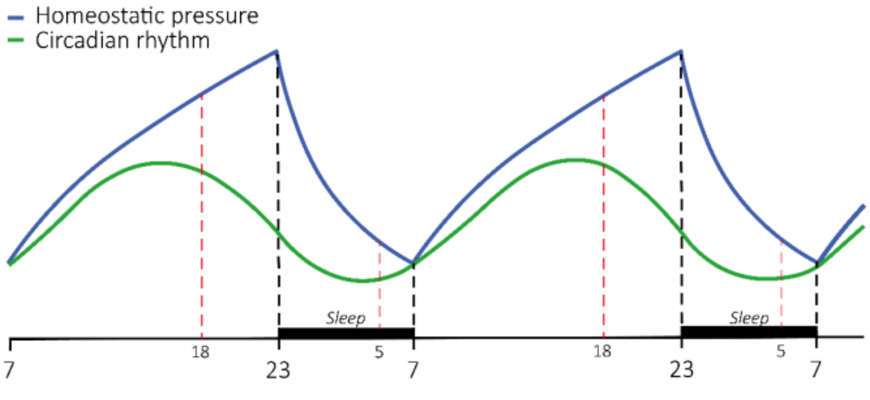


Figure 5 *- Homeostatic pressure and Circadian rhythm. Source: (Carmon, 2020)*

Without external regulation, the human circadian rhythm would naturally vary between 23.5 and 24.7 hours, with an average of 24.2 hours for healthy adults (Carmon, 2020). It is therefore necessary for the body to rely on consistent triggers in order to entrain the duration of this cycle to the constant 24h duration of the alternation between day and night (Marcheva et al., 2013). Among the environmental cues that help to synchronise the circadian system, one of the most potent triggers is indeed the regular exposure to light of a certain intensity, duration, spectrum, timing, and temporal resolution (Brown et al., 2022). Light exposure can also play a great role for mood and learning regulation (Fernandez et al., 2018), over longer timeframes (Houser et al., 2020). In fact, mood disorders have long been associated with light exposure (particularly when this is not adequate or sufficient), including conditions such as the seasonal affective disorder (SAD) (Bedrosian & Nelson, 2017).

Light exposure also orchestrates the synthetization of several hormones to support the physiological processes of the human body. These are called *neuroendocrine responses* to refer to how the brain regulates the secretion of hormones (Houser et al., 2020). The principal hormones are melatonin and cortisol. As shown in Figure 6, before awakening, cortisol increases to facilitate the switch from sleep to wakefulness (Carmon, 2020). It will decrease during the day and this cycle is reproduced every day. It is the same for melatonin, which increases in the body when cortisol is low at the end of the day (Altomonte, 2009). On the image, it is also possible to observe a similar pattern for the cycles of alertness and body temperature, which are not hormonal but still are orchestrated by the circadian rhythm (Boyce, 2014).

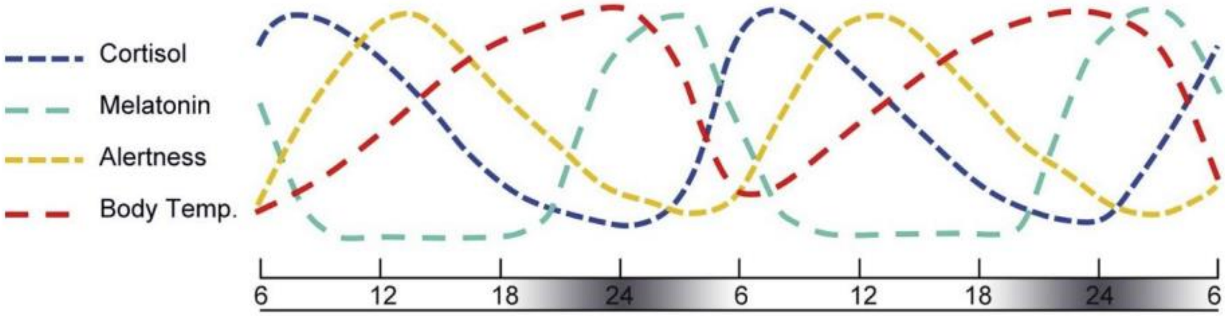


Figure 6 *- Circadian rhythms. Source: (Altomonte, 2009)*

Finally, the regulation of the circadian rhythm plays a fundamental role in our cognitive functions, including learning, mental abilities, thinking, reasoning, remembering, problem-solving, decision-making, and attention (Fisher, Chacon, & Chaffee, 2019). On these bases, various studies have focused on quantifying the non-visual effects that light exposure inside buildings can have on the human body. Among these, research has shown that a high exposure to circadian-effective light during the morning can enhance the performance of office workers, with significant changes to their circadian entrainment, sleep quality and mood (including a reduction of stress) (Figueiro et al., 2017). A study also stated that "*when exposure to light is mistimed or nearly constant, biological and behavioural rhythms can become desynchronized, leading to negative consequences for health*" (Bedrosian & Nelson, 2017). Due to the importance of light for our health, it is easy to understand why staying indoors with inappropriate electrical lighting can have negative impacts on health, sleep, and productivity (Brown et al., 2022). Among the measures defined to evaluate the exposure to luminous stimuli for circadian entrainment, the circadian stimulus (CS) value has been proposed (Figueiro et al., 2017). This will be presented in the following section.

2.1.2. Parameters, Measures and Metrics

For the development of this thesis, it is important to define the parameters, measures, and metrics that the scientific literature has established to benchmark the visual and non-visual performance of spaces.

The previous section has presented the principal measures used in photometry to quantify the ***visual effects*** of light: luminous flux, luminous intensity, illuminance, luminance, and correlated colour temperature. These are respectively expressed in lumens, candela, lux (lm/m^2) – or, more correctly the "*photopic lux*" (Enezi et al., 2011) - cd/m^2, and Kelvin. These metrics will be used throughout the thesis, although other parameters have been recently proposed to also encompass the climate, time and location dependency of light distribution inside spaces (these are generally referred as *Climate-Based Daylight Modelling*, or CBDM metrics).

Before introducing the metrics embedded within the CBDM framework, the *daylight factor* (DF) needs to be mentioned. This is the oldest, and most widely applied, metric used to benchmark the spatial distribution of light within a space. The DF (or FLJ, *facteur de lumiere du jour* in French) is defined by the ratio of the internal illuminance at a point in a building to the external illuminance without any obstacles under a fully overcast sky (often referred as CIE sky, as defined by the Commission Internationale de l'Eclairage). This metric was developed in the United Kingdom in the 20th century (Fuse IQ, 2021) and is expressed as a percentage. For example, assuming that there are 500 lux inside and 10000 lux under an overcast sky, the corresponding daylight factor is 500 lx / 100000 lx = 2% (Reinhart, Mardaljevic, & Rogers, 2006). DF serves as a quick comparison of relative daylight penetration under overcast conditions. The LEED rating system requires DF to be a minimum of 2% for at least 75% of the critical visual task areas (Fuse IQ, 2021).

Among the CBDM metrics, the *Daylight Autonomy* (DA) is an indicator of whether there is sufficient annual daylight on a horizontal plane, often used on working surfaces. DA is a percentage of annual daytime hours when a given point is above a specified illumination level (Reinhart et al., 2006).

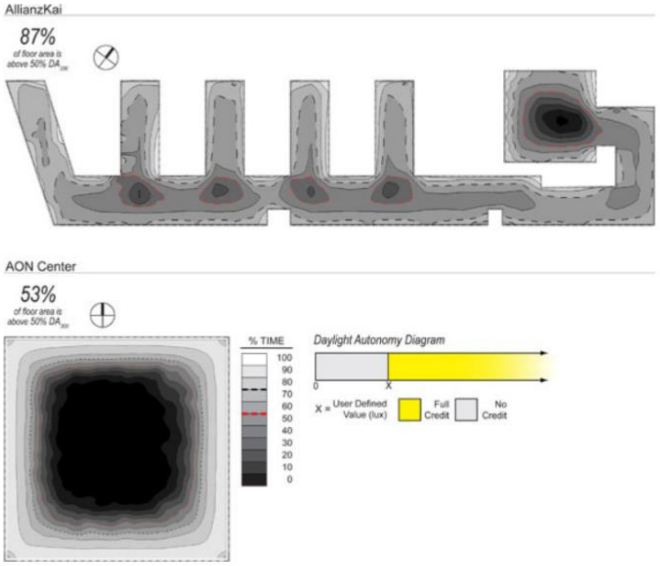


Figure 7 *- Daylight Autonomy. Source: (Fuse IQ, 2021)*

Within the same type of metrics, *continuous Daylight Autonomy* (cDA) is a modification of DA. In this case, partial credits are awarded when annual daylight illuminance lies below the minimal illuminance level. As shown on Figure 8 by the yellow diagram, a line from zero to the minimal level is added.

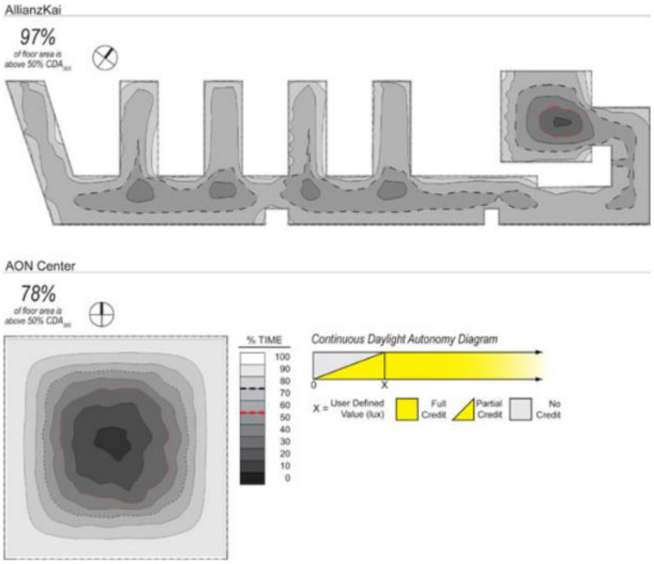


Figure 8 *- continuous Daylight Autonomy. Source: (Fuse IQ, 2021)*

Useful Daylight Illuminance (UDI) is also used throughout this thesis. Proposed by Mardaljevic and Nabil in 2005, it is a modification of the Daylight Autonomy that includes consideration of dynamic daylight performance on a working plane. The principle of this metric is that, if the level of illuminance is too low or too high, then it is not useful to carry out a visual task. For this reason, it has been proposed that annual daylight illuminance in the range 100-2000 lx (at times, also the range 100-3000 lx is used) should be considered as offering potentially useful illumination for the occupants (Nabil & Mardaljevic, 2006). Looking at Figure 7 and Figure 9, it is easy to compare the two metrics due to the colours of the diagrams.

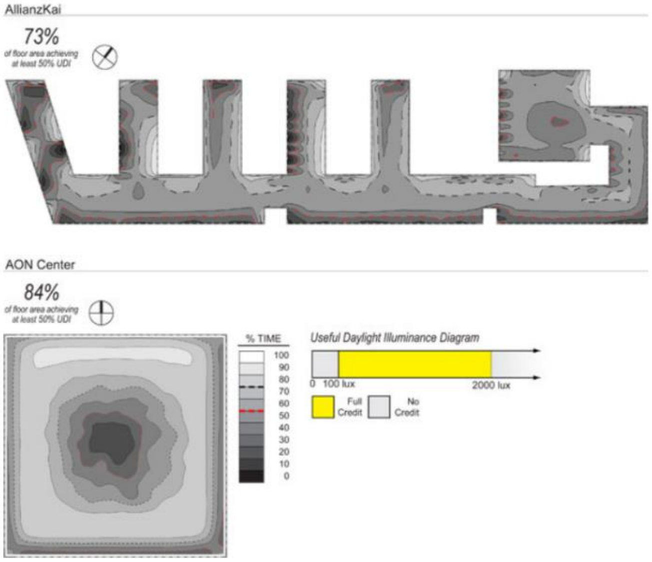


Figure 9 - Useful Daylight Illuminance. Source: (Fuse IQ, 2021)

To benchmark the ***non-visual performance*** of a space, the *Circadian Stimulus* (CS) is a metric that expresses the potential for melatonin suppression and its effects on the synchronisation of the circadian rhythm. The CS metric is based on consideration of the light spectrum, duration, intensity, and timing, since all these parameters can directly (and indirectly) affect the circadian system. The measurement, or simulation, of this metric is particularly relevant as disruption of the CS can have very serious consequences on the health and well-being of people. Figure 10 presents the saturation of the CS produced by daylight, its maximum being established at a value of 0.7. The CS value needs to be at least 0.3 for one hour during the morning for the promotion of good circadian entrainment (Acosta, Campano, Leslie, & Radetsky, 2019). This will be the minimum threshold that will be considered for the development of this research.

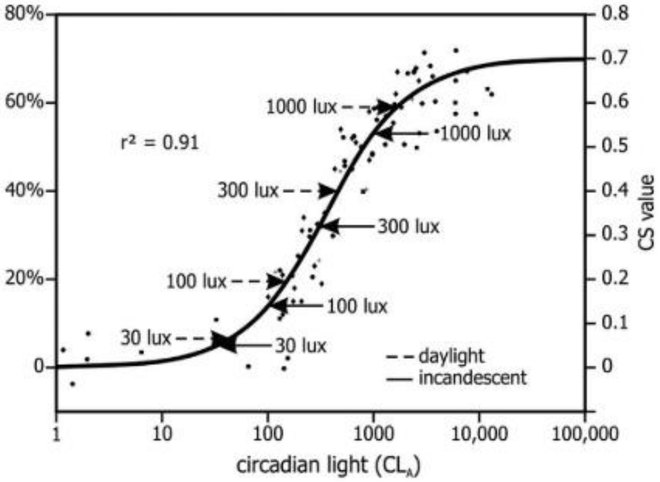


Figure 10 *- Relationship between the spectrally weighted levels of the circadian light and the measured levels of nocturnal melatonin suppression. Source: (Acosta et al., 2019)*

2.1.3. Visual Comfort and Health

Visual comfort is a subjective response that is linked to the quantity, distribution, and quality of light within a space (Architecture et Climat, 2014). A luminous environment can be considered as comfortable when it offers the capacity to see objects clearly and without fatigue, and with good colour rendering. If there is not enough light in the environment, an unacceptable distribution, or if the light spectrum is not adapted to the eyes' sensitivity, then occupants can start to feel fatigue, visual discomfort, loss of concentration or headaches (CEN, 2021). Several parameters influence the achievement of visual comfort (Architecture et Climat, 2014), among which those directly related to the design of architectural spaces are:

- The illuminance level on the visual task;
- An adequate colour rendering (compared to daylight);
- A harmonious distribution of light in spaces;
- The ratios of luminance present in the room;
- The absence of uncomfortable shades or excessive contrast;
- The highlight of reliefs and shape of objects;
- The availability of an unobstructed view to the outside;
- A pleasant combination between daylight and electric light;
- The absence of discomfort due to glare.

This thesis focuses on the analysis and definition of the lighting strategies for an architectural design studio. This building type is seldom included in existing lighting regulations and recommendations, therefore reference will be made in this study to standards such as the recently recast *EN 12464-1:2021 - Lighting of work places* (CEN, 2021b). The advantages of providing visual comfort in offices are multiple since increasing the quality and quantity of light can result in better work and benefit the mood and the motivation of the occupants (Boyce, 2014). In work places, the level of illuminance on a horizontal plane at desk height is the most common criteria used to benchmark the visual comfort of building users, also considering the proper balancing between luminous sources (and with that, the type of lighting systems used) (Boyce, 2014). Other considerations include minimising the risks of reflections on the display screens, while providing sufficient illumination to work on other surfaces (horizontal and vertical). Moreover, provision of abundant daylight and an unobstructed view to the outside can substantially increase the feeling of comfort of building occupants. In fact, daylight can provide high illuminance and excellent colour discrimination and colour rendering. Yet, ingress of daylight needs to be properly managed and controlled, since excessive penetration of daylight can be linked to issues of solar overheating and increase the occurrence of visual discomfort due to glare (Boyce, 2014).

In the recent literature, visual comfort has often been associated to the constructs of health and well-being. Although there are clear connections between these terms, some distinctions need to be made, also to better contextualise the focus of this thesis and identify the different needs of the students who work in architectural design studios. *Comfort* can be broadly defined as a "*physical and material state that is pleasing or grateful to the senses*" (Altomonte, 2019). Yet, people might have different preferences and needs, and their responses depend on many variables, most of which are time-dependent (that is, comfort should be seen as a momentaneous state). Conversely, health can be seen "*as going beyond merely the absence of disease or infirmity"*, a combination of different dimensions, and at different spatio-temporal resolutions, that can contribute to the welfare of building occupants. In a sense, health can be viewed as the "*integration of comfort over time*", a fundamental state for aspiring towards the achievement of well-being, “*an even wider and overarching construct of physical, physiological, and mental aspects combining hedonic and eudemonic dimensions, i.e. feeling good and functioning well*” (Altomonte, 2019).

2.2. Architectural Design Studios

Architectural design studios are very specific places made for the students to draw, learn, create models, work on the computer, etc. As mentioned in the introduction, students spend a considerable amount of time, day and night, working in the studios, therefore it is important for these to offer spatial and environmental characteristics that are purposely adapted to meet the needs of these users.

2.2.1. What is a Design Studio?

Design studios are, first and foremost, a place for students and teachers, where a specific type of education can be conveyed. Indeed, architectural education is a rather distinctive branch of pedagogical sciences, as it requires the practical development of creative and technical knowledge and capabilities (Kesseiba, 2017). A design studio needs to be spacious in order to offer to the students enough space for drawing, creating models, and using computers. Yet, it also entails specific requirements in terms of its lighting, due to the different activities that it needs to host, ranging from stringent visual tasks to exhibition of designs (both on horizontal and on vertical surfaces), and encompassing different qualities and quantities of light access and distribution. But studios are not only spaces for work. For students of architecture, the design studio is also a place for living, due to the long periods of time that they will spend there. A studio is also a place for social engagement, where every student can share their designs with others and work together. Architectural students are a close community, and they need a space to collaborate. As Thomas A. Dutton said: “*studios are active sites where students are engaged intellectually and socially, shifting between analytic, synthetic, and evaluative modes of thinking in different sets of activities*” (Dutton, 1987).

Design studios are the place where students learn the art of designing and creating. It is where creativity can be expressed without limitation, becoming manifest on walls, tables, the floor, etc. It is a place where students will spend also the most stressful times of their academic life, particularly before an important project deadline. At this time of the year, students will practically live in the studios, and they will not go back to their homes for sleep, sometimes for several days. This is also the reason why, in many architectural schools, the students need to have 24-hour access to the studios during the academic year.

According to a study conducted at the University of Washington, the design studio represents the real core of architectural education. For this reason, it is essential that it is equipped with adequate furniture, including desks, shared workspaces, pin-up surfaces, and access to digital networking tools to facilitate the development of students’ work (Hacihasanoglu, 2019). A studio is a place where students will completely immerse themselves into their design elaborations, a den, a home away from home, a space that facilitates individual and independent thinking as much as groupwork and interactions. Indeed, exchange of ideas, confrontations, discussions, are all relevant parts of contemporary architectural pedagogy theories, and the design studios needs to represent the environmental setting that affords the emergence of these qualities (Altomonte, Rutherford, & Wilson, 2012). In conclusion, design studios require a mixture of formal and informal spaces where the internal organisation can often be self-managed by the students but that, at times, can also accommodate the development of activities directed by a professor (Vangrunderbeeck, 2020).

2.2.2. Pedagogy, Space, Technology

To understand why this topic is linked to the aims of this thesis, it is important to characterise the link between pedagogy and the design studios. As shown in Figure 11, particularly in architecture, the pedagogy is strictly related to space and technology. Spaces afford pedagogy and integrate technology; pedagogy is supported by space and is diversified by technology. Technology breaks down the barriers of spaces and can facilitate the pedagogy (Vangrunderbeeck, 2020). Understanding the studio's pedagogy is then necessary to define the spaces required, and therefore the technology, and thus the lighting, required.

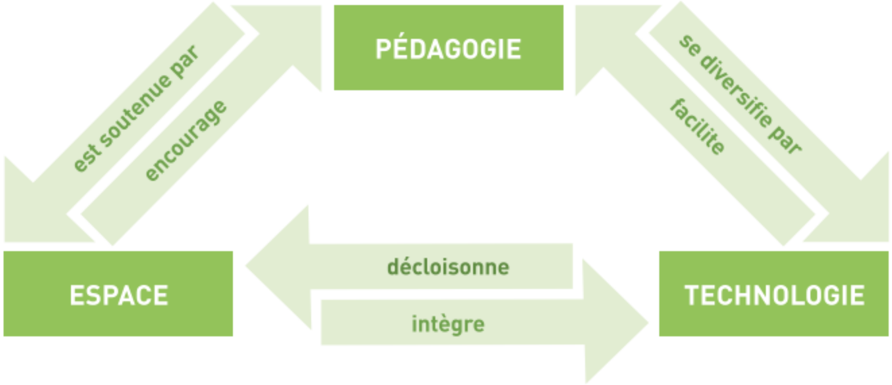


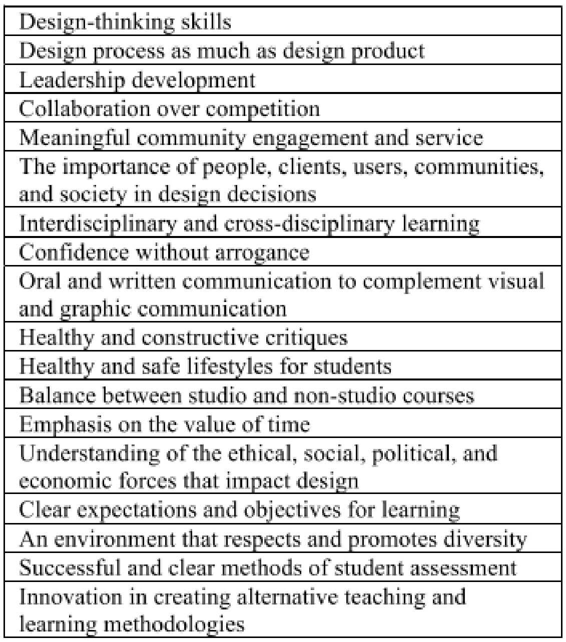
Figure 11 *– Pedagogy, space and technology. Source: (Vangrunderbeeck, 2020)*

Historically, the design studio was seen as a succession of ateliers in the "Ecole des Beaux-Arts". Each studio was led by an accomplished architect and had his own character. There were three parts in the learning process: the first two were focused on the sketching, called the "Esquisse", and the testing of the design proposals, and the last one consisted in the writing of a text to examine the scientific knowledge of the candidates (Kesseiba, 2017). In contemporary education, design studios are the "*heart and head of architectural education*". This situation is not comparable to any other classroom scenarios (Dutton, 1987). Architectural pedagogy aims to convey, conserve, and transmit the values of the profession and the society. An important part of the education focuses on responding to the needs of the occupants of the buildings that students strive to create. The process of creation itself needs to be nurtured by reason, emotion and intuition (Kesseiba, 2017).

According to the US's NAAB (National Architectural Accreditation Board), the learning culture transmitted within the architectural design studio can be defined as follows: "*the program must demonstrate that it provides a positive and respectful learning environment that encourages optimism, respect, sharing, engagement, and innovation between and among the members of its faculty, student body, administration, and staff in all learning environments, both traditional and non-traditional*" (NAAB, 2014).

There are different perspectives that need to be considered: collaboration and leadership, design, professional opportunity, stewardship of the environment, community and social responsibility. Therefore, individual and collective learning opportunities are applied (NAAB, 2014). For social equity, NAAB says: "*the program must have a policy on diversity and inclusion that is communicated to current and prospective faculty, students, and staff and is reflected in the distribution of the program's human, physical, and financial resources*." (NAAB, 2014). A list was made about the qualities that the pedagogy needs to promote in the studio (Table 1). These values are embedded in the teaching at various prestigious universities of architecture such as Harvard and Princeton (Hacihasanoglu, 2019).

Table 1 *- Evaluation parameters of the studio culture. Source: (Hacihasanoglu, 2019)*



Design-thinking skills
Design process as much as design product
Leadership development
Collaboration over competition
Meaningful community engagement and service
The importance of people, clients, users, communities, and society in design decisions
Interdisciplinary and cross-disciplinary learning
Confidence without arrogance
Oral and written communication to complement visual and graphic communication
Healthy and constructive critiques
Healthy and safe lifestyles for students
Balance between studio and non-studio courses
Emphasis on the value of time
Understanding of the ethical, social, political, and economic forces that impact design
Clear expectations and objectives for learning
An environment that respects and promotes diversity
Successful and clear methods of student assessment
Innovation in creating alternative teaching and learning methodologies

Architectural education needs to be founded on providing a balance between theoretical courses and the practice of design in the studios. Theoretical teaching has to support the studio and vice-versa. With this education, the students learn "*the language of design*", mastering the use of 2D and 3D tools to explore and characterise the qualities of spaces. These tools can be practiced on the computer or on paper, e.g., drawings and models, and all are necessary for the proper understanding of the spaces. Students learn how to craft spatial concepts and to contextualise them in their proposals (Kesseiba, 2017).

Another feature of architectural education is the pace of development of design proposals. Students are encouraged to arrive in the first week of the semester with ideas and potential solutions to the given design problem. The benefit of this is to improve the learning experience and enhance the capacity to quickly tackle situations (Kuhn, 2000). Yet, due to this pedagogical setting, the studio is also the place where students receive criticism, which need to be healthy and constructive (Hacihasanoglu, 2019). Critiques take place in both formal and informal ways, from the professors, colleagues or visiting experts (Kuhn, 2000). The nature of studio-based learning is strongly anchored on these critiques, feedback and conversational exchanges between tutors and student, and between student and peers (McClean & Hourigan, 2015).

Finally, the studio needs to afford also other models of education, such as the “collaborative board”. This consists of an interaction between students, which can be very productive. With this method, it is possible to involve everyone in each other’s projects and then encourage informal exchanges and general questioning (Masson, 2019). However, for this pedagogical method to be effective, the spaces need to be flexibly adapted to these collaborative interactions.

2.2.3. After COVID

During the academic years 2019-2020 and 2020-2021, the education of the students was affected by the COVID-19 pandemic. Like every other discipline, the architectural program was impacted by a change of learning process. The courses needed to be given online, and all the students had to stay at home.

Obviously, the online solution was not adapted to the studio courses because the students were suddenly alone. They could not share their work and their experience with each other anymore. The interactions, feedback and design learning in the studios were no longer available to most of the students. This implied an added difficulty, as students were no longer sharing the same space. Indeed, social interactions are one of the most important things in the pedagogy of the studio courses. Furthermore, mixing life at home with design studio work was challenging, particularly due to the lack of space, unsuitable furniture, the presence of family instead of colleagues, etc. Every group’s work became very difficult due to the lack of direct interaction between the students. The feeling of being alone was something very troublesome for students in architecture. Equipment such as luminous tables was only available in the studios, hence students tried to find alternative techniques to draw (e.g., drawing on windows), making the learning process rather arduous. A course based on online teaching was also a problem for the learning of software such as AutoCAD or Rhino due to the lack of physical interactions with tutors, whose screen had to be shared hence hindering the practice of software during the learning. The support from other students is also essential to ask questions instead of losing time to find information on the internet. Finally, the discussion on the design projects with teachers was made very difficult by the fact that this had to be made via online calls. Students had to show pictures of their advancements, and often struggled to convey the principles upon which certain design solutions had been made. Even if the situation forced students to be creative and imaginative, and use simple tools and materials to explain their ideas with models, the communication was often challenging, and the quality of the learning process was necessarily lower, as were the expectations for the final outcomes of the studio course.

This experience made it clear that, even in today’s world, the design studio environment continues to be a fundamental community setting for learning (McClean & Hourigan, 2015). The pandemic demonstrated that online courses cannot provide a proper pedagogical environment for the discipline of architecture. The learning experience of students needs to be properly supported by adequate spaces and facilities that can enhance individual learning and group collaborations and interactions (Peimani & Kamalipour, 2022). These are the key considerations on which the objectives of this thesis have been framed.

2.2.4. Design Studios at UCLouvain

The Faculty LOCI at the University of Louvain (UCLouvain), like any other academic institution, has developed its own pedagogical methods for the teaching of architecture. These are structured on:

- mobility of the teachers between the tables where students work;
- collective table discussion on the projects;
- pin-ups for feedback and assessment.

Personal work made by the students (drawing, model making, screen-based activities) is the main activity during the studio courses. Students work individually or within a group (from 2 to 5 students) most of the time, and one or two times a week they meet the teachers to get some feedback about the main ideas of their project and how to express them. At LOCI, the staff-to-student ratio is based on 12 students/groups per teacher throughout a semester. Generally, the studio courses are given during 8 hours per week, which means that every student/group is allocated at least 40 minutes per session (Masson, 2019).

The expectations for design studio courses are similar to those that apply to any building. They can be distinguished between *general* (e.g., responding to building regulations and norms) and *specific* (e.g., related to each design project, its context, urban or rural, its program, the environmental dimension, etc.). All students learn from the teacher but also from each other; this is an integral part of the learning experience. For this reason, there are different types of collaborations: *tacit* (individual work in a group dynamic), *implicit* (every student's work is different but can help the others), *informal* (outside the courses' hours, students are encouraged to discuss), and *forced* (in groups, students must learn to work together) (Masson, 2019). With reference to the principles presented in Table 1 (Hacihasanoglu, 2019), and based on personal experience of the author, a comparison was made to the studio culture parameters where specific emphasis is given at the Faculty LOCI; these are marked by a x sign in the Table 2 below.

***Table 2** – Studio culture parameters at UCLouvain. Based on Hacihasanoglu, 2019*

Design-thinking skills	x
Design process as much as design product	x
Leadership development	x
Collaboration over competition	x
Meaningful community engagement and service	o
The importance of people, clients, users, communities, and society in design decisions	x
Interdisciplinary and cross-disciplinary learning	x
Confidence without arrogance	o
Oral and written communication to complement visual and graphic communication	x
Healthy and constructive critiques	x
Healthy and safe lifestyles for students	o
Balance between studio and non-studio courses	x
Emphasis on the value of time	o
Understanding of the ethical, social, political, and economic forces that impact design	o
Clear expectations and objectives for learning	x
An environment that respects and promotes diversity	o
Successful and clear methods of student assessment	o
Innovation in creating alternative teaching and learning methodologies	x

At LOCI, the process of design is given relevance as much as the final product, yet it is important that ideas are properly expressed with drawings, models, and in verbal form (oral and written). Students need to present their designs with clarity to the teachers and to other contributors. In addition to this, one of the specificities of the courses in Louvain-la-Neuve is that the programme does not include only architecture but also civil engineering. The studio courses are a main part of the education at LOCI but, at the same time, students need to combine their design skills with theoretical engineering courses. This often presents a difficulty in the programme because these are two very different courses. However, the pedagogy tries to link these two components to reinforce the quality of design outcomes. As an example, students can focus more on the structure and the materials they want to use, since they have the theorical bases to think about these aspects throughout the whole project.

3. Aim and Objectives

Aim of the Research

***The general aim of this thesis is to provide a design framework for the lighting strategies of architectural design studios, supporting the pedagogy and learning experience of students of architecture*.**

To this aim, it will be first of all essential to fully characterise the needs of the students in the Faculty LOCI in Louvain-la-Neuve, particularly in terms of the lighting that is demanded to support their *visual* task performance, and the specific *non-visual* requirements that are dictated by their working and living styles. To contextualise this knowledge, the current design studios within the Vinci building will be taken as a basis for reference via measurements and simulations. On this grounding, this study will analyse the design for the new building that has recently been proposed to host the LOCI design studios over coming years. The proposal will be tested via the use of a new parametric tool to verity the *visual* and *non-visual* potentials that the solutions devised will afford and, where appropriate, guidelines and recommendations will be made to enhance the lighting qualities of the new design. Figure 12 diagrammatically illustrates the structure of the research with all the steps that will be necessary to respond to aim of the research.

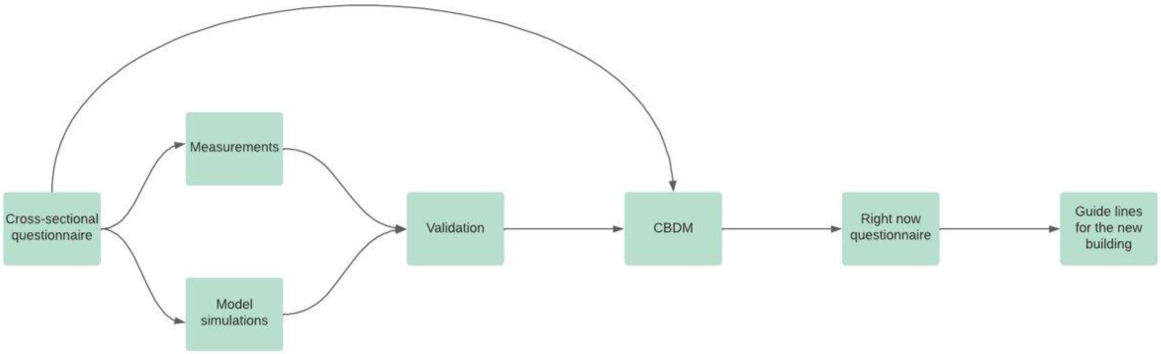


***Figure 12** – Structure of the Research. Source: Author*

This thesis is articulated on three fundamental research methodologies: surveys, measurements, and simulations. Two different questionnaires (cross-sectional and right now) with the students and a campaign of measurements on the current design studios will be conducted. Such measurements will support the validation of the 3D simulation of existing spaces, that will be necessary to contextualise the answers to the surveys and characterise the needs of the students. A further set of simulations will then be conducted on the new design proposal to test and evaluate the lighting conditions in the new studios. Each part of the research structure will be presented in the next chapters of this thesis.

3.2. Specific Objectives

3.2.1. Objective 1

The first specific objective of this research can be formulated as follows:

- *In the design of architectural studios, which lighting strategies (natural and electric) sustain different pedagogical methods and spatial dynamics?*

This objective requires focusing on the specific pedagogy of design education. It can be expressed in two different needs: static lighting scenarios can be used to support task-related needs, and dynamic and spectrally tunable lighting can provide a flexible and adjustable work environment.

The static lighting scenarios need to sustain different pedagogical activities: personal work (drawing, model making, screen-based activities), group discussions, table-based tutorials, pin-up assessments, computer projections, etc. The dynamic and spectrally tunable light can respond to different programs: changes in intensity and directionality of lighting, changes in colour temperature and spectral power distribution.

3.2.2. Objective 2

The second specific objective of this study can be formulated as:

- *In the design studios of architectural schools, how to support the students with an appropriate lighting strategy in order to respond simultaneously to their visual comfort and the needs of non-visual well-being and to their diversified working/living schedule?*

This objective aims to address the various students' needs in the studios to ensure their comfort, health and well-being. The lighting strategy has to be adapted to their work requirements, allowing a clear visibility of their tasks, without risks of excessive contrast or discomfort due to glare, a clear view to the outside, yet with capacity for the lighting conditions to be adapted, e.g., for self-illuminated tasks such as work on computer screens. The lighting needs also to take into account that students spend a large part of their academic life within the studio spaces, at times with limited access to external exposures for circadian entrainment.

In order to meet these two objectives, it is essential to understand the actual requirements of students and the luminous qualities (and quantities) of the spaces they occupy, currently and in the future. Two surveys, a campaign of measurements, and a series of simulations, will help to characterise these needs and to propose lighting strategies that can be adapted to these various demands.

4. Materials and Methods

The “Ateliers” Vinci

4.1.1. Introduction

In order to better identify the specific needs of the students of the Faculty LOCI, it is essential first of all to understand the characteristics of the studio spaces they are currently occupying in the building Vinci, represented in Figure 13. This building houses the Faculty LOCI (Faculty of Architecture, Architectural Engineering and Urbanism), as well as the Department of Civil Engineering of the Polytechnic of Louvain-la-Neuve. The building hosts the offices for the administration and the academics, but also the studios, a great hall, informatic rooms, a library, etc. All these different functions need specific lighting. This building is located in Belgium, in the town of Ottignies Louvain-la-Neuve, in the Walloon Brabant region as shown in Figure 14.

Figure 13 *– The Vinci building Vinci. Source: (Baldwin et al., 2023)*

Figure 14 *- Belgium map. Source: https://fr.wikipedia.org/wiki/Fichier:ZP_5275_-_Zone_de_Police_Ottignies-Louvain-la-Neuve.GIF*

The Vinci was one of the first buildings to be built in this new town during the 1970’s. It is situated at the end of a pedestrian area that cuts through the entire city of Louvain-la-Neuve. Figure 15 clearly shows the circulation within the city, and the squares that are encountered along the pedestrian route (marked in yellow). The figure clearly shows the link between the building (marked in red) and this pedestrian axis.

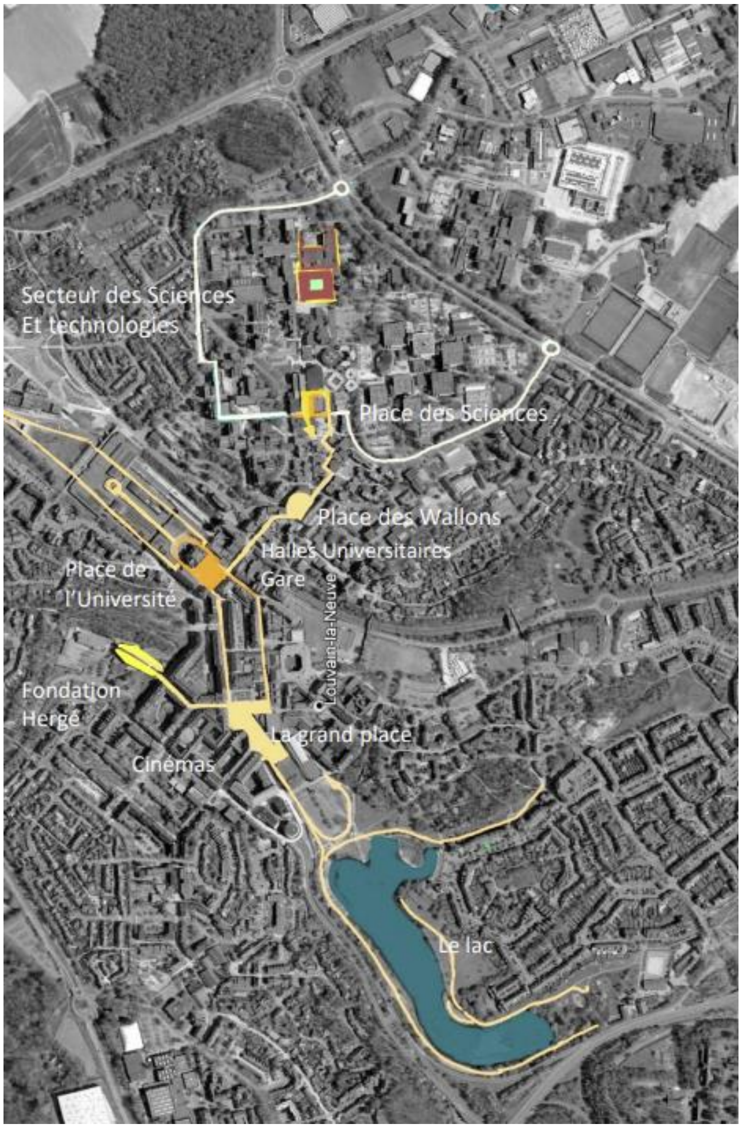


Figure 15 *- "Le site et la ville, les jalons repères du centre-ville". Source: F. Andrieux et Y. Lepère (2022)*

The Vinci building is organised in four wings arranged around a central courtyard. Each of the four wings is oriented in a different direction: north, south, east, and west, as it can be seen in Figure 16, where the 3D sun path is also shown. The distribution of functions follows these orientations, as the northern wing hosts the great hall, juxtaposed to the construction engineering labs, the north and south wings contain offices, and the west wing houses the studios. It is important to notice in that image the six skylights are opened on the roof to let even northern light to the staircases and to the studios on the first floor.

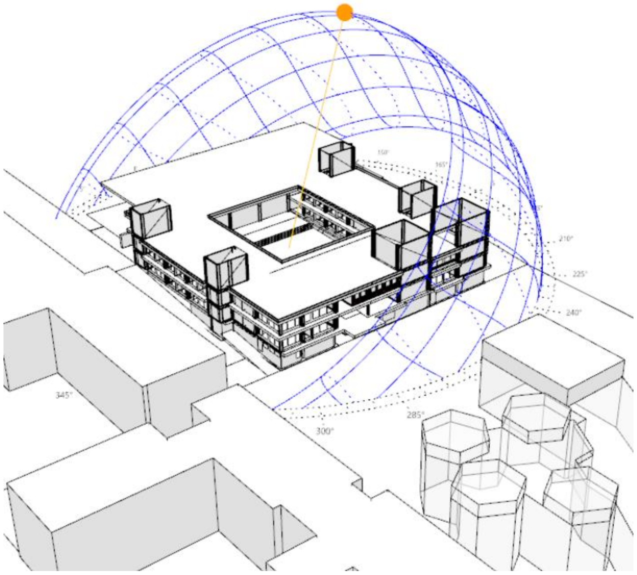


Figure 16 *- The Vinci. Source:(Baldwin et al., 2023)*

The analysis of the Vinci building aims to fully characterise the specific needs of the students of the Faculty LOCI, so that the requirements for appropriate spaces, and their correct lighting strategies, can be transferred to the design of the new building that has been proposed to host the studios in the future.

The analysis has been structured to address three specific questions:

- Collect *cross-sectional quantitative and qualitative data* to understand the levels of comfort that students perceive in the building, while emphasising specific needs, and the potential avenues of development for the arrangements of spaces and their lighting strategies
- Perform a *measurement campaign of the studios spaces* in order to validate the data obtained by building performance simulation software.
- Engage directly with the students via *point-in-time questionnaires* to relate the subjective experience of students to the physical characteristics of the spaces they occupy.

The following paragraphs of this section present the measurement (4.1.2) and simulation tools (4.1.3) used in the study of the Ateliers Vinci, describe the surveys that were conducted in the building (4.1.4), the methods and sequence for the collection of the data (4.1.5), and those used for their analysis (4.1.6).

4.1.2. Measurement Tools

As presented in Figure 12, this research has been structured on a number of steps, each requiring the utilisation of specific instruments that are presented here below.

Camera with Fish-eye Lens

A camera with fish-eye lens was used to evaluate point-in-time lighting scenes through the creation of luminance maps of the studios. This was done via the technique known as *High Dynamic Range* (HDR) modelling in order to identify the quantity and quality of the light that falls in the eyes of the occupants. A HDR image is an addition of multiple exposures of the same scene to have a higher range of brightness.

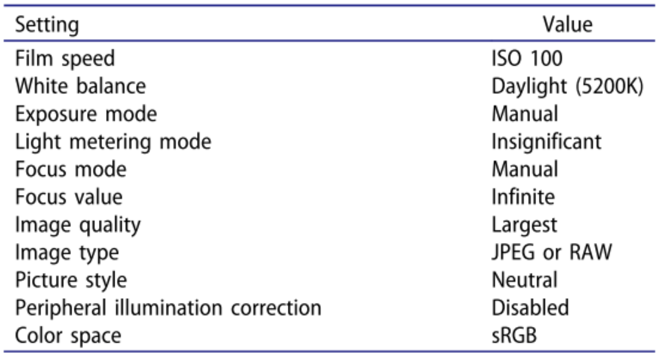
For the creation of a HDR image, it is important to follow a structured methodology, which has been clearly established in the lighting scientific literature (Pierson, Cauwerts, Bodart, & Wienold, 2020).

The methodology requires a software to generate a calibrated HDR fisheye image. For this thesis, *Photosphere* was used to apply photometric adjustments, but other software such as *qDslrDashboard* or *Radiance* can also be used. Then, the other materials needed are:

- A Digital Single-Lens Reflex (DSLR) camera;
- A circular fisheye lens compatible with the camera;
- A tripod to take the sequence of multiple exposures;
- A calibrated spot luminance meter and a middle grey target to calibrate the image;
- A calibrated illuminance meter to check the validity of the calibrated HDR image;
- A computer to process the HDR image;
- A ND filter could be needed if the sun or a very bright surface is in the field of view.

After checking the suitability of all the equipment needed, some camera settings have to be made. These need to be kept constant during the whole calibration process and the elaboration of every luminance maps. Table 3 provides an overview of these settings.

Table 3 *-Camera settings for HDR photography. Source: (Pierson et al., 2020)*



Setting	Value
Film speed	ISO 100
White balance	Daylight (5200K)
Exposure mode	Manual
Light metering mode	Insignificant
Focus mode	Manual
Focus value	Infinite
Image quality	Largest
Image type	JPEG or RAW
Picture style	Neutral
Peripheral illumination correction	Disabled
Color space	sRGB

The step-by-step procedure to generate a HDR fisheye image is here synthetised below and then presented in Figure 17.

1. Capturing a sequence of multiple exposure as Low Dynamic Range (LDR) or traditional images with the settings presented in Table 3 of the visual scene; the camera should be set on a tripod to minimize misalignment problems.
2. Selecting the useful exposures considering that taking the clearest and the darkest is fundamental.
3. Merging the exposures to generate the HDR image by using the predefined camera response function.
4. Nullifying the exposure value.

5. Resizing and cropping the HDR image by using the predefined fisheye view coordinates.
6. Adjusting the projection of the HDR image by using the predefined distortion function.
7. Correcting the vignetting of the HDR image by using the predefined vignetting curves.
8. Correcting the alterations of the HDR image due to the Neutral Density (ND) filter, if one was used, by using the predefined ND correction function.
9. Adjusting the photometry of the HDR image by using the measured spot luminance value.
10. Editing the HDR image header by using the predefined projection type and real viewing angle.
11. Checking the validity of the HDR image by using the measured vertical illuminance, and, if needed, the predefined luminous range (Pierson et al., 2020).

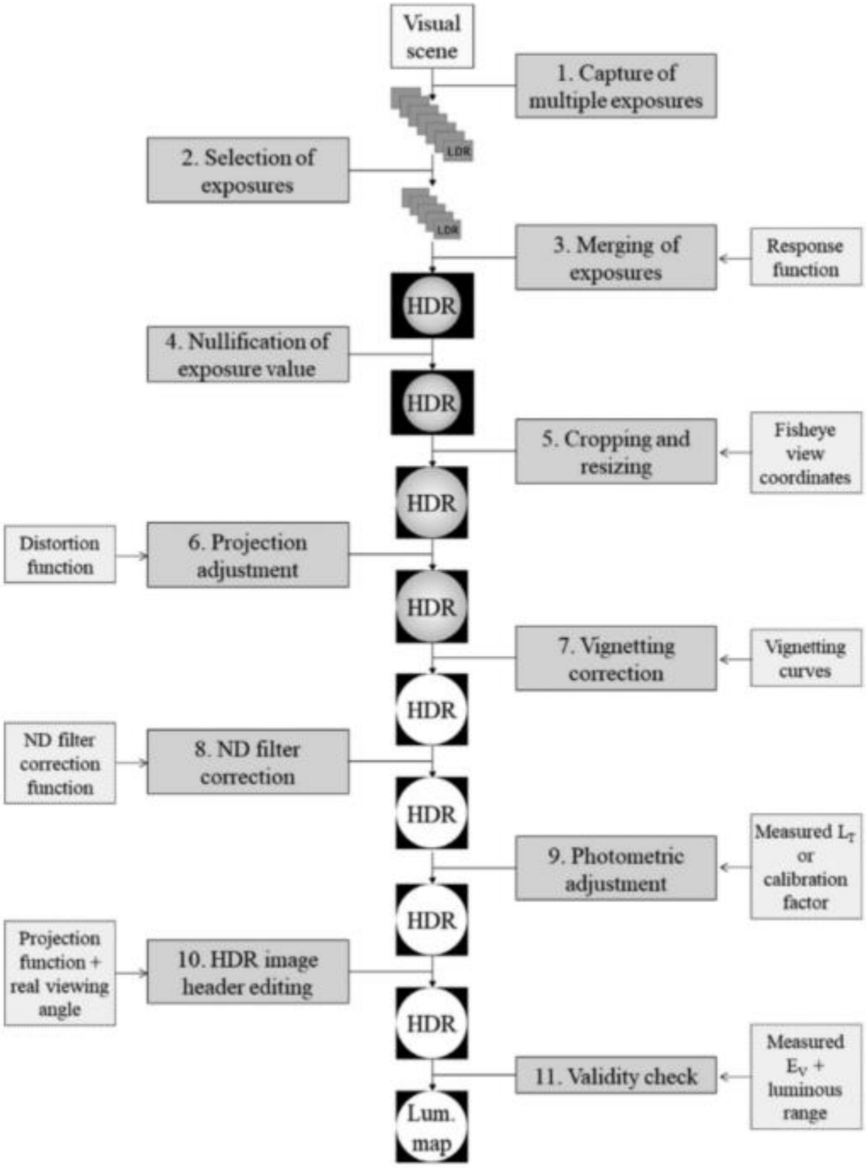


Figure 17 *- Step-by-step procedure to create a 180° luminance map from a visual scene with daylight using HDR photography. Source: (Pierson et al., 2020)*

To realize the sequence of multiple exposure LDR images, Pierson et al. (2020) recommended to take up to 15 images, although a lower number of frames might also be appropriate in scenes that are not characterised by excessive light variations (e.g., as it is often the case inside buildings). In this research, for every HDR image, 7 LDR images were taken under a large range of exposures (from darker to brighter). The time of the aperture chosen were: 1/1000, 1/500, 1/250, 1/125, 1/60, 1/30 and 1/15.

CRI (Colour Rendering Index) Illuminance Meter CL-70F

To measure the physical characteristics of the light available within the current studio building, the CL-70F from Konica Minolta (Konica Minolta, 2020) was used, as shown in Figure 18. This device, made for measuring colour and illuminance, allows to easily capture the quantity, quality, spatial distribution, and spectral characteristics of natural and electric lighting. This CRI illuminance meter takes measures within the 380-780 nm wavelength range by increments up to 1 nm. It is very easy to use because it is compact, lightweight, and handheld. It has a rotating sensor head and a touch screen for ease of operation.

Figure 18 *- CL-70F - Source: (GmbH, 2023)*

The measured light source can either be constant or a flashlight emitting within the range of 1 to 200.000 lux, with a colour temperature ranging from 1.563 to 100.000K. Alternatively, it can have a range of 20 to 20.500 lux with a colour temperature between 2.500 and 100.000K (Carmon, 2020). According to Konica Minolta, the potential applications of this flexible device are the following (GmbH, 2023):

- Measurement and evaluation of special illumination sources used for restaurants, museums, studios, and stages, etc.;
- Measurement and evaluation of indoor light sources such as LEDs, fluorescent lamps, etc.;
- LED billboard development, quality control, and maintenance;
- Evaluating the illuminance distribution characteristics of LED modules or lighting fixtures;
- Building and interior lighting research;
- Spatial lighting production and adjustment;
- Colour-viewing cabinet maintenance;
- Projector light source research and colour inspection;
- Measurement of luminous environments for psychological research experiments.

The CL-70F device allows the visualisation of different diagrams that enable a quick overview of the measurements directly when they are taken (Figure 19). Moreover, a complete .csv file regrouping the recorded information about the lighting can be downloaded from the device memory (Figure 20).


Ra 81.9

lux 5841x
x 0.3653
y 0.3706

lux 5841x
Tcp 4397K
Δuv 0.0018

lux 5841x
Tcp 4397K
Δuv 0.0018
x 0.3653
y 0.3706

Figure 19 *- Display mode examples. Source: (GmbH, 2023)*

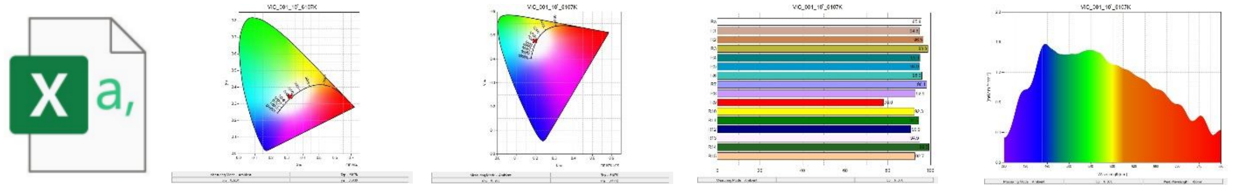
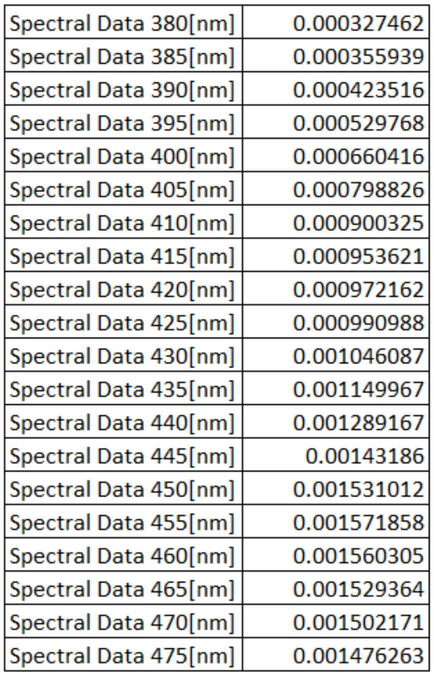

VIC_001_10_6107K VIC_001_10_6107K_CIE1964 VIC_001_10_6107K_CIE1976 VIC_001_10_6107K_ColorRendering VIC_001_10_6107K_SpectralDistribution

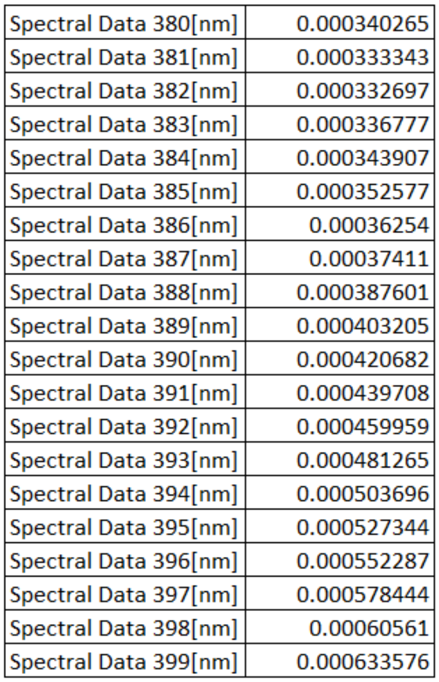
Figure 20 *- CSV file with spectral and Illuminance information, and diagrammatic visualizations of data. Source: Author*

There are four different diagrams generated by the device: a CIE 1931 diagram, a CIE 1976 diagram, a colour rendering diagram, and a spectral distribution diagram. The .csv file contains all the information about the measurements such as date, hour, etc. As it is presented in Figure 21 and Figure 22, it is possible to retrieve the spectral data for all wavelengths between 380 and 780 nm by increments of 1 or 5 nm. These data can be used to plot spectral power distributions, as shown in Figure 23.



Spectral Data 380[nm]	0.000327462
Spectral Data 385[nm]	0.000355939
Spectral Data 390[nm]	0.000423516
Spectral Data 395[nm]	0.000529768
Spectral Data 400[nm]	0.000660416
Spectral Data 405[nm]	0.000798826
Spectral Data 410[nm]	0.000900325
Spectral Data 415[nm]	0.000953621
Spectral Data 420[nm]	0.000972162
Spectral Data 425[nm]	0.000990988
Spectral Data 430[nm]	0.001046087
Spectral Data 435[nm]	0.001149967
Spectral Data 440[nm]	0.001289167
Spectral Data 445[nm]	0.00143186
Spectral Data 450[nm]	0.001531012
Spectral Data 455[nm]	0.001571858
Spectral Data 460[nm]	0.001560305
Spectral Data 465[nm]	0.001529364
Spectral Data 470[nm]	0.001502171
Spectral Data 475[nm]	0.001476263

Figure 21 *- Spectral data every 5 nanometers. Source: Author*



Spectral Data 380[nm]	0.000340265
Spectral Data 381[nm]	0.000333343
Spectral Data 382[nm]	0.000332697
Spectral Data 383[nm]	0.000336777
Spectral Data 384[nm]	0.000343907
Spectral Data 385[nm]	0.000352577
Spectral Data 386[nm]	0.00036254
Spectral Data 387[nm]	0.00037411
Spectral Data 388[nm]	0.000387601
Spectral Data 389[nm]	0.000403205
Spectral Data 390[nm]	0.000420682
Spectral Data 391[nm]	0.000439708
Spectral Data 392[nm]	0.000459959
Spectral Data 393[nm]	0.000481265
Spectral Data 394[nm]	0.000503696
Spectral Data 395[nm]	0.000527344
Spectral Data 396[nm]	0.000552287
Spectral Data 397[nm]	0.000578444
Spectral Data 398[nm]	0.00060561
Spectral Data 399[nm]	0.000633576

Figure 22 *- Spectral data every 1 nanometer. Source: Author*

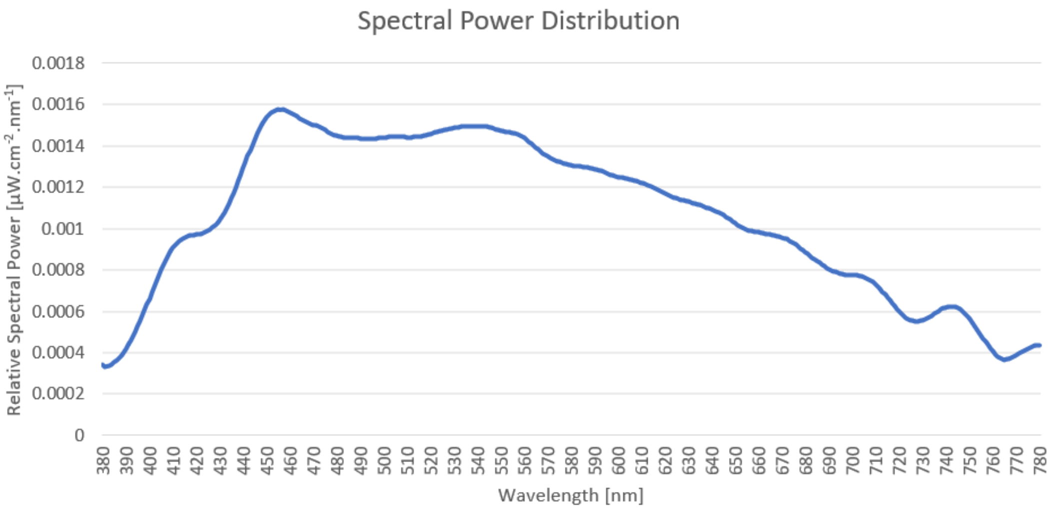


Figure 23 *– Example of spectral power distribution. Source: Author*

4.1.3. Simulations – ClimateStudio

ClimateStudio is a powerful plugin for the Rhinoceros 3D software, performing environmental analysis for the architecture, engineering, and construction sectors. This tool allows running simulations in order to help designers to optimize their buildings in several ways. Simulations with different objectives are possible: energy efficiency, daylight access, electric lighting performance, visual and thermal comfort, and other measures of energy performance and occupant comfort and health (Solemma-LLC, 2022).

Within the context of the research, the sun and daylight analysis were carried out via Climate Studio. Thanks to this software, point-in-time and annual data were able to be considered.

First, as already shown in Figure 16, the *sun path and shadows analysis* can be run to understand how the sun is moving around the building. Then, a *point-in-time* or an *annual glare simulation*, as presented in Figure 24, utilising the metric DGP (Daylight Glare Probability) can be conducted. This simulation allows to visualise – thanks to a scale from grey, yellow, orange, and red (from imperceptible through to intolerable) – the probabilities of glare occurrence for every point within a space and looking in a range of possible directions (from 2 to 16 different orientations).

The diagrams at the bottom of Figure 24 depict the glare sensation that is likely an occupant looking in a given direction might perceive for every hour of a day and year, respectively. The percentage on the y-axis (marked as % view hours) corresponds to the percentage of view hours across the floor area when occupants might experience perceptible, disturbing or intolerable glare for at least 5% of occupied hours. This 5% setpoint can be changed at the user's convenience in order to respond to different lighting regulation requirements (Solemma-LLC, 2020).

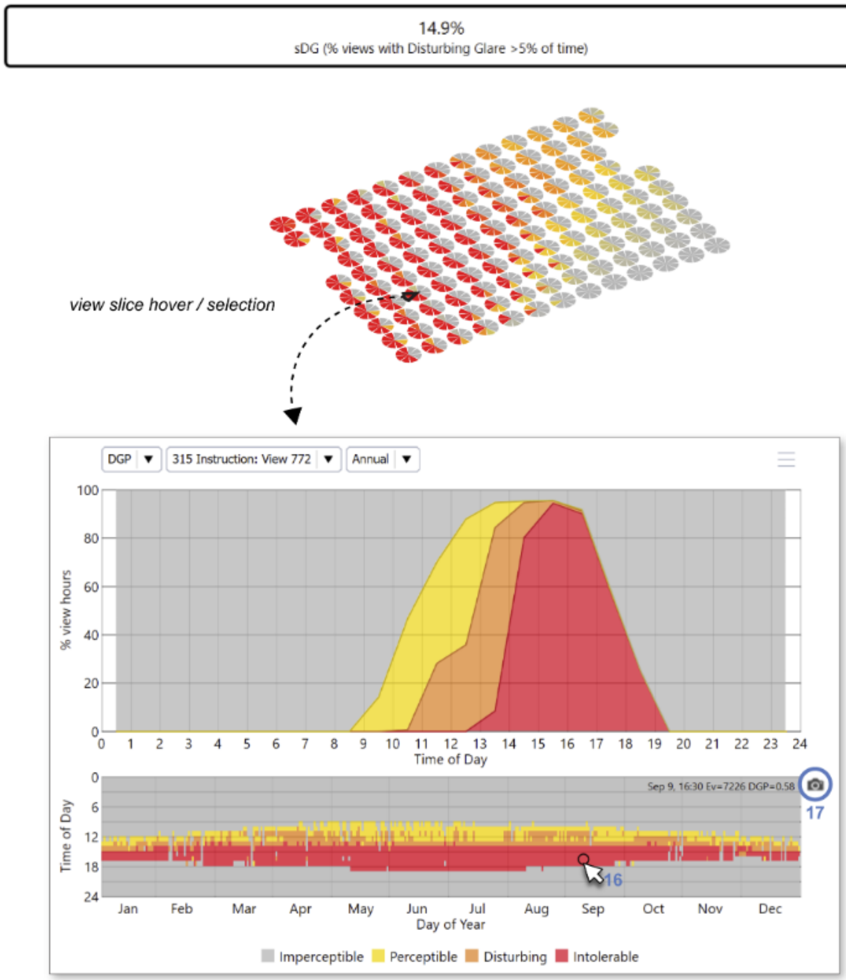
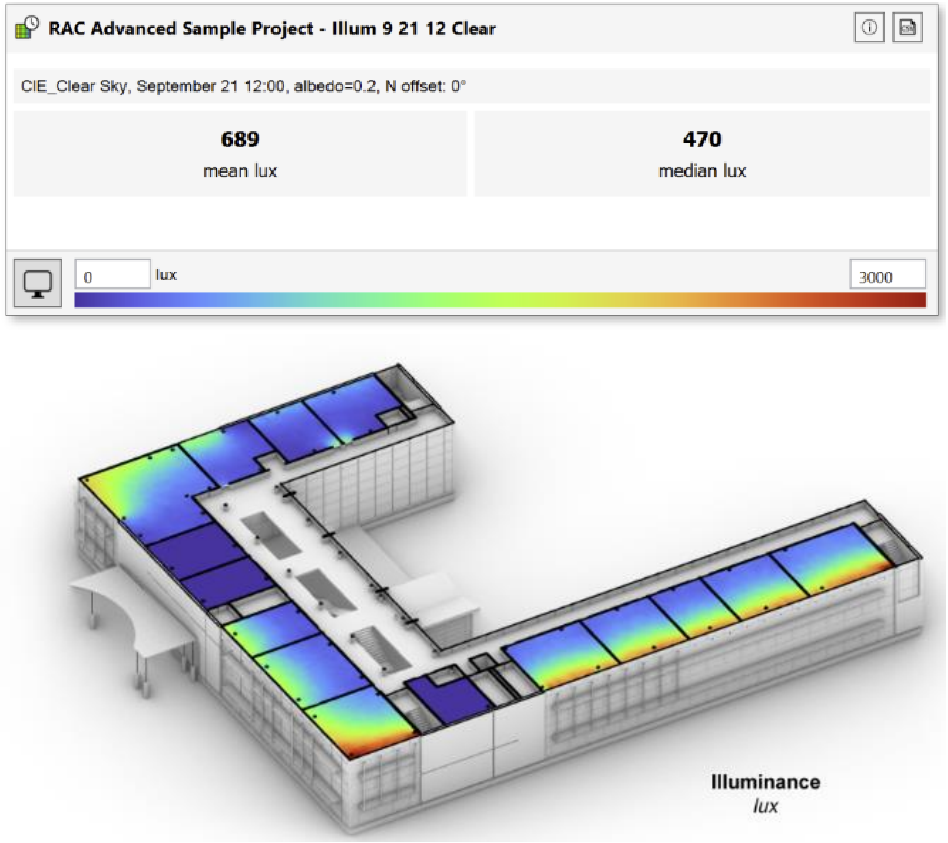


Figure 24 *- Annual glare simulation. Source: (Solemma-LLC, 2020)*

A further type of simulation that was carried out in this thesis looked at *point-in-time illuminance*, which presents illuminance distribution for electric light and/or daylight at a specific moment in time. For the Vinci building, only the illuminance distribution for daylight was simulated with ClimateStudio. Electric lighting was considered for the simulations of the newly proposed building, but these analyses were run through another tool that will be presented in detail in the section 4.2 of this thesis.

An example of daylight simulation results is presented in Figure 25. The dashboard allows the users to visualise the mean and median illuminance for the whole simulated floor area. A heatmap describing the distribution of illuminance over the surface analysed is displayed on the 3D model of the building, developed using Rhino. Before running this simulation, it is necessary to define a grid size to choose the distance between the illuminance's datapoint. The dimension of each grid cell has been defined as a square of 0.4m x 0.4m for the purpose of this thesis, according to the established literature (Reinhart, et al., 2006).



RAC Advanced Sample Project - Illum 9 21 12 Clear

CIE_Clear Sky, September 21 12:00, albedo=0.2, N offset: 0°

689
mean lux

470
median lux

Figure 25 *- Point-in-time illuminance. Source: (Solemma-LLC, 2020)*

The last type of simulation used in this study focused on daylight availability and distribution through the calculation of the *Daylight Factor*, which is defined as the ratio between the illuminance at a point in the building and the illuminance at an upward facing unshaded point on the outside, under a CIE overcast sky. The daylight factor is measured as a percentage and its minimal value in buildings needs to be in a range between 2% and 5%. Again, the dashboard shows the mean and the median data of the daylight factor and the 3D model on the Rhino viewport contains a heatmap showing its distribution across the floor areas selected (Figure *26*).

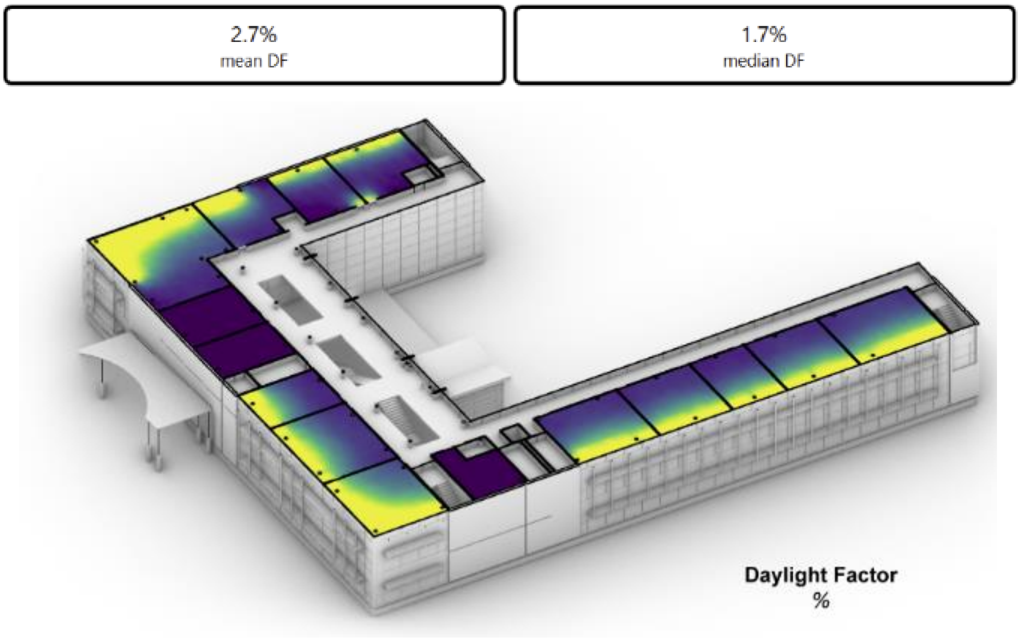


Figure 26 *- Daylight Factor. Source: (Solemma-LLC, 2020)*

4.1.4. Surveys

Another tool used to collect information about the current studios in the Vinci building is represented by surveys. Two different surveys were organized to question the students about their feelings concerning the lighting strategy of the “ateliers” Vinci, to characterise their profiles and requirements (e.g., their chronotype - early or late), and scope their preferences about lighting strategies more appropriate to their needs. In both cases, the participants were architecture students using the building.

Two different types of survey were utilised: cross-sectional and right-now. The questionnaires forms used for both data collection campaigns are presented in the Appendix (A and B) to this thesis. All forms and procedures used in this study to collect human-subject data had previously been submitted for ethical approval to the IPSY ethics committee at the University of Louvain. The *cross-sectional* survey was delivered online in order to get a general understanding of the preferences and needs of the students in terms of the lighting currently delivered in the studios. After the data from the cross-sectional survey had been collected and analysed, a *right-now* survey has been set up in order to get a clearer picture of the specific issues that students had identified (e.g., the lack of lighting in certain areas of the studio, the occurrence of discomfort due to glare at certain times of the day, etc.). In order to contextualise the feedback from the users, the right-now surveys were administered on paper-based forms, which were filled in by the students at the same time while physical and photometric measurements were taken.

It is important to emphasise that cross-sectional surveys (often, also called *transversal*) aim primarily to collect general views and feedback about the building, hence they are not necessarily related to specific conditions, times of day or seasons. Conversely, due to the need to investigate specific issues reported in the transversal data collection, the right now survey had to be organised under particular conditions, e.g., on sunny days to explore issues of glare that are spatially and temporally bound (these surveys, in fact, are also referred to as *point-in-time*).

4.1.5. Methods for Data Collection

The data collection necessary to characterise students' needs in the "ateliers" Vinci was structured on three different steps: measurements, simulations, and surveys. The aim of this section is to describe in detail the methods and sequence used for all these steps, as already illustrated in Figure 12, chapter 3.

As the initial step of this research, a cross-sectional survey was conducted to broadly characterise the occupants of the studios. Following this, photometric measurements were taken in the Vinci studios to contextualise the results from the survey, and also as a way to validate the results that can be obtained by simulation of the building. To this purpose, a 3D model of the Vinci was acquired by the author, this having been already constructed by the Master students taking the course LICAR 2801 - Édification soutenable. This measurement campaign specifically focused on collecting data of horizontal illuminance under an overcast sky in order to compare the data with the 3D simulation of Climate Based Daylight Modelling (CBDM) metrics obtained through the use of the ClimateStudio plugin in Rhinoceros.

Once these steps were completed, an analysis was performed to compare the *quantitative* data (measurements and simulations) with the *qualitative* data provided by the students (cross-sectional survey). This process allowed a better comprehension of the studios in terms of lighting strategies and enabled to identify areas where further explorations and clarifications were needed via the right-now surveys. Finally, when all the information had been gathered, the following step of the work could be taken focusing on the proposal for the new building (whose research methods are described in section 4.2).

Cross-sectional Survey

The cross-sectional survey was carried out to understand the requirements of the students in the current studios, as they will be the same occupants of the newly proposed building. The online questionnaire asked students to respond to questions focused on the natural and electric lighting strategies in the "atelier" Vinci, but also aimed at gathering views and opinions on their preferred lighting strategies. A total of 36 students responded to the survey, which represents more than 30% of the population under investigation.

The questionnaire was divided in four different parts:

- General demographic information to characterise the population responding to the survey;
- The use of the studios, their timing of presence, duration, periods of the year, etc.;
- Their perception of comfort with the current lighting and their preferences and needs;
- Their chronotype to better understand their lighting requirements beyond task performance.

Campaign of Measurements

A campaign of measurements was conducted in the three studios located on the first floor of the Vinci building. The measurements were performed in the presence of daylight only, as one of its main aims consisted in the validation of the results of the CBDM daylight simulations performed via ClimateStudio. For this reason, only the CL-70F CRI Illuminance meter was needed, mounted on a tripod.

A grid of 1.2m x 1.2m was set up – to reduce the number of data points, yet staying coherent with the dimensions of 0.4m x 0.4m of the grid that is normally utilised for building performance simulation – and the points were clearly marked with masking tape on the studio floors. A denser grid for the measurements campaign was considered not necessary for the purpose of the validation. The grid was set at a minimum distance of 0.5. from perimetral walls in order to also capture the contributions from light reflected off vertical surfaces. Figure 27 shows the placement of the CL-70F meter on the tripod with the masking tapes indicating the locations where measurements had to be taken.

***Figure 27** – The CL-70F Illuminance meter mounted on a tripod. Source: Author*

The campaign was realized in March 2023 and required the verification of a number of conditions. An analysis of the sky was first needed since measurements needed to take place under even sky luminance. A day with overcast sky was therefore chosen to collect the data. In fact, if the sky is partly clear, some direct sunlight might penetrate the building, leading to measurements that are going to be very different from one point to another. A HDR image of the sky was created to depict the sky luminance distribution utilising the method explained in the previous section. Then, to have a precise characterisation of external light, a measurement with the CL-70F was required to obtain its spectral power distribution. Secondly, measurements were taken from inside the building. A measure needs to be taken at every point of the grid previously defined. The CL-70F device was mounted on a tripod at the same height than the drawing tables to capture the horizontal illuminance on the work plan of the students. When tables were located at a position corresponding to the points on the grid, the illuminance meter was simply placed on top of the table (Figure 27).

***Figure 28** – Horizontal measurements on a desk surface. Source: Author*

Due to the size of the studios, and its different main orientations (Est, South, West), it was necessary to take external light spectrum recordings from every location to ensure consistency of measurements. In addition, each studio was divided into three or two zones, depending on their size, and in the middle of each zone, a recording of the light spectrum was also made in order to get a better understanding of the characteristics of internal light, for example due to the spectral transmission through the glazing or reflection off internal surfaces (walls, floor, furniture, etc.). At every point of the grid, it was important to note the time and the specific location of the measurement, the illuminance in lux and the colour in Kelvin in order to compare these with the simulations.

A tailored training was provided prior to the actual measurement campaign, to ensure a better understanding of how the instruments worked and how data needs to be collected.

Simulation

After the conclusion of the measurement campaign, simulations were performed on ClimateStudio to compare the results and, thus, validate the 3D model for further lighting investigations.

The simulations of the “ateliers” Vinci comprised point-in-time analyses that were run at the same date, time, and locations as the measurements. For the purposes of the validation, the grid was initially set with the same dimensions of the measurement data, hence 1.2m x 1.2m. A daylight factor analysis was also performed, since this parameter could be easily derived from the internal and external measurements.

The data from the measurements and the simulations were compared in two ways:

- The first was to compare the distribution of the daylight factor obtained from the measurements, by dividing the internal illuminance at each point on the grid by the external illuminance value, with that obtained from the point-in-time simulations, obtained with a similar procedure.
- After that, a comparison with the annual daylight factor computed by the simulation was made.

All results presented and explained in the Results chapter. Following the validation, further lighting simulations (with a denser grid) were run to contextualise the feedback obtained within the cross-sectional survey and, consequently, determine the areas where the right-now survey had to be carried out.

Right-now Survey

The last analysis to be performed in the current design studios at the Vinci consisted in administering to students the right-now survey. This involved engaging five students, whose working desks were located at different places within the studios. The locations and times for the surveys were determined as follows:

- two desk locations parallel to the windows facing east to run analysis in the morning;
- one desk location in front of the windows facing east;
- one desk location situated below a north-facing aperture in the roof;
- one desk location parallel to the windows facing south to run analysis at midday.

The instruments required to run this survey included a tripod, a camera with fish-eye lens, the CL-70F, a luminance gun and a sensor to measure temperature and relative humidity. The method implied providing a paper-based form of the questionnaire to the students after having collected their informed agreement to participate. While the survey was being filled in, measurements were taken to characterise the physical and photometric quantities and qualities of the lighting conditions.

The measurements included a HDR image from the student's viewpoint in order to make a luminance map of their visual scene, horizontal and vertical illuminance, the spectral power distribution of the lighting (irrespective of whether daylight was complemented or not by electric lighting at the time of the survey), and finally a recording of thermal conditions. The luminance gun was used to calibrate the HDR image. Indeed, a grey card located at the centre of each LDR image was used to know exactly the luminance (cd/m²) on this target while the HDRI was constructed.

4.1.6. Analysis methods

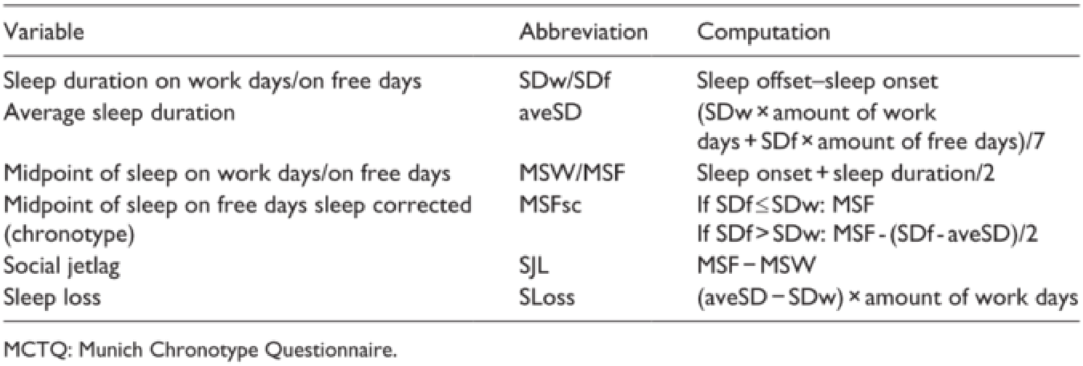
Cross-sectional Survey

Given that the needs of students are a priority in this research, it was essential to carry out a precise analysis of the cross-sectional survey data, looking specifically at the answers to each question.

First, an analysis of the demographic data of the population responding to the survey was performed in order to determine the profiles of the students. Then, it was necessary to evaluate the statistical distributions of every response focused on the "atelier" Vinci, including considering where students' desks are located, how much time per day and per week they spend in these working spaces, and how they feel in the studios. The answers related to the lighting strategies were then analysed, also including an evaluation of students' preferences and aspirations. Finally, a characterisation of the respondents' chronotype was completed in order to ascertain subjective habits and needs, and therefore inform the definition of non-visual lighting strategies.

For the definition of chronotype, it was considered that : "*the assessment of [chronotype] phase is a central task in circadian biology*" (Roenneberg, 2012). To find everyone's type, the Munich Chronotype Questionnaire (MCTQ) was included in the survey, collecting the variables shown in Table 4. Individual chronotype was calculated through the MSFsc variable, which is defined as the "*midpoint of sleep during free days sleep corrected*" (Dimitrov, et al., 2020). Consideration was given also to other variables, such as social jetlag and average duration of sleep. To analyse these them, various descriptive statistics were calculated, including the mean, median, standard deviation, and minimum and maximum values.

Table 4 *- MCTQ variables with their abbreviations and computation. Source: (Dimitrov et al., 2020)*



Variable	Abbreviation	Computation
Sleep duration on work days/on free days	SDw/SDf	Sleep offset–sleep onset
Average sleep duration	aveSD	(SDw × amount of work days + SDf × amount of free days)/7
Midpoint of sleep on work days/on free days	MSW/MSF	Sleep onset + sleep duration/2
Midpoint of sleep on free days sleep corrected (chronotype)	MSFsc	If SDf ≤ SDw: MSF If SDf > SDw: MSF - (SDf - aveSD)/2
Social jetlag	SJL	MSF − MSW
Sleep loss	SLoss	(aveSD − SDw) × amount of work days

MCTQ: Munich Chronotype Questionnaire.

To have the correct statistics, people who set an alarm during their free days were excluded. It was also considered that age and gender of participants could influence their chronotype (Roenneberg et al., 2007): for instance, women's chronotype is on average earlier than men (Dimitrov et al., 2020). To give an example, Figure 29 presents a diagram with the chronotype distribution across a population of 55,000 people, observed in a study by (Roenneberg et al., 2007)

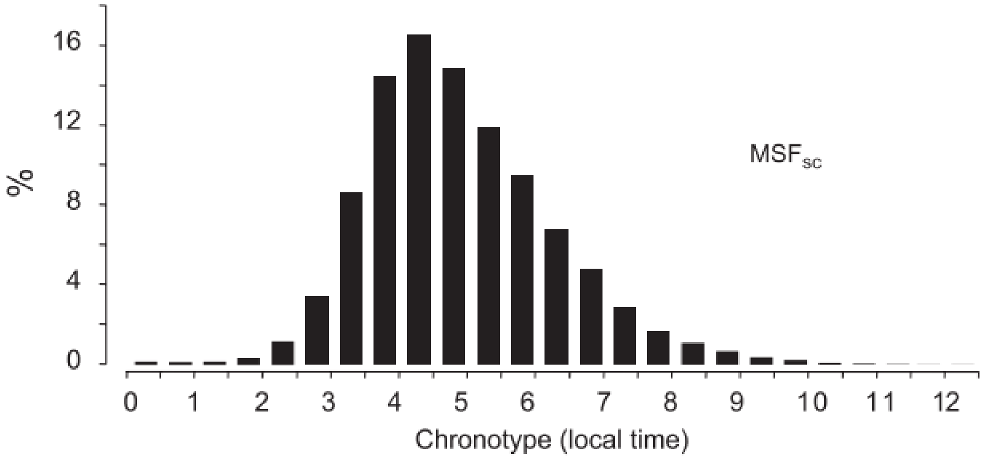


Figure 29 *– Distribution of chronotypes judged by MSF corrected for the sleep-debt accumulated during the workweek (MSFsc). Source: (Roenneberg et al., 2007)*

According to Roenneberg, the distribution of MSF$_{SC}$ in central Europe is centred around 4:00, this signalling that people generally go to bed on free days at midnight and wake up at around 8:00. With this average, people having a MSF$_{SC}$ at 3:00 or earlier can be associated to the *early* (often called 'larks') chronotypes and those with a MSF$_{SC}$ at 5:00 or later to the *late* (often called 'owls') types (Roenneberg, 2012).

Measurement Campaign and Simulations

The data collected during the measurement campaign and the results of the simulations performed via ClimateStudio were compared primarily through line charts. Obviously, the comparisons were not made on the basis of absolute values since external illuminance coming from the sky vault might differ based on the specific lighting conditions available during the measurements also when conducted under an overcast sky (e.g., due to differences in cloud density, moving clouds, or other sudden change in atmospheric conditions). These effects could imply alterations in distribution of sky luminance, intensity, and colour of the lighting. Instead, trends were considered to analyse the distribution of horizontal illuminance throughout the spaces. This approach was used for the three studios analysed in the existing building.

In addition, it must be considered that the measured data might also be dependent on the level of maintenance of the existing building (e.g., the cleanliness of glazing) or due to obstructions from the furniture that could not be included in the simulated model (as, for example, seen in Figure 30). These considerations, of course, could justify some differences between measured and simulated data, whereas perfectly diffusive material properties (Lambertian) were mostly assigned to internal objects and surfaces.

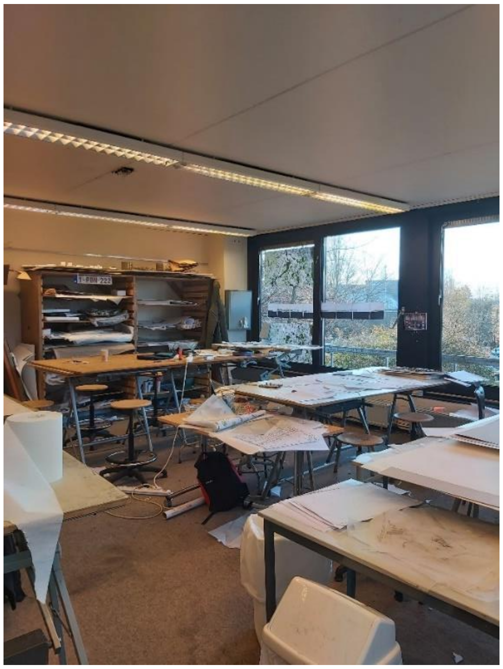


Figure 30 *- Obstructions within the current studios. Source: Author*

Following the validation of the 3D model through measured data, further simulations were run to contextualise the feedback obtained from students within the cross-sectional survey. This included analysis of other metrics, such as horizontal daylight autonomy, useful daylight illuminance, and annual glare, as per the example presented in Figure 24, Figure 25 and Figure 26. These simulations focused specifically on analysing areas that had been reported as critical within the answers to the questionnaires, as for example, the working areas located in the vicinity of the north-facing skylight, or the perimeter of the studios where risk of glare occurrence were reported. The information gathered was then used to select the specific zone in which further investigation was conducted through the right-now surveys.

Right-Now Survey

The final step of the analysis conducted within the “ateliers” Vinci included consideration of the results of the right-now survey and of the data measured while the five students provided their responses. This analysis was mostly conducted on a qualitative basis to emphasise how students perceive the lighting conditions in their working space, and to consider the need to address individual requirements such as the avoidance of visual discomfort due to glare. The HDR images collected during the right-now campaign also allowed a comparison with similar luminance maps that could be elaborated via computer simulations. Such modelling also included testing of the tool to be utilised for the analysis of the new studio building (OWL, Occupant Well-being through Lighting), which will be described in the following section (4.2).

Ultimately, the data collected within the right-now survey allowed the complete characterisation of the lighting conditions existing at the Vinci, and consideration of the specific needs that students of architecture require to comfortably perform their work, but that also meet the requirements of their profiles. This information will be paramount to test the lighting solutions proposed for the new studios, and propose guidelines and recommendations as part of the specific objectives of this thesis.

4.2. A New Studio Building

Following the analysis centred on the "ateliers" Vinci, the second phase of this research aims to focus on the new building that has been proposed to host the design studios for the LOCI students of architecture. This section will first present the design principles that are proposed to be implemented in this new building. Secondly, the tools used for its analysis will be introduced and, finally, a reflection will be made about recommendations for lighting strategies and solutions.

4.2.1. Introduction

The new building will be built on the university campus and will be an extension of the Vinci, completely dedicated to host the studios for the students in architecture. This building, designed by Yves Lepère and Fréderic Andrieux is currently in the conclusive stages of the design process and, therefore, not yet in construction. Unfortunately, during its final stages of definition, the architect Yves Lepère has passed away. For this reason, the thesis will be based on the current state of development of the project, aiming to test and validate the design solutions in terms of its lighting performance, and recommending some complementary strategies that could improve meeting the needs of the pedagogy and the specific requirements of the students (including both, visual and non-visual effects of light).

Figure 31 and Figure 32 present the driving principles of the project. The entrance of the new building will be the extension of the great hall of the Vinci and the shape of the new construction will be inspired by the skyline of the current building so that the façade of the studios can capture plenty of northern light.

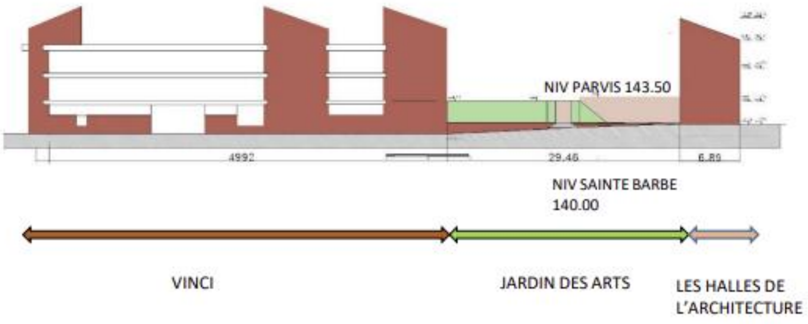


Figure 31 *– Concept section. Source: F. Andrieux and Y. Lepère*

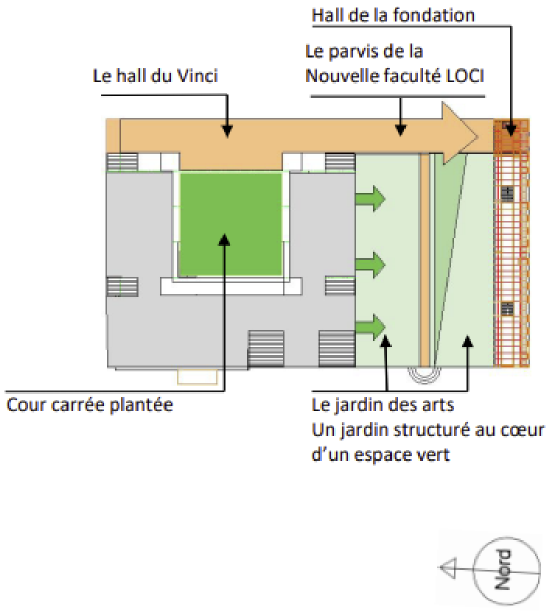


Figure 32 *- Concept plan. Source: F. Andrieux and Y. Lepère*

A garden will be located between the two buildings. It will be called the "Jardin des arts", which means the garden of the arts. The distance between the two structures has been adjusted to respect the design proportions of the Vinci building. All images are reproduced in this thesis courtesy of the design team.

4.2.2. Design Principles

The design principles of this building are intended to support all the activities that take place in an architectural studio. This means that the light that enters these spaces is really important because, as said in the chapter about the pedagogy, students (and teachers) are going to perform very visually demanding tasks, such as drawing or making models.

The most significant principle is to let abundant light ingress from the north and to obstruct almost entirely the light coming from the south. Indeed, in a studio, occupants prefer working constant light from the north than very variable light coming from the south. This strategy, in fact, allows to have less contrasts and to keep an even luminous environment from the start to the end of the day.

The two main façades, north and south, are hence very different from each other, as it can be seen in Figure 33. The north façade is very open, with high windows to collect light from the sky in contrast to the south façade that has very small openings to reduce as much as possible the penetration of direct sun light.

Figure 33 *– F1: Facade north (top) and facade south (bottom). Source: F. Andrieux and Y. Lepère*

Another interesting principle of this building is represented by the interior design. The spaces are divided in such a way to let the maximum space on the north for students to work. Figure 34 and Figure 35 present the plans of the three floors of the building, showing three big areas for the drawing and working tables at the ground and first floor oriented to the north. These three areas are separated by the stairs so that three different activities can take place at the same time. A gallery is located towards the south façade, at the mezzanine level. In this way, students can use the partitioning walls to display their drawings. On the ground and first floor, the internal distribution includes the positioning of shelves that can be closed, so as to form an additional vertical surface to display drawings. Working tables are also located at the mezzanine level, overlooking towards the studios and protected from the south light by partitioning walls.

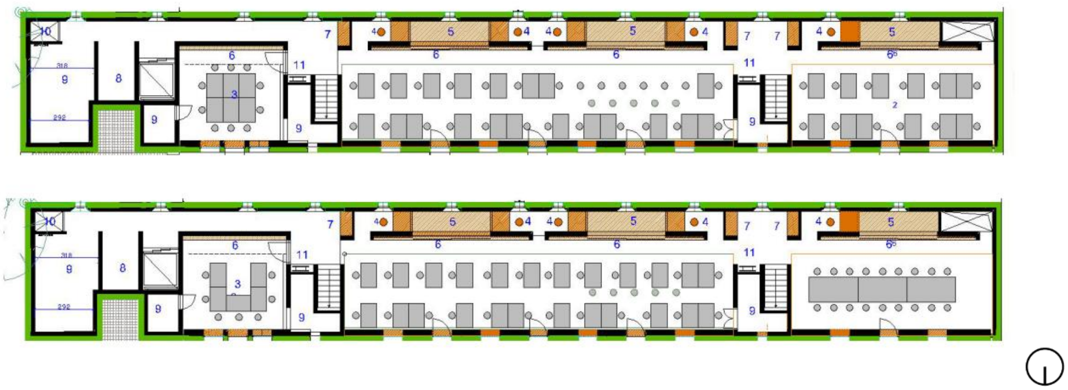


Figure 34 *- Ground floor and first floor. Source: F. Andrieux et Y. Lepère*

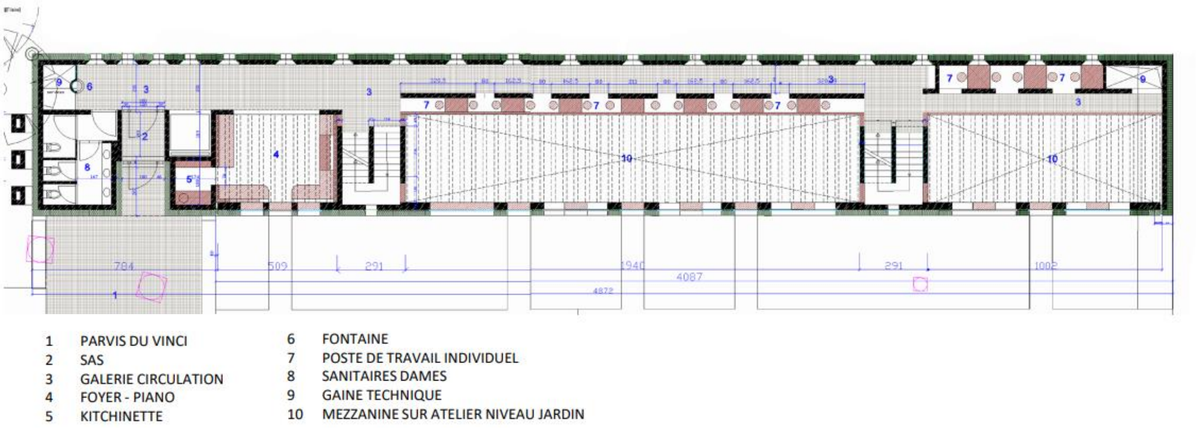


Figure 35 *- Gallery/mezzanine floor. Source: F. Andrieux et Y. Lepère*

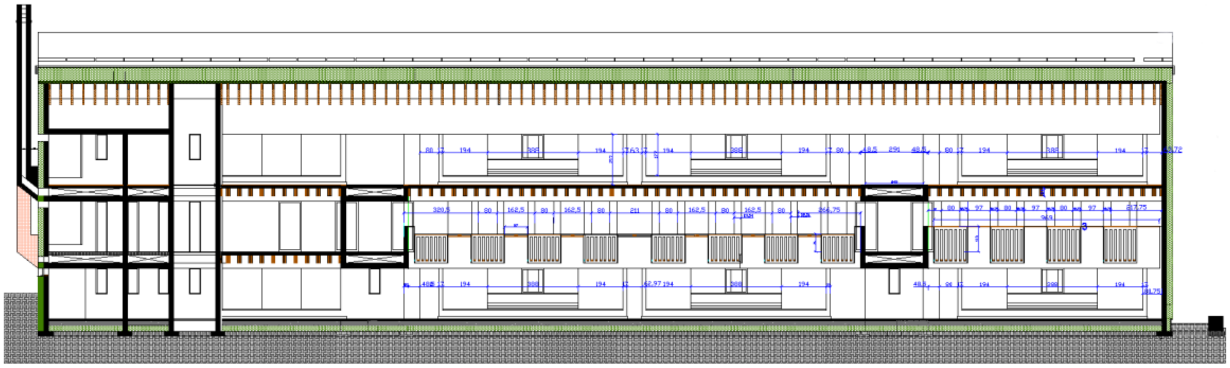


Figure 36 *- longitudinal cross-section. Source: F. Andrieux et Y. Lepère*

The principles for the internal distribution of spaces are also visible in the cross-sections presented in Figure 36 and Figure 37. On these, it is easy to observe the two different spaces: shelves and the mezzanine on the left (towards the south), and studios on the right (towards the north). These cross-sections also show how the walls separate the ground floor studios, but these are not present at the first-floor level, so that there is a visual connection between these spaces.

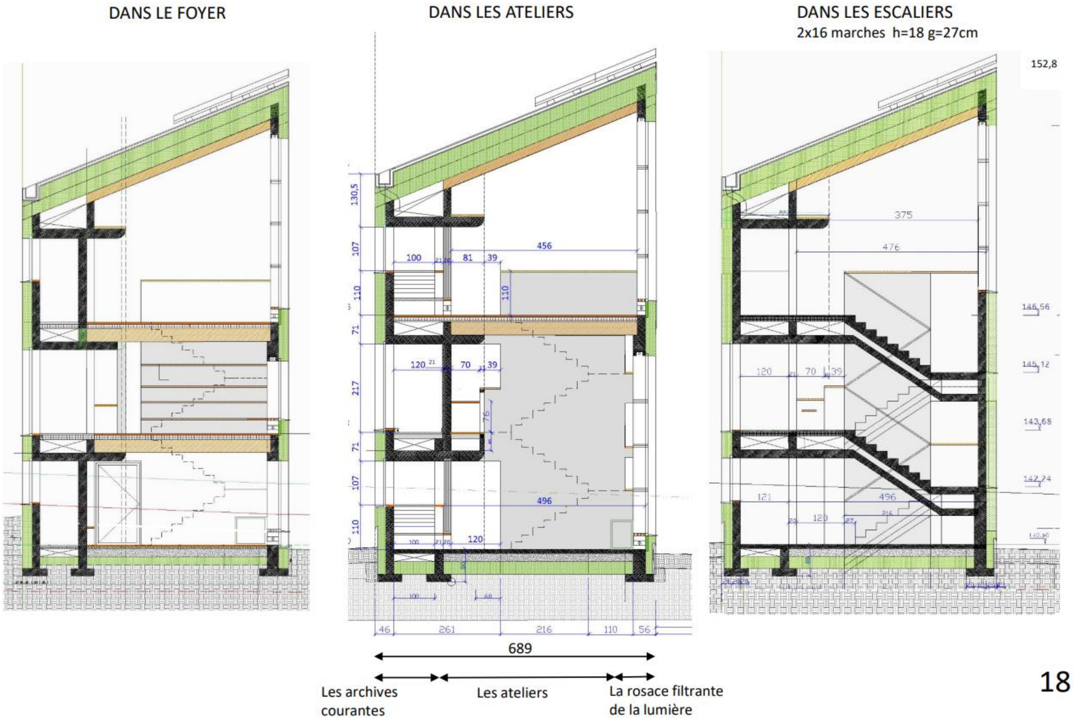


Figure 37 *- Cross-sections. Source: F. Andrieux et Y. Lepère*

An alternative design of the façade will also be analysed, since this was another option that was considered at some point of the design development. This option is very different from the other one, with windows that have a rectangular shape rather than the trapezoidal form presented in the other version as presented in Figure 38.

Figure 38 *– F2: Alternative design for the north façade. Source: F. Andrieux et Y. Lepère*

To simplify the reader's understandings, the first façade shown will be labelled as Façade 1 (F1) and the second one will be Façade 2 (F2). For each option, large windows are placed on the north side to provide as much constant light as possible for working. The east, west and south façade (which is very obstructed) are the same in the two different versions. Only the shape of the northern windows has been changed between the simulations performed to analyse the lighting performance of the two façade options.

4.2.3. The OWL Simulation Tools

In addition to the lighting analysis performed with ClimateStudio, other simulations with new tools will be carried out to evaluate the lighting conditions of the new building for visual and non-visual performance. For this purpose, this research has implemented in its methods the use of a recently released simulation tool – developed by Dr Marshal Maskarenj and called OWL (Occupant Well-being through Lighting) – which is currently being extended with new functionalities. In the following parts of this thesis, reference will be made to OWL1 and OWL2, to distinguish the two versions of this software tool.

OWL1 has already been published as a tool that can evaluate the non-image-forming effects (NIF) of light to support the human circadian rhythm. To quantify the potential NIF effects available within an internal visual scene, OWL uses different non-visual metrics: melanopic irradiance, melanopic-ELR, melanopic-DER, melanopic-EDI, Circadian Light and Circadian Stimulus (Marshal Maskarenj, Deroisy, & Altomonte, 2022). The most relevant for the purpose of this thesis is the Circadian Stimulus (CS), since this metric has been chosen also in OWL2 as the most immediate measure of the circadian effects of light for comparison of different lighting scenarios.

Courtesy of its developer, this section presents the simulation workflow of the yet unpublished OWL2 tool (nicknamed *Annu-OWL*, to distinguish its annual-based evaluations from the point-in-time analysis of OWL1), its origin, how it works and the outputs it provides. This section of the thesis directly derives from a research paper describing the functioning and potentials of the OWL2 tool for annual simulation. The paper, for which the author of this thesis is also a co-author, will be presented at a forthcoming Radiance workshop in Innsbruck, Austria, in summer 2023 (M. Maskarenj, Crevits, & Altomonte, 2023).

Origin and Use

As already presented in earlier sections of this thesis, ClimateStudio is a commercial tool for building performance simulations that can be used for lighting simulations and for evaluating the point-in-time and annual performance of a space. Moreover, it is also capable of performing thermal simulations. However, lighting evaluation needs much higher spatial resolution in comparison with thermal simulations, and even higher one if the simulations need to be resolved for multiple view angles. This increases the complexity of annual lighting simulations for a given space. In the context of this thesis, ClimateStudio allows to analyze the lighting performance of the spaces: areas without sufficient daylight are identified using horizontal CBDM metrics, such as the quality of their distribution. The visual needs of students can, therefore, be understood thanks to ClimateStudio, while the non-visual requirements for current studios can only be inferred based on the information gathered within the cross-sectional survey. However, application of the new OWL2 tool is needed to determine the non-visual performance of the new building. Most importantly, the tool is necessary to perform simultaneous evaluations of visual, nonvisual, and energy needs, in order to provide comprehensive lighting design recommendations. This, in fact, needs a concurrent assessment of metrics for visual comfort (e.g., DGP), lighting sufficiency (e.g., DA), and circadian potential (e.g., CS).

Functioning

This section aims to explain step by step how to perform these simulations with a given building geometry in Rhino. The first step is to edit the location of the file where all the data will be stored. The simulation takes as inputs hourly environmental data, such as direct normal radiation, diffuse horizontal illuminance, etc., which are recorded in EPW (Energy Plus Weather) files. In addition to that, a SPD file (which is a .csv file) needs to be specified to clarify the location data in Grasshopper.

The second step is to import a geometry on a 3D Rhino model and import it as inputs on Grasshopper. The different geometries that have been used here are shown in Figure 39 (e.g., walls, glazing, etc).

The geometrical parameters of the space, along as material definitions (reflectance, transmittance, bidirectional scattering distribution function, etc.), define the interaction between light and the space, and thus are important as inputs. In this given geometry, it is necessary to add points where people will be sitting to specify them as inputs for the position where the vertical metrics will be evaluated. After these inputs are entered, they will be used to transform the data into annual information. The framework of these first steps can be seen in Figure 39 and Figure 40, and explanations are provided below:

- **‘*ExportOBJ*’:** This custom Grasshopper component exports selected Rhino geometry as .obj files for further processing in Radiance command line. Groups of objects with similar material compositions (e.g.: walls, or glazing, etc.) need to be selected together in the geometry for parallel export (ideally using Rhino layers).
- **‘*GenMat*’:** It generates a 'materials.rad' file at the intended folder, for performing the Radiance ***obj2mesh*** function. The materials.rad file is generated based on the su2rad repository maintained by Thomas Bleicher (Bleicher, 2014), along with custom inputs from SpectralDB (Design for Climate &Comfort Lab, 2021).
- **‘*DCMatrix*’**: This custom Grasshopper component generates a daylight coefficient matrix, to be used for annual Radiance simulations. It reads the *.obj* files with material files and a *.sky* file, and renders a Daylight Coefficient Matrix as precursor to Radiance grid-based illuminance. First the Radiance ***obj2mesh*** command is used to generate individual *.rtm* files for each geometry layer, by combining with the *.obj* file and the respective material definition (extracted from the *materials.rad* file).
- **‘*IllumAnn*’**: This component takes the Daylight Coefficient matrix along with EPW weather file, to generate annual illuminance distribution via 2-phase DC method. The Annual illuminance data is generated in a .csv form. First the Radiance ***epw2wea*** command converts the *.epw* file into a *.wea* file, and further the Radiance ***gendaymtx*** command is used to convert the *.wea* file into a *.smx* file.

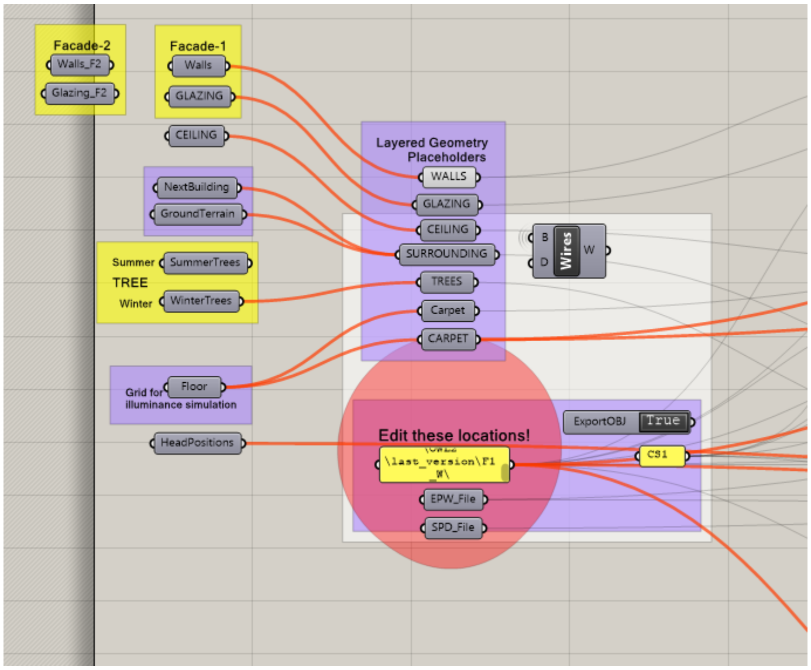
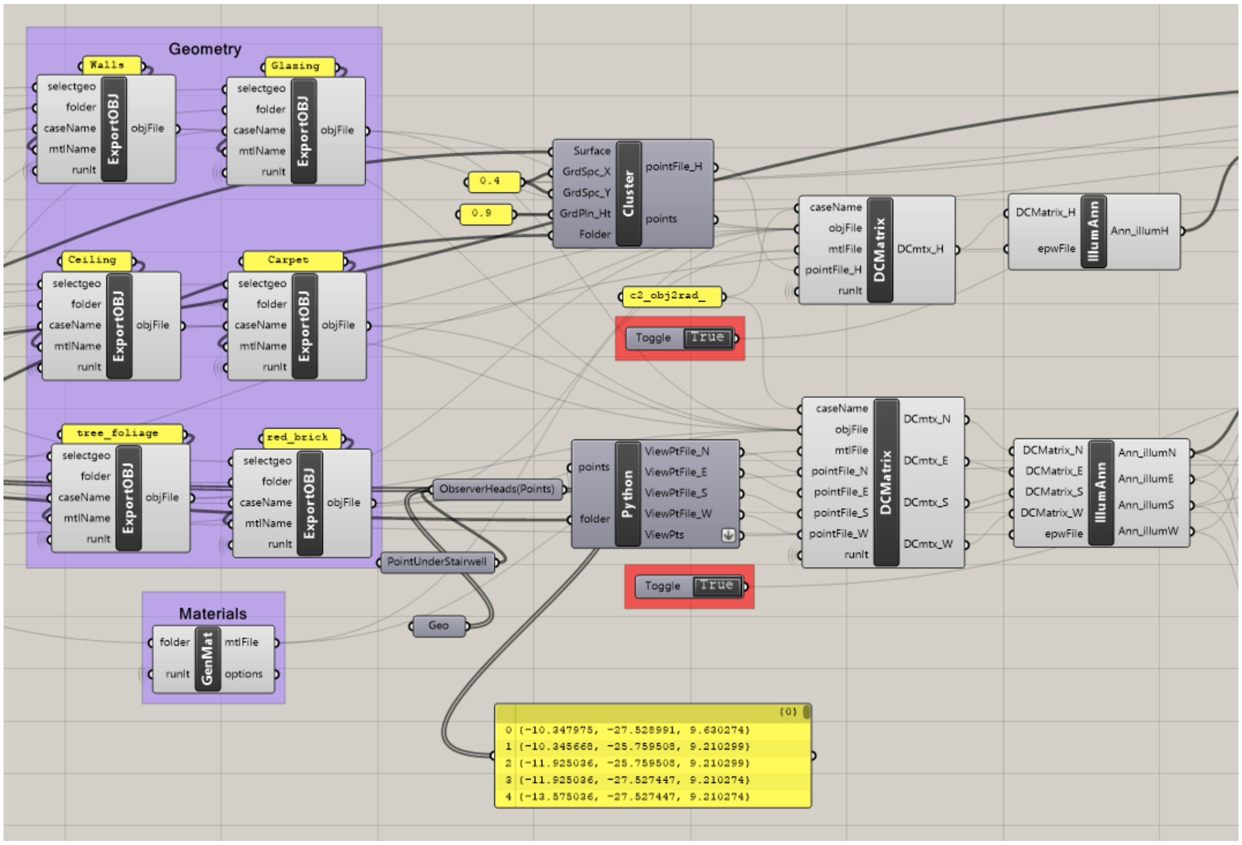


Figure 39 - *Inputs of OWL2. Source: Author*

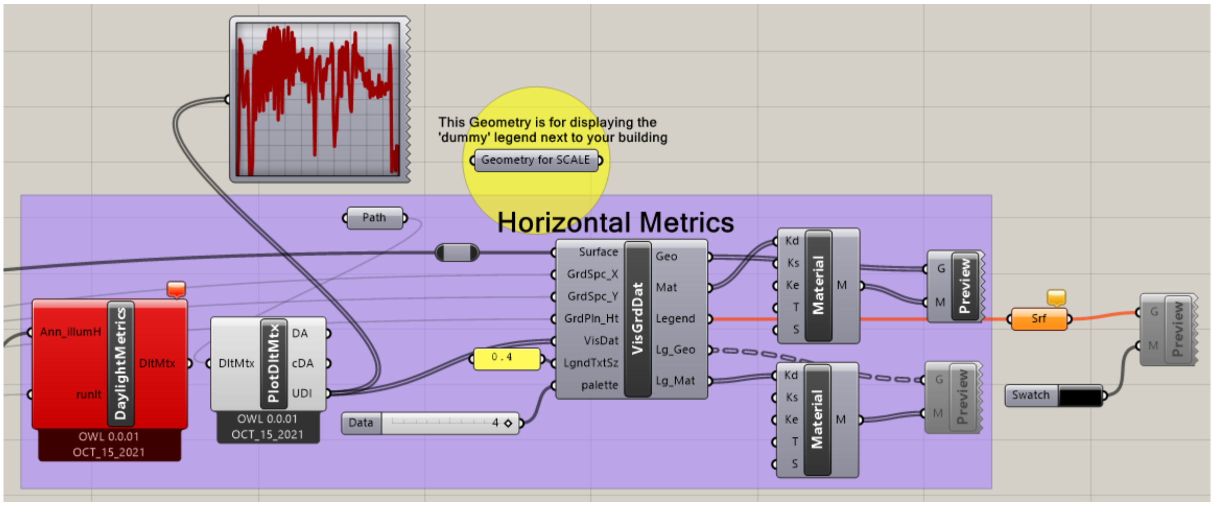


```
                                        {0}
0 {-10.347975, -27.528991, 9.630274}
1 {-10.345668, -25.759508, 9.210299}
2 {-11.925036, -25.759508, 9.210299}
3 {-11.925036, -27.527447, 9.210274}
4 {-13.575036, -27.527447, 9.210274}
```

Figure 40 - *Second part of the framework. Source: Author*

The third step is to choose the size of the grid that is needed for the evaluation of the horizontal metrics, as presented in Figure 41. In this case, a grid of 0.4m was chosen but it can easily be altered by changing the number in the yellow panel that can be seen on the image. Again, the components necessary to estimate the horizontal metrics are explained below:

- ***'DaylightMetrics'***: This component takes the illuminance data for each point over the year (from *IllumAnn* component) and evaluates the Daylight Metrics for each point. This evaluates Daylight Autonomy, Continuous Daylight Autonomy, and Useful Daylight Illuminance. For each point on the grid, this component reads the horizontal illuminance data for each of the 8760 annual hours, and depending upon the credit scoring scheme for DA, cDA, or UDI, assigns credit for each hour of the year. The credits are summed and saved in a *.csv* file that includes 3 rows (for each of the three CBDMs) across columns defined by number of grid-points. In conjunction with the *PlotDltMtx* component, this component parses and returns the CBDM credit for each grid point depending upon the defined CBDM. The data can then be visualized on the Grasshopper canvas using the *VisGrdDat* component (Visualise Grid Data), along with Grasshopper Custom Preview component.



This Geometry is for displaying the 'dummy' legend next to your building

Figure 41 *- Horizontal metrics. Source: Author*

Concerning the estimation of vertical metrics, two different types of components are necessary, for Circadian Stimulus potential and for identifying potential risks of glare:

- ***'AnnualCS'***: This component takes the annual sky SPD data (which includes CIE_Z value in addition to spectral data) and illuminance data at each vertical sensor point. It uses Truong's approximation (Truong, Trinh, & Khanh, 2020) to evaluate circadian stimulus for each point over the year. While integrating the pre-calculated spectral data (81 datapoints each annual hour) with the vertical illuminance data (number of grid points) for each hour of the year (8760 timepoints) is a possible alternative for evaluating Circadian Stimulus, Truong's approximation was found to increase the speed of the code by at least 650 times (1826sec in standard process vs 2.7sec in the presented process). This component, for each orientation, generates a CSV file (*ann_CS_X.csv*) containing the Circadian Stimulus for each grid point for each hour of the year.

- ***'CSautonomy'***: This component takes the CS data for each point over the year (from *AnnualCS* component) and evaluates the CS Autonomy for each point. CS Autonomy is defined as the percentage of days in a year when CS exceeds 0.35 for at least 1 hour in the morning (between 0800-1200 inclusive). For each vertical grid-point, for each of the 365 days of the year, the CS data is parsed between 0800h and 1200h inclusive, and if even one of these hours receives CS above 0.35, it is assigned 1 credit. The component generates a summation of credits for each grid point, as the number of annual days when sufficient CS (>0.35) is received for a morning hour at that point. This data can then be visualized on the Rhino canvas, as the inner ring of a sombrero diagram using further visualization components via Grasshopper Custom Preview component.
- ***'CS_AnnVis'***: To dig deeper into the credits received for CS for each grid point, this component generates annual heatmaps. By taking the Circadian Stimulus data for each point over the year (as a *.csv* file from the *AnnualCS* component) along with the index of the specific grid point, this component parses through the specific row for every defined grid point. This data is then transposed as a 365 x 24 array, representing the hours and days of the year, and then saved as a *.csv* file and as a heatmap as a *.png* file. The *.csv* output of this component makes it possible to define the schedule of operating circadian effective lighting for various grid points lacking sufficient CS potential.
- ***'AnnualDGPs'***: This component takes the annual vertical illuminance data at each sensor point and uses simplified DGP approach to evaluate DGPs for each point over the year. The simplified DGP approach takes the saturation component of the DGP formula, and makes an approximation of daylight glare probability from vertical illuminance at the eye level. The illuminance data at each vertical sensor point for every hour of the year (*annualillum.csv* from the *IllumAnn* component) serves as the input, which is then translated into respective simplified DGP, as: DGPs = (0.0000622 × vertical_illuminance) + 0.184.

  This component then generates a csv file (ann_DGP_X.csv) for each orientation, which includes 8760 rows for each annual hour across number of columns defined by the number of grid points.
- ***'AnnSDGP'***: This component parses through the annual DGP csv files generated by the *AnnualDGPs* component for each orientation, and post-processes it to generate credit (or debit) points for instances of glare. Glare is considered disturbing if DGP for that hour is above 0.42 (Wienold, 2014), and for each grid point across each hour of the year, the points are summed up to generate annual points for each position. This component generates a summation of credits for each vertical grid point, as the number of annual hours when disturbing glare (sDGP>0.42) is received at that point. This data can then be visualized on the Rhino canvas, as the outer ring of a sombrero diagram using further visualization components via the Grasshopper Custom Preview component.
- ***'DGP_AnnVis'***: To dig deeper into the credits/debits received for sDGP for each grid point, this component generates annual heatmaps. By taking the sDGP data for each point over the year (as a *.csv* file from the *AnnualCS* component) -- along with the index of the specific grid point, this component parses through the specific row corresponding to a grid point, and the data is then transposed as a 365 x 24 array, representing the hours and days of the year. The data is then saved as a *.csv* file and also as a heatmap in the *.png* image format.

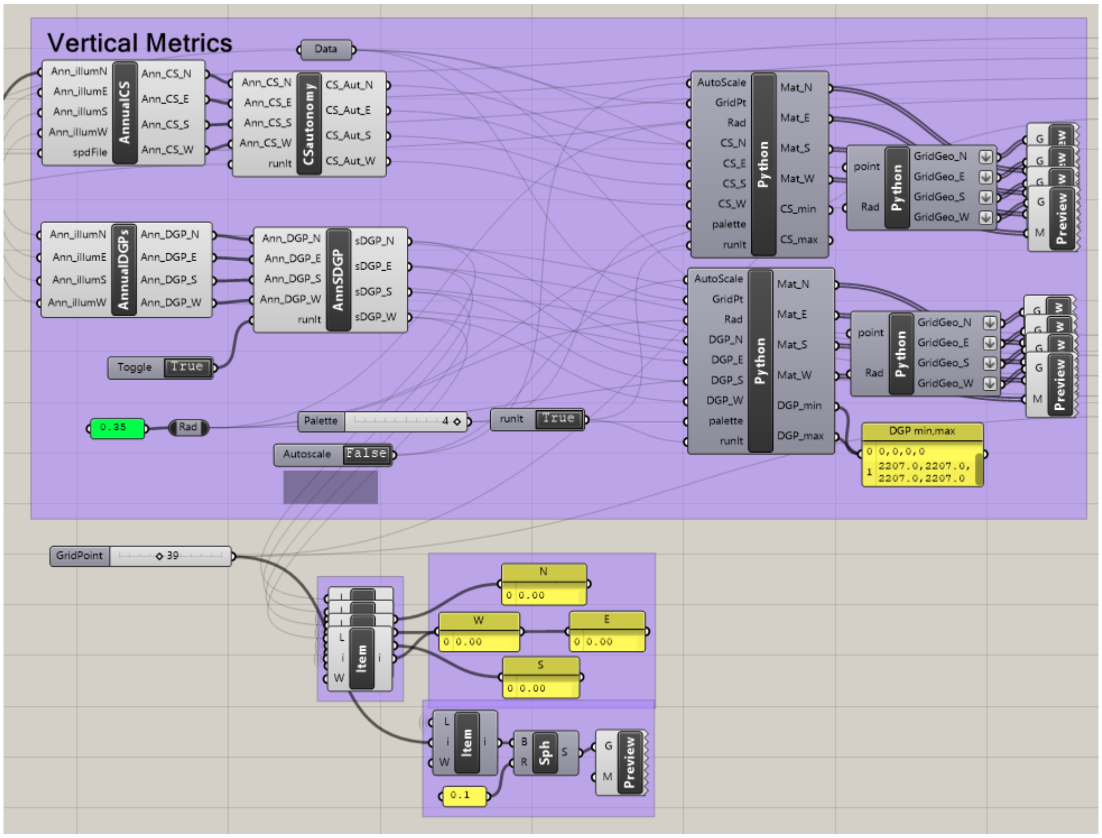


Figure 42 *– Evaluation of vertical lighting metrics. Source: Author*

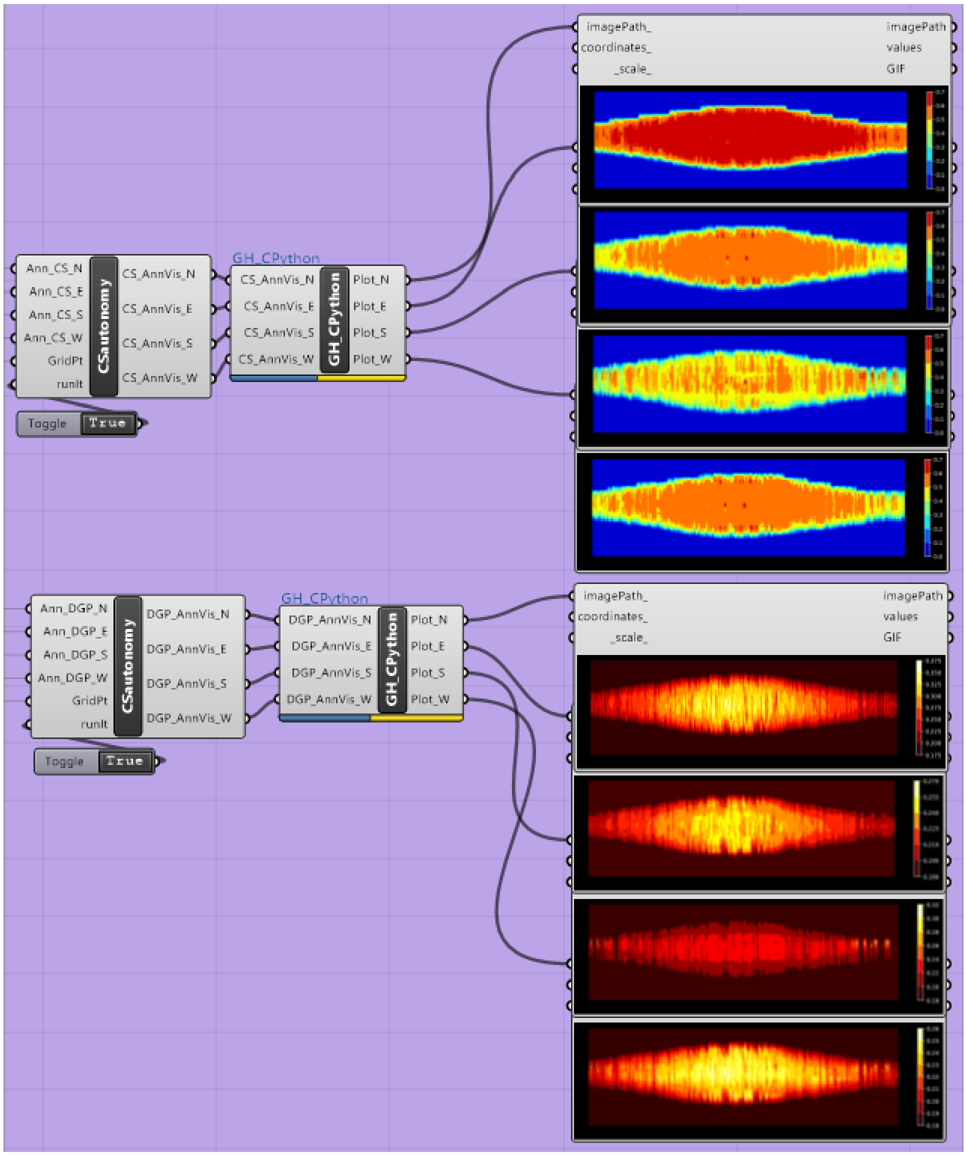


***Figure 43** – Vertical simulation results. Source: Author*

Results Provided

The results provided by OWL2 are displayed in two parts: horizontal and vertical metrics.

The horizontal results present the DA, cDA and UDI metrics that can be chosen in the *PlotDltMtx* component seen in Figure 41. To illustrate the different visualizations obtained for each metric, examples are provided in Figure 44, Figure 45 and Figure 46. These results are visible in the 3D Rhino geometry, not in Grasshopper. The scale needs to be added manually for every simulation and is expressed in hours. The grid used in the examples is the recommended 0.4m x 0.4m grid.

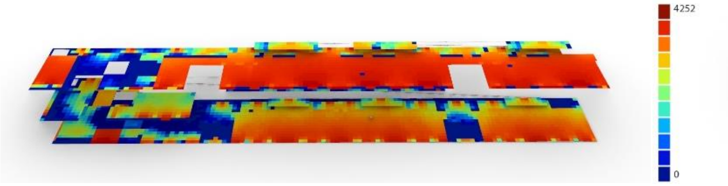


***Figure 44** - Example of DA results. Source: Author*

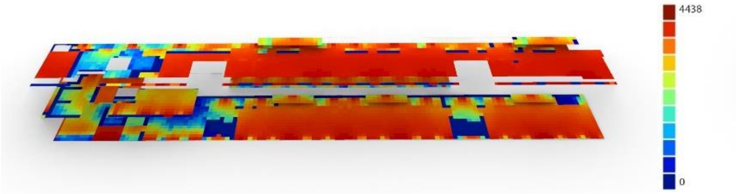


***Figure 45** - Example of cDA results. Source: Author*

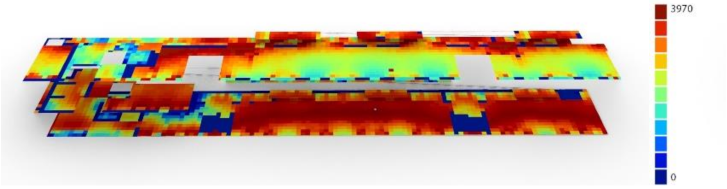


***Figure 46** - Example of UDI results. Source: Author*

The vertical results provided by OWL2 can be visualized within the Grasshopper framework (Figure 43), on the 3D Rhino geometry (Figure 47), and on the.csv files provided.

Sombrero (circle) diagrams are created on the geometry: the inner rings give us information about the CS and the external ring about the DGP. As explained before, the inner circle is red when the CS is at 100%, which is reached when CS is above 0.35 during at least one hour in the morning. The DGP has a specific scale in hours; in Figure 47, the maximum reached is 2207 hours with glare.

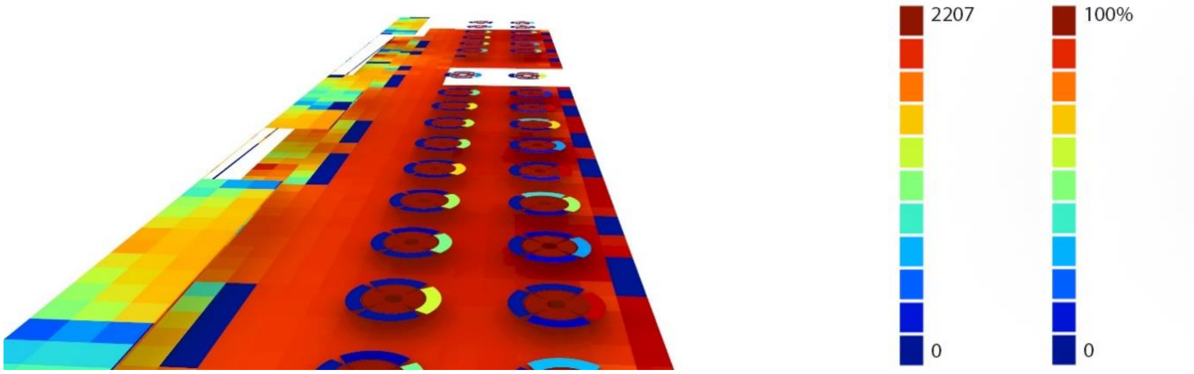


***Figure 47** - Example of vertical results. Source: Author*

This tool is powerful since it allows the visualization of different information at the same time: horizontal metrics (DA, cDA and UDI) and vertical metrics (CS and DGP). OWL2 provides accurate information as well as global estimations to globally evaluate the annual visual and non-visual performance of a space.

4.2.4. Lighting Standards

The lighting recommendations that this thesis will offer for the new building are based on the European standards EN-17037 and EN-12464-1 (CEN, 2021a, 2021b).

The EN-17037, also known as the “daylight” standard, aims primarily to increase the availability and use of daylight in buildings, providing adequately lit environments, recommending strategies to optimise the time of sun exposure of the rooms, while limiting glare, and offering an external view (Bodart, 2019). The fundamental principle on which this standard is based can be summarised as: “*a space is considered to benefit from an adequate amount of illuminance if the target illuminance level is achieved over a portion of the reference plane for at least half of the daylight hours*.”(Bodart, 2019).

The following tables summarise the recommendations for, respectively, vertical and inclined windows (Table 5) and horizontal openings (Table 6).

Table 5 *- Recommendations for vertical/inclined openings. Source: (Bodart, 2019)*

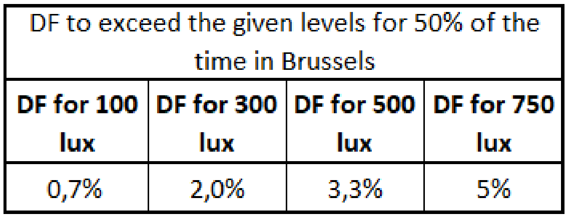
Recommendation level	**Target Illuminance [lux]**	**% of the space**	**Minimum Illuminance [lux]**	**% of the space**	**% of hours per day**
Minimum	300	50	100	95	50
Medium	500	50	300	95	50
High	750	50	500	95	50

Table 6 *- Recommendations for horizontal openings. Source: (Bodart, 2019)*

Recommendation level	**Target Illuminance [lux]**	**% of the space**	**% of hours per day**
Minimum	300	95	50
Medium	500	95	50
High	750	95	50

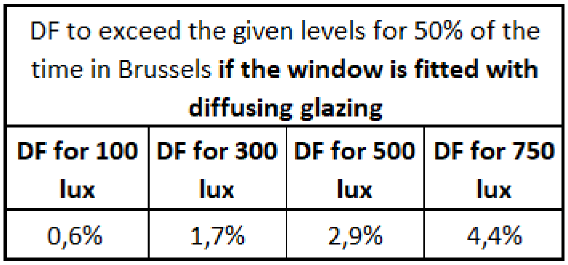
The level of illuminance required is defined by two different calculation methods: the simplified method is centred around the daylight factor (DF), as explained in Table 7 and Table 8; the second method calculates the availability and distribution of illuminance through dynamic simulations.

Table 7 *– Minimum Daylight Factor to achieve (normal glazing). Source: (Bodart, 2019)*



DF to exceed the given levels for 50% of the time in Brussels			
DF for 100 lux	**DF for 300 lux**	**DF for 500 lux**	**DF for 750 lux**
0,7%	2,0%	3,3%	5%

Table 8 *– Minimum Daylight Factor to achieve (diffuse glazing). Source: (Bodart, 2019)*



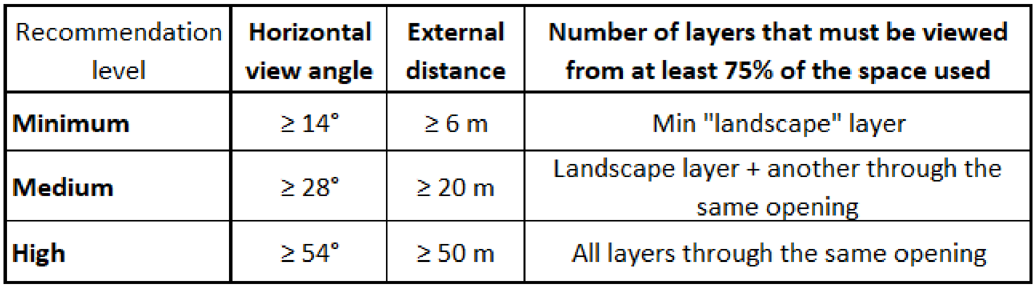
DF to exceed the given levels for 50% of the time in Brussels **if the window is fitted with diffusing glazing**			
DF for 100 lux	**DF for 300 lux**	**DF for 500 lux**	**DF for 750 lux**
0,6%	1,7%	2,9%	4,4%

The standard also sets up recommendations in terms the view that buildings need to offer to the occupants. Different principles are explained for the angle and the distance of the view:

- Natural view vs. artificial view;
- Large and distant view vs. small and closed view;
- Dynamic view vs. monotonous view;
- Clear and neutral glazing that does not distort the view.

In terms of the angle of horizontal view, distance of nearby objects and number of layers visible from the occupants' positions, the following recommendations are given (Table 9):

Table 9 *- Recommendations for the view of the outside. Source: (Bodart, 2019)*



Recommendation level	**Horizontal view angle**	**External distance**	**Number of layers that must be viewed from at least 75% of the space used**
Minimum	≥ 14°	≥ 6 m	Min "landscape" layer
Medium	≥ 28°	≥ 20 m	Landscape layer + another through the same opening
High	≥ 54°	≥ 50 m	All layers through the same opening

For optimal sun exposure, the standard recommends direct solar penetration for at least 1.5h a day between the 1st of February and the 1st of March. Conversely, the exposure is considered to be high if it is above 4h a day still within the same time period.

Finally, the EN-17037 standard gives recommendations regarding discomfort due to glare, using the Daylight Glare Probability (DGP) as a reference metric to protect the occupants from excessive light. The DGP value should not exceed the values presented in Table 10 for more than 5% of the occupancy time.

Table 10 *- Recommended Daylight Glare Probability. Source: (Bodart, 2019)*

Recommendation level	**DGP_{exceed} < 5%**
Minimum	0,45
Medium	0,40
High	0,35

The EN 12464-1 standard – "*Light and lighting. Lighting of workplaces - Indoor workplaces*" – focuses on interior lighting projects for spaces of work. The recommendations from the standard include the following parameters: illuminance (lux), Unified Glare Rating (UGR) and Colour Rendering Index (CRI).

The density of luminous flux, i.e., the quantity of light incident on a given horizontal surface, needs to satisfy the visual comfort requirements of the occupants. Minimum thresholds are provided for the work surfaces and their associated areas, such as immediate surrounding and background spaces, as shown in Figure 48. The minimum level of 500 Lux is recommended in an office because a lack of light can produce headaches, reduction of concentration, and visual problems. For design studios, given that the visual tasks are more demanding, it might be appropriate to guarantee an even higher level of horizontal illuminance, up to 750 lux (Lampesdirect.fr, 2023).

Table 11 *- Minimum illuminance and uniformity index. Source:(Baldwin et al., 2023)*

	Working area	**Immediate surrounding area**	**Background area**
Illuminance to maintain	500 lux (office) 750 lux (studios)	300 lux (office) 500 lux (studio)	1/3 of the immediate surronding area
Uniformity index		0,4	0,1

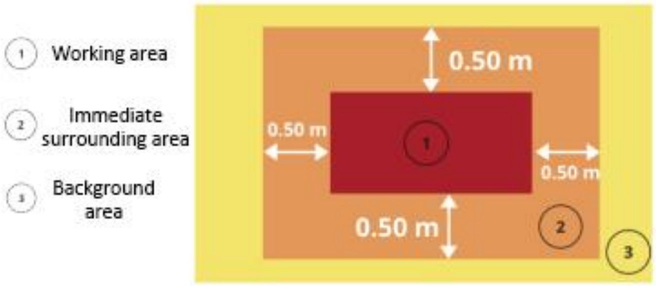


Figure 48 *– Illuminance over different areas. Source: (Baldwin et al., 2023)*

To respect the criteria for the Colour rendering index, it is important to take into account the Kruithof diagram presented in Figure 49. The colour of the light (that is, its correlated colour temperature) needs to be adapted to the level of illuminance: when illuminance increases, the colour temperature also needs to increase. Only the area B on the diagram is considered to be within the comfort zone. The luminous atmosphere of the area A is considered to be too warm, and the area C might be seen as too cold (Architecture-et-Climat, 2014).

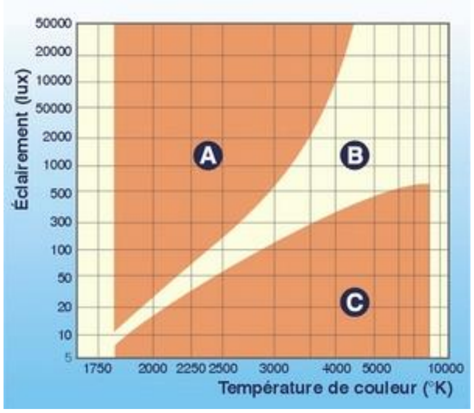


Figure 49 *- Kruithof's diagram. Source: (Architecture-et-Climat, 2014)*

These criteria are particularly relevant for artificial lighting, since specific attention needs to be given to the colour rendering index of the luminous environment. The standard advises to have a CRI above 80 for spaces occupied during a long period of the day, as presented in Table 12 (Lampesdirect.fr, 2023).

Table 12 *- Recommended CRI. Source: (Lampesdirect.fr, 2023)*

Range of CRI	**Colour perception**
CRI < 25	Low
25 < CRI < 65	Medium
65 < CRI < 90	Good
90 < CRI	High

Finally, for the Unified Glare Rating, a metric that is used to indicate the risk of discomfort due to glare from luminous sources of small size (such as luminaires), the value needs to be in the range between 16 to 28, as shown in Table 13. Yet, the recommended UGR value can vary based on the activities to be performed in the space (Lampesdirect.fr, 2023).

Table 13 *- Recommended UGR. Source: (Lampesdirect.fr, 2023)*

Room	UGR
Office	<19
Rest room	<16
Precision work (studio)	<19
Corridor	<28

5. Results

5.1. Occupant Responses

Occupants' responses to the *cross-sectional survey* were collected between the 12th and the 22nd of March 2023. As a reminder, the aim of the survey was primarily to understand the profile, needs and preferences of the students in terms of the natural and electrical lighting available in the studios, and their times of occupancy and utilisation of these spaces.

Overall, 36 people responded to the questionnaire, of whom 58.3% were female, 33.3% male and 8.3% preferred not to answer. Most participants were aged between 20 and 24 years, the median being 23 years old, as shown in Figure 50. The majority of the respondents were in the final years of study (Master students). In fact, most of the participants declared to have spent 4 to 5 years, or more, in the ateliers Vinci, as presented in Figure 51.

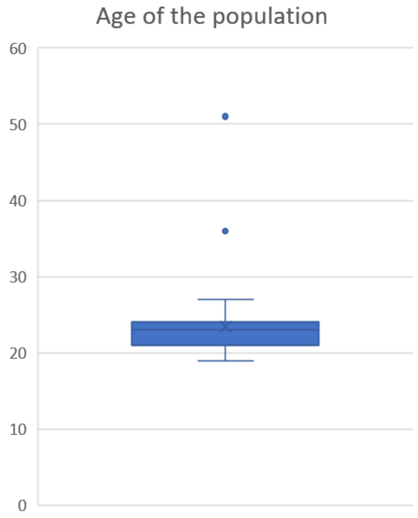


Figure 50 *- Age of the population. Source: Author*

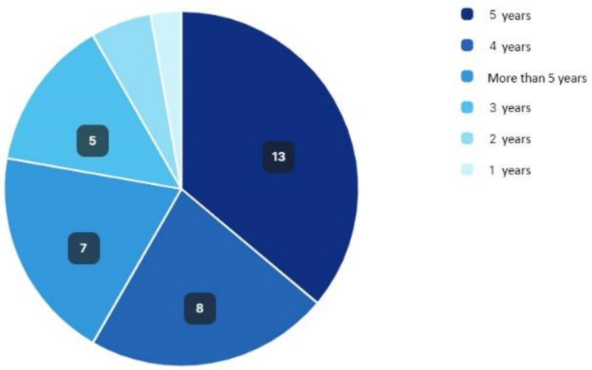


Figure 51 *– Time spent in the studios - Source: Survio*

Only one person declared to have troubles with colour vision. The students responding to the survey stated to use principally the studios that are located towards the west (bottom of Figure 52 (1)) and east orientation (top of Figure 52 (2)) on the first floor of the Vinci building. On this image, the three different areas dedicated to the studios are coloured in blue. For the following parts of the thesis, the Vinci studios will be referred to by their numbers: 1= west studio; 2= east studio; 3= south studio (3). The studio called "Epure", conversely, is located on the ground floor of the building, and is mostly used by students in their Bachelor degree The distribution of the students within each studio is presented in Figure 53.

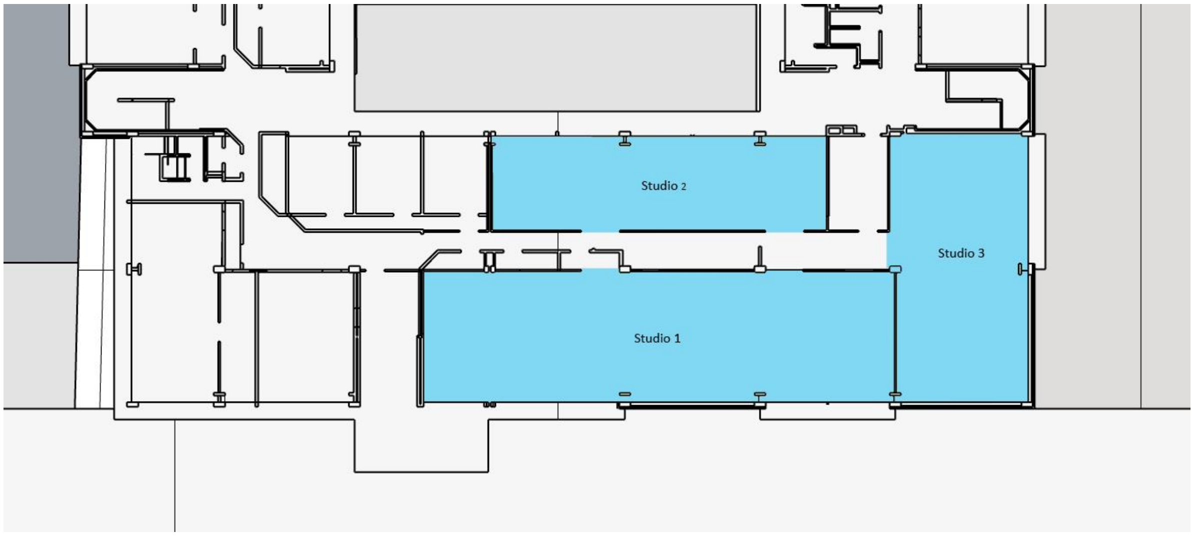


Figure 52 *– Location of the studios on the first floor of the Vinci. Source: Author*

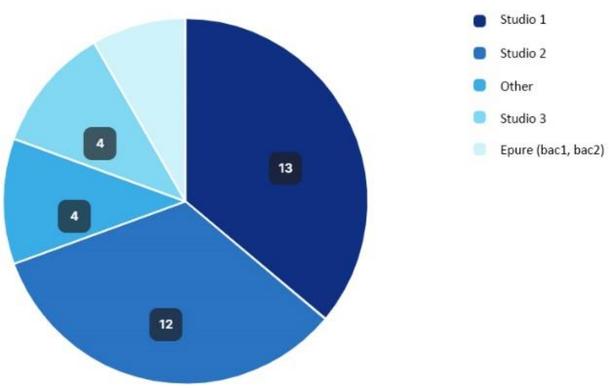


Figure 53 *- Distribution of the students in the studios. Source: Survio*

As studios are not strictly assigned to students in a specific year of their study, from this distribution it can be postulated that students tend to appreciate more working in the spaces available in studio 1 and 2. Conversely, studio 3 does not seem to be much utilised. In this area, there are two window openings: one is represented by a series of vertical windows with a south orientation, and the other one is a skylight with a north aperture in the roof. The 77.8% of participants declared to work close to a window (less than 5 m from it), thus, potentially benefitting from direct natural light from the outside.

Concerning the frequency of occupation of the studios, the survey asked students to report the number of days per week, and the number of hours per day, that they generally spend in these spaces. Figure 54 and Figure 55 present, respectively, the distribution of students' responses. The images show that students effectively spend a considerable amount of time in the studios, especially before a project submission (called "charrette" in French). Sometimes, students can stay in these spaces up to 24 hours per day during the week, or up to 20 hours in the weekends. These results demonstrate that the studios are much more than simply a place to work, these spaces define almost entirely their life, hence showing the relevance of this research to support their comfort, learning experience, but also health and well-being.

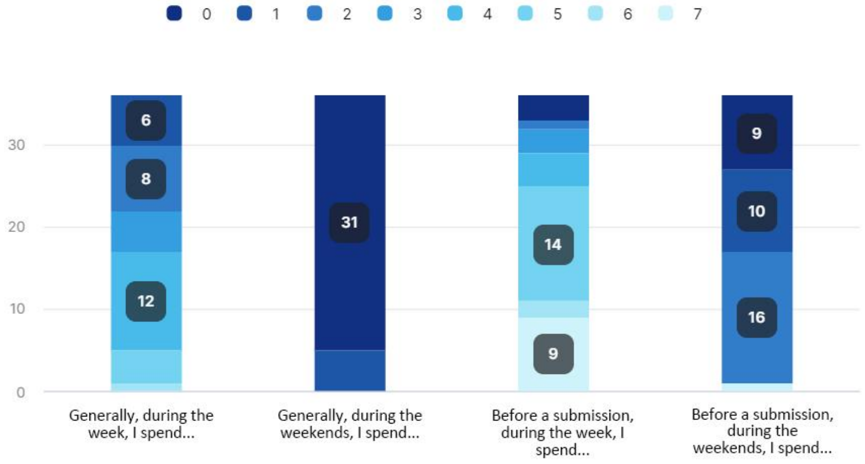


Figure 54 *– Number of days per week spent in the studios. Source: Survio*

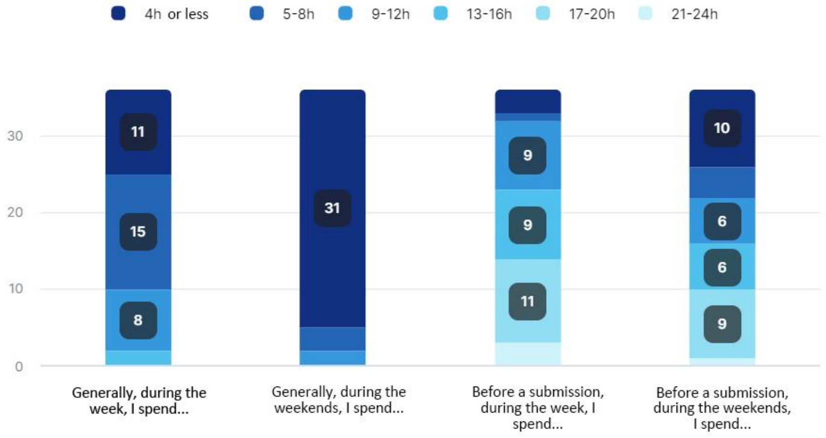


Figure 55 *– Number of hours per day spent in the studios. Source: Survio*

Further questions were asked about the personal feelings and perceptions that students have within the current studios. The 97% of respondents declared to feel tired after a day working there, although 67% of the students reported that these spaces can increase their work productivity. These results are shown in Figure 56 and Figure 57, respectively.

It should be noted that, irrespective of the scale reported on the y-axes of the boxplots, all the questions in the survey allowed a response on a Likert-scale within the ranges from -3, not at all, to +3, strongly. Due to the software used for the creation of the boxplots (MS Excel), the y-axes at times also extends to values of -4 or +4, when the minimum or maximum value of the data corresponds to -3 or +3, respectively.

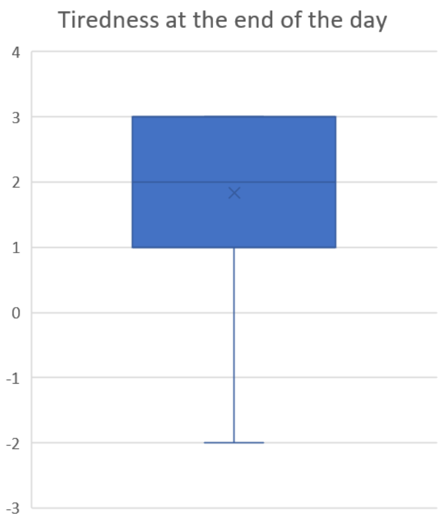


Figure 56 *- Tiredness at the end of the day. Source: Author*

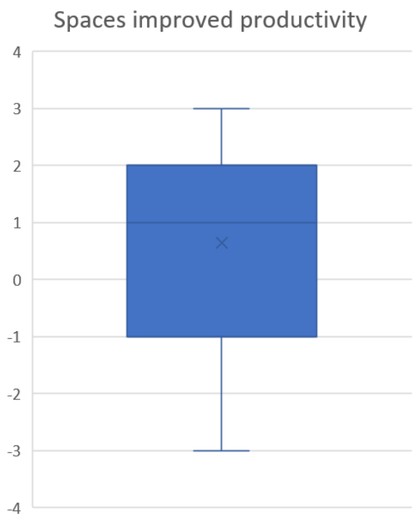


Figure 57 *- Spaces improved productivity. Source: Author*

Asked whether they believe if the lighting solutions implemented in the studios can improve their work performance, the cohort of respondents was rather divided (half of the students were satisfied and half were not), but 75% stated that the distribution of horizontal light (natural and electric) is not sufficiently homogeneous. Looking at the means and medians of responses in the boxplots shown in Figure 58 and Figure 59 leads to postulate that lighting strategies in the current studios could much be improved.

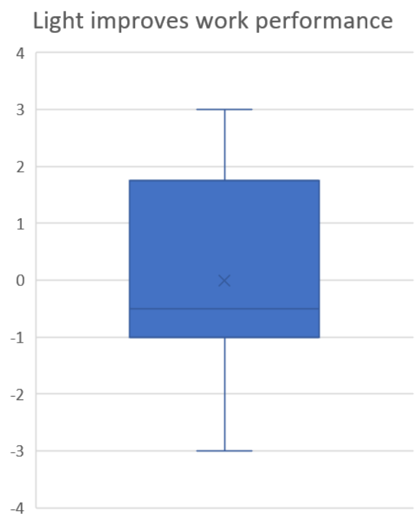


Figure 58 *- Light improves work performance. Source: Author*

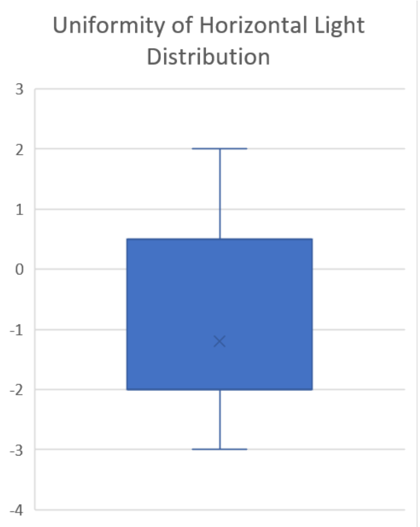


Figure 59 *- Uniformity of horizontal light distribution. Source: Author*

The 83% of students declared to occasionally be disturbed by glare, particularly coming from a window during the afternoon or during the morning depending on the orientation of their workspace (respectively, west and east). Issues of visual discomfort were reported also from luminaires and reflections of interior surfaces. The distribution of responses to this question are presented in Figure 60.

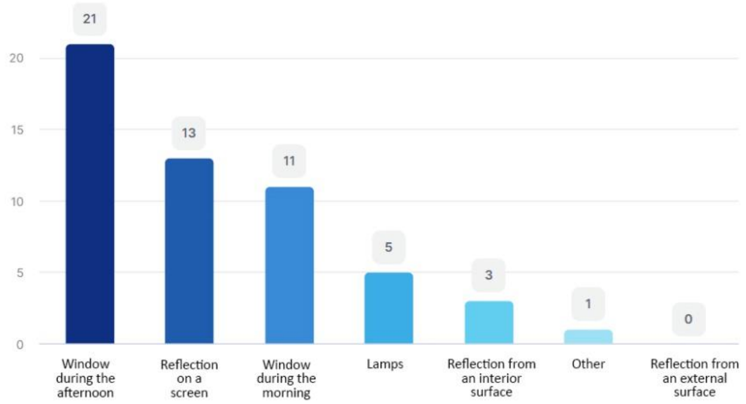


Figure 60 *- Sources of glare. Source: Survio*

From these initial responses, it can already be gathered that many students practically live in the studios, but that the solutions and strategies for the natural and electric light of their spaces are not felt to be consistently adapted to their working and living requirements.

Other than accommodating students' work in the studios, these spaces also host most of the assessments and evaluations within design criticisms, and occasionally, computer-based presentations by the teaching staff. The 70% of respondents stated that the vertical lighting for pin-up review is mostly not suitable to the purpose, with the only exception being the areas located underneath the northern rooflight in studio 3. The boxplots of the results related to this question are shown in Figure 61 (ranging from -3, not well distributed at all, to 3, properly distributed). Another important aspect that is also relevant to the assessment of drawings and renderings is the colour rendering of the lighting. As shown in Figure 62 , most students responded that the lighting does not feel natural inside the studios (this corresponded to the value of +3 in the Likert scale for this question, -3 corresponding to unnatural).

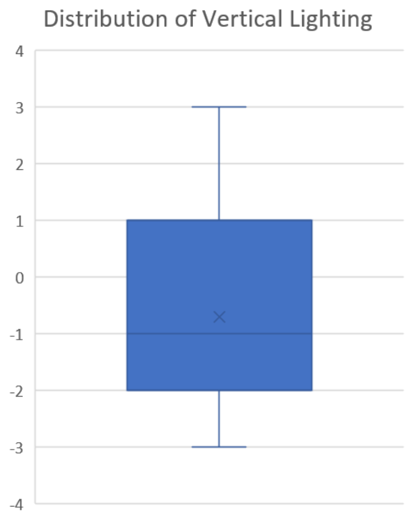


Figure 61 *- Distribution of vertical lighting. Source: Author*

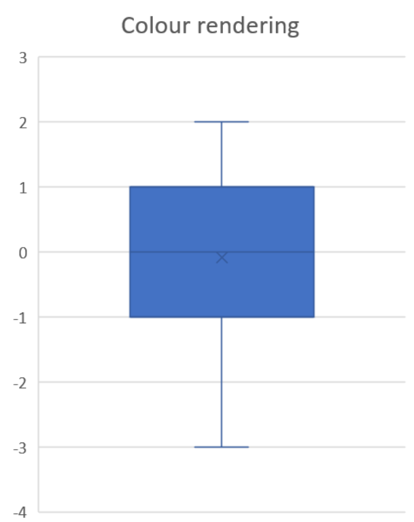


Figure 62 *- Colour rendering. Source: Author*

The final part of the cross-sectional survey asked students to respond to questions and include open-ended comments related to their choices and preferences The great majority, 72% of responses, stated to prefer to have mostly daylight in the working areas, while 28% declared to prefer a mixture of natural and electric light. In addition, all the respondents reported that access to an external view is an absolute necessity.

The last question of the survey was aimed at collecting personal views in terms of desired lighting solutions and strategies. It was asked as follows: "*If you had the chance to design the lighting strategies in your workspace, what would be your priorities?*". The answer to this question was open-ended, but respondents were asked to categorise the order of priority within their preferences. The statements reported by students were analysed thematically, and recurrent keywords were extracted. As expected, the most recurrent theme was referred to the use of *daylight* and, with that, access to *quality views*. Among the priorities reported by students, particular attention was given to the need to have adequate *horizontal light distribution*, but also the need for the light to respond to the changes in *intensity* and *colour* that characterise the passing of days and seasons. Students also articulated that studios are places where *different activities* are performed, often at the same time, each implying *different lighting requirements*. For this reason, students recurrently mentioned the need for *adapted lighting*, that is differentiated lighting sources that can concurrently support working on computers or drawings, modelling or sketching, etc., maybe also allocated to different areas within the studios. Often students stated that they would require having a personal *task lighting* on their desk, so as to more flexibly adapt to the orientation of their design or the times of use. Finally, *vertical lighting* needs to be homogeneously distributed, to ensure adequate appreciation of the work within pin-up assessments and evaluations.

These key thematic areas – *daylight*, *views*, *glare*, *horizontal distribution*, *changes in intensity and colour*, *adapted lighting*, *task lighting*, *vertical homogeneity* – will be among the driving principles to be considered for the lighting recommendations of the new design studio building.

A second section of the cross-sectional survey was aimed at defining the circadian profiles of students by the use of the Munich Chronotype Questionnaire (MCTQ). Based on the responses obtained, a calculation of the students' chronotype was made in Excel, and a breakdown of data is included in the Appendix A. A comprehensive overview of descriptive statistics is presented in Table 14 and illustrated through boxplots in Figure 63. Based on this information, it is possible to better understand the rhythms around which the life and working activities of this particular population of building users is structured.

Among the results obtained, it is first of all evident that, taken as a group, students do reflect average values within the urban population of Europe (e.g., the mean and median of chronotype is around 04:00, similarly to what reported in the study by Roenneberg, 2012). However, looking at the distributions of data, it can be clearly emphasised that there is a large variance in the chronotypes of students, ranging from the earliest to the latest types (e.g., distance between the upper and lower whiskers). The large differentiations existing in this specific group of building users is also evident through other variables, such as average weekly sleep duration, weekly sleep loss, and average weekly light exposures. In all these cases, in fact, the standard deviation of these parameters exceeds 1 hour. Also, the social jet lag is worth of specific consideration, this accounting in mean and median values for almost 1 hour of delay with respect to the general population. These results need to be considered with great care, as the large variation highlighted for various chronotype-related variables implies the capacity for a building hosting a large part of students' daily life and work to be able to adapt flexibly and address different requirements.

Table 14 *- Students' MCTQ variables - Source: Author*

	Average weekly sleep duration	**Chronotype**	**Weekly sleep loss**	**Absolute social jetlag**	**Average weekly light exposure**
Average	08:09	03:53	01:50	00:55	01:57
Median	08:03	04:08	01:32	00:59	01:55
Minimum	04:34	00:00	00:00	00:10	00:20
Maximum	09:52	05:52	05:35	01:50	07:00
Standard deviation	01:11	00:50	01:12	00:29	01:15

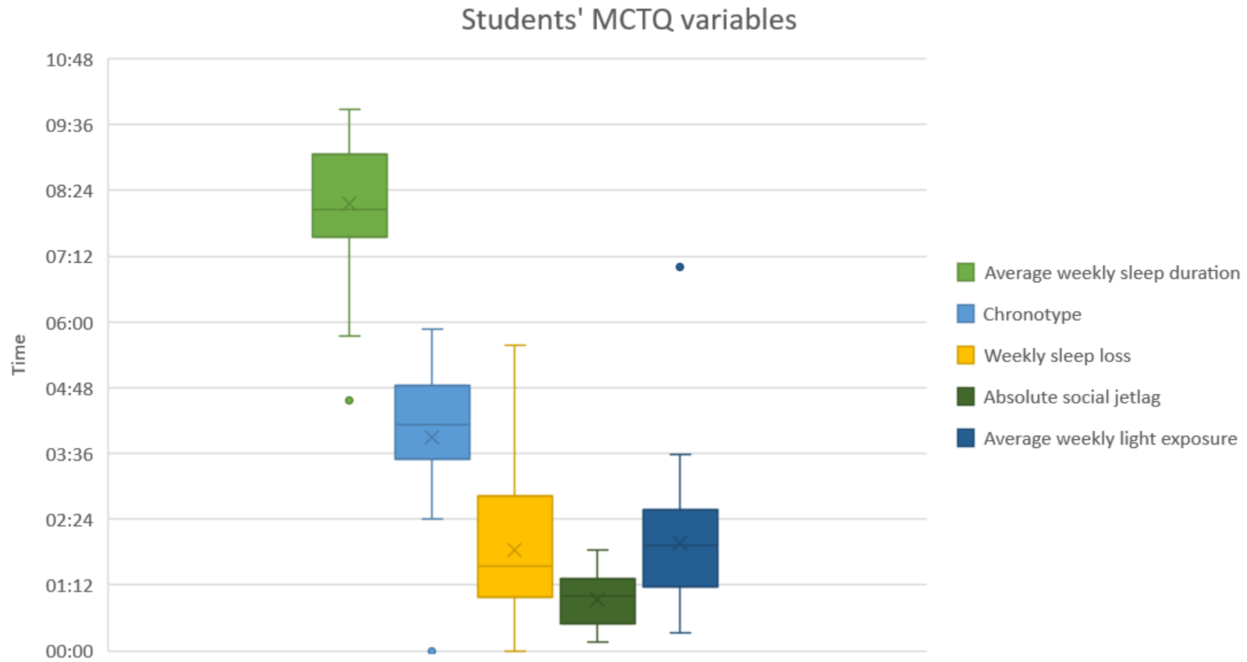


Figure 63 *– Boxplots of students' MCTQ variables. Source: Author*

Occupant responses were also collected in this research through the administration of a *right-now survey.* Five participants responded to the questionnaire, these students working in areas of the studios whose lighting qualities could raise some concerns following the analysis of the data from the cross-sectional survey. Two of the students had desk oriented towards the east façade in studio 2, and the monitoring was conducted in the morning to emphasize eventual issues of discomfort due to glare. Participant 1 had the sun in the back while Participant 2 was sitting in a position facing the sun. The other students participating to the survey had desks located below the northern rooflight (participant 3), looking towards the south (participant 4), and facing the window in studio 2 but in a position far from the facade (participant 5). The synthesis of all responses collected is provided in Table 15.

Overall, the results of the occupants' responses to the right-now survey show that students prefer to work under natural light, but they need their workspaces to be properly located, or adequately protected, to avoid issues of glare. They consistently expressed the need to have adjustable blinds and personal task lights in order to be able to flexibly adapt their luminous environment to their needs, offer homogeneous distribution of light within the spaces, yet avoiding excessive contrast or risks of glare occurrence. Interestingly, students also mentioned the wish to have access to spectrally-tunable light that could better correspond to the hour of the day and the season to increase their feeling of comfort and well-being.

Table 15 *– Synthesis of the results for the Right-Now survey. Source: Author*

	PARTICIPANT 1	**PARTICIPANT 2**	**PARTICIPANT 3**	**PARTICIPANT 4**	**PARTICIPANT 5**
Studio	2	2	1	3	2
Window Orientation	East	East	North	South	East
Age	23 years old	22 years old	23 years old	21 years old	22 years old
Vision Problem	Yes (not corrected via glasses/lenses)	No	No	Yes (corrected via glasses/lenses)	Yes (corrected via glasses/lenses)
Time	10 :00	10 :10	11 :00	12 :00	14 :45
Sun Direction	Sun in the back	Facing the sun	No sun	Facing sun	Facing a window
Horizontal Illuminance	2940 lx	3230 lx	881 lx	901 lx	576 lx
Vertical Illuminance	5990 lx	5520 lx	578 lx	514 lx	1110 lx
Global Feeling About Light	The horizontal and vertical lighting are well distributed, and the colour rendering is strongly reliable. According to her the light increases her work performances.	He is not satisfied with the general lighting, the vertical lighting is not well distributed, the colour rendering unacceptable, and the light disturbs his work performances.	The light increases her work performances because the vertical and horizontal lighting are well distributed. Besides the colour rendering is very reliable.	According to her, the horizontal and vertical lighting are well distributed, and the colour rendering is strongly reliable, but the lighting does not have an impact on her work performances.	She is sitting far from a window, and she finds that the horizontal lighting is not well distributed but the vertical one is better. The colour rendering is reliable but still, the lighting disturbs her.
Glare Perception	Perceptible glare from a window	Disturbing glare from a window	Imperceptible	Perceptible glare from an interior surface	Perceptible glare from a reflection of an external surface
Outside View	Yes, and strongly important to her	Yes, and strongly important to him	Yes, but less important for her than the other participants	Yes, but it is not important at all for her	Yes, and strongly important to her
Desired Priorities	Electrical blinds Personal electrical light	Electrical blinds (or more accessible) Artificial light less “yellow” Spectrally tunable light	Personal electrical light No glare Natural light	Adjustable blinds that filter light	Natural light Uniform horizontal light Adjustable blinds

5.2. Measured Data

The first campaign of measurements in the Vinci studios was conducted on the 23rd of April 2023 and comprised the collection of horizontal illuminance values using an internal grid of 1.2x1.2m, as explained in Section 4.1.5. All measurements were taken under an overcast sky so that a comparison could be made between the data recorded throughout the campaign and those resulting from the simulations performed on the Rhino model at the same date and under the same sky conditions. The full data from the measurements, and the point-by point comparisons with the simulations, are presented in the Appendix C.

Figure 64 presents an example of the simulations performed to compare and validate the 3D model with the measured values. This is a Point-in-Time simulation done with Climate Studio to observe the distribution of illuminance in the three different studios.

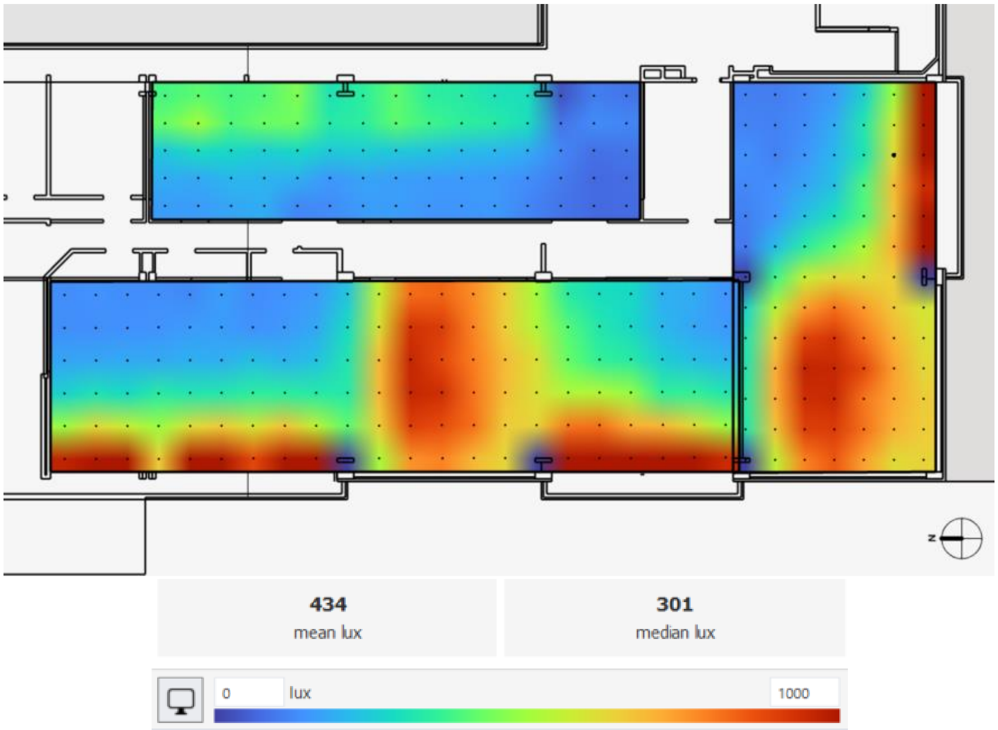


Figure 64 - *Point in Time illuminance simulation for April 23 at 16:52. Source: Author*

Table 16 shows some of the data points for studio 1. In the first column the measured data is reported, and in the second, the data resulting from the simulations are reported.

Table 16 *- Horizontal illuminance comparison. Source : Author*

	Measured (lux)	Simulated (lux)
6	611	740
7	696	875
8	703	985
9	717	917
10	451	677
11	214	2
12	1320	1661

It must be remembered here, however, that comparison of absolute values of illuminance might have some limitations, due to likely errors that could occur based on differences in external sky luminance, variation of reflective properties of the internal (and external) surfaces, maintenance and cleanliness, etc. For this reason, the comparison between measured and simulated data also included an analysis of the values of the daylight factor. The DF, in fact, allows a more reliable evaluation since illuminance data can be normalised by the measured (and simulated) external horizontal illuminance. On these bases, stacked line diagrams were plotted to compare the DFs at every position. To do that, three curves were drawn:

- the first (DF measured, blue line) with the horizontal illuminance measured at every point on the grid divided by the simultaneous external horizontal illuminance;
- the second (DF manually simulated, orange line), with the horizontal illuminance simulated at every point on the grid, at the same time and date of the measured campaign, divided by the simultaneous external horizontal illuminance under an overcast sky;
- the third (DF simulated, grey line), with the absolute values of daylight factors given by ClimateStudio at every point on the grid, calculated under an ideal CIE overcast sky (daylight factor simulation do not require the setting of a specific date or time of day).

This method was applied for every studio, and the curves are shown in Figure 66, Figure 67, and Figure 68. The positions in these diagrams are organised in parallel rows starting from the windows, Figure 65 gives an example in studio 3 for a better understanding.

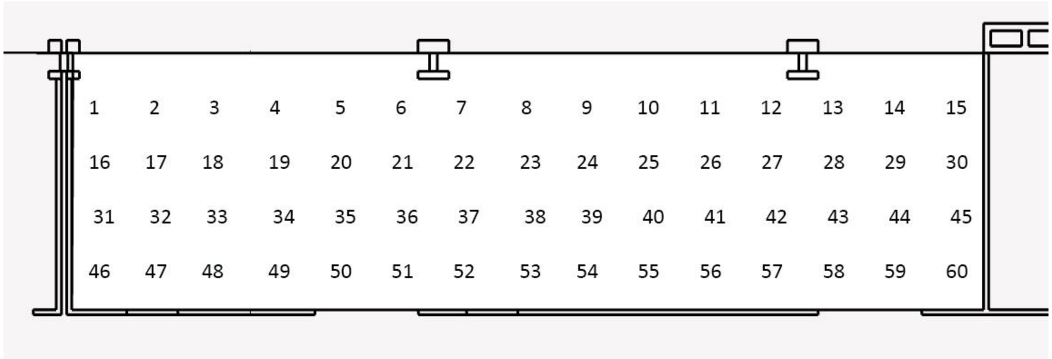


Figure 65 *- Positions example for studio 3. Source: Author*

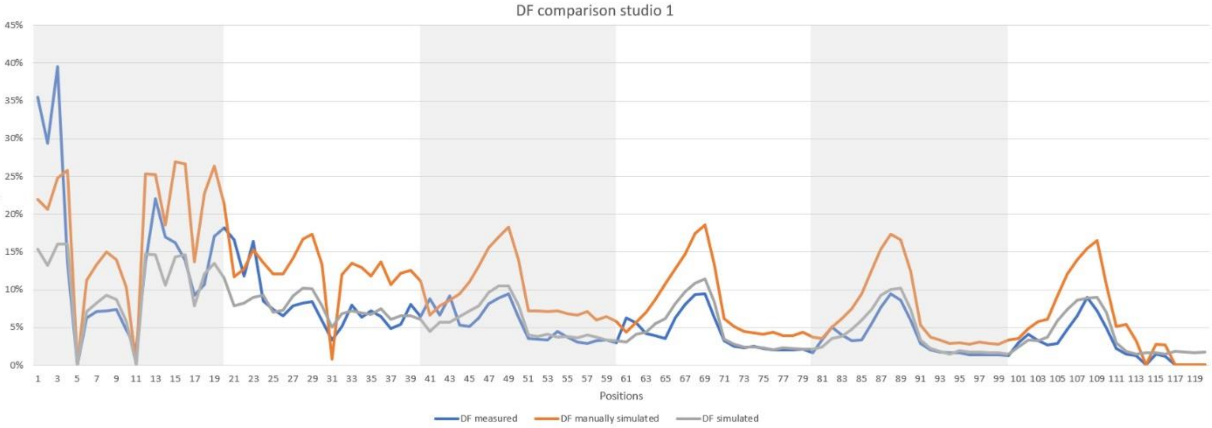


Figure 66 *- DF comparison for studio 1 -Source: Author*

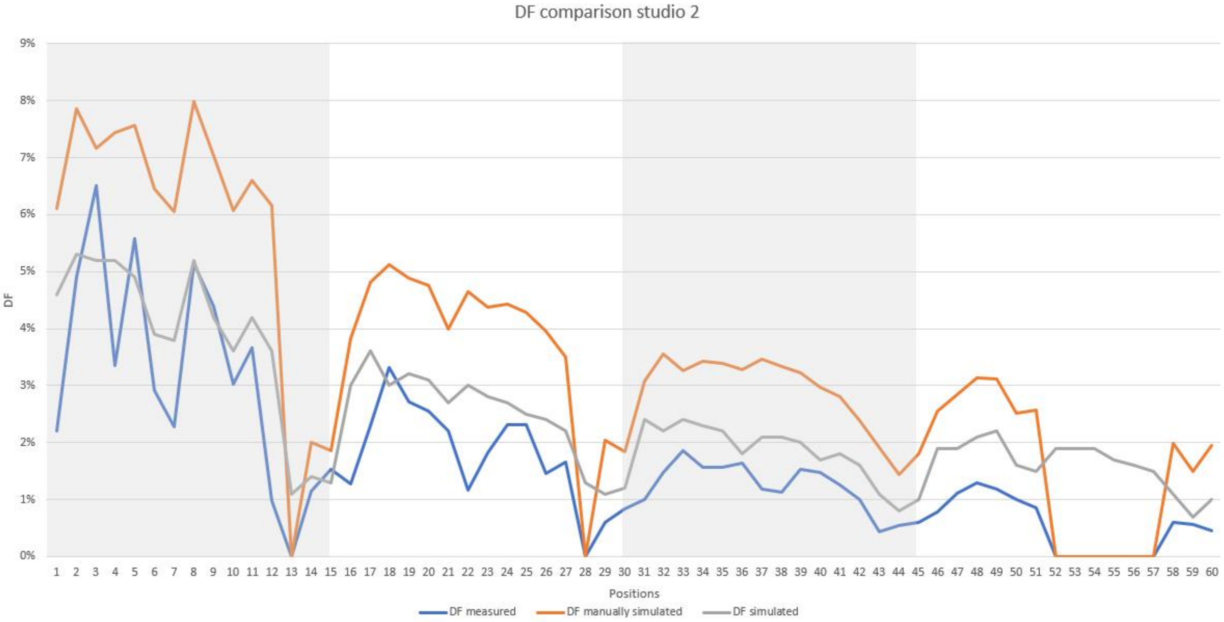


Figure 67 *- DF comparison for studio 2. Source: Author*

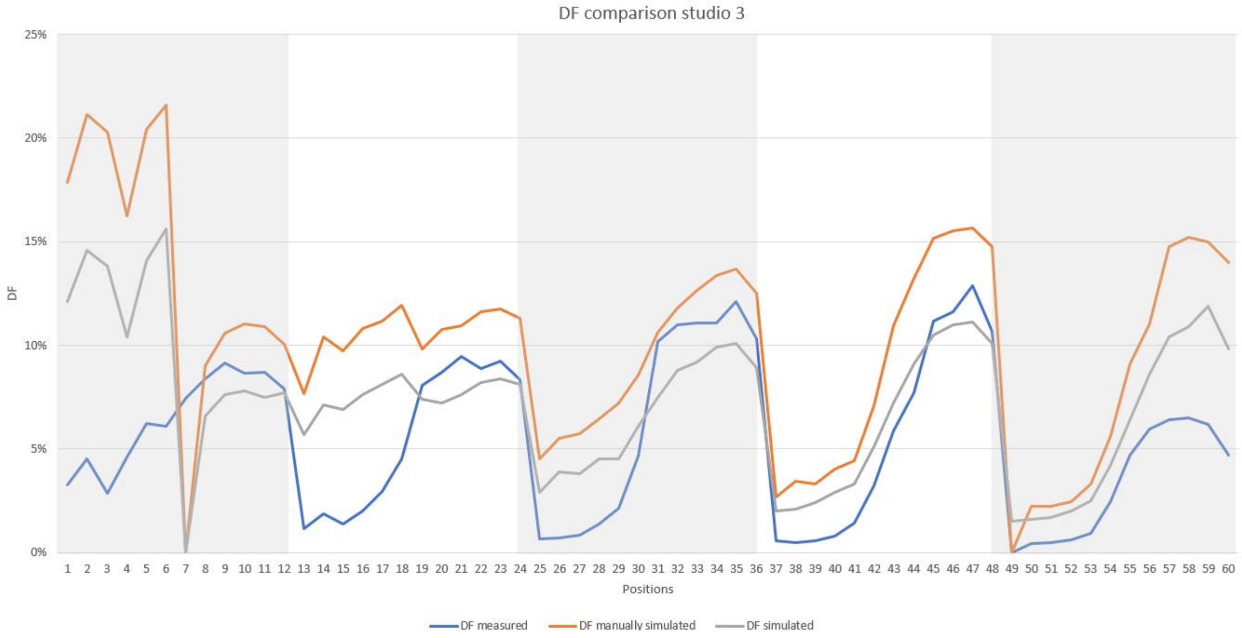


Figure 68 *– DF comparison for studio 3. Source: Author*

The stacked lines were compared primarily by visual inspection of their trends. Logically, a statistical analysis of results would have been more rigorous, with measure of square root mean errors and effect sizes of differences. Yet, this was not considered strictly necessary for the aims of this thesis, since the recognised tendencies revealed very similar patterns. This was especially the case when measured values (blue line) were compared with the simulated daylight factors (grey line). This was to be expected, as the manual derivation of the DF values from the point-in-time illuminance simulations is not a rigorous method, as this may be biased by the position of the external point where the value of horizontal illuminance is taken (e.g., if obstructions or reflections off external surfaces are not properly represented in the model). Yet, when looking at the diagrams, some regular patterns of differences might still be noticed between the measured and the simulated DF values.

It must be noted that, in the diagrams, the points are reported with an ascending order of numbering, proceeding at regular and repeated intervals, from left to right, from the perimetral walls to the points located at the back of the studios. The differences detected are particularly evident for points that were close to windows. Again, this was to be expected as, in the simulated model, the degree of visual transmittance of the glazing was hypothesized and not measured, nor a weighting factor was assigned to the actual level of cleanliness of windows. As an example, in the south oriented spaces (studio 3), the glazing of the windows has a solar protection layer attached. This, of course, can radically change the level of daylight entering the rooms, but no information could be obtained for its rigorous modelling.

A similar consideration can also be made for the surface properties of internal walls, objects, and furniture, which could have strongly influenced measured data, but that could not be systematically estimated for inclusion in the simulated model. To provide an example of the challenges that had to be faced, Figure 69 presents the actual state of the studios throughout the measurement campaign. These limitations in the methods employed for the comparison between measured and simulated data need to be acknowledged, and will be more specifically discussed in the conclusive parts of this thesis.

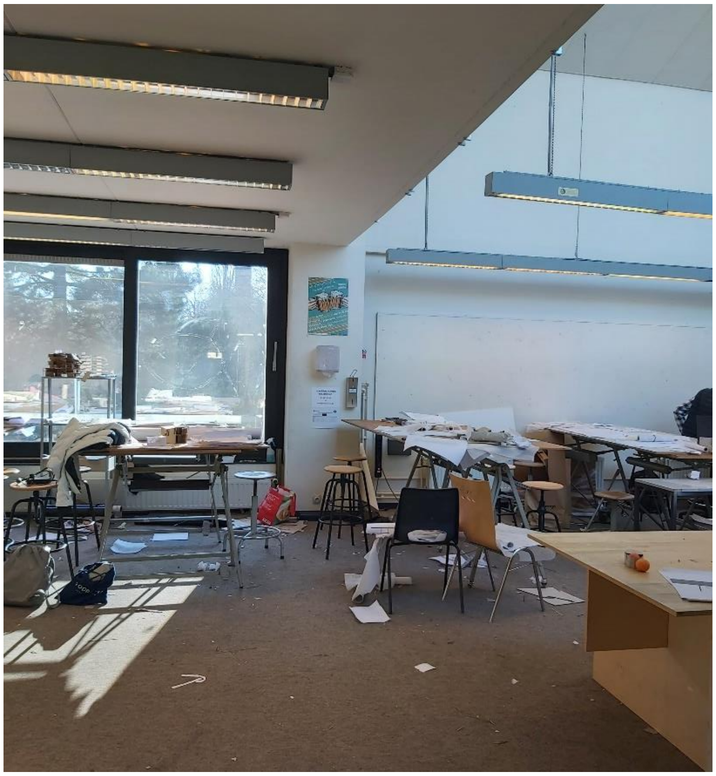


Figure 69 *– Current state of the studios. Source: Author*

The second measurement campaign was performed during the right-now surveys, while participants were filling in the paper-based questionnaire. The previous sections of the thesis have already presented the criteria based on which the areas to analyse were selected within the design studios.

The first issue to consider from the results of the cross-sectional surveys was concerned with perception of discomfort due to glare. For this, students' locations in the east-oriented studio 2 were chosen, with measurements being conducted in the morning during a mostly sunny day. HDR images were created to visualise the luminance maps of Participant 1 and Participant 2, and these are shown in Figure 70 and Figure 71. As per the results presented in Table 15 of the previous section, both participants reported the perception of discomfort due to glare from the windows. The illuminance received at their eyes was, respectively, of 5990 lx and 5520 lx. However, in the case of Participant 2, brighter patches of luminance can be clearly seen in the HDR images due to the presence of the sun in the field of view and reflections off internal surfaces. In fact, Participant 2 reported issues of disturbing glare, while the discomfort was only perceptible for Participant 1. In both cases, the horizontal illuminance was around 3000 lx, which is still a rather high value, especially since this was associated with patterns of light and shadow on their working surfaces. Both participants also gave a high priority to the availability of adjustable blinds.

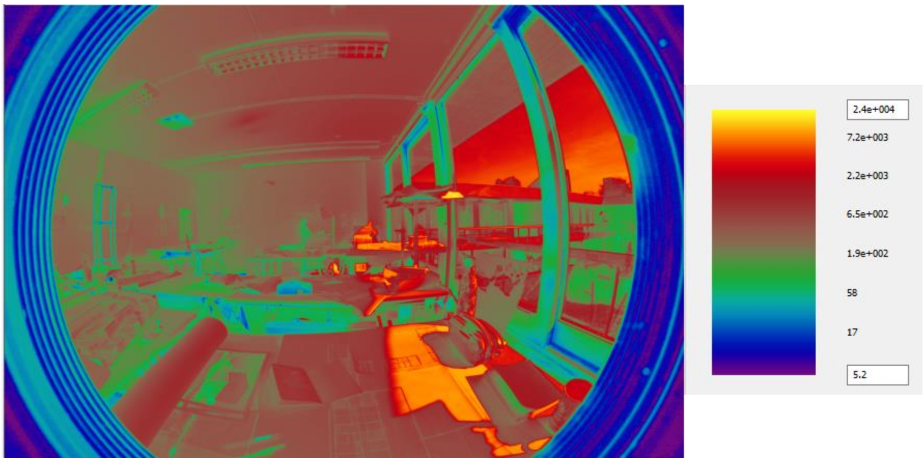


***Figure 70** – False colour HDR image, participant 1. Source: Author*

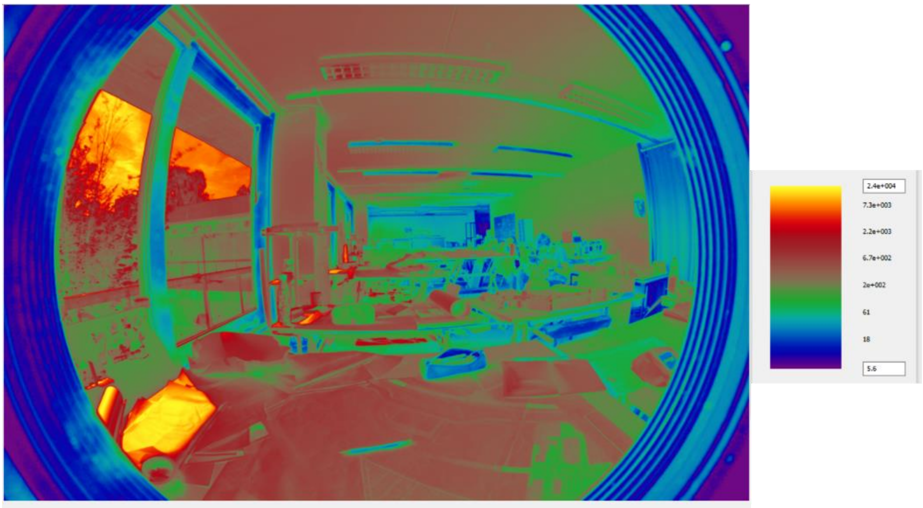


***Figure 71** – False colour HDR image, participant 2. Source: Author*

Participant 3, sitting under a north facing aperture in the roof, had much less vertical and horizontal illuminance, 578 lx and 881 lx respectively. Indeed, the HDR image presented in Figure 72 shows a stark contrast with the luminance maps of the previous two participants. The only light source of diffuse light that can be seen in the image is the rooflight, which also explains clearly the opinion given by the student of imperceptible glare and the availability of adequately distributed natural light.

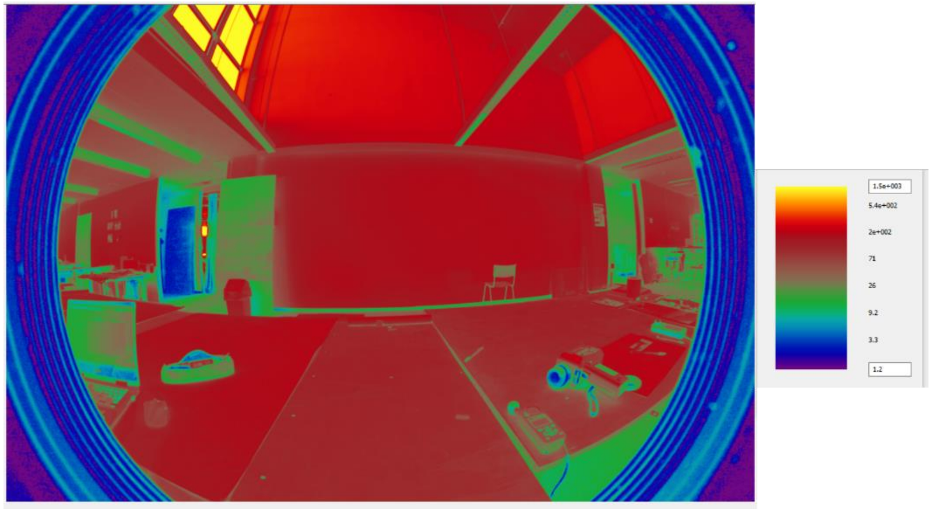


Figure 72*– False colour HDR image, participant 3. Source: Author*

Participant 4 was sitting in the south-facing studio, with a desk position parallel to the windows. The illuminance received on the horizontal and vertical planes were, respectively, of 901 lx and 514 lx. The measurements were taken at 12:00 noon, with the sun perpendicular to the façade, but the student reported issues of perceptible glare only due to reflections off interior surfaces. From the HDR image of Figure 73, it can be gathered that, at this time of the year (April), the sun has an altitude in the sky such that the external overhang protects the field of view of the observer from direct radiation, although its horizontal depth is not sufficient to also guard from patches of direct illumination to be visible on the floor. Also, this participant stated a preference for having adjustable blinds that can be deployed upon necessity.

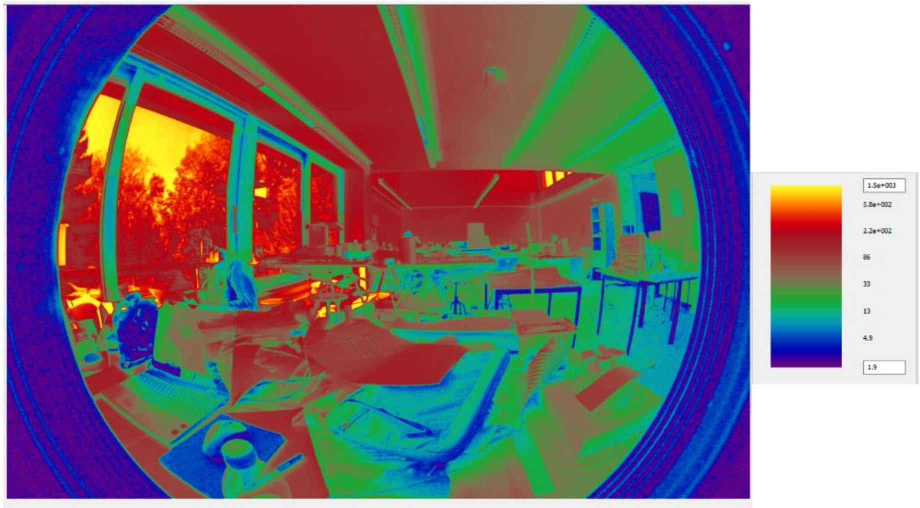


Figure 73 *– False colour HDR image, participant 4. Source: Author*

Participant 5 also had a desk located in the east-facing studio, but the measurements were taken in the afternoon (at 14:45) to explore issues of horizontal light distribution. For this student, the vertical illuminance reached 1110 lx, but the horizontal illuminance was only 576 lx, a value that still responds to the requirements of standards, but that was considered not sufficient due to the stringent nature of the student's visual task. For this participant, the view to the outside was particularly important, hence probably the reason why a desk location perpendicular to the window was chosen. Yet, in the early hours of the afternoon, and with the sun having moved towards the west, issues of perceptible glare due to reflection of the façade from the other side of the court were reported. In the HDR image of Figure 74, this is evident from the brighter patches seen in the higher parts of the surrounding buildings.

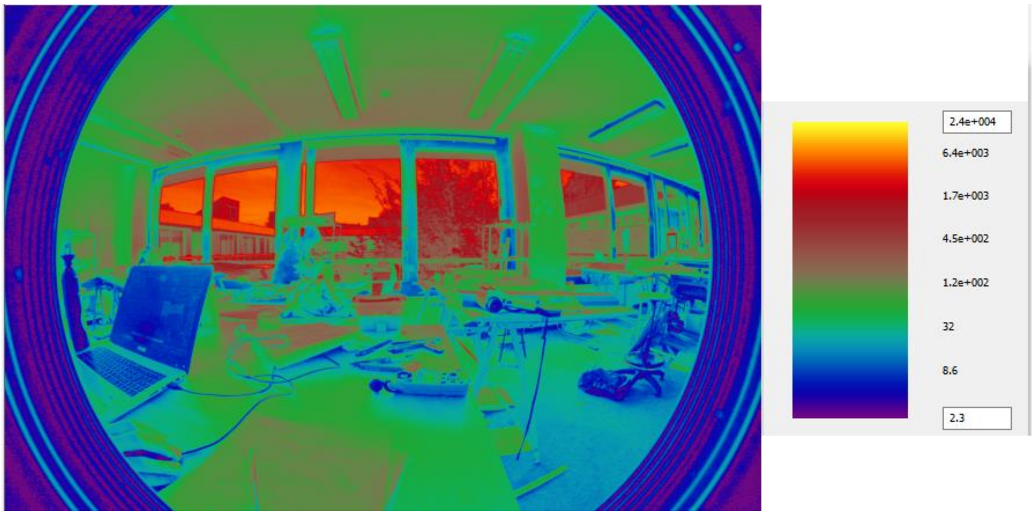


Figure 74 *– False colour HDR image, participant 5. Source: Author*

The results of the measurements performed concurrently with the right-now surveys clearly show the importance of contextualisation of the feedback received from building occupants, particularly when tackling issues that might be directly or indirectly correlated with the dynamic nature of daylight, different times of the day, and the locations and viewpoints that occupants may have inside a space.

5.3. Lighting Simulations

As explained in Chapter 4, lighting simulations were performed in three steps: 1) ClimateStudio was used to analyse CDBM metrics and annual glare probabilities in the design studios of the Vinci building; 2) OWL1 was used to run point-in-time analysis and evaluate the non-visual effects of light corresponding to the times and locations of the measurements taken during the right-now surveys; 3) OWL2 was used to run annual analysis of visual performance metrics and potential for circadian simulation in the new building.

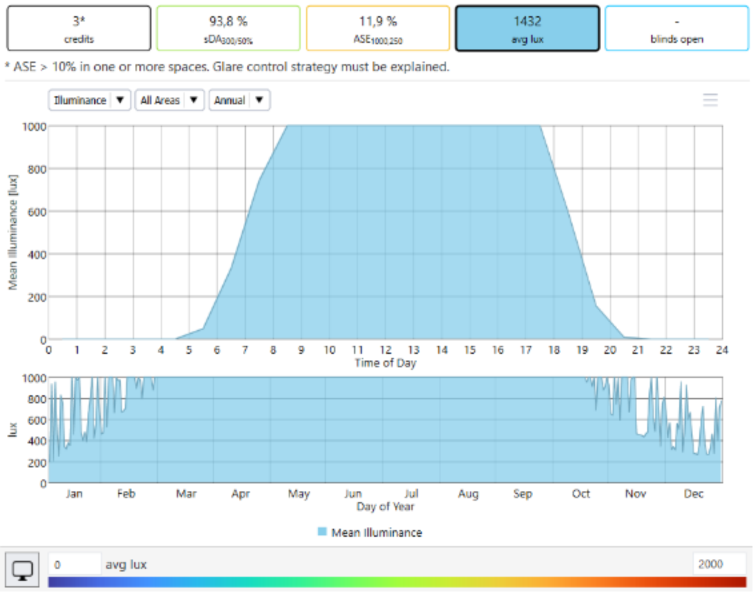
Climate Studio

The first lighting simulations to be performed for this research were conducted on ClimateStudio to offer an understanding of horizontal distribution of illuminance within the Vinci design studios. The point-in-time results of these simulations were validated through comparison with measured data. Table 17 provides an overview of the material properties that were defined in Rhino.

***Table 17** - Rhino's settings. Source: Author*

Walls	Beige plaster wall
Floor	Carpet E14 526
Surrounding’s floor	Road Paver Blocks
Surrounding’s building	Brick facade
Glazing	Clear

Following the point-in-time analysis, annual simulations were performed in ClimateStudio. The dashboard in Figure 75. shows the mean horizontal illuminance over a year and on selected days and times. Figure 76 presents the distribution of annual mean illuminance in the three studios. From these images, the initial observation can be made that the horizontal distribution of daylight is indeed not homogeneous. This confirms the feedback from the students, i.e., that studios have excessive contrasts and lack uniformity, and this might also be the reason why they asked for better electric lighting to complement daylight.



3* credits

93,8 % $sDA_{300/50\%}$

11,9 % $ASE_{1000,250}$

1432 avg lux

- blinds open

* ASE > 10% in one or more spaces. Glare control strategy must be explained.

***Figure 75** - Dashboard of annual mean illuminance in the Vinci studios. Source: Author*

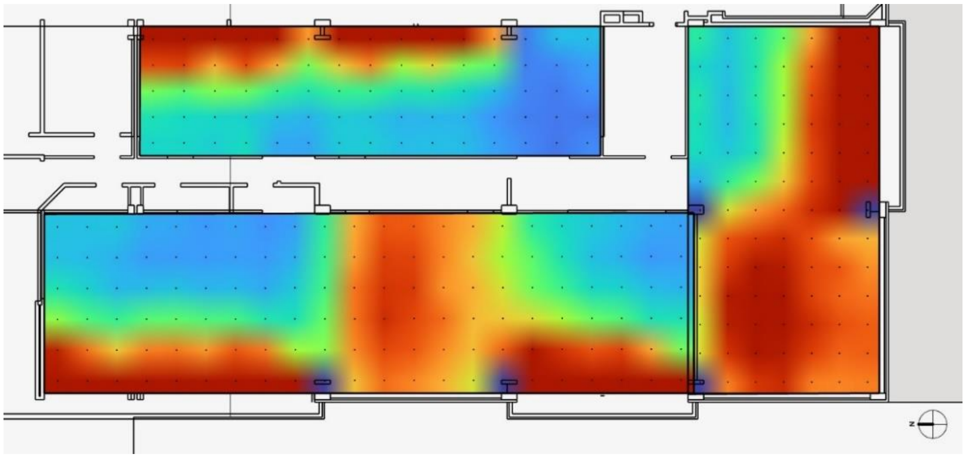
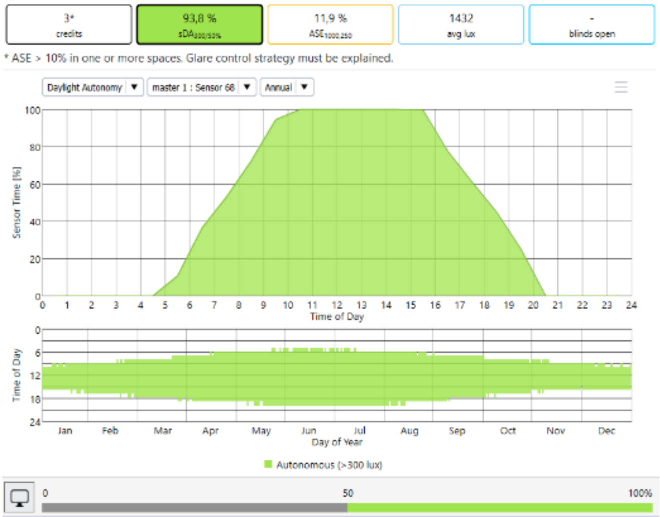


Figure 76 *- Annual mean illuminance in the Vinci studios. Source: Author*

Figure 78 shows that the continuous Daylight Autonomy, set at the minimum value of 300 lux (applicable to general ambient lighting), and for 50% of occupancy time as per the requirements of lighting standards, is satisfactory throughout the three studios. Although it has previously been stated that studios would require higher levels of horizontal illuminance on the working surfaces (between 500 lux and 750 lux), this analysis shows that the availability of light is not a major concern in these spaces. Conversely, the horizontal and vertical distribution of light, and its colour qualities, might represent liabilities for the students. Annual and daily distributions can be seen on the dashboard in Figure 77, and in Figure 78.



3* credits

93,8 % $sDA_{300/50\%}$

11,9 % $ASE_{1000,250}$

1432 avg lux

- blinds open

* ASE > 10% in one or more spaces. Glare control strategy must be explained.

Daylight Autonomy ▼ master 1 : Sensor 68 ▼ Annual ▼

Figure 77 *– Dashboard of sDA300/50% in the Vinci studios. Source: Author*

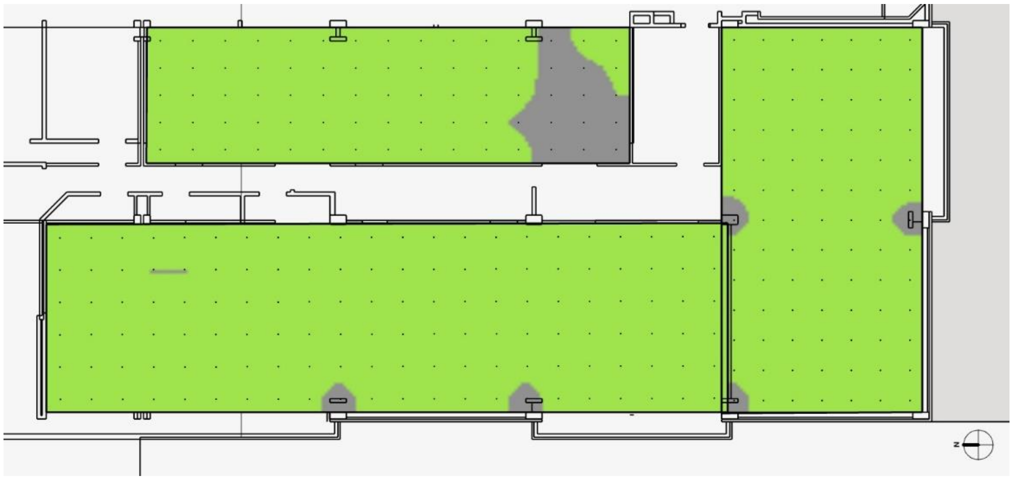
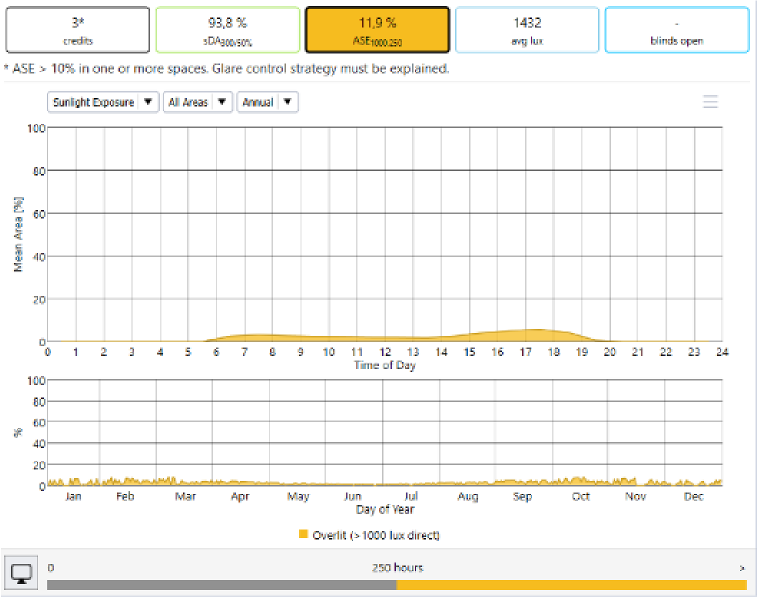


__Figure 78__ - sDA300/50% in the Vinci studios. Source: Author

The majority of the students requested accessible blinds that they can manually operate at their convenience. From the simulations of annual solar exposure, presented in Figure 79 and Figure 80, it is easy to see how direct solar radiation enters the studios from the east, south and west facades. Not only this can cause uncomfortable patches of bright light on work surfaces, and risks of solar overheating during the spring, summer and early autumn period (as evidenced by the yearly evolution of ASE in Figure 79), but direct solar penetration can also be associated to occurrence of discomfort due to glare. These issues are presented within Figure 81 and Figure 82, and emphasise the risks of disturbing (in orange) and intolerable (in red) from most of the students' workstations. Again, the results of this simulations confirm the feedback that students had provided in the cross-sectional surveys and the data that was collected during the right-now surveys and the simultaneous lighting measurements.



3* credits

93,8 % $sDA_{300/50\%}$

11,9 % $ASE_{1000,250}$

1432 avg lux

- blinds open

* ASE > 10% in one or more spaces. Glare control strategy must be explained.

Sunlight Exposure ▼ | All Areas ▼ | Annual ▼

__Figure 79__ - Dashboard of annual sunlight exposure in the Vinci studios. Source: Author

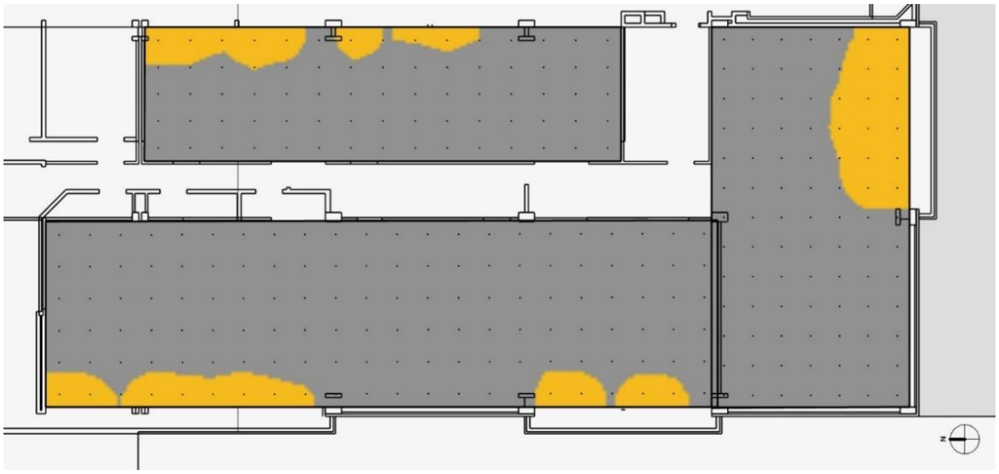
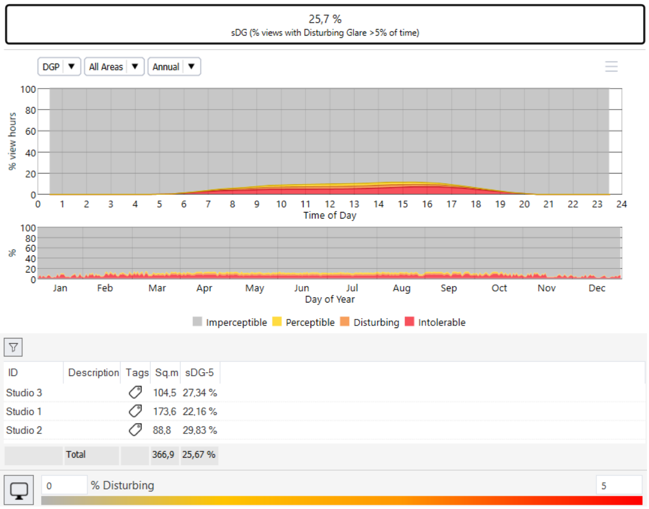


__Figure 80__ - Annual sunlight exposure in the Vinci studios. Source: Author



25,7 %
sDG (% views with Disturbing Glare >5% of time)

ID	Description	Tags	Sq.m	sDG-5
Studio 3			104,5	27,34 %
Studio 1			173,6	22,16 %
Studio 2			88,8	29,83 %
	Total		366,9	25,67 %

__Figure 81__ - Dashboard of annual glare in the Vinci studios. Source: Author

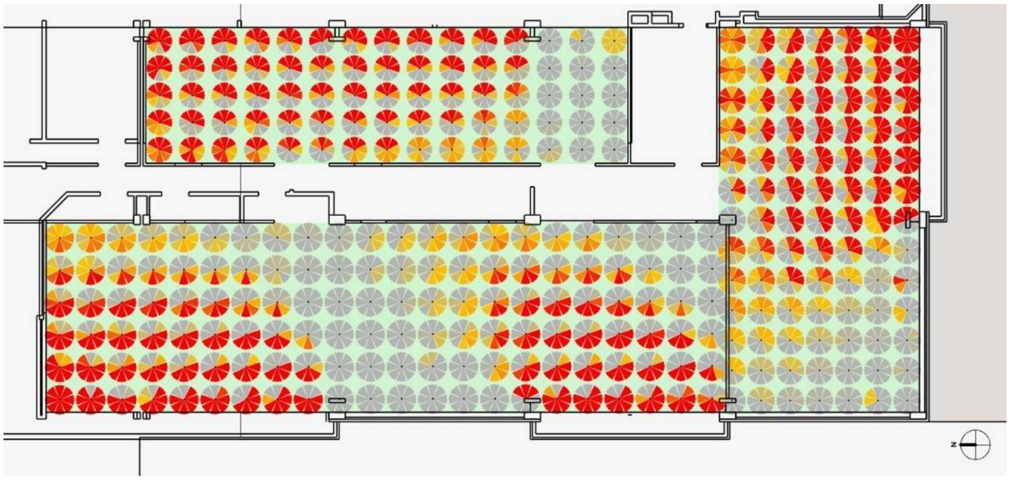
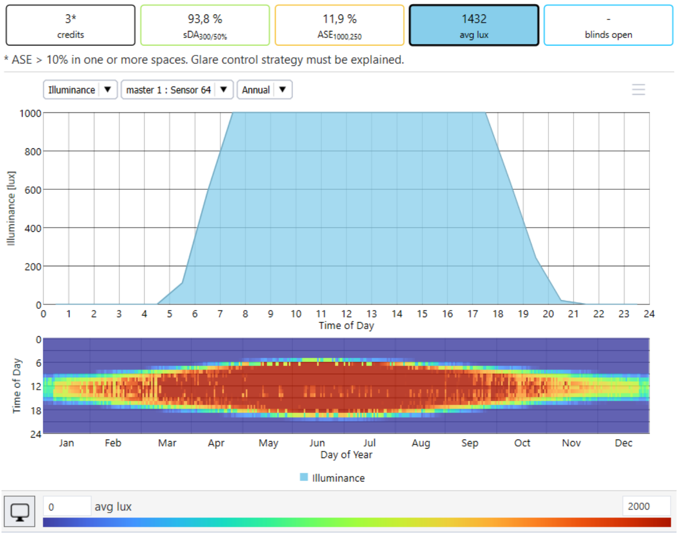


__Figure 82__ - Annual glare in the Vinci studios. Source: Author

After having performed spatial analysis of CBDM metrics across the three studio spaces, further simulations were conducted on specific locations. Figure 83 and Figure 84 present the annual illuminance analysis for the position where Participant 3 of the right-now surveys was sitting (location in studio 1, underneath the rooflight facing north; the student position is marked by the value of 1753 lx in Figure 84). As per the results of the simulation, annual horizontal illuminance at that point is rather homogenously distributed and, generally, abundant for performing visual tasks on the desk surface. However, across the seasons, it can be seen in Figure 83 that illuminance levels change drastically between summer and winter, both in terms of hours of illumination as with respect to daylight availability. In this case, it is possible to understand the need expressed by the participant to have complementary electric lighting, and personal task light, that can be used upon necessity during the year. Indeed, light is most abundant during the summer season, but this is the period when students are generally not present in the studios.



* ASE > 10% in one or more spaces. Glare control strategy must be explained.

Illuminance ▼ master 1 : Sensor 64 ▼ Annual ▼

Figure 83 *– Dashboard of a point's annual illuminance in the Vinci studios. Source: Author*

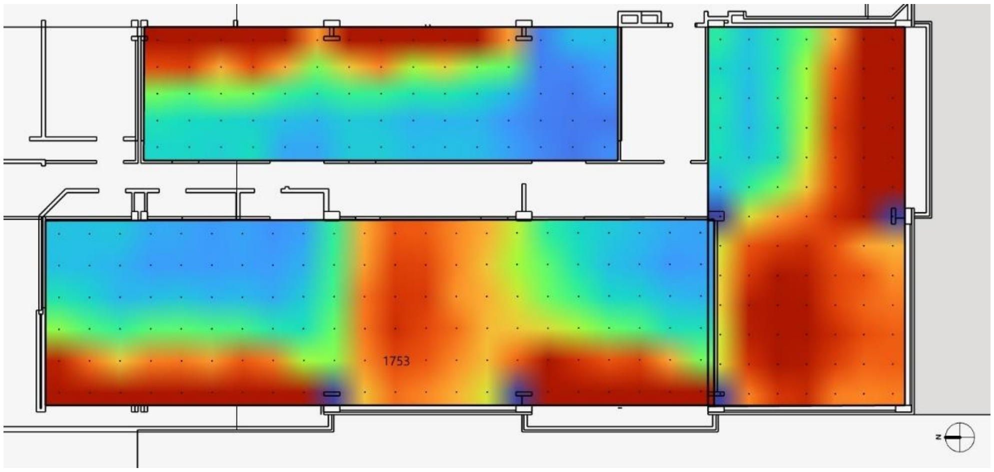
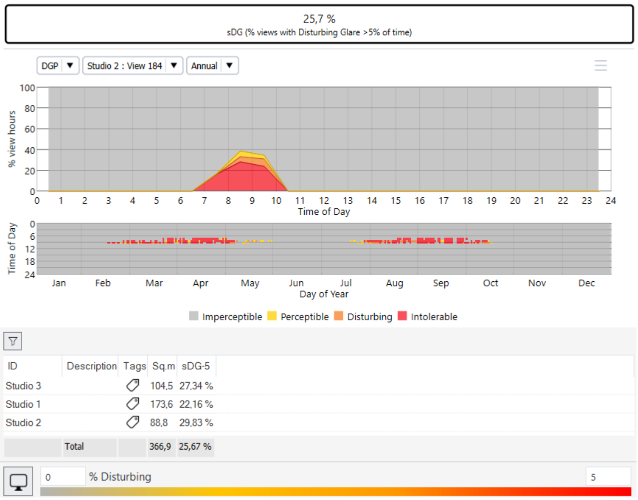


Figure 84 *– Point's annual illuminance in the Vinci studios. Source: Author*

The position of Participant 2 in the east-facing studio was also selected to perform annual glare simulations, and verify the magnitude of the visual discomfort that was reported in the right-now survey. The analysis was performed at the same day and time of the measurement, 10am, confirming the risk of glare reported by the student (Figure 85 and Figure 86). Yet, ClimateStudio evaluated the risk of glare as intolerable while the participant indicated the level of glare as disturbing. One more time, this result confirms the potential gap that often exists between software-based glare prediction and the actual perception of building occupants (which could be moderate, for example, by the presence of a view to the outside). The software, in addition, emphasised the risk of intolerable glare for different periods of the year, between February and May, and between July and October. This can be seen in the dashboard of Figure 85. Blinds adjustable to respond to the students' needs would certainly be required in these spaces.


25,7 %
sDG (% views with Disturbing Glare >5% of time)

ID	Description	Tags	Sq.m	sDG-5
Studio 3			104,5	27,34 %
Studio 1			173,6	22,16 %
Studio 2			88,8	29,83 %
	Total		366,9	25,67 %

Figure 85 *- Dashboard point's annual glare in the Vinci studios. Source: Author*

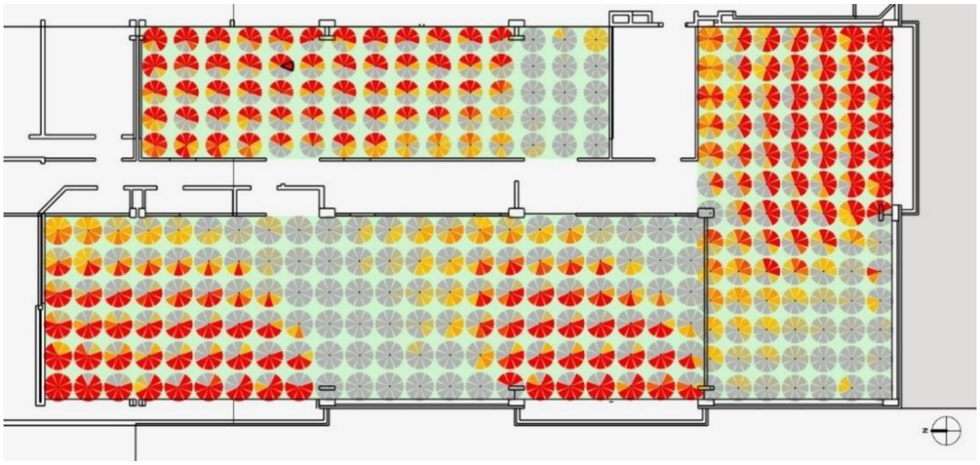


Figure 86 *- Point's annual glare in the Vinci studios. Source: Author*

In conclusion, annual simulations confirm the feedback received from the students and allow a more thorough understanding of the lighting conditions that would be required in the new building.

OWL1

The following part of lighting simulations in the Vinci building was performed with OWL1 to calculate, at each position of the right-now surveys, a series of non-visual (or non-image forming, NIF) metrics. This series of simulations was conducted to complete the characterisation of the lighting strategies within the Vinci, and verify whether students working within the studios receive sufficient circadian stimulation to sustain their health and well-being. Before performing the simulations, the settings of the materials properties had to be selected for the simulation via Radiance, and these are presented in Table 18.The values in the right column of the table indicate the reflectance, or transmittance, properties of each surface, listing distinguished in the Red, Green, and Blue channel, the global value, and the roughness.

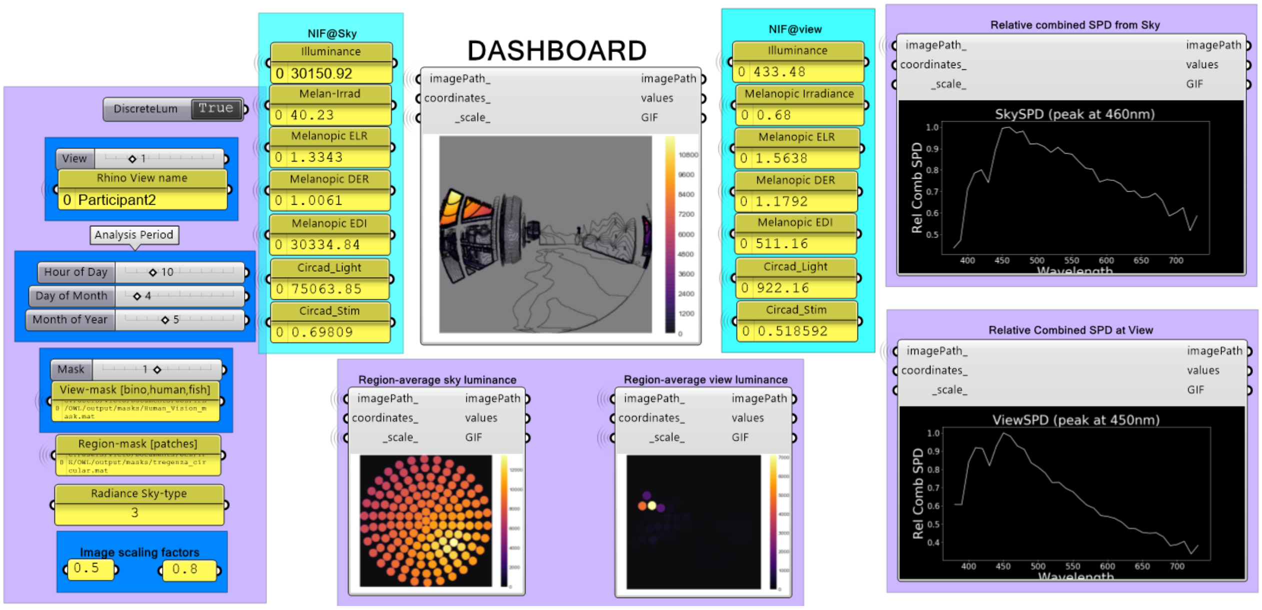
Table 18 *- Materials' settings OWL1. Source: Author*

Carpet	void plastic grey_carpet 0 0 5 0.1048 0.0989 0.0824 0.0003 0.3000
Walls	void plastic grey_painted_wall 0 0 5 0.4494 0.4587 0.4604 0.0035 0.2000
External floor	void plastic brick_facade 0 0 5 0.1381 0.0813 0.0598 0.0000 0.3000
Ceiling	void plastic white_painted_wall 0 0 5 0.8836 0.8857 0.8401 0.0109 0.2000
Roof	void plastic soil 0 0 5 0.0419 0.0292 0.0208 0.0000 0.0000
Glazing	void glass fouth_madison_glass 0 0 3 0.342 0.448 0.473

The simulations in OWL1 require the geometrical definition of the characteristics of the internal location, and the indication of a specific day and time when the analysis will be performed.

The results provided by the tool can distinguish between “absolute” non-visual stimulation given by the sky vault and that reaching the eyes of the observer from their specific point of view inside a built space. The outputs of the analysis provide visualisations in region and view luminance, together with the graphical spectral characterisation of the incident light, and a tabular series of metrics that are useful to estimate the non-image forming (NIF) effects of light. These include the mEDI, or *melanopic equivalent daylight illuminance*, a metric that has been officially adopted recently by the CIE to benchmark in standards the non-visual responses to light, and the circadian stimulus (Maskarenj et al, 2012).

Figure 87 below offers an example of the Grasshopper dashboard from where the visual and non-visual metrics generated by OWL1 for Participant 2 of the right-now survey could be appraised.



DiscreteLum True

View 1

Rhino View name: 0 Participant2

Analysis Period

Hour of Day 10

Day of Month 4

Month of Year 5

Mask 1

View-mask [bino,human,fish]

Region-mask [patches]

Radiance Sky-type: 3

Image scaling factors: 0.5 0.8

NIF@Sky

Illuminance: 0 30150.92

Melan-Irrad: 0 40.23

Melanopic ELR: 0 1.3343

Melanopic DER: 0 1.0061

Melanopic EDI: 0 30334.84

Circad_Light: 0 75063.85

Circad_Stim: 0 0.69809

NIF@view

Illuminance: 0 433.48

Melanopic Irradiance: 0 0.68

Melanopic ELR: 0 1.5638

Melanopic DER: 0 1.1792

Melanopic EDI: 0 511.16

Circad_Light: 0 922.16

Circad_Stim: 0 0.518592

***Figure 87** - Dashboard of OWL1 for participant 2. Source: Author*

The simulations performed on the five locations (Appendix D) from where students filled in the right-now surveys returned, in all cases, satisfactory values for NIF metrics and, therefore, potential for circadian stimulation. Indeed, this supports the previous finding that the actual availability of natural light is not a significant factor of concern, at least during the spring season, for the Vinci building.

As an example, in Figure 87, the table for NIF stimulation at the view indicates a CS of 0.51, this responding to the need for the circadian stimulus to be at least 0.3 for one hour in the morning (simulation was performed for 10am) (Figueiro et al., 2017). This level of non-visual stimulation can help the entrainment of the circadian rhythm of students and improve their performance and perception of well-being for the rest of the day. However, the availability of abundant daylight from where the non-visual stimulation is generated might also come with its challenges, particularly when it is associated with risks of discomfort due to glare from bright patches of light in the sky or off reflective internal surfaces (as this was the case when Participant 2 filled in the right-now questionnaire).

A semi-transparent blind that can filter the light, yet without altering its colour properties, or excessively reducing its horizontal and vertical illuminance, might seem to be an appropriate solution in this case.

OWL2

The final set of computer-based simulations for this research comprised annual analysis performed on the design proposal of the new building, to verify the annual distribution of visual (horizontal illuminance, glare analysis) and non-visual (circadian stimulus) metrics. These set of simulations respond to the need to analyse issues of *sufficiency* (lighting energy necessary for illumination), *comfort* (lack of visual contrast or glare), and *well-being* (entrainment of the circadian cycle). Since these outputs could not be comprehensively available within ClimateStudio, the OWL2 tool was used to generate the necessary data.

All simulations were performed on the basis of a grid spaced at 0.4m x 0.4m intervals, and located at 0.9m from the floor, this corresponding to the general height of a drawing table.

]

The first step of the simulation was specifying the settings for the materials' properties (Table 19).

Table 19 *- Materials' settings OWL2. Source: Author*

Carpet	void plastic Carpet 0 0 5 0.1555 0.1556 0.1461 0.0001 0.3000
Walls	void plastic Walls 0 0 5 0.6589 0.5826 0.4518 0.0015 0.2000
Red brick	void plastic red_brick 0 0 5 0.1295 0.0967 0.0737 0.0000 0.3000
Ceiling	void plastic Ceiling 0 0 5 0.8394 0.8284 0.7931 0.0009 0.3000
Tree foliage	void plastic tree_foliage 0 0 5 0.1176 0.1523 0.0558 0.0011 0.2000
Glazing	void glass Glazing 0 0 3 0.989889 1 0.984464

When settings were chosen, it was important to decide on other hypotheses such as the most appropriate way to model existing and new trees, which will populate the garden between the Vinci and the new building. This is indeed quite relevant, as the new studios will have a large façade orientated towards the north, so the presence of the trees will be a relevant element to influence the amount of diffuse daylight available from the visible sky vault or due to reflections from the foliage, or the façade of the Vinci itself. Based on the literature (Balakrishnan & Jakubiec, 2023), simplified trees were modelled, distinguishing between their foliage density for summer and winter. This is shown in Figure 88 and Figure 89.

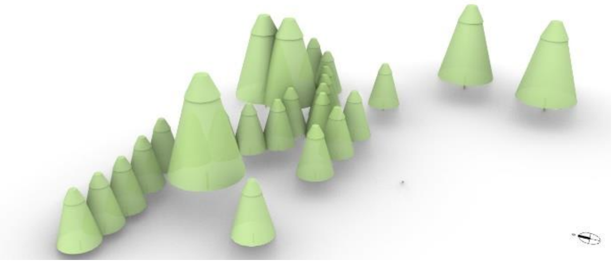


Figure 88 *- Simulation of summer trees. Source: Author*

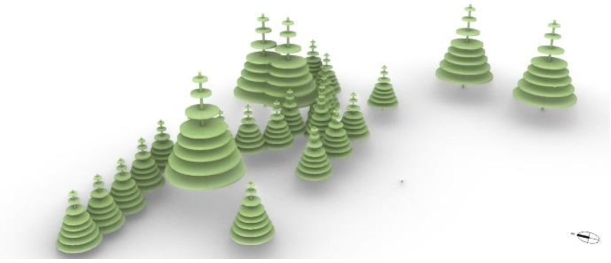


Figure 89 *- Simulation of winter trees. Source: Author*

The winter trees were used for the annual simulations since it was considered that the periods of the year when the studios will be mostly used will correspond to the winter months. Also, this is the time of the year when the risk of insufficient daylight, for visual performance or circadian stimulation, will create the most stringent conditions that the lighting strategies implemented in the building will need to address.

In any case, since the trees are located on the northern side of the new building, initial simulations performed with the two models of trees returned results that were very close each other. In fact, as Figure 90 and Figure 91 show, the maximum Daylight Autonomy returned the same value for both cases.

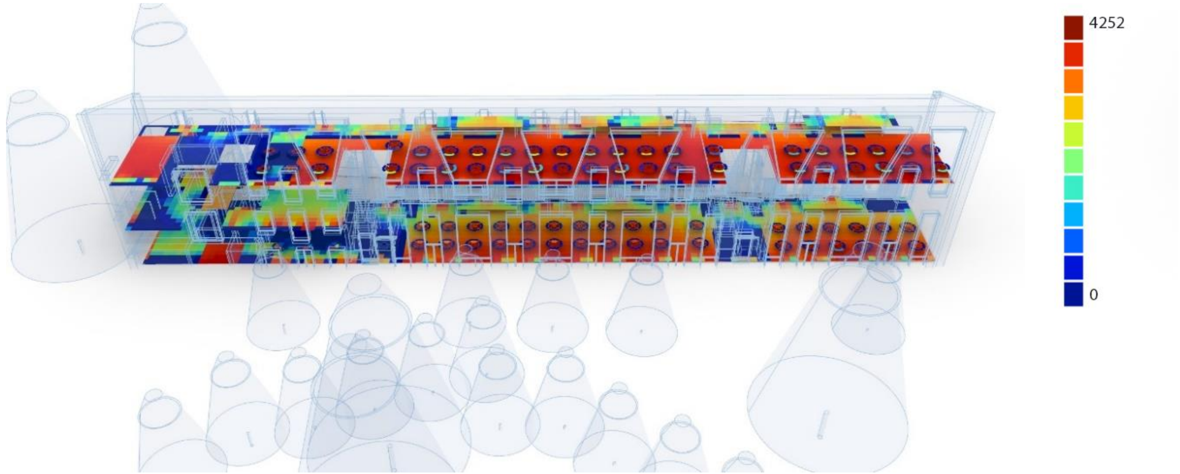


Figure 90 *- DA of the new building (F1) with summer trees. Source: Author*

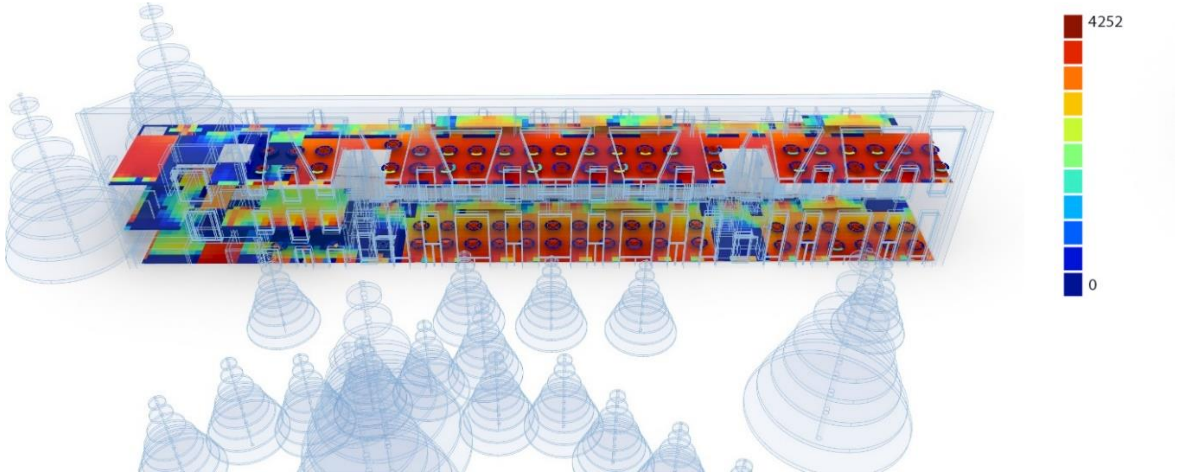


Figure 91 *- DA of the new building (F1) with winter trees. Source: Author*

Results with continuous Daylight Autonomy (cDA) were also rather similar, returning a maximum hours with summer and winter trees of, respectively, 4437 hours and 4438 hours. On these bases, all of the other simulations performed for the new design studio building were performed with winter trees.

The following simulations on the new design studios analysed and compared the distribution of CBDM metrics (DA, cDA, UDI) based on the two options of facades, F1 and F2, that were presented in Section 4.2. To remind the reader, these two façade options were considered by the design team during the development of the project, although the chief architect, Yves Lepere, unfortunately passed away before its conclusions.

For this reason, a decision was made for this thesis not to propose any modification to the existing façade proposals, but rather to test their performance and, eventually, propose some complementary lighting (natural and electric) or shading strategies, if so required.

Façade 1

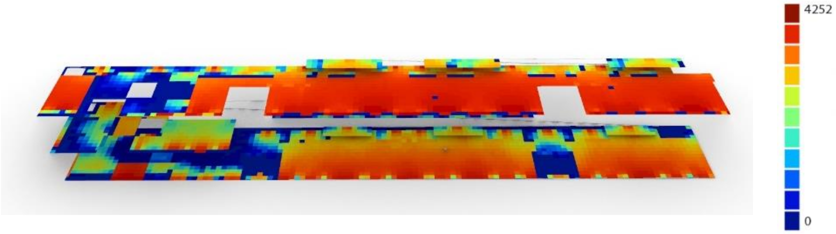


__Figure 92__ - DA of the new building (F1) with winter trees. Source: Author

Façade 2

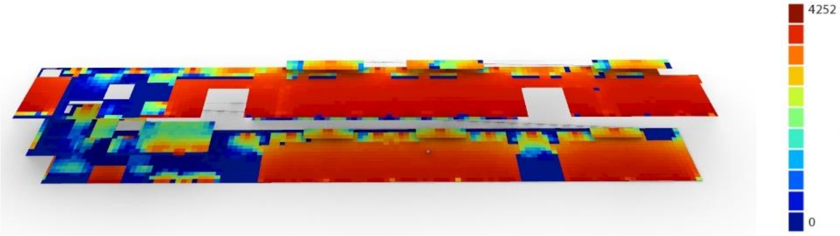


__Figure 93__ - DA of the new building (F2) with winter trees. Source: Author

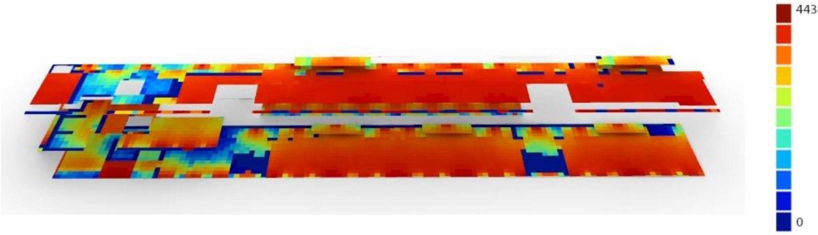


__Figure 94__ - cDA of the new building (F1) with winter trees. Source: Author

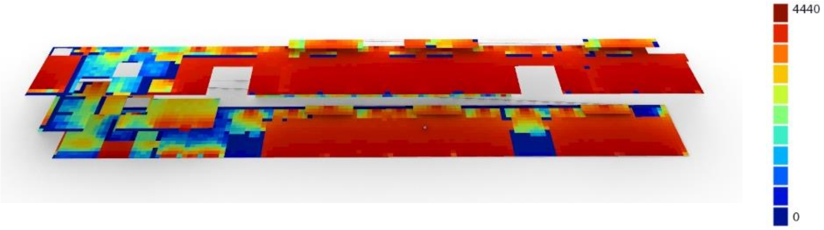


__Figure 95__ - cDA of the new building (F2) with winter trees. Source: Author

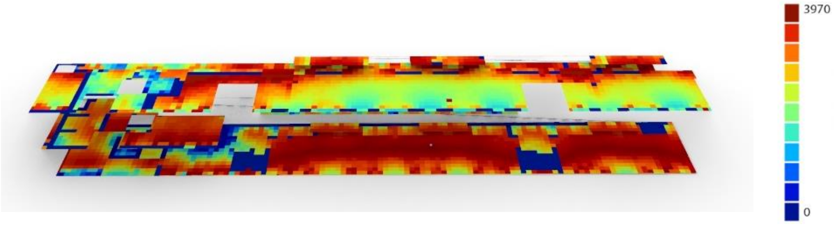


__Figure 96__ - UDI of the new building (F1) with winter trees. Source: Author

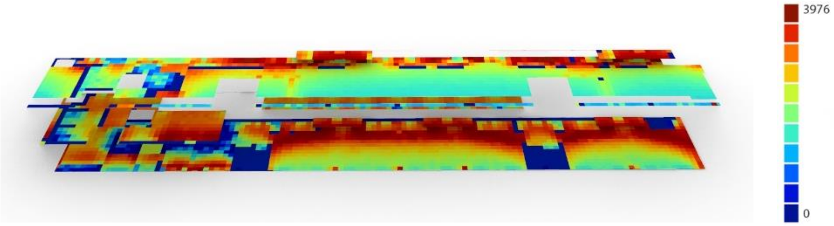


__Figure 97__ - UDI of the new building (F2) with winter trees. Source: Author

To compare the results obtained with façade 1 and façade 2, the outcomes of the simulations were justaxposed side by side. On the left side, Figure 92, Figure 94 and Figure 96, present the DA, the cDA and the UDI produced by façade 1. Figure 93, Figure 95 and Figure 97 presents the outcomes of the simulations performed with façade 2. In all cases, the winter trees models have been used to run the analyses.

From the comparison, it can be gathered that the global maximum value for the Daylight Autonomy (set at the minimum acceptable benchmark of 300 lx) is 4252 hours a year for both façade options. However, for façade 1, it can be observed that the ground floor received less light than the first floor (Figure 92). Also, at ground floor level, horizontal light distribution is higher towards the perimeter of the building, and gets lower with distance from the façade. This was to be expected as the design of façade 1 includes trapezoidal windows that become larger towards the top of the building. Conversely, with façade 2, horizontal light distribution is more homogeneous, both between the two floors, as in the direction perpendicular to the windows (Figure 93). Similar results can be observed when continuous Daylight Autonomy was tested (Figure 94 and Figure 95). However, when the UDI was simulated, on the ground and first floors of façade 1 (Figure 96), light reaches more satisfactory values than the values of UDI detected for façade 2 (Figure 97), where excessive daylight illuminance is less "useful" as there would be a lower number of hours where illuminance would be in the range between 100 and 2000 lx.

This first set of CBDM simulations for the two façade options leads to infer that the regular shape of the windows in façade 2 allows a more homogeneous distribution of horizontal illuminance over the floor surface, and between the ground and the first floor. Nevertheless, the size of the windows for façade 2 might be too large to avoid issues of excessive illumination on the horizontal surfaces, although it should be considered that the risks of solar overheating would be limited since this is a façade oriented towards the north. Also, it should be considered that all CBDM simulations were performed based on the standard settings required by regulations that require a minimum illuminance benchmark set at 300 lux. For design studios, higher values of horizontal illuminance (between 500 lx and 750 lx) might still be acceptable and, actually, recommended.

In the four following images (Figure 98, Figure 99,Figure 100, and

Figure **101**), verticals metrics are represented, alongside a simulation of Daylight Autonomy across the floor surfaces. Vertical metrics included the simulation of risks of discomfort due to glare (DGP, daylight glare probability) and potential for circadian stimulation (CS, circadian stimulus). These two metrics were calculated at the eyes of the occupants, with a grid located in the points where the design of the new building has positioned the students' working desks. Vertical metrics are represented by sombrero diagrams, each divided in four different potential view orientations. The inner circle of the sombrero diagram corresponds to the estimation of CS, and the outer circle presents the values of DGP. CS is expressed as a percentage, with 100% meaning that during at least one hour in the morning, the CS value was greater than 0.3. The DGP is expressed in hours of the year when the probability of glare occurrence exceeds the value of 0.35.

From the simulations, it can be gathered that the CS is almost everywhere at 100%, with the exception of some desk positions on the ground floor of façade 1, when the students' point of view is oriented away from the northern façade, and towards the partition walls located at the back of the studio spaces. In terms of risks of glare occurrence, for façade 1, no issues of glare were detected on the ground floor, while some mild issues of visual discomfort might be perceived on the first floor (where the width of the windows get larger) when looking towards the outside. For façade

2, some issues of glare might be perceived on the ground floor for students sitting nearby the façade. Potential issues of glare become more pronounced on the first floor, and these involve most desk positions, also when students' point of view is oriented parallel to the façade.

Façade 1

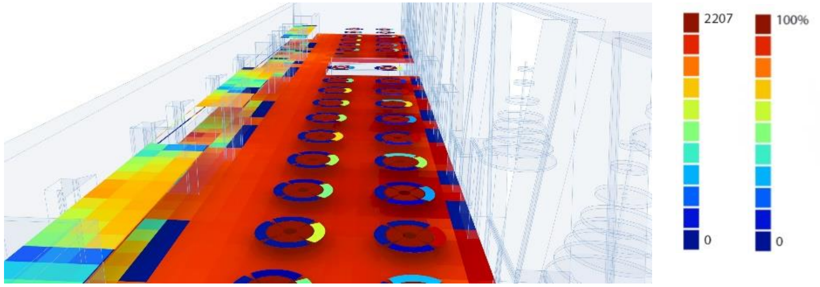


Figure 98 *- Vertical and DA horizontal metrics, first floor (F1). Source: Author*

Façade 2

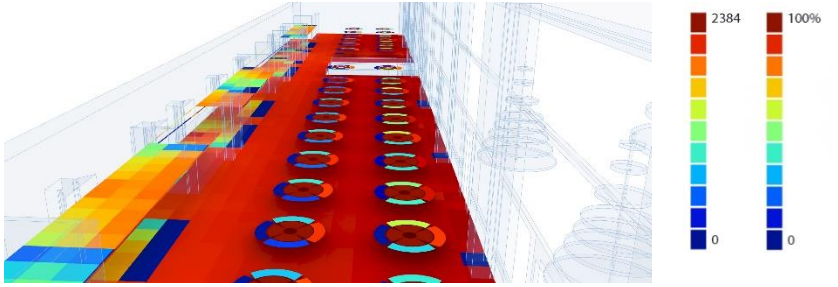


Figure 99 *- Vertical and DA horizontal metrics, first floor (F2). Source: Author*

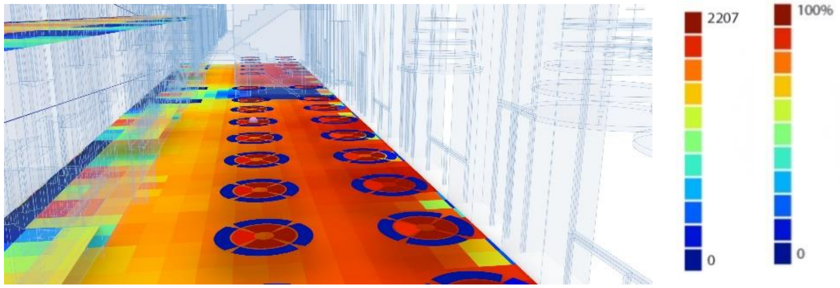


Figure 100 *- Vertical and DA horizontal metrics, ground floor (F1). Source: Author*

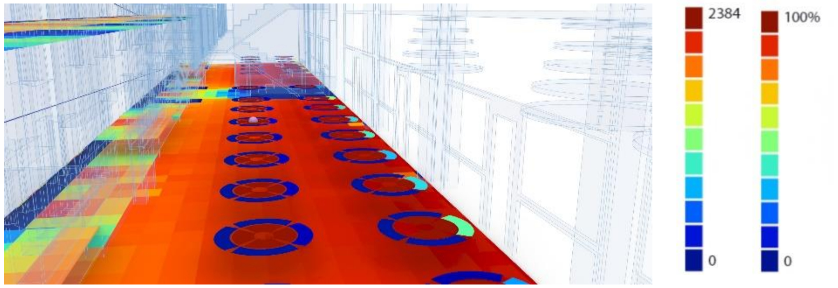


Figure 101 *- Vertical and DA horizontal metrics, ground floor (F2). Source: Author*

For every grid points used to generate the sombrero diagrams, it is possible to calculate more precise vertical metrics (both CS and DGP) under every orientation of the viewing position. In Figure 100 and in Figure 101, a purple dot (corresponding to position 39) on the second row of desks, and in the middle of the floor surface, can be observed. From this point, annual Circadian Stimulus and DGP diagrams can be plotted, these providing a visualisation of the likelihood of discomfort due to glare and the non-visual stimulation that a student sitting in this position will receive along the year, based on the view direction of the working desk. The analyses have been performed for both façade options, in order to evaluate their performance and offer recommendations in support of the lighting experience offered to students (and teaching staff) of architecture.

In the tables below, Figure 102, Figure 104, Figure 106 and Figure 107 plot the CS for the location highlighted, when the observers look in the four main orientations, respectively East, North, South and West, for façade 1. Figure 103, Figure 105, Figure 108 and Figure 109 offer the same analyses, at the same point, performed for façade 2. The colours on the scale represent the measure of CS, from 0 to its maximum value of 0.7. Similarly, for DGP, Figure 110, Figure 112, Figure 114 and Figure 116plot the DGP, at the set viewing position and in different orientations for façade 1. Figure

111, Figure 113, Figure 115 and Figure 117 present the same analysis for façade 2. In this case, the scale presents the actual values of DGP measured at the point for all times of the day and along the entire year. It should be reminded here that the lighting standard EN 17037 recommends DGP not to exceed the value of 0.35 for more than 5% of occupancy time (this benchmark corresponds to a high performance of the space).

Façade 1

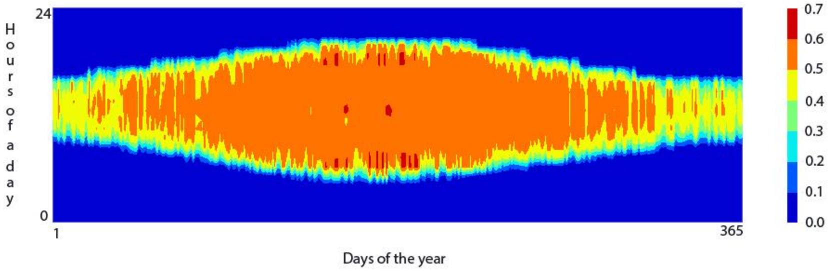


Figure 102 *- East Circadian Stimulus (F1). Source: Author*

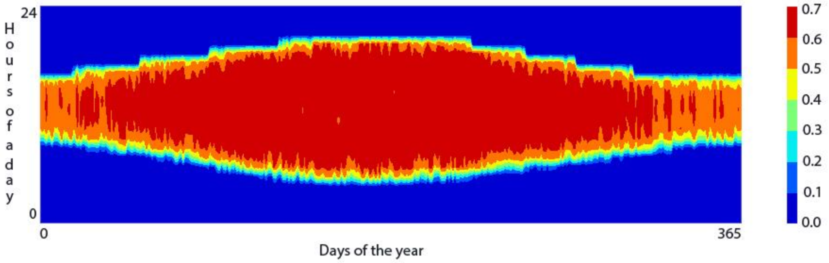


Figure 104 *- North Circadian Stimulus (F1). Source: Author*

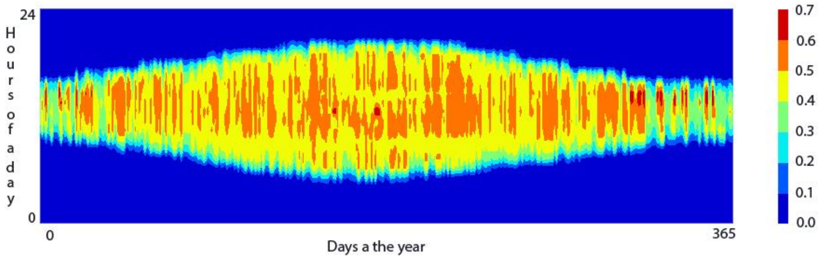


Figure 106 *- South Circadian Stimulus (F1). Source: Author*

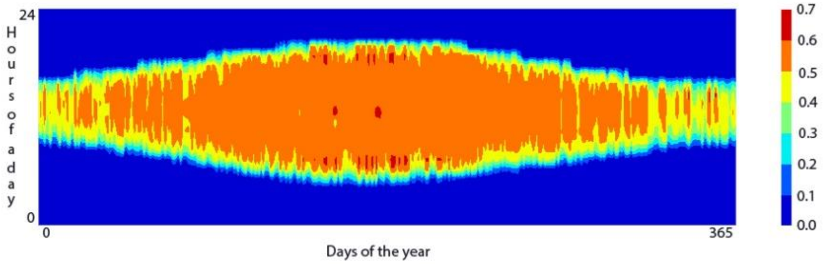


Figure 107 *- West Circadian Stimulus (F1). Source: Author*

Façade 2

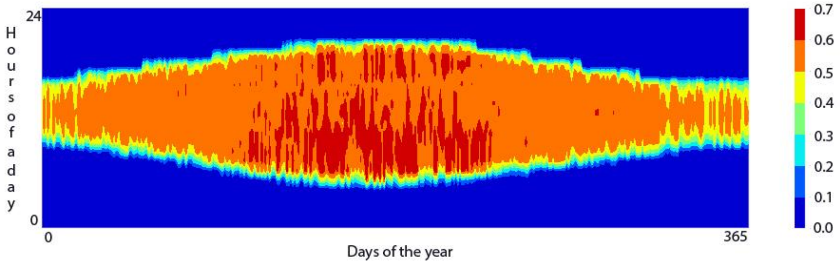


Figure 103*- East Circadian Stimulus (F2). Source: Author*

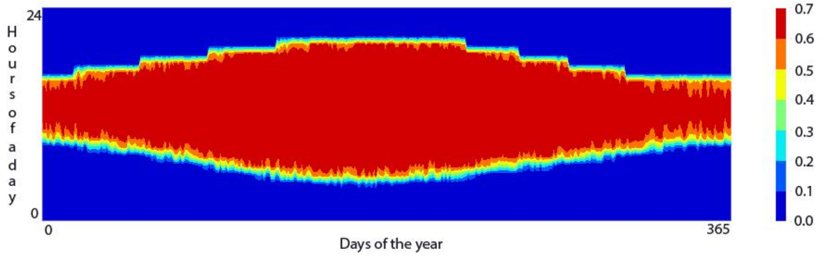


Figure 105 *- North Circadian Stimulus (F2). Source: Author*

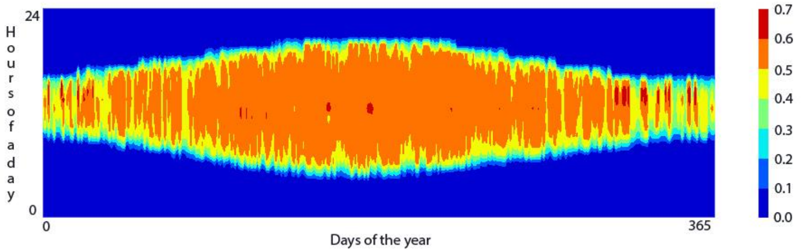


Figure 108 *- South Circadian Stimulus (F2). Source: Author*

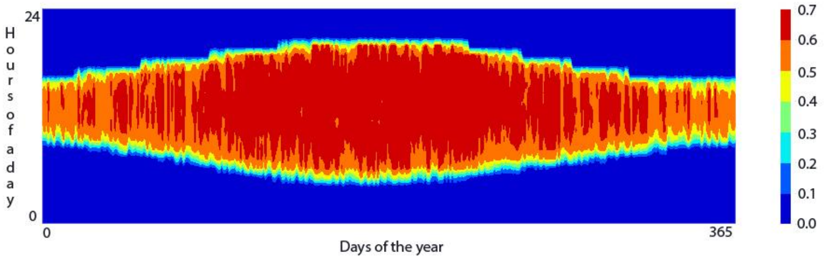


Figure 109 *- West Circadian Stimulus (F2). Source: Author*

Façade 1

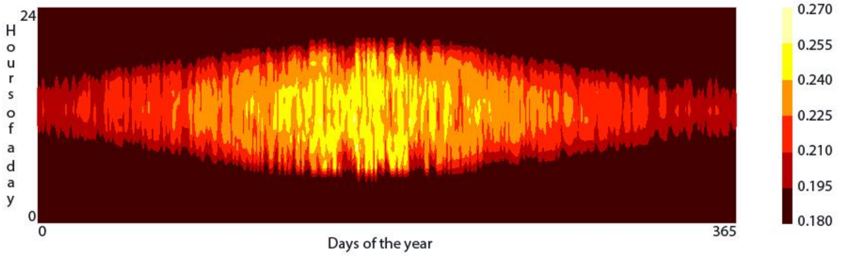


Figure 110 *- East Daylight Glare Probability (F1). Source: Author*

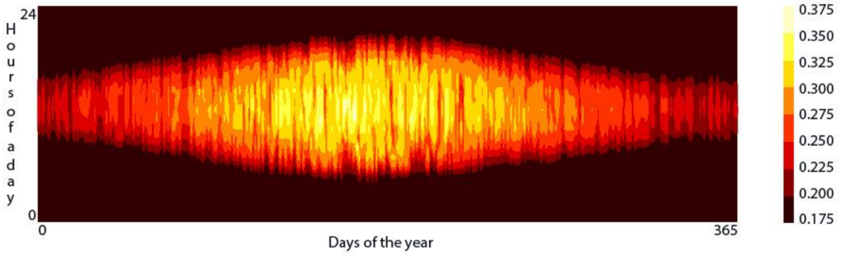


Figure 112 *- North Daylight Glare Probability (F1). Source: Author*

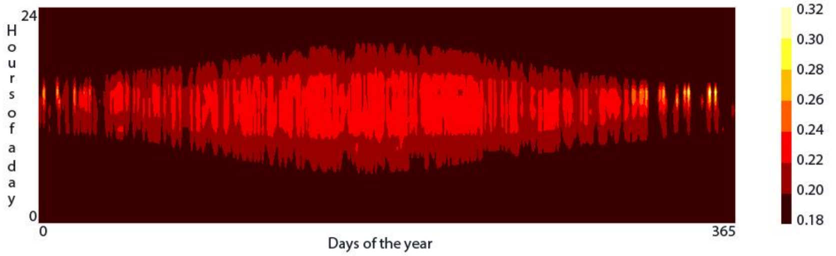


Figure 114 *- South Daylight Glare Probability (F1). Source: Author*

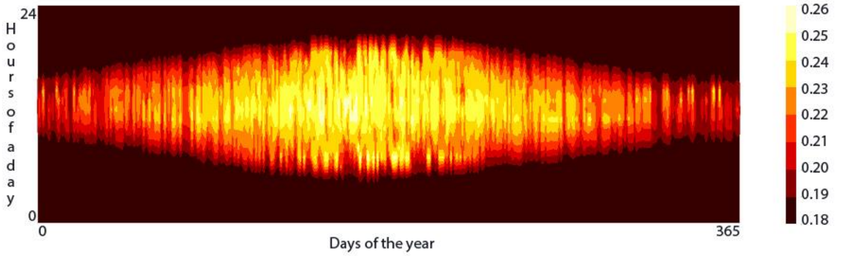


Figure 116 *- West Daylight Glare Probability (F1). Source: Author*

Façade 2

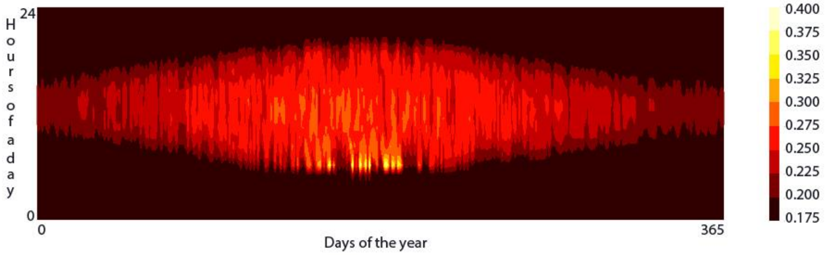


Figure 111 *- East Daylight Glare Probability (F2). Source: Author*

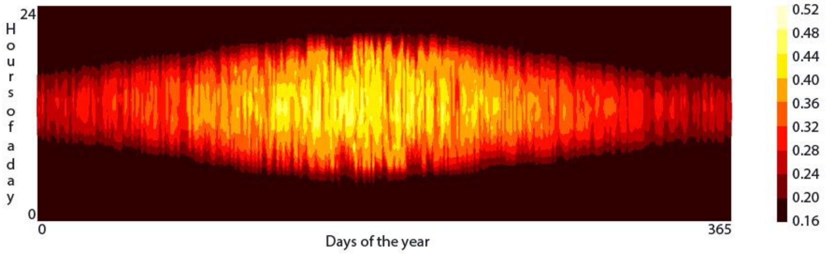


Figure 113 *- North Daylight Glare Probability (F2). Source: Author*

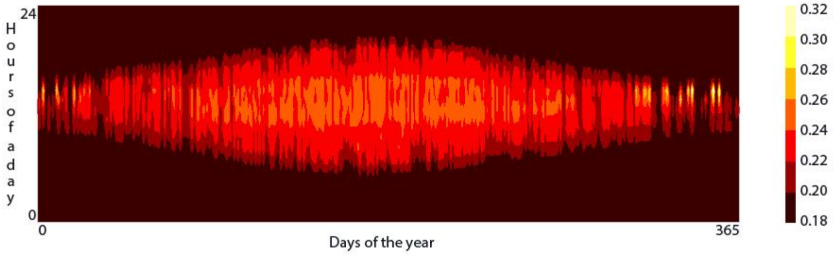


Figure 115 *- South Daylight Glare Probability (F2). Source: Author*

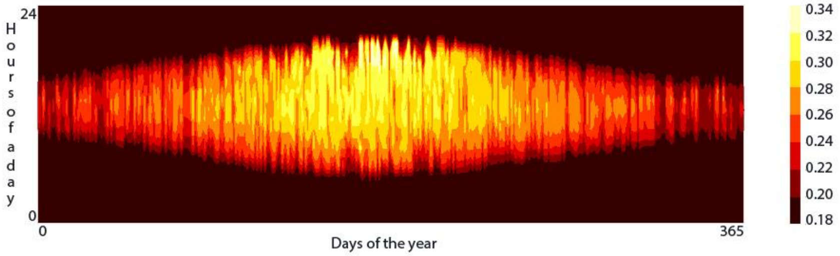


Figure 117 *- West Daylight Glare Probability (F2). Source: Author*

From the CS analysis it is evident that, at the chosen location, both floors received abundant light to entrain circadian stimulation irrespective of the direction towards which the observer looks. The two façade options have fairly similar results, although façade 2 offers a higher level of light for entraining non-visual effects, as it could be expected due to the larger size of the windows.

Yet, it must be noticed that the values of CS for the morning hours are often particuarly low during the winter months (from October through to March). This, of course, has little to do with the design of the façades, but is an effect that derives purely from the latitude of Louvain-la-Neuve (50.6681° N), which is such that the sun rises in the sky rather late in the morning in winter. Often, then, students will reach the studios without having received any useful daylight exposure in the early hours of the day. This suggests that the building lighting strategy could integrate complementary electric lighting that are blue-shifted in order to stimulate the circadian entrainment, or spectrally-tunable in order to be adapted also to different uses throughout the days and the seasons. These could be both provided in the form of task lighting (as many students requested in the cross-sectional survey), and as ambient lighting in the studio that could complement daylight at times when natural light is not available.

In terms of Daylight Glare Probability, the DGP analysis at the chosen location reveals that concerns for glare occurrence are rather limited, as it could be expected considering that the design studios are oriented towards the north. This reinforces the validity of the design principles that were established as the basis for the new building project.

For façade 1, the risks of glare occurrence are consistently below the threshold of imperceptible glare (DGP< 0.35) and only show values reaching 0.375 in the central hours of the day during summer months, when students are looking towards the north. This risk of glare is likely to be associated to bright patches of the northern sky vault, or maybe to reflections off the southern façade of the Vinci building. Yet, it must be remembered that the simulation used a modelling of the trees adapted to their winter conditions, so it is likely that the foliage of the vegetation during summer months would help reduce the risks of visual discomfort (while studios are also much less occupied during summer). Therefore, no additional shading devices or other protective system should be recommended for visual comfort under this façade option.

For façade 2, the risks of discomfort due to glare are slightly more pronounced, particularly when the orientation of the viewpoint is towards the East (desk parallel to the façade) or towards the North (desk perpendicular to the façade, looking out). For the former view direction, values up to DGP = 0.40 can be achieved in the early hours of the day in summer (these are marked as bright yellow patches in Figure 102 for example). Conversely, when the observer looks towards the north, the risks of glare are much more evident, reaching values of DGP= 0.52 for the central hours of the day, between the months of March and September. A value of daylight probability exceeding 0.45 is, in fact, beyond the minimum recommendations of standard EN 17037, hence, if façade 2 was to be implemented, the glazing would need to be protected with a shading device. Naturally, in the selection of the most appropriate protection strategy, it should be considered that façade 2 also had the most homogeneous light distribution due to the more regular shape of its windows, although the UDI simulation had emphasised some risk of excessive illuminance due to the larger size of the glazing. A simple, and appropriate solution might possibly be represented by lightly textured internal fabric curtains covering the entire height of the windows, which could be operated manually by the students upon need (and maybe retracted automatically at the end of the day). This might reduce the risks of glare and excessive illumination, while not preventing a clear view towards the external garden.

6. Discussion

6.1. The Vinci and the New Studios

To start the discussion on the results of this work, it is important first of all to trace the links between the existing building and the new one, as the pedagogy, and the occupants of the spaces, will be the same.

According to the literature (Dutton, 1987), the pedagogy of design courses is very specific and it is closely intertwined with the spatial characteristics of the place where it is delivered (Kuhn, 2000). Architectural education at UCLouvain implies the concurrent development of several activities in the studios – drawing, model making, work on computer screens, alongside table-based tutorials and pin-up assessments – these requiring different lighting strategies and solutions that can be flexibly adapted to the diverse methods for teaching and learning that are adopted at the LOCI faculty.

A thorough study of the lighting conditions in the current design studios at the ateliers Vinci, together with a through characterisation of the profiles of architectural students, and their needs, preferences and aspirations for their visual environment, has allowed to emphasise the key areas that represent a priority to tackle in the design of the new spaces. The measurements and simulations presented in the previous chapter have emphasised that *availability of daylight* is not a major concern for most of the working areas in the current design studios. Nevertheless, data collection and analysis has allowed to emphasise key lighting issues that should be addressed, these including the following:

- the adequate horizontal and vertical distribution of natural light;
- the importance of providing an unobstructed view to the outside;
- the relevance of avoiding discomfort due to glare – according to façade orientation, times of day, and seasons – by the availability and direct control of adjustable blinds;
- issues related with control of changes in luminous intensity and colour characteristics of light, particularly in connection with the existing, generalised, electric lighting system;
- the capacity to adapt the lighting to different pedagogical requirements (e.g., studio crits and projections, evaluations, daily studio-based activities, etc.)
- the wish to provide every workstation with spectrally-tunable task lights to accommodate specific students' requirements.

These points of attention for the lighting strategies could not only strongly benefit the development of the pedagogical activities within the studios, and improve the learning experience of students (Masson, 2019). The definition of more adaptable and flexible solutions to manage the ingress of natural light, combined with a dynamic and responsive complementary electric lighting system, would also respond to the specific and varied characteristics of the students in terms of their 'spectral diet' (Webler, et al. 2019) and their demanding lifestyles and circadian profiles (Roenneberg, et al., 2007).

Analysis of the results of the MCTQ questionnaire, in fact, revealed that, although the student population under analysis can be said to generally correspond to the average chronotype characteristics of the European urban population (Roenneberg, 2012), significant variability was detected among many other indicators of circadian responses. The survey's results showed that some students are out of step with society with a social jetlag that goes from 00:10 to 01:50. Moreover, the extremes of their chronotype can vary from 00:00 to 05:52, this representing a considerable variation in individual habits and metabolic cycles. Some students also reported to have very little weekly exposure to natural light, while other parameters such as weekly sleep loss and average sleep duration also varied remarkably. Certainly, this large variance cannot be adequately addressed with ‘one-size-fit-all’ automated and generalised lighting strategies and solutions, but rather require the provision of flexibly adaptable solutions to meet individual students’ requirements and needs.

In conclusion, based on the results obtained from the analysis of the Vinci design studios, and its inhabitants, verification and recommendations can be provided for the design of the new building recently proposed to host architectural students’ activities in the future. These will be discussed in the next section.

6.2. Lighting Strategies for the New Building

This thesis has been entirely centred on addressing the needs and requirements of students in architecture for their visual and non-visual responses, and to sustain at once, their learning experience, as much as their comfort, health and wellbeing. This has allowed, in the previous chapter, to drive the evaluation of the lighting performance of the proposed new building, and to critically compare two alternative façade options, façade 1 and façade 2. Clearly, the scenarios thought for the new studios are going to be only considered as propositions that could benefit the students and the pedagogy, without wishing to modify the principles and criteria adopted by the design team. Ultimately, buildings are created to offer to their occupants all possible opportunities to answer their needs, requirements, preferences, and aspirations.

With all information collected during the year, some scenarios have been presented in the results chapter based on the annual simulations of visual and non-visual metrics conducted through the OWL2 tool. These scenarios can be useful in order to define the design characteristics of the façade to be chosen (option 1 or option 2), but also could be considered for defining the surface properties of internal materials and objects (e.g., table surfaces, floor, walls), the type of electric lighting to be implemented and its strategies for control, the use of task lighting at the students’ desks, the provision of internal shading devices, and also the most appropriate location and orientation of the different workstations.

As an example, for the arrangement of furniture and students’ desks, the simulation of horizontal illuminance metrics (DA, cDA, UDI) can offer valuable information on which design decisions can be made. The new building has a limited width, hence there are not many options for the placement of the tables, unless these are organised in rows parallel to the northern façade. In this case, however, the simulations performed under façade 1 revealed the risk of potential contrast, and not perfectly homogeneous distribution of daylight away from the façade. This is also evident when looking at the light distribution within the two smaller working space located at the sides of the main studio area. Daylight availability was, moreover, rather different when comparing results for the ground and the first floor.

Other than the position of the tables across the studio spaces, also their orientation and the direction of view from the sitting location of students can be discussed. In fact, the vertical metrics evaluated through OWL2 allowed to consider simultaneously the potential for circadian stimulation (CS), as well as the risks of discomfort due to glare (DGP). For façade 1, the potential for circadian entrainment would be almost equally available for students regardless of their viewing orientation (unless they look towards the back wall in the south), while some mild issues of glare might arise particularly for those sitting on the first floor and looking in a direction perpendicular to the façade, hence towards the garden in the north.

This might suggest an orientation of the working desks parallel to the façade, that is with students looking towards the east or west, although in this case the occupants of the space might benefit only partially of a direct view to the outside. If a direct view towards the outside was to be preferred, issues of potential glare would be anyway relatively easy to counteract, for example by the use of a light fabric veil or curtain, which might filter the incoming light, reduce excessive contrast or the view of bright patches of sky or reflections, yet without completely obstructing the view to the outside. Due to the large size of the windows, a potential proposal could consist in curtains covering the entire northern wall, like the curtains of a theatre, opening onto the arts garden but separated into sections, so that they may be adjusted to suit different requirements and be flexibly adaptable to different pedagogical activities at the same time.

To respond to the results of the data collection in the Vinci, another strategy to propose could consist in a spectrally-tunable and flexibly-controlled electric lighting system. Changes in the spectral characteristics and colour temperature of the lighting, or utilisation of movable luminaires horizontally-mounted on a lightweight secondary structure above the working desks, could allow adjustments in intensity and directionality of lighting, and to adapt the colour rendering to the qualities of daylight based on times of the day or the seasons. A secondary structure (e.g., easily relocatable) might also offer the opportunity for impromptu partitioning of areas within the studios, projects, blacking out of specific spaces, etc. This might also facilitate spatial adaptations, particularly for projections or pin-up assessments. The general lighting system might also be complemented by spectrally-tunable task lighting available for each student for them to control more directly the quantity and quality of lighting at their work station.

Similar principles and strategies could also be applied to the second proposal for the northern façade, the option that has been labelled in the OWL2 simulations as façade 2. The two facades are rather different from an architectural perspective, and they also entail different light performance.

Indeed, the results showed that façade 2, with its larger and more regularly shaped windows, would bring a higher amount of light (DA and cDA), which would be more homogeneously distributed than façade 1 over the design studio spaces, and between the ground and first floor. Yet, UDI simulations revealed that this façade option might also bring issues of excessive illuminance (>2000 lx). Although this parameter is obviously to be considered with care, it must also be remembered that risks of solar overheating would not be relevant as the façade is perfectly oriented towards the north. Also, thanks to its larger windows, equally sized at both floors, façade 2 would offer more opportunities for external views, which have been suggested as highly important for the students. Some more stringent issues would anyway arise in terms of glare occurrence, both on the ground floor for students sitting in the vicinity of the façade, as on the first floor for workstations looking towards the East or towards the North. Yet, these results need to be evaluated with care. Glare issues for work positions looking towards the East are likely to happen over the summer months at the very early hours of the day, these corresponding to times where the design studios will be hardly utilised by students. For positions looking over the North, conversely, risks of glare occurrence are more relevant, and they would require the definition of appropriate measures. As already emphasised, however, these issues of glare are likely due to bright patches of sky or reflections off the Vinci façade, which could be partially or totally masked by the foliage that would grow on trees in summer.

Alternatively, a shading solution similar to that proposed for façade 1, that is a light fabric curtain or veil covering the entire window wall, and organised in section for flexible deployment, might address the issues of visual discomfort, while allowing a more abundant and homogeneous light availability both to enhance visual performance and to address circadian non-visual requirements of studio users.

7. Conclusions

This section aims to conclude the thesis summarising the findings, acknowledging the limitations of this work, and suggesting potential possibilities for future research.

7.1. Main Findings

The thesis was guided during all its development by the following question: *What type of light is necessary for supporting the pedagogy of architectural design studios and the learning experience of students?*

To answer this question, research was done focusing on two core topics: 1) *light* for visual and non-visual needs; and, 2) the *pedagogy* of design studios. A broad literature review has allowed to set the proper foundations to better understand the multiple roles of light in buildings, and its effects on the visual and non-visual systems of their occupants. This was followed by the documentary collection of information about architectural design studios, different modes of education, and their dependencies with spatial qualities and technological devices. Once these data were assembled, two specific objectives were defined in order to help to respond to the original research question:

- In the design of architectural studios, which lighting strategies (natural and electric) sustain different pedagogical methods and spatial dynamics?
- In the design studios of architectural schools, how to support the students with an appropriate lighting strategy in order to respond simultaneously to their visual comfort and the needs of non-visual well-being and to their diversified working/living schedule?

Having set up the general research framework of this work, the necessary materials and methods were defined. The first step was to introduce the initial case study on which this work has been based, the Vinci building in Louvain-la-Neuve, and the design studios that are used by the students and staff of the LOCI faculty of architecture. The characteristics of the spaces, and the requirements, needs and aspirations of their users, were investigated through three research methods: 1) occupants surveys (cross-sectional and right-now); 2) measurements and data collection; 3) building performance simulations.

The results of surveys allowed to better comprehend the profiles of the students, their lifestyles, the way they use the design studios, and the potential issues that the current spaces might entail in terms of lighting strategies. These were then verified via a comprehensive campaign of measurements, including the collection of both vertical and horizontal luminous metrics. The data were used to validate a simulation model from where further information could be gathered, encompassing visual performance as well as opportunities to address circadian needs of building users. These lessons were transferred to evaluate the design proposal for a new building that will host, over coming years, the students of architecture.

In so doing, some of the answers necessary to respond to the aim of this thesis, and its specific objectives, could be found. The lighting strategy for an architectural design studio should be delivered with great homogeneity, horizontal and vertical, good colour rendering, and consistent luminous intensity. Daylight would always be the preferred source of this light, but this has to be complemented by a spectrally-tunable and flexibly adaptable electric lighting systems to respond to the varied needs of the pedagogy, and the individual requirements of users. Daylight also often comes with a view, which is really appreciated by building users, and a priority to consider in design. Yet, personal control is an element of major importance, both for avoiding issues such as discomfort due to glare, as to address individual demands that might be connected to the task or the individual profile of people. Indeed, all users of an architectural design studio should be able to choose, and adapt, the lighting they need at the time they want. Clearly, this would also imply "education" of users, students and staff, instructing on what lighting could provide a better response to various visual needs and/or circadian phases. But, after all, providing this "*enlightened education*" should be part of the mission of a pedagogical program in architecture and architectural engineering.

7.2. Limitations

Considering that this thesis had to be completed during one academic year, the time was the first limitation to succeed in comprehensively acquiring and deploying three different methods to conduct research: surveys, measurements, and simulations. This was a complex exercise, to be completed in a relatively short period of time, which required the appropriation of a number of techniques that were either completely new, or that had been only partially encountered during the previous course of the study.

The choice to use the current design studios of the Vinci as the initial case study, and to then transfer the lessons learnt to the design of the new building, also represent a limitation, since some of the recommendations provided might not be universally applicable to educational institutions that utilise a different type of pedagogy, or whose students have a different lifestyle and working patterns. Indeed, an important limitation is also given by the relatively small size of the sample used to characterise students' profiles, and define their needs, aspirations and visual and non-visual requirements. This was a limitation imposed by the small time available, but also by the wish to respond more directly to the specific demands of the students of the LOCI faculty of architecture.

The simulation tools used for performing visual and non-visual analysis, OWL1 and OWL2, are also new, and not yet comprehensively validated. However, the thesis also provided the opportunity to contribute to their development, while also offering results that could not be available using other currently available software, unless different platforms were combined.

Finally, the definition of the lighting strategies in support of the pedagogy of architecture were also constrained by the design principles of the new building. As mentioned, also due to the recent passing away of the chief architect, it was not the intention of this thesis to modify its design or propose alternative solutions, but only to evaluate the performance of the proposed spaces, compare the available options for the façade, and suggest complementary scenarios to enhance the lighting qualities of the spaces. Other possibilities could have implied a modification of design criteria or maybe alternative solutions for the façade openings.

7.3. Further Research

This thesis obviously leaves some areas that deserve to be investigated with further research.

For this study, it was decided to define lighting recommendations that can be applied by the LOCI faculty in its new building. Clearly, similar studies could be conducted in other educational institutions, also including programmes that can be different from architecture, so as to define solutions for lighting that can be adapted to different pedagogical methods and respond to the requirements of other students.

These might not only include academic institutions, but also be extended to other degrees of education (as example, school children).

Further instruments could also be used for data collection. As an example, simulation tools were used to define the visual and non-visual exposure that students receive (or would likely get) in the studios. Conversely, wearable devices – such as the LYS buttons, which are easily clipped on clothes – could be integrated in the data collection campaign to better characterise the actual ‘spectral diet’ of students of architecture. Similarly, new or other tools could be used for the simulations of spaces, maybe more comprehensively integrating the visual and non-visual inputs of daylight and electric lighting (this is part of multi-channel spectral simulation, which is currently under development in the context of OWL3).

Finally, another possible step could be to work directly with the architects of a project and to associate the research of light with the development of the design. In this case, façade openings could be defined alongside the verification of lighting strategies, for the benefit of both the pedagogical programme and the experience of users.

8. Bibliography

Acosta, I., Campano, M. A., Leslie, R., & Radetsky, L. (2019). Daylight design for healthy environments: Analysis of educational spaces for optimal circadian stimulus. *Solar Energy 193*.

Altomonte, S. (2009). Daylight for Energy Savings and Psycho-Physiological Well-Being in Sustainable Built Environments. *Journal of Sustainable Development, 1*(3). doi:10.5539/jsd.v1n3p3

Altomonte, S. (2019). Defining comfort, satisfaction, health and well-being. In *Regenerative Design in Digital Practice / Lisanne Emanuele ; Havinga Naboni*: Eurac Research.

Altomonte, S., Rutherford, P., & Wilson, R. (2012). Mapping the Way Forward: Education for Sustainability in Architecture and Urban Design. *Corporate Social Responsibility and Environmental Management, 21*(3), 143-154. doi:https://doi.org/10.1002/csr.1311

Architecture-et-Climat. (2014). L'éclairage natural des bâtiments - le confort visuel. Retrieved from https://sites.uclouvain.be/eclairage-naturel/guide_confort.htm

Balakrishnan, P., & Jakubiec, J. A. (2023). Trees in Daylight Simulation – Measuring and Modelling Realistic Light Transmittance through Trees. *LEUKOS, 19*(3), 241-268. doi:10.1080/15502724.2022.2112217

Baldwin, N., Biard, J., Darche, L., Geubel, L., Picard, S., & Wauthier, L. (2023). *Etude de cas : l'éclairage (Eclairage naturel et éclairage artificiel dans le bâtiment Vinci).* (Master 1). Catholic University of Louvain, Louvain-la-Neuve.

Barrionuevo, P. A., Issolio, L. A., & Tripolone, C. (2023). Photoreceptor contributions to the human pupil light reflex. *Journal of Photochemistry and Photobiology, 15*. doi:10.1016/j.jpap.2023.100178

Bedrosian, T. A., & Nelson, R. J. (2017). Timing of light exposure affects mood and brain circuits. *Translational Psychiatry, 7*(1), e1017-e1017. doi:10.1038/tp.2016.262

Bleicher, T. (2014). Material description file for RADIANCE models. Retrieved from https://github.com/tbleicher/su2rad/blob/master/su2rad/su2radlib/ray/materials.rad

Bodart, M. (2019). Eclairage : conception et régulation. *Ecalirage naturel : objectifs et réglementations : La nouvelle norme Européenne EN 17037*.

Boyce, P. R. (2014). *Human Factors in Lighting*.

Brown, T. M., Brainard, G. C., Cajochen, C., Czeisler, C. A., Hanifin, J. P., Lockley, S. W., . . . Wright, K. P., Jr. (2022). Recommendations for daytime, evening, and nighttime indoor light exposure to best support physiology, sleep, and wakefulness in healthy adults. *PLoS Biol, 20*(3), e3001571. doi:10.1371/journal.pbio.3001571

Cannon, W. B. (1929). ORGANIZATION FOR PHYSIOLOGICAL HOMEOSTASIS. *Physiological Reviews, 9*(3), 399-431. doi:10.1152/physrev.1929.9.3.399

Carmon, D. (2020). *Lighting for an Ageing population* (Master 2). Catholic University of Louvain, Louvain-la-Neuve.

CEN. (2021a). Daylight in buildings. Retrieved from https://standards.cencenelec.eu/dyn/www/f?p=CEN:110:0::::FSP_PROJECT,FSP_ORG_ID:74896,6150&cs=1A881977D76E17ACB03F11F7528CB20B8

CEN. (2021b). EN 12464-1:2021. Light and lighting - Lighting of work places - Part 1: Indoor work places. European Standardisation. Retrieved from https://standards.iteh.ai/catalog/standards/cen/53fc4ff7-e7df-4ebd-a730-0d5f0ea888e0/en-12464-1-2021

Collins. (2023). Collins Dictionary. Retrieved from https://www.collinsdictionary.com/dictionary/english

Design for Climate &Comfort Lab. (2021). Spectral materials database. Retrieved from https://spectraldb.com/

Dimitrov, A., Veer, I. M., Kleeblatt, J., Seyfarth, F., Roenneberg, T., Ising, M., . . . Adli, M. (2020). Chronotype is associated with psychological well-being depending on the composition of the study sample. *J Health Psychol, 25*(9), 1236-1247. doi:10.1177/1359105317751618

Dutton, T. A. (1987). Design and Studio Pedagogy. *Journal of Architectural Education 41*, 11. Retrieved from https://www.jstor.org/stable/1424904#metadata_info_tab_contents

Enezi, J., Revell, V., Brown, T., Wynne, J., Schlangen, L., & Lucas, R. (2011). A "melanopic" spectral efficiency function predicts the sensitivity of melanopsin photoreceptors to polychromatic lights. *J Biol Rhythms, 26*(4), 314-323. doi:10.1177/0748730411409719

Fernandez, D. C., Fogerson, P. M., Lazzerini Ospri, L., Thomsen, M. B., Layne, R. M., Severin, D., . . . Hattar, S. (2018). Light Affects Mood and Learning through Distinct Retina-Brain Pathways. *Cell, 175*(1), 71-84.e18. doi:https://doi.org/10.1016/j.cell.2018.08.004

Figueiro, M. G., Steverson, B., Heerwagen, J., Kampschroer, K., Hunter, C. M., Gonzales, K., . . . Rea, M. S. (2017). The impact of daytime light exposures on sleep and mood in office workers. *Sleep Health, 3*(3), 204-215. doi:10.1016/j.sleh.2017.03.005

Fisher, G. G., Chacon, M., & Chaffee, D. S. (2019). Chapter 2 - Theories of Cognitive Aging and Work. In B. B. Baltes, C. W. Rudolph, & H. Zacher (Eds.), *Work Across the Lifespan* (pp. 17-45): Academic Press.

Fuse IQ. (2021). Daylight Pattern Guide. Retrieved from https://patternguide.advancedbuildings.net/using-this-guide.html

GmbH, K. M. B. S. E. (2023). Konica Minolta. Retrieved from https://www.konicaminolta.eu/eu-en/hardware/measuring-instruments/light-and-display-measurement/illuminance-meters/cl-70f

Hacihasanoglu, O. (2019). Architectural Design Studio Culture. *Journal of Design Studio*.

Houser, K. W., Boyce, P. R., Zeitzer, J. M., & Herf, M. (2020). Human-centric lighting: Myth, magic or metaphor? *Lighting Research & Technology, 53*(2), 97-118. doi:10.1177/1477153520958448

Kesseiba, K. (2017). Introducing Creative Space: Architectural Design Studio for Architecture

Students; Challenges and Aspirations. *Journal of Advance in Social Science and Humanities, 3*. doi:10.15520/jassh38240

Kuhn, S. (2000). Learning from the Architecture Studio: Implications for Project-Based Pedagogy. *International Journal of Engineering Eduction*.

Lampesdirect.fr. (2023). La norme EN 12464-1 qu'est ce que c'est? Retrieved from https://www.lampesdirect.fr/blog/norme-en-124641-eclairage-des-lieux-de-travail-interieurs

Liu, Y., Zhang, S., Wu, Y., & Yang, D. (2021). Studies on visual health features of luminous environment in college classrooms. *Building and Environment, 205*. doi:10.1016/j.buildenv.2021.108184

Marcheva, B., Ramsey, K. M., Peek, C. B., Affinati, A., Maury, E., & Bass, J. (2013). Circadian clocks and metabolism. *Handb Exp Pharmacol*(217), 127-155. doi:10.1007/978-3-642-25950-0_6

Maskarenj, M., Crevits, V., & Altomonte, S. (2023). *A new Radiance-based simulation workflow for modelling annual visual and non-visual metrics*. Paper presented at the Radiance Workshop, Innsbruck (Austria).

Maskarenj, M., Deroisy, B., & Altomonte, S. (2022). A new tool and workflow for the simulation of the non-image forming effects of light. *Energy and Buildings, 262*. doi:10.1016/j.enbuild.2022.112012

Masson, O. (2019). Tableau collaboratif. *HAL open science*

McClean, D., & Hourigan, N. (2015). Critical Dialogue in Architecture Studio: Peer Interaction and Feedback. *Journal for Education in the Built Environment, 8*(1), 35-57. doi:10.11120/jebe.2013.00004

NAAB. (2014). 2014 Conditions for Accreditation.

Nabil, A., & Mardaljevic, J. (2006). Useful daylight illuminances: A replacement for daylight factors. *Energy and Buildings, 38*.

Peimani, N., & Kamalipour, H. (2022). The Future of Design Studio Education: Student Experience and Perception of Blended Learning and Teaching during the Global Pandemic. *Education Sciences, 12*(2), 140. Retrieved from https://www.mdpi.com/2227-7102/12/2/140

Pierson, C., Cauwerts, C., Bodart, M., & Wienold, J. (2020). Tutorial: Luminance Maps for Daylighting Studies from High Dynamic Range Photography. *LEUKOS, 17*(2), 140-169. doi:10.1080/15502724.2019.1684319

Reinhart, C. F., Mardaljevic, J., & Rogers, Z. (2006). Dynamic Daylight Performance Metrics for Sustainable Building Design. *LEUKOS, 3*(1), 7-31. doi:10.1582/LEUKOS.2006.03.01.001

Roenneberg, T. (2012). What is chronotype? *Sleep and Biological Rhythms, 10*(2), 75-76. doi:10.1111/j.1479-8425.2012.00541.x

Roenneberg, T., Kuehnle, T., Juda, M., Kantermann, T., Allebrandt, K., Gordijn, M., & Merrow, M. (2007). Epidemiology of the human circadian clock. *Sleep Medicine Reviews, 11*(6), 429-438. doi:https://doi.org/10.1016/j.smrv.2007.07.005

Solemma-LLC. (2020). Welcome to the ClimateStudio User Guide. Retrieved from https://climatestudiodocs.com/index.html

Solemma-LLC. (2022, 03-03-2022). ClimateStudio. Retrieved from https://www.solemma.com/climatestudio

Truong, W., Trinh, V., & Khanh, T. Q. (2020). A computation model with photometric and colorimetric quantities. *Lighting Research and Technology, 52*, 11.

Vangrunderbeeck, P. (2020). *Les espaces physiques d'apprentissageMettre en relation espaces et méthodes pédagogiques pour optimiser l'apprentissage*.

Webler, F. S., Spitschan, M., Foster, R. G., Andersen, M., & Peirson, S. N. (2019). What is the 'spectral diet' of humans? *Curr Opin Behav Sci, 30*, 80-86. doi:10.1016/j.cobeha.2019.06.006

Wienold, J. (2014). *Daylight Glare analysis and metrics*. Paper presented at the 13th International Radiance Worshop, London.

9. Appendix

A. Cross-sectional Survey

B. Right-now survey

C. Measurement campaign

D. Lighting simulations

A. Cross-sectional Survey

A.1. General Questionnaire

Questionnaire transversal

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de 'Louvain research institute for Landscape, Architecture, Built environment (LAB)', Directeur du groupe de recherche 'Architecture et Climat', Université Catholique de Louvain.

Nature et sujet de l'étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d'architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.

Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l'investigateur de comprendre la population qui répond à cette enquête.

- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Période de temps requise : 20 min maximum

En cliquant sur le bouton "LANCER LE QUESTIONNAIRE" ci-dessous, vous acceptez de participer à cette étude et consentez à ce que des données statistiques anonymes soient extrapolées à partir des réponses que vous donnerez. Vous conserverez le droit de retirer à tout moment les données que vous avez fournies dans le cadre de l'étude.

CONTEXTE

1 Quel est votre genre ?

Propositions de réponse: *Choisissez une seule réponse*

☐ Femme ☐ Homme ☐ Préfère ne pas répondre

2 Quel est votre âge ?

3 Quelle est votre année d'étude ?

Propositions de réponse: *Choisissez une seule réponse*

○ Bac 1 ○ Bac 2 ○ Bac 3 ○ Master 1 ○ Master 2

4 Quelle est votre origine ?

Propositions de réponse: *Choisissez une seule réponse*

○ Blanc ○ Groupes ethniques multiples / mixtes ○ Asie ○ Noirs / Africains / Caraïbes / Britanniques noirs
○ Autre...

5 Est que vous avez des problèmes au niveau de votre vue ?

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

Si oui,

6 Portez-vous des lunettes ?

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

7 Portez-vous des lentilles ?

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

8 Avez-vous une vision normale de la couleur ?

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

9 Avez-vous d'autres problèmes au niveau de votre vision ?

Propositions de réponse: *Si oui, décrivez le problème.*

ATELIERS

10 Depuis combien de temps fréquentez-vous les ateliers du Vinci ?

Propositions de réponse: *Choisissez une seule réponse*

○ 1 an ○ 2 ans ○ 3 ans ○ 4 ans ○ 5 ans ○ Plus de 5 ans

11 Dans quel atelier travaillez-vous le plus souvent?

Propositions de réponse: *Choisissez une seule réponse*

○ Epure (bac 1, bac 2) ○ Fond (bac 3) ○ Droite (master 1) ○ Gauche (master 2)

○ Autre...

12 Depuis combien de temps travaillez-vous dans cet atelier ?

13 Quelle est l'orientation principale de votre espace de travail habituel dans les ateliers?

Propositions de réponse: *Choisissez une seule réponse*

○ Nord (pas d'ensoleillement direct) ○ Est (ensoleillement direct le matin) ○ Sud (ensoleillement direct à midi) ○ Ouest (ensoleillement direct l'après-midi)

14 Travaillez-vous souvent près d'une fenêtre (à moins de 5m) ?

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

15 Combien de jours au total dans une semaine passez-vous dans les ateliers ?

Propositions de réponse: *Choisissez une seule réponse dans chaque rangée*

	0	1	2	3	4	5	6	7
En général, durant la semaine, je passe ...	○	○	○	○	○	○	○	○
En général, durant les weekends, je passe ...	○	○	○	○	○	○	○	○
Pendant une charrette, durant la semaine, je passe ...	○	○	○	○	○	○	○	○
Pendant une charrette, durant le weekends, je passe ...	○	○	○	○	○	○	○	○

16 Combien d'heures par jour passez-vous dans les ateliers ?

Propositions de réponse: *Choisissez une seule réponse dans chaque rangée*

	4h ou moins	5-8h	9-12h	13-16h	17-20h	21-24h
En général, durant la semaine, je passe ...	○	○	○	○	○	○
En général, durant les weekends, je passe ...	○	○	○	○	○	○

Pendant une charrette, durant la semaine, je passe ...	○	○	○	○	○	○
Pendant une charrette, durant le weekends, je passe ...	○	○	○	○	○	○

17 A la fin d'une journée de travail en atelier, vous sentez-vous fatigué ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

18 Pensez-vous que ces espaces améliorent votre productivité ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

19 Pensez-vous que la lumière dans les ateliers améliore vos performances de travail ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

20 Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est homogène dans l'atelier où vous êtes ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

21 Comment jugez-vous la couleur de la lumière artificielle à l'intérieur des ateliers ?

	-3	-2	-1	0	1	2	3	
Froide (blue)	○	○	○	○	○	○	○	Chaude (rouge)

22 La lumière dans les ateliers vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur).

	-3	-2	-1	0	1	2	3	
Mauvais (pas naturel)	○	○	○	○	○	○	○	Bon (naturel)

23 Ressentez-vous parfois des épisodes d'éblouissement (c.à.d. luminosité excessive) dans les ateliers ?

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

Si oui,

24 D'où vient la source de l'éblouissement ?

Propositions de réponse: *Choisissez une ou plusieurs réponses*

☐ D'une fenêtre le matin
☐ D'une réflexion d'une surface extérieure
☐ Autre... ☐
☐ D'une fenêtre l'après-midi
☐ Des luminaires
☐ D'une réflexion sur l'écran
☐ D'une réflexion d'une surface intérieure

25 Pensez-vous que l'éclairage vertical soit bien distribué dans le cadre d'un affichage ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

26 Précisez le lieu où vous vous référez pour la question précédente.

27 Y a-t-il d'autres informations qui ne sont pas posées dans les questions ci-dessus que vous pensez devoir donner à l'investigateur par rapport à la qualité lumineuse des ateliers ? Si oui, veuillez remplir le cadre mis à votre disposition.

CONFORT LUMINEUX

28 Quand vous travaillez sur l’ordinateur, utilisez-vous les stores ?

	-3	-2	-1	0	1	2	3	
Jamais	○	○	○	○	○	○	○	Souvent

29 Si vous aviez le choix préférez-vous travailler avec de la lumière naturelle ou artificielle ?

Propositions de réponse: *Choisissez une seule réponse*

○ Naturelle ○ Artificielle ○ Mélange des deux

30 Est-il important pour vous d'avoir accès à une vue sur l'extérieur depuis votre lieu de travail ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

31 Vous considérez-vous comme sensible à la lumière artificielle ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

32 Vous considérez-vous comme sensible à la lumière naturelle ?

	-3	-2	-1	0	1	2	3	
Pas du tout	○	○	○	○	○	○	○	Fortement

33 Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

CYCLE CIRCADIEN

En semaine,

34 Je me lève généralement à ...

35 J'ai besoin de ... minutes pour me réveiller.

36 Je suis généralement réveillé ...

Propositions de réponse: *Choisissez une seule réponse*

○ Avant mon alarme ○ Avec mon alarme

37 A ... je suis parfaitement réveillé.

38 Autour de ..., J'ai normalement un pic d'énergie.

39 Je vais dormir généralement à …

40 Il me faut … minutes pour m’endormir.

41 Si j’ai l’occasion, je fais une sieste.

Propositions de réponse: *Choisissez une seule réponse*

○ Non, je ne me sentirais pas bien après

○ Oui, je dors pendant …

42 Combien de temps par jour restez-vous dehors exposé à la lumière naturelle en général ?

Pendant les weekends,

43 J’aimerais dormir jusque …

44 Je me lève généralement à …

45 Si je me réveille à l'heure de mon alarme de la semaine, j'essaie de me rendormir.

Propositions de réponse: *Choisissez une seule réponse*

○ Non

○ Oui pour encore … ☐

46 A … je suis parfaitement réveillé.

47 A … j'ai un pic d'énergie

48 Je vais au lit généralement à …

49 Il me faut ... minutes pour m’endormir.

50 Si j’ai l’occasion, je fais une sieste.

Propositions de réponse: *Choisissez une seule réponse*

○ Non, je ne me sentirais pas bien après.

○ Oui, je dors pendant ...

51 Combien de temps par jour restez-vous dehors exposé à la lumière naturelle ?

En général,

52 J’aime dormir dans une chambre entièrement noire.

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

53 Je me réveille plus facilement quand la lumière du soleil rentre dans ma chambre.

Propositions de réponse: *Choisissez une seule réponse*

○ Oui ○ Non

54 Comment caractérisez-vous votre type de personne ?

Propositions de réponse: *Si par exemple, vous aimez (et réussissez) à dormir un peu plus longtemps les jours libres que les jours ouvrables, ou si vous ne pouvez pas vous lever le lundi matin, même sans soirée le dimanche soir, alors vous êtes plutôt du soir. Si, toutefois, vous vous réveillez régulièrement et que vous vous sentez guilleret une fois que vous sautez du lit, et si vous préférez vous coucher tôt plutôt qu'à un concert du soir, vous êtes du matin.*

	-3	-2	-1	0	1	2	3	
Tout à fait du matin	○	○	○	○	○	○	○	Tout à fait du soir

55 Si vous avez des commentaires additionnels à faire, veuillez remplir le cadre ci-dessous.

Merci pour votre participation !

A.2. Chronotype

				Etudiant 1		Etudiant 2		Etudiant 3		Etudiant 4	
				Male		Male		Female		Female	
Name	Statement	Format		Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days
Local time ofgoing to bed	I go to bed at …o'clock'.	hh:mm	BT	23:00	23:59	23:00	23:00	23:30	23:59	23:00	23:59
Local time ofpreparing tosleep	I actually getready to fallasleep at …o'clock.	hh:mm	Sprep	23:30	23:59	23:00	23:00	23:30	23:59	23:00	23:59
Sleep latency	I need ... minutesto fall asleep.	mm	Slat	00:30	00:30	00:30	00:30	00:10	00:10	00:30	00:30
Sleep end	I wake up at …o'clock.	hh:mm	SE	06:30	09:00	09:00	10:00	06:00	08:30	07:30	08:30
Alarm clock use	with an alarmclock/without analarm clock	y/n	Alarm	n	n	y	n	y	y	y	n
Sleep inertia	After ... minutes,I get up.	mm	SI	00:05	00:30	00:30	00:05	00:01	00:01	00:10	01:30
Number ofwork-/work-freedays per week	I have a regularwork scheduleand work … daysper week.	n	WD/FD	5	2	5	2	5	2	5	2
Light exposure	On average, Ispend thefollowing amountof time outdoorsin daylight(without a roofabove my h	hh:mm	LE	01:30	00:30	00:40	01:00	01:30	04:00	03:00	05:00
		Computed variables									
Sleep onset	SPrep + Slat	hh:mm	SO	00:00	00:29	23:30	23:30	23:40	00:09	23:30	00:29
Local time ofgetting out ofbed	SE + SI	hh:mm	GU	06:35	09:30	09:30	10:05	06:01	08:31	07:40	10:00
Sleep duration	SE - SO	hh:mm	SD	06:30	08:31	09:30	10:30	06:20	08:21	08:00	08:01
Total time inbed	GU - BT	hh:mm	TBT	07:35	09:31	10:30	11:05	06:31	08:32	08:40	10:01
Mid-Sleep	SO + SD/2	hh:mm	MS	03:15	04:44	04:15	04:45	02:50	04:19	03:30	04:29
Average weekly sleep duration	(SDw x WD + SDf x FD) x 7	hh:mm	Sdweek	07:04		09:47		06:54		08:00	
Chronotype		hh:mm	MSFsc	**03:43**		**04:15**				**04:28**	
Weekly sleep loss		hh:mm	Slossweek	02:50		01:25		02:50		00:00	
Relative social jetlag	MSF - MSW	hh:mm	SJLref	01:29		00:30		01:29		00:59	
Absolute social jetlag	| MSF - MSW |	hh:mm	SJL	01:29		00:30		01:29		00:59	
Average weekly light exposure	(LEw x WD + LEf x FD)/7	hh:mm	LEWeek	01:12		00:45		02:12		03:34	
						sieste oui					
				3.716666667		4.25				4.466666667	

Etudiant 5		Etudiant 6		Etudiant 7		Etudiant 8		Etudiant 9		Etudiant 10		Etudiant 11		Etudiant 12		Etudiant 13		Etudiant 14		Etu
Male		Male		Female		Female		Female		Male		X		Male		Female		Female		
Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays
23:00	23:00	23:30	23:30	23:30	23:30	23:00	01:00	00:30	23:00	22:00	22:30	01:30	23:30	23:30	01:00	23:00	23:30	00:30	01:00	23:30
23:00	23:00	23:30	23:30	23:30	23:30	23:00	01:00	00:30	23:00	22:00	22:30	01:30	23:30	23:30	01:00	23:00	23:30	00:30	01:00	23:30
00:10	00:10	00:15	00:15	00:45	00:45	00:20	00:30	00:30	01:00	00:05	00:10	00:01	00:01	00:02	00:02	00:20	00:20	00:20	01:00	01:00
06:00	08:30	07:30	08:00	08:45	09:30	07:30	08:00	08:30	08:30	07:35	09:00	09:30	10:00	08:00	09:30	08:30	09:30	08:00	10:30	07:30
n	n	y	n	y	n	n	n	y	n	y	n	n	n	n	n	n	y	y	n	n
00:15	00:30	00:15	01:00	00:10	01:30	00:10	00:30	01:00	00:30	00:05	02:00	00:01	00:30	00:30	02:00	00:05	00:15	00:10	04:30	00:00
5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5
02:30	05:30	03:00	03:00	01:30	04:00	01:00	01:00	00:30	03:00	02:30	06:00	00:20	00:20	01:30	03:30	01:00	01:00	02:00	04:00	02:00
23:10	23:10	23:45	23:45	00:15	00:15	23:20	01:30	01:00	00:00	22:05	22:40	01:31	23:31	23:32	01:02	23:20	23:50	00:50	02:00	00:30
06:15	09:00	07:45	09:00	08:55	11:00	07:40	08:30	09:30	09:00	07:40	11:00	09:31	10:30	08:30	11:30	08:35	09:45	08:10	15:00	07:30
06:50	09:20	07:45	08:15	08:30	09:15	08:10	06:30	07:30	08:30	09:30	10:20	07:59	10:29	08:28	08:28	09:10	09:40	07:10	08:30	07:00
07:15	10:00	08:15	09:30	09:25	11:30	08:40	07:30	09:00	10:00	09:40	12:30	08:01	11:00	09:00	10:30	09:35	10:15	07:40	14:00	08:00
02:35	03:50	03:37	03:52	04:30	04:52	03:25	04:45	04:45	04:15	02:50	03:50	05:30	04:45	03:46	05:16	03:55	04:40	04:25	06:15	04:00
07:32		07:53		08:42		07:41		07:47		09:44		08:41		08:28		09:18		07:32		
02:35		**03:37**		**04:29**		**04:45**		**03:45**		**03:25**		**03:30**		**05:16**				**05:35**		
03:30		00:40		01:00		02:22		01:25		01:10		03:30		00:00		00:40		01:50		
01:15		00:15		00:22		01:20		-00:30		01:00		-00:45		01:30		00:45		01:50		
01:15		00:15		00:22		01:20		00:30		01:00		00:45		01:30		00:45		01:50		
03:21		03:00		02:12		01:00		01:12		03:30		00:20		02:04		01:00		02:34		
sieste oui				sieste oui						sieste oui 20 min		Sieste oui 30min		sieste oui 20 min ou 2h		sieste oui 30 min à 2h		sieste oui 30 min		
2.583333333		3.616666667		4.483333333		4.75		3.75		3.416666667		3.5		5.266666667				5.583333333		

diant 15	Etudiant 16		Etudiant 17		Etudiant 18		Etudiant 19		Etudiant 20		Etudiant 21		Etudiant 22		Etudiant 23		Etudiant 24		Etudiant 25	
X	Male		Male		Female		Female		X		Female		Female		Female		Male		Male	
Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free days	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day
23:30	01:00	01:00	02:30	01:30	00:00	01:00	00:00	00:00	00:00	02:00	00:00	23:00	00:30	00:30	22:00	22:00	01:00	01:00	00:00	22:00
23:30	01:00	01:00	02:30	01:30	00:00	01:00	00:00	00:00	00:00	02:00	00:00	23:00	00:30	00:30	22:00	22:00	01:00	01:00	00:00	22:00
01:00	00:15	00:15	00:05	00:05	00:20	00:10	00:10	00:15	00:30	00:05	00:30	00:30	00:10	00:10	00:30	00:30	02:00	02:00	00:10	00:45
09:30	10:30	12:00	07:40	09:00	08:00	10:00	08:00	09:00	07:00	09:00	09:00	10:00	08:30	09:00	07:00	07:00	07:00	09:00	07:30	10:00
n	y	n	n	n	n	n	y	n	y	n	y	n	y	n	n	n	y	n	n	n
00:00	00:20	00:00	00:10	00:00	00:15	00:00	00:30	00:00	00:15	01:00	00:30	01:00	00:05	02:00	00:15	02:00	00:30	00:30	00:30	00:00
2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2
02:00	01:00	01:00	02:00	04:00	00:30	00:30	07:00	07:00	01:00	02:00	02:00	04:00	01:00	03:00	01:00	02:00	00:45	06:00	02:00	03:00
00:30	01:15	01:15	02:35	01:35	00:20	01:10	00:10	00:15	00:30	02:05	00:30	23:30	00:40	00:40	22:30	22:30	03:00	03:00	00:10	22:45
09:30	10:50	12:00	07:50	09:00	08:15	10:00	08:30	09:00	07:15	10:00	09:30	11:00	08:35	11:00	07:15	09:00	07:30	09:30	08:00	10:00
09:00	09:15	10:45	05:05	07:25	07:40	08:50	07:50	08:45	06:30	06:55	08:30	10:30	07:50	08:20	08:30	08:30	04:00	06:00	07:20	11:15
10:00	09:50	11:00	05:20	07:30	08:15	09:00	08:30	09:00	07:15	08:00	09:30	12:00	08:05	10:30	09:15	11:00	06:30	08:30	08:00	12:00
05:00	05:52	06:37	05:07	05:17	04:10	05:35	04:05	04:37	03:45	05:32	04:45	04:45	04:35	04:50	02:45	02:45	05:00	06:00	03:50	04:22
07:34	09:40		05:45		08:00		08:05		06:37		09:04		07:58		08:30		04:34		08:27	
04:00	**05:52**		**04:07**		**05:00**		**04:09**		**05:19**		**03:45**		**04:35**		**02:45**		**05:00**		**02:24**	
02:50	02:05		03:20		01:40		01:15		00:35		02:50		00:40		00:00		02:50		05:35	
01:00	00:45		00:10		01:25		00:32		01:47		00:00		00:15		00:00		01:00		00:32	
01:00	00:45		00:10		01:25		00:32		01:47		00:00		00:15		00:00		01:00		00:32	
02:00	01:00		02:34		00:30		07:00		01:17		02:34		01:34		01:17		02:15		02:17	
	sieste oui 30min mais pas le weekend				sieste oui 30 min		sieste oui 20 à 40min				sieste oui 1h				sieste oui 30min				sieste oui 20min	
4	5.866666667		4.116666667		5		4.15		5.316666667		3.75		4.583333333		2.75		5		2.4	

Etudiant 26		Etudiant 27		Etudiant 28		Etudiant 29		Etudiant 30		Etudiant 31		Etudiant 32		Etudiant 33		Etudiant 34		Etudiant 35		Etudiant 36	
Female		Female		Male		Female		Female		Female		Female		Female		Female		Male		Female	
Workdays	Work-free days	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day	Workdays	Work-free day
00:00	00:00	23:15	23:15	02:00	01:00	22:30	23:00	23:30	22:30	23:00	00:00	23:30	23:30	23:00	00:00	00:00	23:00	23:00	23:00	23:00	00:00
00:00	00:00	23:15	23:15	02:00	01:00	22:30	23:00	23:30	22:30	23:00	00:00	23:30	23:30	23:00	00:00	00:00	23:00	23:00	23:00	23:00	00:00
00:30	00:10	00:15	00:15	00:20	00:10	00:03	00:03	00:05	03:00	00:25	00:20	00:05	00:05	00:05	00:05	00:10	01:00	00:15	00:15	00:20	00:20
07:00	08:30	07:30	08:30	10:00	09:00	08:00	10:00	09:00	09:30	07:50	09:30	08:00	10:30	08:30	11:00	07:30	08:00	08:00	09:00	09:00	09:00
n	n	y	n	y	n	y	n	n	n	y	n	y	n	y	n	y	y	y	n	y	n
00:10	02:00	00:45	00:05	00:40	02:00	00:10	02:00	00:30	01:30	00:15	00:30	00:30	00:30	00:15	00:00	00:05	01:00	00:15	01:00	00:10	01:00
5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2	5	2
02:00	05:00	01:15	01:15	02:00	04:00	01:30	01:00	00:30	01:00	02:00	02:30	01:00	02:30	01:00	04:00	01:00	05:00	01:00	02:00	00:30	00:25
00:30	00:10	23:30	23:30	02:20	01:10	22:33	23:03	23:35	01:30	23:25	00:20	23:35	23:35	23:05	00:05	00:10	00:00	23:15	23:15	23:20	00:20
07:10	10:30	08:15	08:35	10:40	11:00	08:10	12:00	09:30	11:00	08:05	10:00	08:30	11:00	08:45	11:00	07:35	09:00	08:15	10:00	09:10	10:00
06:30	08:20	08:00	09:00	07:40	07:50	09:27	10:57	09:25	08:00	08:25	09:10	08:25	10:55	09:25	10:55	07:20	08:00	08:45	09:45	09:40	08:40
07:10	10:30	09:00	09:20	08:40	10:00	09:40	13:00	10:00	12:30	09:05	10:00	09:00	11:30	09:45	11:00	07:35	10:00	09:15	11:00	10:10	10:00
03:45	04:20	03:30	04:00	06:10	05:05	03:16	04:31	04:17	05:30	03:37	04:55	03:47	05:02	03:47	05:32	03:50	04:00	03:37	04:07	04:10	04:40
07:01		08:17		07:42		09:52		09:00		08:37		09:07		09:50		07:31		09:02		09:22	
03:25		**03:30**		**05:00**		**03:46**		**05:30**		**04:32**		**03:47**		**04:47**				**03:37**		**04:40**	
02:35		01:25		00:10		02:05		02:00		01:00		03:30		02:05		00:55		01:25		01:24	
00:35		00:30		-01:05		01:15		01:13		01:18		01:15		01:45		00:10		00:30		00:30	
00:35		00:30		01:05		01:15		01:13		01:18		01:15		01:45		00:10		00:30		00:30	
02:51		01:15		02:34		01:21		00:38		02:08		01:25		01:51		02:08		01:17		00:28	
				sieste oui 1h								sieste oui 30min		sieste oui 25 min et bien plus lgt le weekend							
3.416666667		3.5		5		3.766666667		5.5		4.533333333		3.783333333		4.783333333				3.616666667		4.666666667	

B. Right-now survey

B.1. General Questionnaire

Right-Now questionnaire

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de ‘Louvain research institute for Landscape, Architecture, Built environment (LAB)’, Directeur du groupe de recherche ‘Architecture et Climat’, Université Catholique de Louvain.

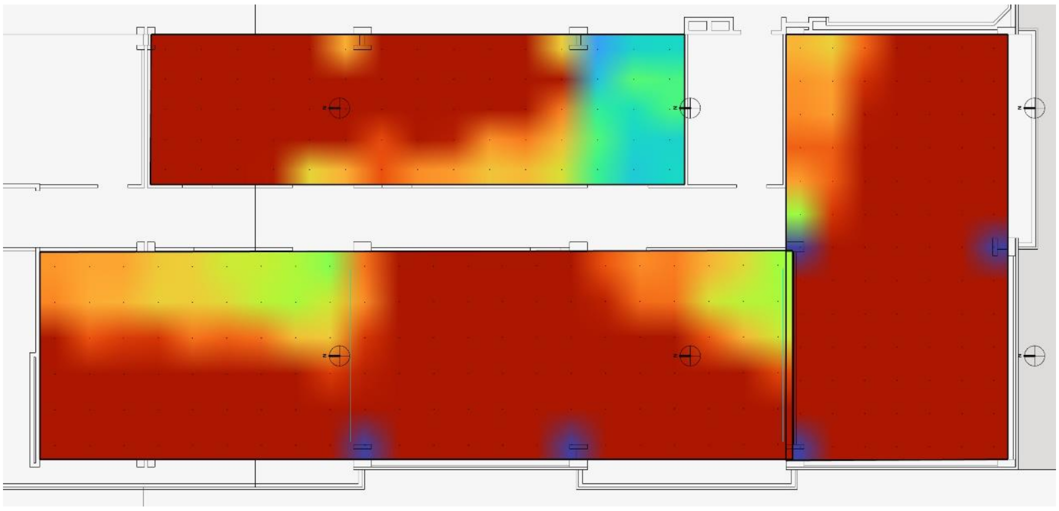
Nature et sujet de l’étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d’architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.
Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l’investigateur de comprendre la population qui répond à cette enquête.
- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Cette partie sera complétée par l'investigateur.

1. Nombre du participant :
2. Date :
3. Heure :
4. Conditions du ciel :
5. Position dans l'atelier :



6. Température :
7. RH :
8. Illuminance horizontale (plan de travail) :
9. Illuminance verticale :

Contexte :

Les questions suivantes visent à comprendre votre état actuel, il est donc important que vous y répondiez en considérant votre état à l'instant présent.

1. Quel est votre genre ? Femme / Homme / Préfère ne pas répondre
2. Quel est votre âge ? ……………………………..
3. Quelle est votre année d'étude ? ………………..
4. Est que vous avez des problèmes au niveau de votre vue ? Oui / Non

   Si oui,

   - Portez-vous des lunettes ? Oui / Non
   - Portez-vous des lentilles ? Oui / Non
   - Avez-vous une vision normale de la couleur ? Oui / Non
   - Avez-vous d'autres problèmes au niveau de votre vision ? Oui / Non

     Si oui, donnez une courte description ici

5. Quel est votre état actuel de santé ?

Malade Bien

○ ○ ○ ○ ○ ○ ○

6. Avez-vous passé du temps dehors avant de venir dans les ateliers ? Oui / Non

   Si oui, combien de temps ?

7. Avez-vous consommé une de ces choses dans les dernières 15 min ?
   - Boisson chaude
   - Boisson avec de la caféine
   - Snack ou repas
   - Boisson froide
   - Cigarette

8. Vous sentez-vous fatigué ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ○

Lumière dans les ateliers :

Les questions suivantes visent à comprendre vos ressentis de la lumière dans les ateliers à l'instant présent à l'endroit où vous êtes installé maintenant.

1. Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ○

2. Est-ce que vous pensez que la distribution verticale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ○

3. Pensez-vous que la lumière améliore ou gêne vos performances de travail ?

Améliore Gêne

○ ○ ○ ○ ○ ○ ○

4. Comment jugez-vous la couleur de la lumière (naturelle et artificielle) ?

Froide (bleue) Chaude (rouge)

○ ○ ○ ○ ○ ○ ○

5. La lumière vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur) ?

Mauvais (pas fiable) Bon (très fiable)

○ ○ ○ ○ ○ ○ ○

6. Veuillez donner une évaluation de votre sensation d’éblouissement actuel

☐	☐	☐	☐
Imperceptible	Perceptible	Dérangeant	Intolérable

7. Si vous sentez la présence d’éblouissement (c.a.d. luminosité excessive) maintenant, quelle est la source principale ?
   - ☐ Une fenêtre
   - ☐ Une réflexion sur l’écran
   - ☐ Une réflexion d’une surface intérieure
   - ☐ Une réflexion d’une surface extérieure
   - ☐ Les luminaires
   - ☐ Autre : ……..
   - ☐ Il n’y a pas d’éblouissement

Préférences lumineuses :

Les questions suivantes visent à comprendre vos préférences lumineuses.

1. Utilisez-vous souvent les stores ? Oui / Non

2. Travaillez-vous de préférence avec de la lumière naturelle ou artificielle ?
   - Naturelle
   - Artificielle
   - Mélange des deux

3. Dans votre espace de travail habituel, avez-vous un accès direct à une vue vers l’extérieur ? Oui / Non

4. Est-il important pour vous d’y avoir accès ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ○

5. Vous considérez-vous comme sensible à la lumière artificielle ?

Pas du tout						Fortement
○	○	○	○	○	○	○

6. Vous considérez-vous comme sensible à la lumière naturelle ?

Pas du tout						Fortement
○	○	○	○	○	○	○

7. Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités à l'instant présent (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

Merci pour votre participation !

B.2. Participant 1

Right-Now questionnaire

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de 'Louvain research institute for Landscape, Architecture, Built environment (LAB)', Directeur du groupe de recherche 'Architecture et Climat', Université Catholique de Louvain.

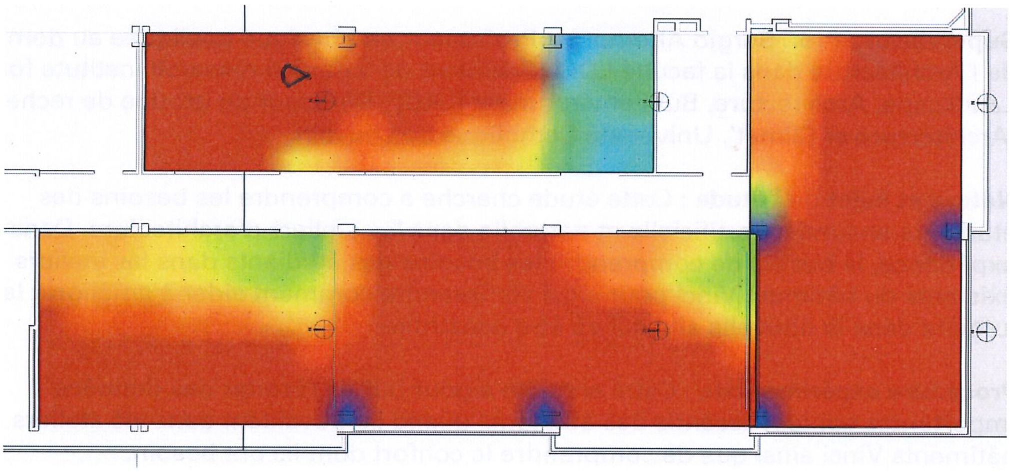
Nature et sujet de l'étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d'architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.
Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l'investigateur de comprendre la population qui répond à cette enquête.
- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Cette partie sera complétée par l'investigateur.

1. Nombre du participant : 1 (dessin à la main).
2. Date : 04/05/23
3. Heure : 10h.
4. Conditions du ciel : dégagé très fins nuages.
5. Position dans l'atelier :



6. Température : 22°
7. RH : 46,2 % (8,5 C°) 10h21.
8. Illuminance horizontale (plan de travail) : 2940 lux 5838K. 0,0017
9. Illuminance verticale : avec (4540 lux 4975K. Δuv = 0,0028. 5990 lux 5312 K 0, 0015) sans

279,5. 10 h. 18.

Contexte :

Les questions suivantes visent à comprendre votre état actuel, il est donc important que vous y répondiez en considérant votre état à l'instant présent.

1. Quel est votre genre ? [✓ Femme] / Homme / Préfère ne pas répondre
2. Quel est votre âge ? ...23 ans...
3. Quelle est votre année d'étude ? ...Master 2
4. Est que vous avez des problèmes au niveau de votre vue ? [✓ Oui] / Non

   Si oui,

   - Portez-vous des lunettes ? Oui / [✓ Non]
   - Portez-vous des lentilles ? Oui / [✓ Non]
   - Avez-vous une vision normale de la couleur ? Oui / [✓ Non]
   - Avez-vous d'autres problèmes au niveau de votre vision ? Oui / [✓ Non]

     Si oui, donnez une courte description ici

5. Quel est votre état actuel de santé ?

Malade   Bien

○ ○ ○ ● ○ ○ ○

6. Avez-vous passé du temps dehors avant de venir dans les ateliers ? [✓ Oui] / Non

   Si oui, combien de temps ? 15 minutes

7. Avez-vous consommé une de ces choses dans les dernières 15 min ?
   - [✓ Boisson chaude] thé.
   - Boisson avec de la caféine
   - Snack ou repas
   - Boisson froide
   - Cigarette

8. Vous sentez-vous fatigué ?

Pas du tout   Fortement

● ○ ○ ○ ○ ○ ○

Lumière dans les ateliers :

Les questions suivantes visent à comprendre vos ressentis de la lumière dans les ateliers à l'instant présent à l'endroit où vous êtes installé maintenant.

1. Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ○ ⊗ ○

2. Est-ce que vous pensez que la distribution verticale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ○ ⊗ ○

3. Pensez-vous que la lumière améliore ou gêne vos performances de travail ?

Améliore Gêne

○ ⊗ ○ ○ ○ ○ ○

4. Comment jugez-vous la couleur de la lumière (naturelle et artificielle) ?

Froide (bleue) Chaude (rouge)

○ ○ ○ ○ ⊗ ○ ○

5. La lumière vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur) ?

Mauvais (pas fiable) Bon (très fiable)

○ ○ ○ ○ ○ ○ ⊗

(les ☒ c'était avec les stores fermés)

6. Veuillez donner une évaluation de votre sensation d'éblouissement actuel

☒ Imperceptible ☒ Perceptible ☐ Dérangeant ☐ Intolérable

7. Si vous sentez la présence d'éblouissement (c.a.d. luminosité excessive) maintenant, quelle est la source principale ?

☒ Une fenêtre
☐ Une réflexion sur l'écran
☐ Une réflexion d'une surface intérieure
☐ Une réflexion d'une surface extérieure
☐ Les luminaires
☐ Autre : ……..
☒ Il n'y a pas d'éblouissement

références lumineuses :

es questions suivantes visent à comprendre vos préférences lumineuses.

1. Utilisez-vous souvent les stores ? [✓ Oui] / Non

2. Travaillez-vous de préférence avec de la lumière naturelle ou artificielle ?
   - [✓ Naturelle]
   - Artificielle
   - Mélange des deux

3. Dans votre espace de travail habituel, avez-vous un accès direct à une vue vers l'extérieur ? [✓ Oui] / Non

4. Est-il important pour vous d'y avoir accès ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ☒

5. Vous considérez-vous comme sensible à la lumière artificielle ?

Pas du tout … Fortement

○ ○ ● ○ ○ ○ ○

6. Vous considérez-vous comme sensible à la lumière naturelle ?

Pas du tout … Fortement

○ ○ ● ○ ○ ○ ○

7. Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités à l'instant présent (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

1. Un store électrique
2. Une lumière artificielle personnalisable (qui n'influe que sur mon post de travail)

Merci pour votre participation !

B.3. Participant 2

Right-Now questionnaire

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de 'Louvain research institute for Landscape, Architecture, Built environment (LAB)', Directeur du groupe de recherche 'Architecture et Climat', Université Catholique de Louvain.

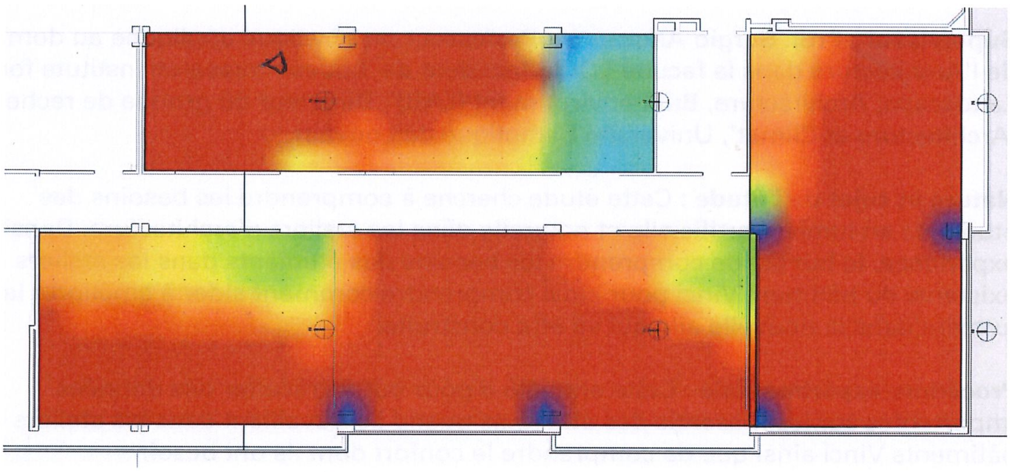
Nature et sujet de l'étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d'architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.
Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l'investigateur de comprendre la population qui répond à cette enquête.
- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Cette partie sera complétée par l’investigateur.

1. Nombre du participant : 2 (dessin à la main)
2. Date : 04/05/23
3. Heure : 10h10
4. Conditions du ciel : dégagé qq nuages fins
5. Position dans l’atelier :



6. Température : 22,3 °C
7. RH : 40,4% (8,2 °C)
8. Illuminance horizontale (plan de travail) : 10h38 3230 lux 5965K 0,0022
9. Illuminance verticale : 5210 lux 4999 K 0,0028 { ~~sans~~ avec 5520 lux 5392 K 0,0025 } sans

10h23 299,4 cd / m^2.

Contexte :

Les questions suivantes visent à comprendre votre état actuel, il est donc important que vous y répondiez en considérant votre état à l'instant présent.

1. Quel est votre genre ? Femme / [✓ Homme] / Préfère ne pas répondre
2. Quel est votre âge ? ......22........................
3. Quelle est votre année d'étude ? .Master 2....
4. Est que vous avez des problèmes au niveau de votre vue ? Oui / [✓ Non]

   Si oui,

   - Portez-vous des lunettes ? Oui / Non
   - Portez-vous des lentilles ? Oui / Non
   - Avez-vous une vision normale de la couleur ? Oui / Non
   - Avez-vous d'autres problèmes au niveau de votre vision ? Oui / Non

   Si oui, donnez une courte description ici

   ☐

5. Quel est votre état actuel de santé ?

Malade ○ ○ ○ ○ ○ ○ ☒ Bien

6. Avez-vous passé du temps dehors avant de venir dans les ateliers ? [✓ Oui] / Non

   Si oui, combien de temps ? 15 minutes

7. Avez-vous consommé une de ces choses dans les dernières 15 min ?

   - [✓ Boisson chaude] } café
   - Boisson avec de la caféine } café
   - [✓ Snack ou repas]
   - Boisson froide
   - Cigarette

8. Vous sentez-vous fatigué ?

Pas du tout ○ ○ ☒ ○ ○ ○ ○ Fortement

Lumière dans les ateliers :

Les questions suivantes visent à comprendre vos ressentis de la lumière dans les ateliers à l'instant présent à l'endroit où vous êtes installé maintenant.

1. Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout — Fortement

○ ○ ○ ○ ● ○ ○

2. Est-ce que vous pensez que la distribution verticale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout — Fortement

○ ● ○ ○ ○ ○ ○

3. Pensez-vous que la lumière améliore ou gêne vos performances de travail ?

Améliore — Gêne

○ ○ ○ ○ ● ○ ○

4. Comment jugez-vous la couleur de la lumière (naturelle et artificielle) ?

Froide (bleue) — Chaude (rouge)

○ ○ ● ○ ○ ○ ○

5. La lumière vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur) ?

Mauvais (pas fiable) — Bon (très fiable)

○ ○ ● ○ ○ ○ ○

6. Veuillez donner une évaluation de votre sensation d'éblouissement actuel

☐ Imperceptible ☐ Perceptible ☒ Dérangeant ☐ Intolérable

7. Si vous sentez la présence d'éblouissement (c.a.d. luminosité excessive) maintenant, quelle est la source principale ?

☒ Une fenêtre
☐ Une réflexion sur l'écran
☐ Une réflexion d'une surface intérieure
☐ Une réflexion d'une surface extérieure
☐ Les luminaires
☐ Autre : ....
☐ Il n'y a pas d'éblouissement

Préférences lumineuses :

Les questions suivantes visent à comprendre vos préférences lumineuses.

1. Utilisez-vous souvent les stores ? [✓ Oui] / Non

2. Travaillez-vous de préférence avec de la lumière naturelle ou artificielle ?
   - [✓ Naturelle]
   - Artificielle
   - Mélange des deux

3. Dans votre espace de travail habituel, avez-vous un accès direct à une vue vers l'extérieur ? [✓ Oui] / Non

4. Est-il important pour vous d'y avoir accès ?

Pas du tout — Fortement

○ ○ ○ ○ ○ ○ ●

5. Vous considérez-vous comme sensible à la lumière artificielle ?

Pas du tout Fortement

○ ○ ○ ○ ○ ☒ ○

6. Vous considérez-vous comme sensible à la lumière naturelle ?

Pas du tout Fortement

○ ○ ○ ○ ○ ☒ ○

7. Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités à l'instant présent (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

1 : stores électriques (ou facilement ~~[illegible]~~ accessible)
3 : des néons moins jaunes
2 : pouvoir "dimer" les lampes.
↳ ajustable en intensité.

Merci pour votre participation !

De rien !

B.4. Participant 3

Right-Now questionnaire

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de 'Louvain research institute for Landscape, Architecture, Built environment (LAB)', Directeur du groupe de recherche 'Architecture et Climat', Université Catholique de Louvain.

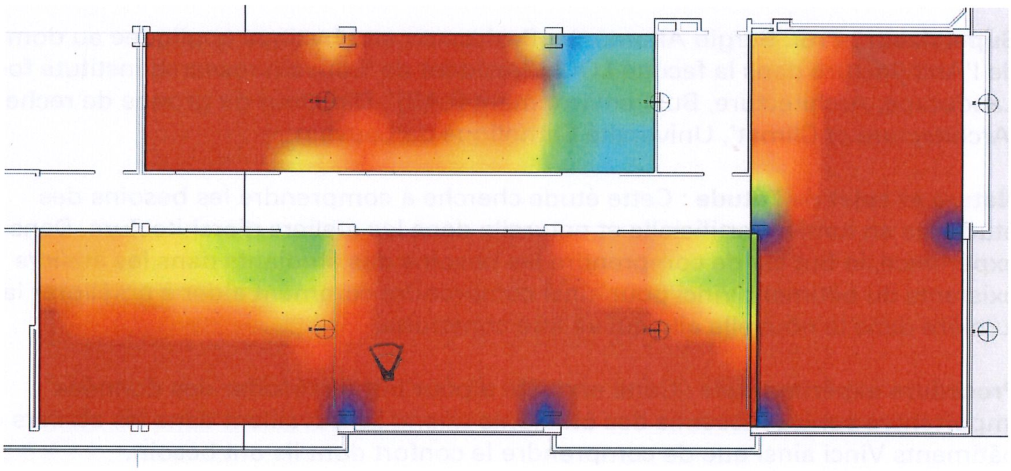
Nature et sujet de l'étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d'architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.
Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l'investigateur de comprendre la population qui répond à cette enquête.
- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Cette partie sera complétée par l'investigateur.

1. Nombre du participant : 3 (ordinateur).
2. Date : 04/05/23
3. Heure : 11h.
4. Conditions du ciel : Dégagé.
5. Position dans l'atelier :



6. Température : 22,6 °C
7. RH : 38,4 % (7,7 °C).
8. Illuminance horizontale (plan de travail) : (11h01) 881 lux 5814 K 0,0037
9. Illuminance verticale : (11h01) 578 lux 5600 K 0,0036.

87,41 cd/m² 11h04.

Contexte :

Les questions suivantes visent à comprendre votre état actuel, il est donc important que vous y répondiez en considérant votre état à l'instant présent.

1. Quel est votre genre ? [✓ Femme] / Homme / Préfère ne pas répondre
2. Quel est votre âge ? ....23........................
3. Quelle est votre année d'étude ? ......Ma2.....
4. Est que vous avez des problèmes au niveau de votre vue ? Oui / [✓ Non]

   Si oui,

   - Portez-vous des lunettes ? Oui / Non
   - Portez-vous des lentilles ? Oui / Non
   - Avez-vous une vision normale de la couleur ? [✓ Oui] / Non
   - Avez-vous d'autres problèmes au niveau de votre vision ? Oui / Non

     Si oui, donnez une courte description ici

     ☐

5. Quel est votre état actuel de santé ?

Malade ○ ○ ○ ○ ○ ○ ☒ Bien

6. Avez-vous passé du temps dehors avant de venir dans les ateliers ? [✓ Oui] / Non

   Si oui, combien de temps ? 20min

7. Avez-vous consommé une de ces choses dans les dernières 15 min ? /
   - Boisson chaude
   - Boisson avec de la caféine
   - Snack ou repas
   - Boisson froide
   - Cigarette

8. Vous sentez-vous fatigué ?

Pas du tout ○ ○ ☒ ○ ○ ○ ○ Fortement

Lumière dans les ateliers :

Les questions suivantes visent à comprendre vos ressentis de la lumière dans les ateliers à l'instant présent à l'endroit où vous êtes installé maintenant.

1. Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ⊗

2. Est-ce que vous pensez que la distribution verticale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ○ ○ ⊗

3. Pensez-vous que la lumière améliore ou gêne vos performances de travail ?

Améliore Gêne

○ ⊗ ○ ○ ○ ○ ○

4. Comment jugez-vous la couleur de la lumière (naturelle et artificielle) ?

Froide (bleue) Chaude (rouge)

○ ○ ○ ○ ⊗ ○ ○

5. La lumière vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur) ?

Mauvais (pas fiable) Bon (très fiable)

○ ○ ○ ○ ○ ⊗ ○

6. Veuillez donner une évaluation de votre sensation d'éblouissement actuel

☒	☐	☐	☐
Imperceptible	Perceptible	Dérangeant	Intolérable

7. Si vous sentez la présence d'éblouissement (c.a.d. luminosité excessive) maintenant, quelle est la source principale ?
   - ☐ Une fenêtre
   - ☐ Une réflexion sur l'écran
   - ☐ Une réflexion d'une surface intérieure
   - ☐ Une réflexion d'une surface extérieure
   - ☐ Les luminaires
   - ☐ Autre : ....
   - ☒ Il n'y a pas d'éblouissement

Préférences lumineuses :

Les questions suivantes visent à comprendre vos préférences lumineuses.

1. Utilisez-vous souvent les stores ? Oui / [✓ Non]

2. Travaillez-vous de préférence avec de la lumière naturelle ou artificielle ?
   - [✓ Naturelle]
   - Artificielle
   - Mélange des deux

3. Dans votre espace de travail habituel, avez-vous un accès direct à une vue vers l'extérieur ? [✓ Oui] / Non

4. Est-il important pour vous d'y avoir accès ?

Pas du tout						Fortement
○	○	○	○	☒	○	○

5. Vous considérez-vous comme sensible à la lumière artificielle ?

Pas du tout Fortement

○ ☒ ○ ○ ○ ○ ○

6. Vous considérez-vous comme sensible à la lumière naturelle ?

Pas du tout Fortement

○ ☒ ○ ○ ○ ○ ○

7. Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités à l'instant présent (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

avoir sa propre lampe orientable à chaque poste de travail, et toujours être proche d'une fenêtre mais, ~~sans être~~ orientée de manière à ne pas être éblouie

(lumière naturelle, mais sans soleil direct).

Merci pour votre participation !

B.5. Participant 4

Right-Now questionnaire

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de 'Louvain research institute for Landscape, Architecture, Built environment (LAB)', Directeur du groupe de recherche 'Architecture et Climat', Université Catholique de Louvain.

Nature et sujet de l'étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d'architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

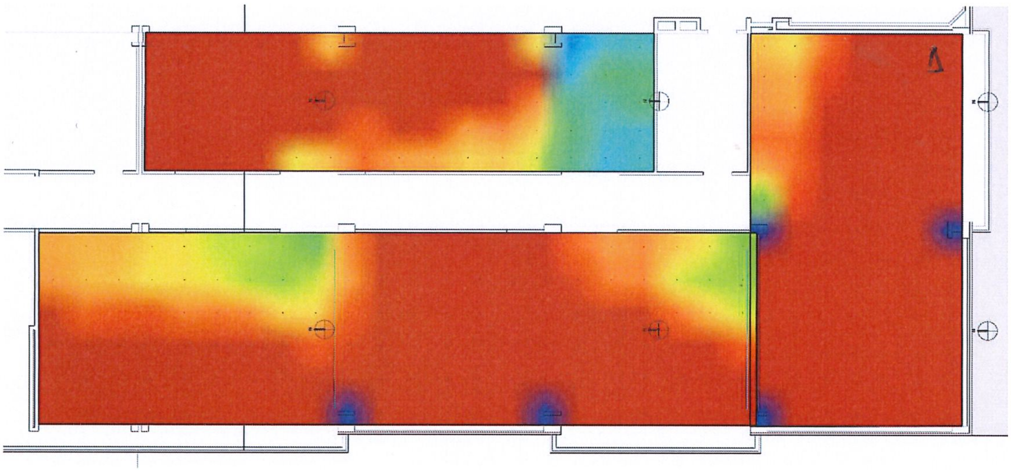
Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.
Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l'investigateur de comprendre la population qui répond à cette enquête.
- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Cette partie sera complétée par l’investigateur.

écran pas encore de soleil
qui touche mais presque.

1. Nombre du participant : 4
2. Date : 04/05/23
3. Heure : 12h07
4. Conditions du ciel : dégagé
5. Position dans l’atelier :



6. Température : 21,5 °C
7. RH : 41,2 % (7,9 °C)
8. Illuminance horizontale (plan de travail) : 901 lux 8377 K 0,005 12:09
9. Illuminance verticale : 514 lux 7065 K 0,0057 12:08

37,21 cd/m²
12:10

Contexte :

Les questions suivantes visent à comprendre votre état actuel, il est donc important que vous y répondiez en considérant votre état à l'instant présent.

1. Quel est votre genre ? [✓ Femme] / Homme / Préfère ne pas répondre
2. Quel est votre âge ? ……21……………………
3. Quelle est votre année d'étude ? ……M1………
4. Est que vous avez des problèmes au niveau de votre vue ? [✓ Oui] / Non

   Si oui,

   - Portez-vous des lunettes ? [✓ Oui] / Non
   - Portez-vous des lentilles ? Oui / Non
   - Avez-vous une vision normale de la couleur ? [✓ Oui] / Non
   - Avez-vous d'autres problèmes au niveau de votre vision ? Oui / Non

     Si oui, donnez une courte description ici

5. Quel est votre état actuel de santé ?

Malade						Bien
○	○	○	○	○	○	☒

6. Avez-vous passé du temps dehors avant de venir dans les ateliers ? [✓ Oui] / Non

   Si oui, combien de temps ?
   Marche de 20 minutes (arrivée 9h - heure actuelle : 12h)

7. Avez-vous consommé une de ces choses dans les dernières 15 min ?

   - ~~Boisson chaude~~
   - ~~Boisson avec de la caféine~~
   - ~~Snack ou repas~~
   - Boisson froide eau
   - ~~Cigarette~~

8. Vous sentez-vous fatigué ?

Pas du tout						Fortement
○	○	○	○	☒	○	○

Lumière dans les ateliers :

Les questions suivantes visent à comprendre vos ressentis de la lumière dans les ateliers à l'instant présent à l'endroit où vous êtes installé maintenant.

1. Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ● ○ ○

2. Est-ce que vous pensez que la distribution verticale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout Fortement

○ ○ ○ ○ ● ○ ○

3. Pensez-vous que la lumière améliore ou gêne vos performances de travail ?

Améliore Gêne

○ ○ ○ ● ○ ○ ○

4. Comment jugez-vous la couleur de la lumière (naturelle et artificielle) ?

Froide (bleue) Chaude (rouge)

○ ○ ○ ○ ● ○ ○

5. La lumière vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur) ?

Mauvais (pas fiable) Bon (très fiable)

○ ○ ○ ○ ○ ○ ●

6. Veuillez donner une évaluation de votre sensation d'éblouissement actuel

☐ Imperceptible ☒ Perceptible ☐ Dérangeant ☐ Intolérable

7. Si vous sentez la présence d'éblouissement (c.a.d. luminosité excessive) maintenant, quelle est la source principale ?

☐ Une fenêtre
☐ Une réflexion sur l'écran
☑ Une réflexion d'une surface intérieure bureau.
☐ Une réflexion d'une surface extérieure
☐ Les luminaires
☐ Autre : ....
☐ Il n'y a pas d'éblouissement

Préférences lumineuses :

Les questions suivantes visent à comprendre vos préférences lumineuses.

1. Utilisez-vous souvent les stores ? Oui / [✓ Non]

2. Travaillez-vous de préférence avec de la lumière naturelle ou artificielle ?
   - Naturelle
   - Artificielle
   - [✓ Mélange des deux]

3. Dans votre espace de travail habituel, avez-vous un accès direct à une vue vers l'extérieur ? Oui / [✓ Non]

4. Est-il important pour vous d'y avoir accès ?

Pas du tout Fortement

○ ● ○ ○ ○ ○ ○

5. Vous considérez-vous comme sensible à la lumière artificielle ?

Pas du tout Fortement

○ ○ ○ ○ ○ ☒ ○

6. Vous considérez-vous comme sensible à la lumière naturelle ?

Pas du tout Fortement

○ ○ ○ ○ ☒ ○ ○

7. Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités à l'instant présent (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

1. Stores que l'on peut ajuster manuellement de manière à limiter l'éblouissement sans pour autant bloquer toute lumière naturelle

Merci pour votre participation !

B.6. Participant 5

Right-Now questionnaire

Informations pour les participants et formulaire de consentement

Etude : Besoins des étudiants pour l'éclairage des ateliers d'architecture

Investigateur : Victoria Crevits, étudiante en Master 2 en ingénieur architecte, faculté LOCI, Université Catholique de Louvain.

Superviseur : Prof. Sergio Altomonte, Professeur en Physique appliquée au domaine de l'Architecture dans la faculté LOCI, Président de 'Louvain research institute for Landscape, Architecture, Built environment (LAB)', Directeur du groupe de recherche 'Architecture et Climat', Université Catholique de Louvain.

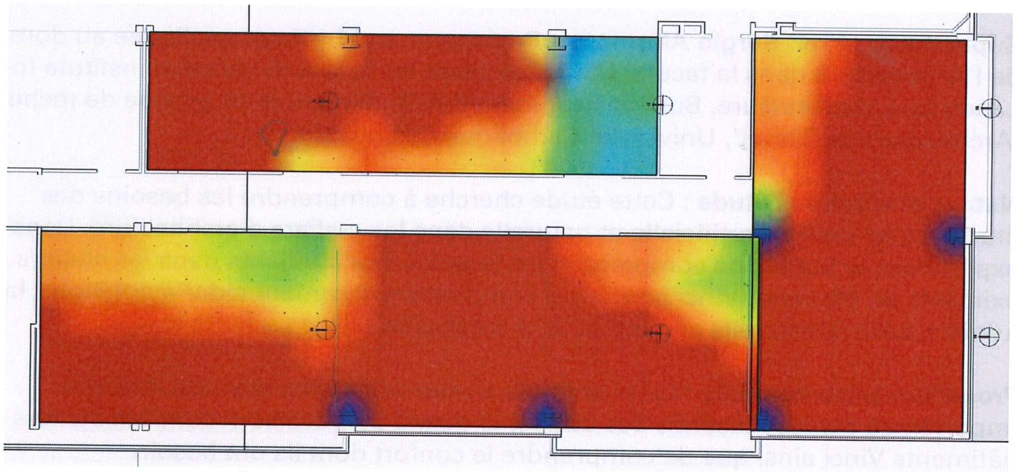
Nature et sujet de l'étude : Cette étude cherche à comprendre les besoins des étudiants en lumière artificielle et naturelle dans les ateliers d'architecture. Dans cette expérience, le but est de comprendre les besoins des étudiants dans les ateliers existants du bâtiment Vinci pour ainsi comprendre comment aider à améliorer la lumière dans la nouvelle aile qui va être construite.

Procédure expérimentale : Cette enquête a pour but de récolter des données importantes sur les ressentis des étudiants quand ils travaillent dans les ateliers du bâtiments Vinci ainsi que de comprendre le confort dont ils ont besoin.
Pour cette étude :

- Vous allez devoir répondre à un test préalable pour permettre à l'investigateur de comprendre la population qui répond à cette enquête.
- Vous allez devoir répondre à une série de questions sur vos ressentis de la lumière dans les ateliers.

Cette partie sera complétée par l'investigateur.

1. Nombre du participant : 5
2. Date : 14h45
3. Heure : 04/05
4. Conditions du ciel : nuages fins.
5. Position dans l'atelier :



6. Température : 22°C
7. RH : 39,5% (7,6°C).
8. Illuminance horizontale (plan de travail) : 576 lux 5669K 0,0034
9. Illuminance verticale : 14h45 1110lux 14h46.
5880K
0,0046.

25,11 cd/m².

Contexte :

Les questions suivantes visent à comprendre votre état actuel, il est donc important que vous y répondiez en considérant votre état à l'instant présent.

1. Quel est votre genre ? [✓ Femme] / Homme / Préfère ne pas répondre
2. Quel est votre âge ? 22
3. Quelle est votre année d'étude ? Master 2
4. Est que vous avez des problèmes au niveau de votre vue ? [✓ Oui] / Non

   Si oui,

   - Portez-vous des lunettes ? [✓ Oui] / Non
   - Portez-vous des lentilles ? Oui / [✓ Non]
   - Avez-vous une vision normale de la couleur ? [✓ Oui] / Non
   - Avez-vous d'autres problèmes au niveau de votre vision ? Oui / [✓ Non]

   Si oui, donnez une courte description ici

   —

5. Quel est votre état actuel de santé ?

Malade — Bien

○ ○ ○ ○ ○ ○ ☒

6. Avez-vous passé du temps dehors avant de venir dans les ateliers ? [✓ Oui] / Non

   Si oui, combien de temps ? 5 minutes

7. Avez-vous consommé une de ces choses dans les dernières 15 min ?

   - ~~Boisson chaude~~
   - ~~Boisson avec de la caféine~~
   - ~~Snack ou repas~~
   - [✓ Boisson froide] eau
   - ~~Cigarette~~

8. Vous sentez-vous fatigué ?

Pas du tout — Fortement

○ ○ ○ ○ ☒ ○ ○

Lumière dans les ateliers :

Les questions suivantes visent à comprendre vos ressentis de la lumière dans les ateliers à l'instant présent à l'endroit où vous êtes installé maintenant.

1. Est-ce que vous pensez que la distribution horizontale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout — Fortement

○ ○ ○ ⊗ ○ ○ ○

2. Est-ce que vous pensez que la distribution verticale de la lumière (naturelle et artificielle) est adéquate où vous êtes ?

Pas du tout — Fortement

○ ○ ○ ○ ○ ⊗ ○

3. Pensez-vous que la lumière améliore ou gêne vos performances de travail ?

Améliore — Gêne

○ ○ ○ ○ ⊗ ○ ○

4. Comment jugez-vous la couleur de la lumière (naturelle et artificielle) ?

Froide (bleue) — Chaude (rouge)

○ ○ ○ ○ ⊗ ○ ○

5. La lumière vous offre-t-elle un rendu des couleurs adéquat (c.a.d. vous pouvez bien apprécier les couleurs de vos dessins ou de l'écran de l'ordinateur) ?

Mauvais (pas fiable) — Bon (très fiable)

○ ○ ○ ○ ○ ⊗ ○

6. Veuillez donner une évaluation de votre sensation d'éblouissement actuel

☐ Imperceptible ☒ Perceptible ☐ Dérangeant ☐ Intolérable

7. Si vous sentez la présence d'éblouissement (c.a.d. luminosité excessive) maintenant, quelle est la source principale ?
   - ☐ Une fenêtre
   - ☐ Une réflexion sur l'écran
   - ☐ Une réflexion d'une surface intérieure
   - ☒ Une réflexion d'une surface extérieure
   - ☐ Les luminaires
   - ☐ Autre : ……..
   - ☐ Il n'y a pas d'éblouissement

Préférences lumineuses :

Les questions suivantes visent à comprendre vos préférences lumineuses.

1. Utilisez-vous souvent les stores ? Oui / [✓ Non]

2. Travaillez-vous de préférence avec de la lumière naturelle ou artificielle ?
   - [✓ Naturelle]
   - Artificielle
   - Mélange des deux

3. Dans votre espace de travail habituel, avez-vous un accès direct à une vue vers l'extérieur ? [✓ Oui] / Non

4. Est-il important pour vous d'y avoir accès ?

Pas du tout … Fortement

○ ○ ○ ○ ○ ○ ●

5. Vous considérez-vous comme sensible à la lumière artificielle ?

Pas du tout Fortement

○ ○ ○ ○ ☒ ○ ○

6. Vous considérez-vous comme sensible à la lumière naturelle ?

Pas du tout Fortement

○ ○ ○ ○ ☒ ○ ○

7. Si vous aviez la chance de concevoir l'éclairage de votre espace de travail dans les ateliers, quelles seraient vos priorités à l'instant présent (vous pouvez lister 1, 2, 3, etc. par ordre d'importance) ?

1. Lumière naturelle
2. Lumière assez uniforme sur la profondeur de l'espace
3. Possibilité de baisser des stores qui ne deviennent pas une source d'éblouissement

Merci pour votre participation !

C. Measurement campaign

C.1. Studio 1

	X		X		X		X		X		X		X		3		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	16.25		16.15		16.14		16.09				16.02		16.02		15.58		15.57		15.51		15.5		15.39		15.38		15.33		15.32		15.25		15.25		15.2		15.2		15.15	
Illuminance	3460	1443	2860	1352	3850	1628	1320	1696			611	740	696	875	703	985	717	917	451	677	214	2	1320	1661	2150	1659	1650	1220	1580	1769	1350	1748	900	896	1040	1493	1660	1734	1770	1397
Couleur	5820		5896		5978		5934				5312		5356		5447		5547		5404		4649		5920		6079		5970		6056		6039		5958		5872		5961		593	
Spectre																																								

	X		X		X		X		X		X		X		3		X		X		X		X		X		X		X		3		X		X		X		X	
Heure	16.24		16.16		16.14		16.1		16.08		16.02		16.01		15.58		15.57		15.51		15.49		15.39		15.38		15.34		15.32		15.26		15.24		15.21		15.19		15.15	
Illuminance	1620	770	1150	839	1600	1002	830	889	722	792	639	794	763	930	800	1097	820	1139	569	872	326	53	496	787	773	883	619	848	699	776	631	895	469	701	523	797	787	823	630	731
Couleur	5637		5594		5745		5698		5691		5390		5371		5431		5544		5500		5025		5451		5762		5629		5750		5786		5636		5560		5667		5484	
Spectre																																								

	X		X		X		X		X		X		X		3		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	16.24		16.16		16.14		16.1		16.08		16.03		16.01		15.58		15.55		15.52		15.45		15.41		15.37		15.35		15.32		15.26		15.24		15.22		15.18		15.16	
Illuminance	861	438	650	516	889	563	517	623	502	728	608	861	789	1019	862	1117	922	1201	615	919	344	474	330	473	325	466	431	474	366	449	301	433	280	466	317	392	329	420	289	382
Couleur	5368		5361		5549		5467		5519		5371		5386		5474		5577		5529		4938		5181		5308		5478		5509		5493		5413		5362		5327		5078	
Spectre			VIC - 010														VIC - 08														VIC - 006									

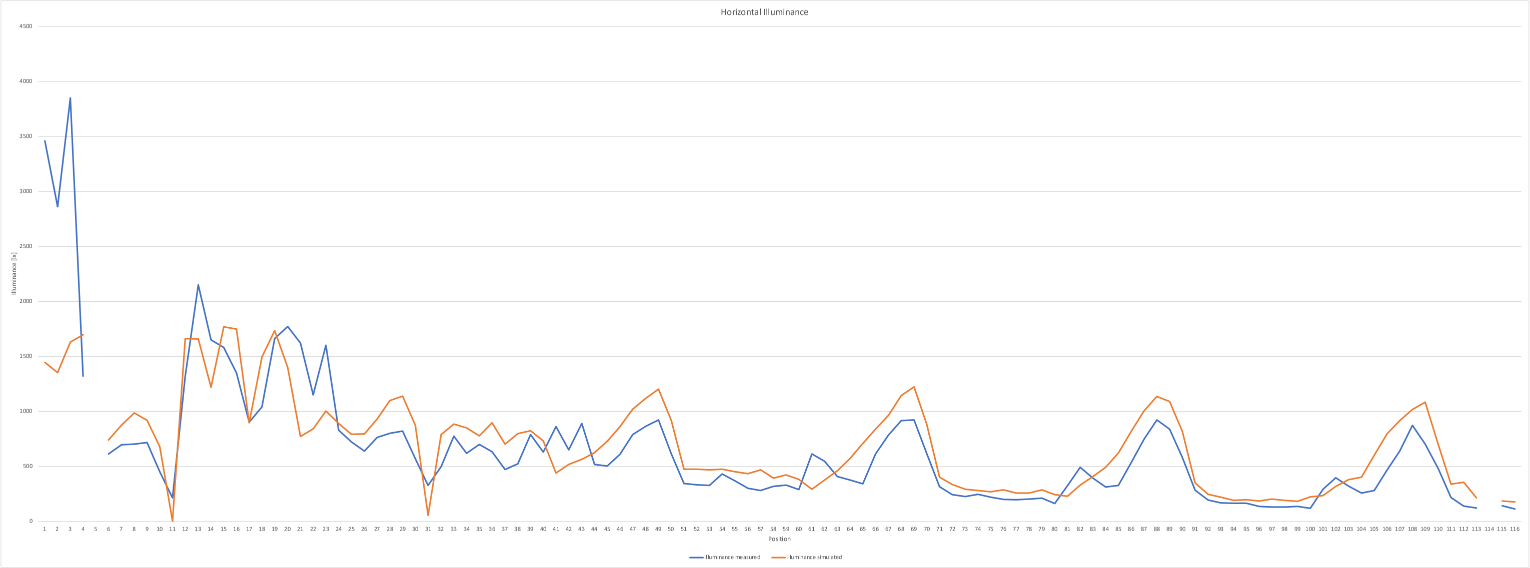
	X		X		X		X		X		X		X		3		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	16.23		16.18		16.13		16.1		16.07		16.03		16.01		15.59		15.54		15.52		15.45		15.42		15.37		15.35		15.31		15.28		15.23		15.22		15.18		15.17	
Illuminance	611	290	544	376	406	459	376	571	341	707	612	838	786	965	916	1144	922	1221	616	882	314	402	242	334	226	291	246	279	219	268	199	285	196	256	200	255	209	286	161	243
Couleur	5206		5166		5205		5335		5397		5398		5391		5491		5596		5527		4886		5027		5188		5237		5256		5302		5293		5217		5056		4922	
Spectre																																								

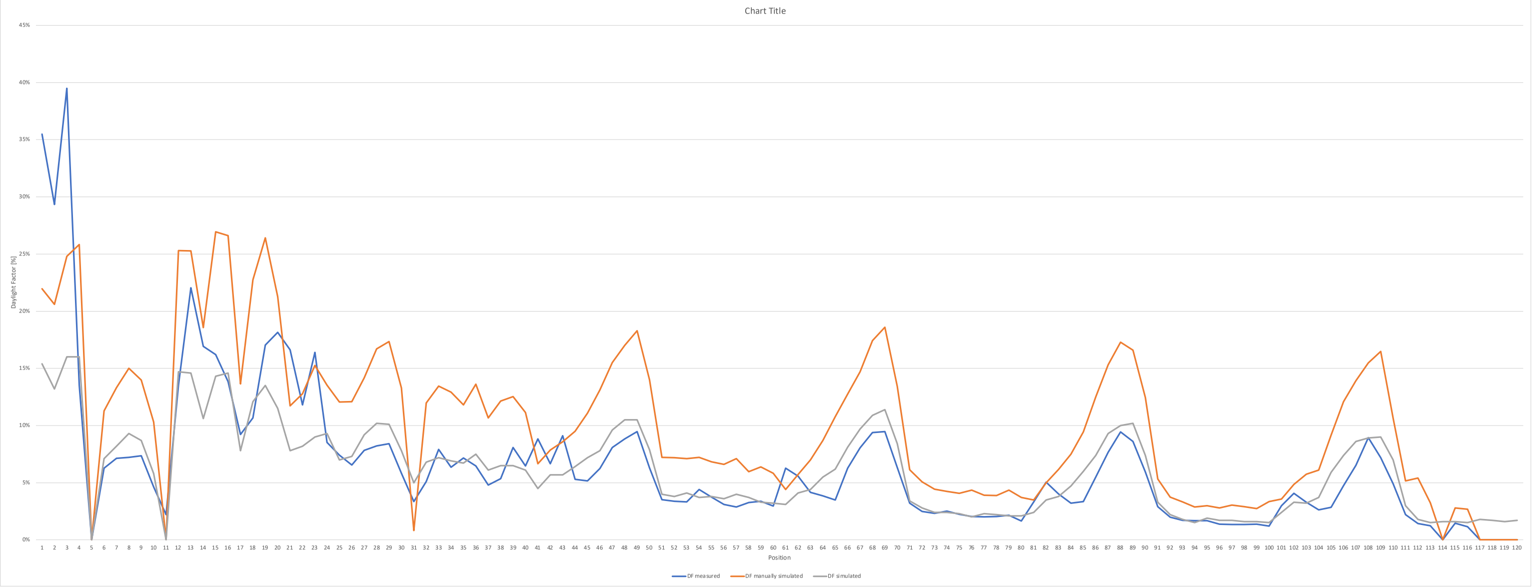
	X		X		X		X		X		X		X		3		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	16.23		16.21		16.13		16.11		16.07		16.03		16		15.59		15.54		15.53		15.44		15.42		15.36		15.36		15.31		15.29		15.23		15.22		15.17		15.17	
Illuminance	323	229	492	328	392	405	312	492	327	620	536	821	748	1006	920	1136	838	1089	580	818	283	349	194	246	168	218	163	189	163	196	134	183	130	201	130	191	134	180	119	221
Couleur	4882		5045		5200		5254		5355		5338		5372		5530		5573		5521		4841		4922		4998		4957		5169		5071		5034		4976		4790		4751	
Spectre																																								

	X		X		X		X		X		X		X		3		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	16.22		16.22		16.12		16.11		16.06		16.04		16		15.59		15.54		15.53		15.44		15.43		15.43				15.3		15.29									
Illuminance	291	234	396	318	320	377	257	401	278	601	463	794	637	914	873	1017	702	1083	479	699	216	338	139	355	121	212			141	183	112	177								
Couleur	4669		4753		5094		5130		5345		5285		5339		5531		5573		5493		4842		4855		4857				4955		4905									
Spectre																																								

DEHORS		DEHORS		DEHORS	
15.28		15.56		16.17	
7310	7067	9750	6567	16800	6112
622		6129		6094	
VIC - 007		VIC - 009		VIC - 011	

measured	simulated
3460	1443
2860	1352
3850	1628
1320	1696
611	740
696	875
703	985
717	917
451	677
214	2
1320	1661
2150	1659
1650	1220
1580	1769
1350	1748
900	896
1040	1493
1660	1734
1770	1397
1620	770
1150	839
1600	1002
830	889
722	792
639	794
763	930
800	1097
820	1139
569	872
326	53
496	787
773	883
619	848
699	776
631	895
469	701
523	797
787	823
630	731
861	438
650	516
889	563
517	623
502	728
608	861
789	1019
862	1117
922	1201
615	919
344	474
330	473
325	466
431	474
366	449
301	433
280	466
317	392
329	420
289	382
611	290
544	376
406	459
376	571
341	707
612	838
786	965
916	1144
922	1221
616	882
314	402
242	334
226	291
246	279
219	268
199	285
196	256
200	255
209	286
161	243
323	229
492	328
392	405
312	492
327	620
536	821
748	1006
920	1136
838	1089
580	818
283	349
194	246
168	218
163	189
163	196
134	183
130	201
130	191
134	180
119	221
291	234
396	318
320	377
257	401
278	601
463	794
637	914
873	1017
702	1083
479	699
216	338
139	355
121	212
141	183
112	177





DF measured	DF simulated	DF via Rhino
35%	22%	15%
29%	21%	13%
39%	25%	16%
14%	26%	16%
0%	0%	0%
6%	11%	7%
7%	13%	8%
7%	15%	9%
7%	14%	9%
5%	10%	6%
2%	0%	0%
14%	25%	15%
22%	25%	15%
17%	19%	11%
16%	27%	14%
14%	27%	15%
9%	14%	8%
11%	23%	12%
17%	26%	14%
18%	21%	12%
17%	12%	8%
12%	13%	8%
16%	15%	9%
9%	14%	9%
7%	12%	7%
7%	12%	7%
8%	14%	9%
8%	17%	10%
8%	17%	10%
6%	13%	8%
3%	1%	5%
5%	12%	7%
8%	13%	7%
6%	13%	7%
7%	12%	7%
6%	14%	8%
5%	11%	6%
5%	12%	7%
8%	13%	7%
6%	11%	6%
9%	7%	5%
7%	8%	6%
9%	9%	6%
5%	9%	6%
5%	11%	7%
6%	13%	8%
8%	16%	10%
9%	17%	11%
9%	18%	11%
6%	14%	8%
4%	7%	4%
3%	7%	4%
3%	7%	4%
4%	7%	4%
4%	7%	4%
3%	7%	4%
3%	7%	4%
3%	6%	4%
3%	6%	3%
3%	6%	3%
6%	4%	3%
6%	6%	4%
4%	7%	4%
4%	9%	6%
3%	11%	6%
6%	13%	8%
8%	15%	10%
9%	17%	11%
9%	19%	11%
6%	13%	8%
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3%	3%	2%
5%	5%	4%
4%	6%	4%
3%	7%	5%
3%	9%	6%
5%	13%	7%
8%	15%	9%
9%	17%	10%
9%	17%	10%
6%	12%	7%
3%	5%	3%
2%	4%	2%
2%	3%	2%
2%	3%	2%
2%	3%	2%
1%	3%	2%
1%	3%	2%
1%	3%	2%
1%	3%	2%
1%	3%	2%
3%	4%	2%
4%	5%	3%
3%	6%	3%
3%	6%	4%
3%	9%	6%
5%	12%	7%
7%	14%	9%
9%	15%	9%
7%	16%	9%
5%	11%	7%
2%	5%	3%
1%	5%	2%
1%	3%	2%
0%	0%	2%
1%	3%	2%
1%	3%	2%
0%	0%	2%
0%	0%	2%
0%	0%	2%
0%	0%	2%

C.2. Studio 2

	X		X		X		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	17.1		17.1		17.05		17.05		17.03		16.58		16.57		16.53		16.52		16.5		16.44		16.43				16.38		16.36	
Illuminance	455	326	1010	419	1340	382	692	397	1150	403	600	344	470	323	1060	426	905	375	622	324	755	352	203	328			236	107	316	99
Couleur	5643		5940		5821		5552		5721		5586		5514		5729		5705		5355		5737		4668				5015		5257	
Spectre																														

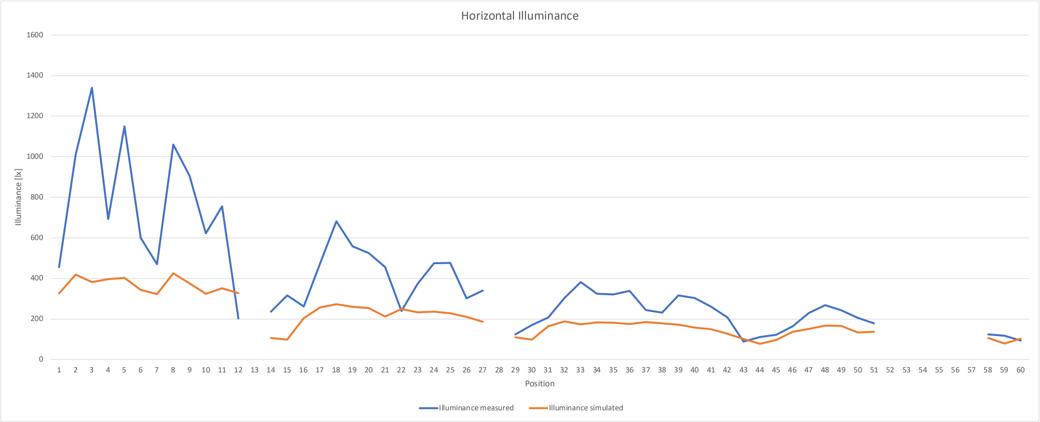
	X		X		X		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	17.09		17.09		17.06		17.04		17.03		16.59		16.56		16.53		16.52		16.49		16.45		16.41				16.37		16.35	
Illuminance	262	204	474	257	682	273	559	260	524	254	456	213	239	248	374	233	475	236	477	228	301	211	340	187			124	109	171	98
Couleur	5233		5619		5571		5402		5408		5437		5017		5366		5385		5332		5150		5095				4564		4794	
Spectre											VIC - 014										VIC - 012									

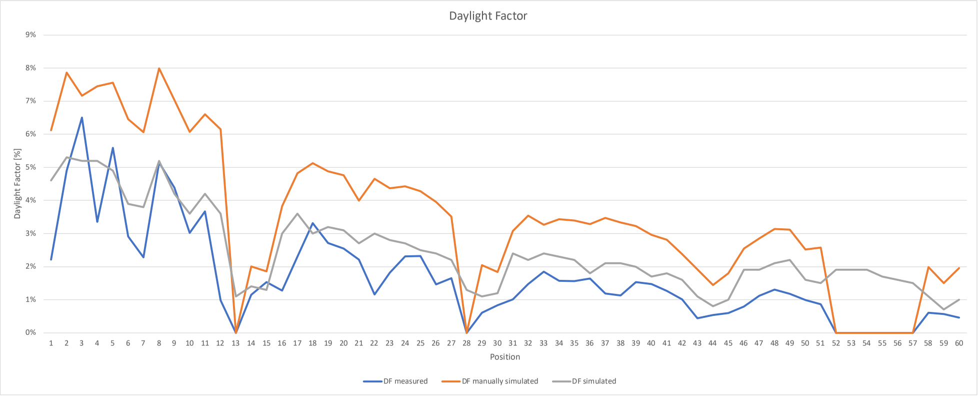
	X		X		X		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	17.08		17.08		17.06		17.04		17.02		17.01		16.55		16.54		16.5		16.48		16.47		16.4		16.39		16.37		16.34	
Illuminance	208	164	304	189	381	174	324	183	322	181	338	175	244	185	232	178	316	172	303	158	260	150	208	127	89.4	102	111	77	122	96
Couleur	5015		5197		5189		5151		5174		5290		5113		5037		4971		5066		5081		5217		446		4496		461	
Spectre																														

	X		X		X		X		X		X		X		X		X		X		X		X		X		X		X	
Heure	17.08		17.07		17.07		17.04		17.02		17.01														16.36		16.36		16.33	
Illuminance	163	136	230	152	268	167	243	166	205	134	178	137													124	106	117	80	94.3	104
Couleur	4701		4868		5083		4975		5004		5008														4769		4454		4536	
Spectre																														

DEHORS		DEHORS	
16.46		17	
20600	5331	11200	5011
6108		6154	
VIC - 013		VIC - 015	

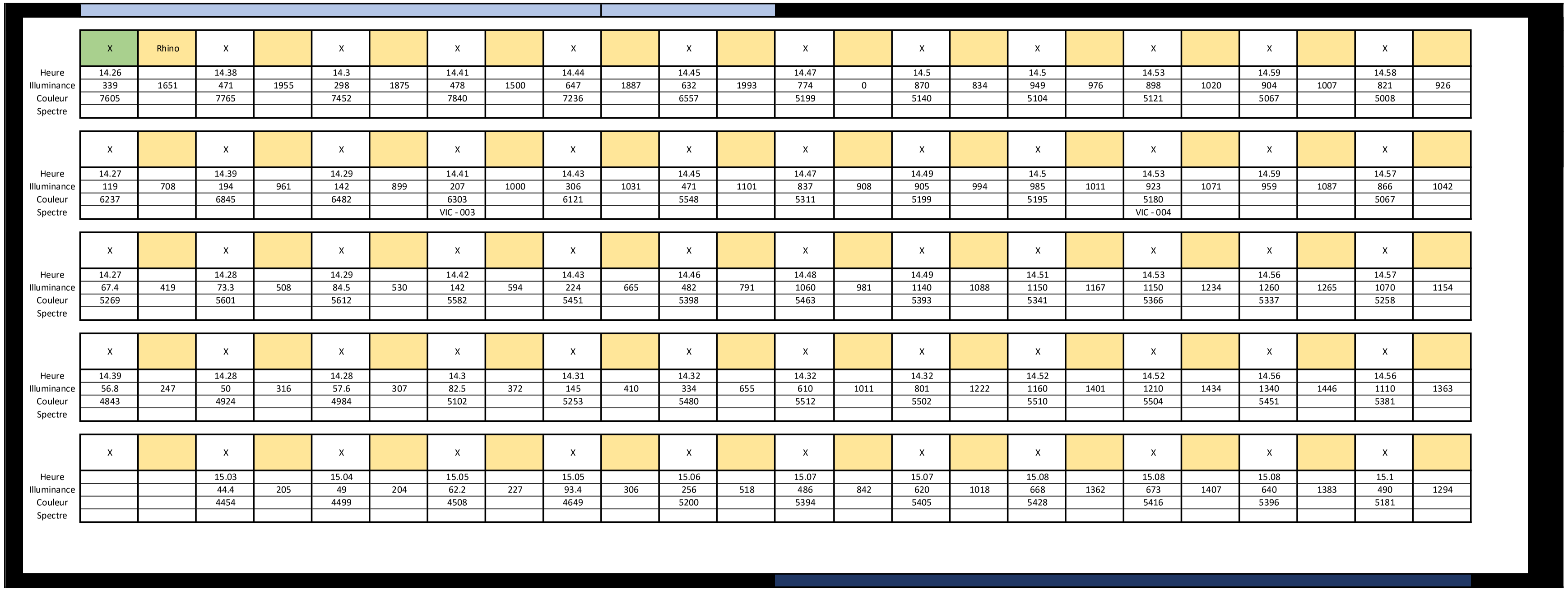
Measured	Simulated
455	326
1010	419
1340	382
692	397
1150	403
600	344
470	323
1060	426
905	375
622	324
755	352
203	328
236	107
316	99
262	204
474	257
682	273
559	260
524	254
456	213
239	248
374	233
475	236
477	228
301	211
340	187
124	109
171	98
208	164
304	189
381	174
324	183
322	181
338	175
244	185
232	178
316	172
303	158
260	150
208	127
89.4	102
111	77
122	96
163	136
230	152
268	167
243	166
205	134
178	137
124	106
117	80
94.3	104





DF measured	DF simulated	DF via Rhino
2%	6%	5%
5%	8%	5%
7%	7%	5%
3%	7%	5%
6%	8%	5%
3%	6%	4%
2%	6%	4%
5%	8%	5%
4%	7%	4%
3%	6%	4%
4%	7%	4%
1%	6%	4%
0%	0%	1%
1%	2%	1%
2%	2%	1%
1%	4%	3%
2%	5%	4%
3%	5%	3%
3%	5%	3%
3%	5%	3%
2%	4%	3%
1%	5%	3%
2%	4%	3%
2%	4%	3%
2%	4%	3%
1%	4%	2%
2%	4%	2%
0%	0%	1%
1%	2%	1%
1%	2%	1%
1%	3%	2%
1%	4%	2%
2%	3%	2%
2%	3%	2%
2%	3%	2%
2%	3%	2%
1%	3%	2%
1%	3%	2%
2%	3%	2%
1%	3%	2%
1%	3%	2%
1%	2%	2%
0%	2%	1%
1%	1%	1%
1%	2%	1%
1%	3%	2%
1%	3%	2%
1%	3%	2%
1%	3%	2%
1%	3%	2%
1%	3%	2%
0%	0%	2%
0%	0%	2%
0%	0%	2%
0%	0%	2%
0%	0%	2%
0%	0%	2%
1%	2%	1%
1%	2%	1%
0%	2%	1%

C.3. Studio 3



	X	Rhino	X		X		X		X		X		X		X		X		X		X		X	
Heure	14.26		14.38		14.3		14.41		14.44		14.45		14.47		14.5		14.5		14.53		14.59		14.58	
Illuminance	339	1651	471	1955	298	1875	478	1500	647	1887	632	1993	774	0	870	834	949	976	898	1020	904	1007	821	926
Couleur	7605		7765		7452		7840		7236		6557		5199		5140		5104		5121		5067		5008	
Spectre																								

	X		X		X		X		X		X		X		X		X		X		X		X	
Heure	14.27		14.39		14.29		14.41		14.43		14.45		14.47		14.49		14.5		14.53		14.59		14.57	
Illuminance	119	708	194	961	142	899	207	1000	306	1031	471	1101	837	908	905	994	985	1011	923	1071	959	1087	866	1042
Couleur	6237		6845		6482		6303		6121		5548		5311		5199		5195		5180				5067	
Spectre							VIC - 003												VIC - 004					

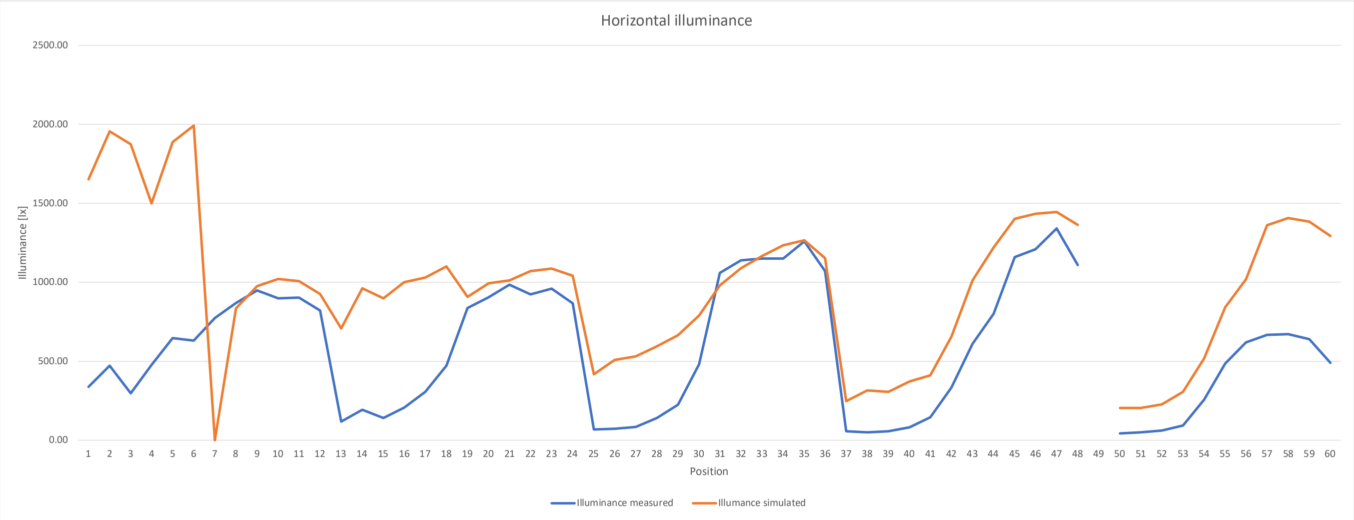
	X		X		X		X		X		X		X		X		X		X		X		X	
Heure	14.27		14.28		14.29		14.42		14.43		14.46		14.48		14.49		14.51		14.53		14.56		14.57	
Illuminance	67.4	419	73.3	508	84.5	530	142	594	224	665	482	791	1060	981	1140	1088	1150	1167	1150	1234	1260	1265	1070	1154
Couleur	5269		5601		5612		5582		5451		5398		5463		5393		5341		5366		5337		5258	
Spectre																								

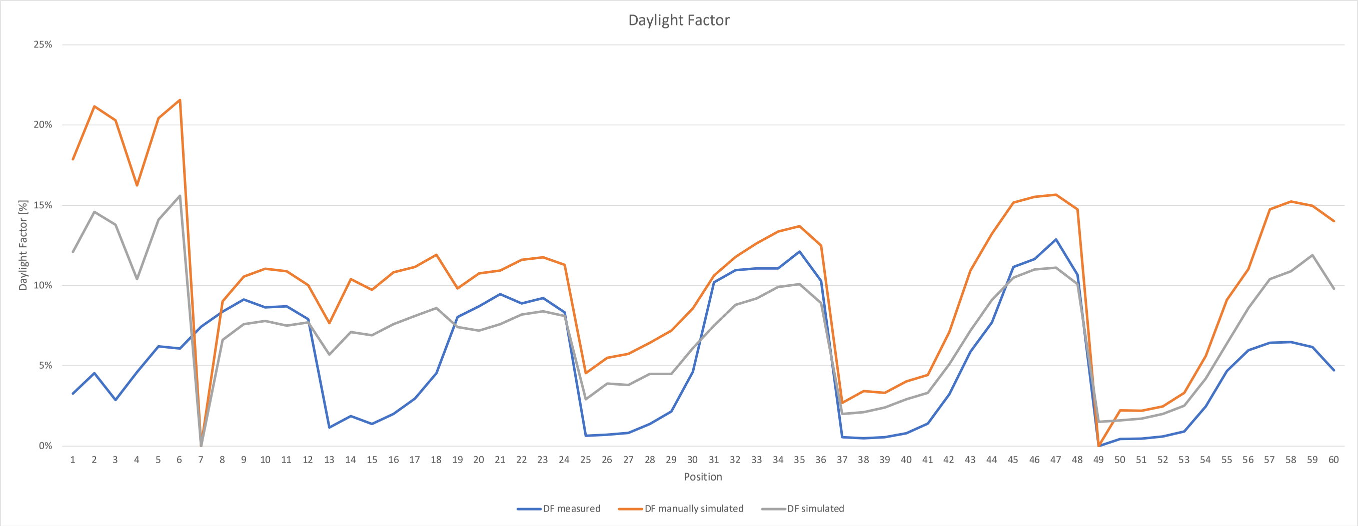
	X		X		X		X		X		X		X		X		X		X		X		X	
Heure	14.39		14.28		14.28		14.3		14.31		14.32		14.32		14.32		14.52		14.52		14.56		14.56	
Illuminance	56.8	247	50	316	57.6	307	82.5	372	145	410	334	655	610	1011	801	1222	1160	1401	1210	1434	1340	1446	1110	1363
Couleur	4843		4924		4984		5102		5253		5480		5512		5502		5510		5504		5451		5381	
Spectre																								

	X		X		X		X		X		X		X		X		X		X		X		X	
Heure			15.03		15.04		15.05		15.05		15.06		15.07		15.07		15.08		15.08		15.08		15.1	
Illuminance			44.4	205	49	204	62.2	227	93.4	306	256	518	486	842	620	1018	668	1362	673	1407	640	1383	490	1294
Couleur			4454		4499		4508		4649		5200		5394		5405		5428		5416		5396		5181	
Spectre																								

DEHORS		DEHORS	
14.35		14.54	
10400	9239	13100	8825
612		6091	
VIC - 002		VIC - 005	

measured	simulated
339.00	1651.00
471.00	1955.00
298.00	1875.00
478.00	1500.00
647.00	1887.00
632.00	1993.00
774.00	0.00
870.00	834.00
949.00	976.00
898.00	1020.00
904.00	1007.00
821.00	926.00
119.00	708.00
194.00	961.00
142.00	899.00
207.00	1000.00
306.00	1031.00
471.00	1101.00
837.00	908.00
905.00	994.00
985.00	1011.00
923.00	1071.00
959.00	1087.00
866.00	1042.00
67.40	419.00
73.30	508.00
84.50	530.00
142.00	594.00
224.00	665.00
482.00	791.00
1060.00	981.00
1140.00	1088.00
1150.00	1167.00
1150.00	1234.00
1260.00	1265.00
1070.00	1154.00
56.80	247.00
50.00	316.00
57.60	307.00
82.50	372.00
145.00	410.00
334.00	655.00
610.00	1011.00
801.00	1222.00
1160.00	1401.00
1210.00	1434.00
1340.00	1446.00
1110.00	1363.00
44.40	205.00
49.00	204.00
62.20	227.00
93.40	306.00
256.00	518.00
486.00	842.00
620.00	1018.00
668.00	1362.00
673.00	1407.00
640.00	1383.00
490.00	1294.00

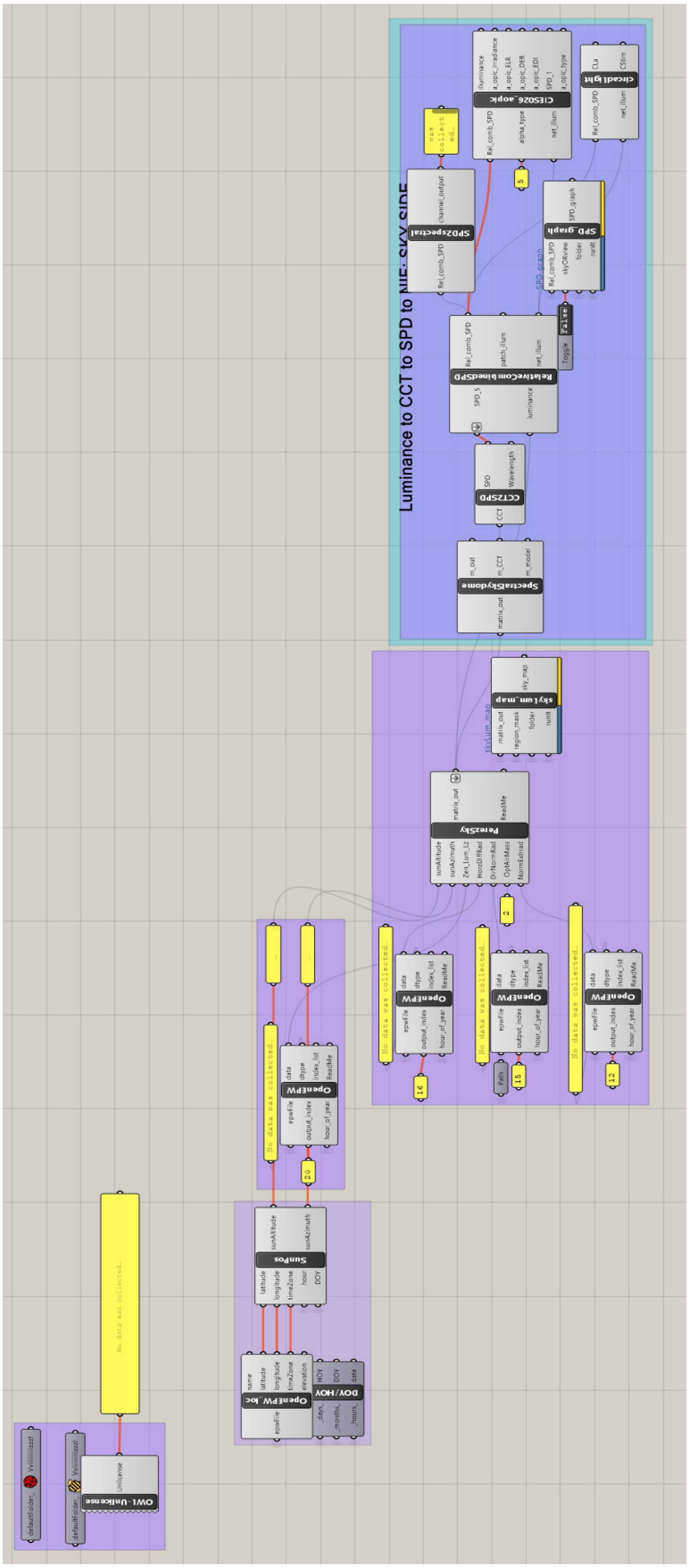

Horizontal illuminance

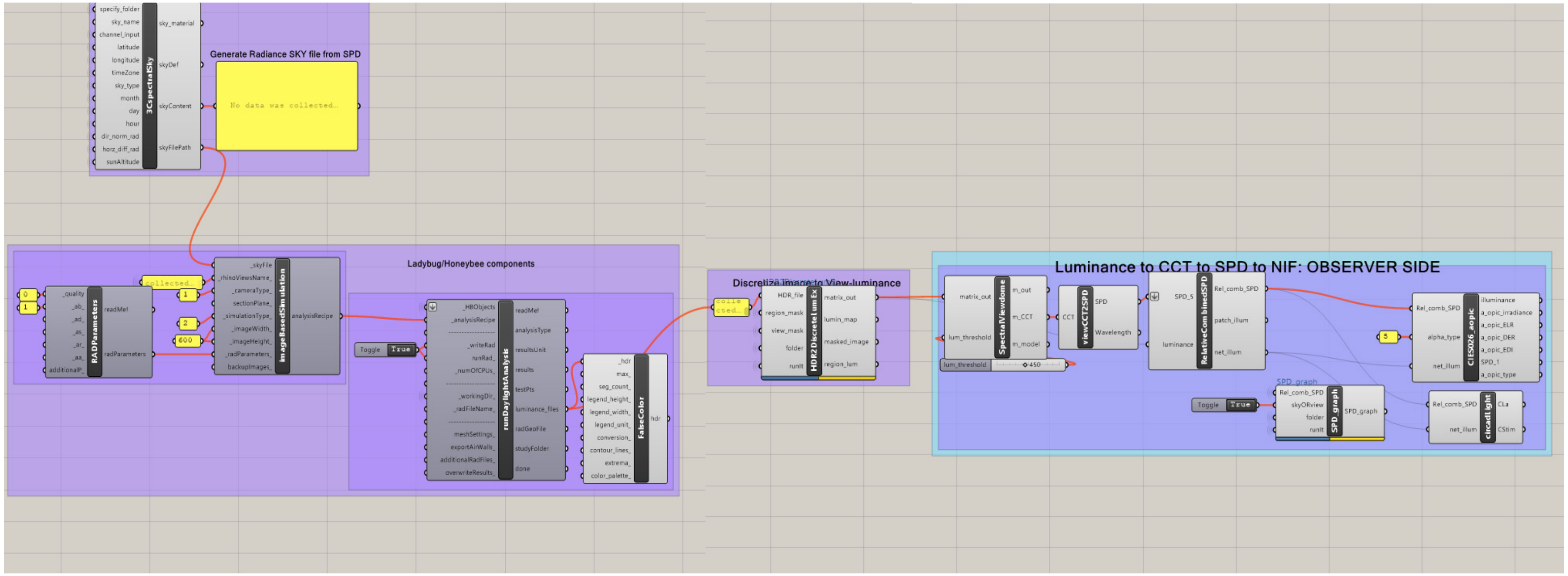

Daylight Factor

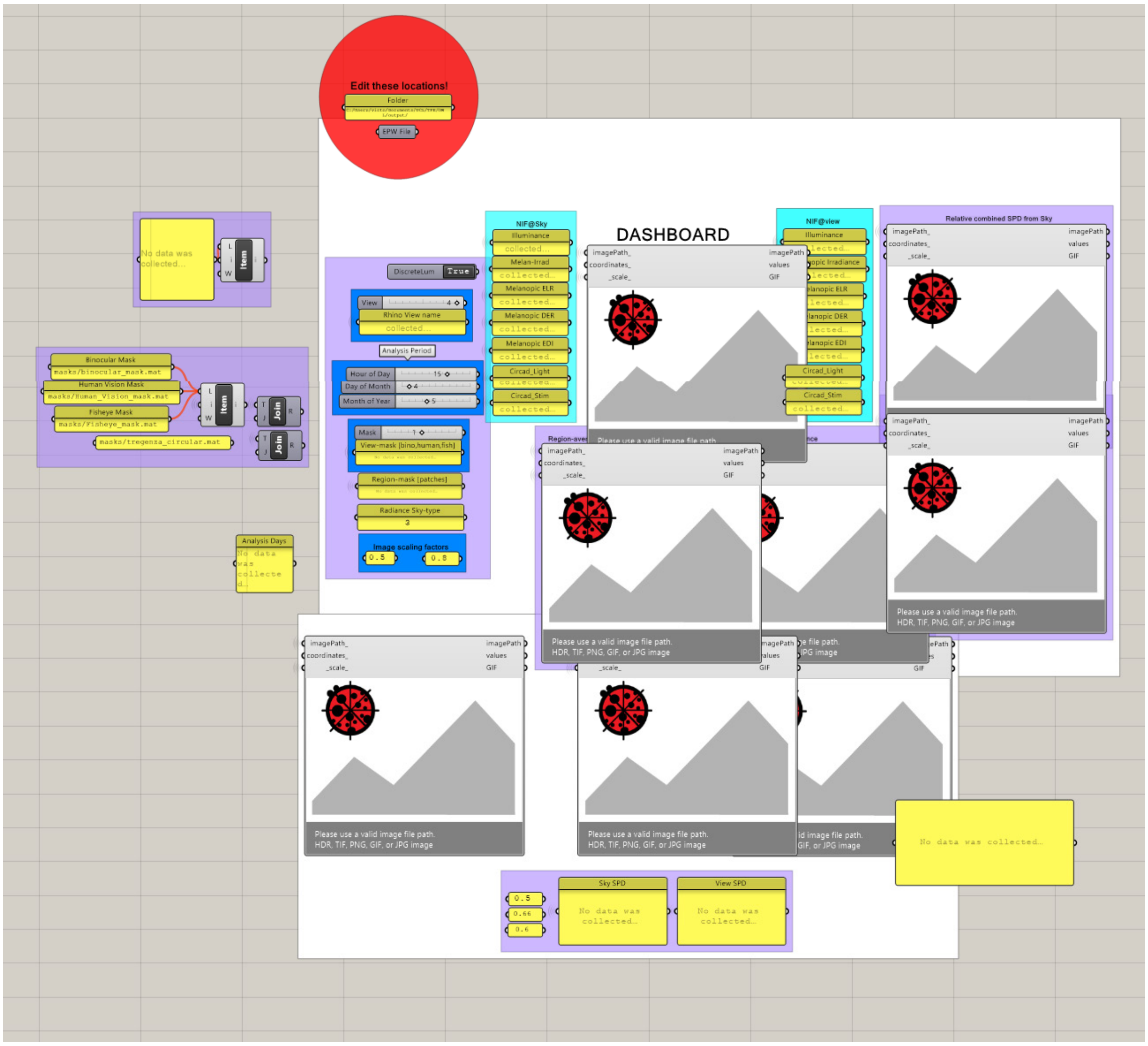
DF measured	DF simulated	DF via Rhino
3%	18%	12%
5%	21%	15%
3%	20%	14%
5%	16%	10%
6%	20%	14%
6%	22%	16%
7%	0%	0%
8%	9%	7%
9%	11%	8%
9%	11%	8%
9%	11%	8%
8%	10%	8%
1%	8%	6%
2%	10%	7%
1%	10%	7%
2%	11%	8%
3%	11%	8%
5%	12%	9%
8%	10%	7%
9%	11%	7%
9%	11%	8%
9%	12%	8%
9%	12%	8%
8%	11%	8%
1%	5%	3%
1%	5%	4%
1%	6%	4%
1%	6%	5%
2%	7%	5%
5%	9%	6%
10%	11%	8%
11%	12%	9%
11%	13%	9%
11%	13%	10%
12%	14%	10%
10%	12%	9%
1%	3%	2%
0%	3%	2%
1%	3%	2%
1%	4%	3%
1%	4%	3%
3%	7%	5%
6%	11%	7%
8%	13%	9%
11%	15%	11%
12%	16%	11%
13%	16%	11%
11%	15%	10%
0%	0%	2%
0%	2%	2%
0%	2%	2%
1%	2%	2%
1%	3%	3%
2%	6%	4%
5%	9%	6%
6%	11%	9%
6%	15%	10%
6%	15%	11%
6%	15%	12%
5%	14%	10%

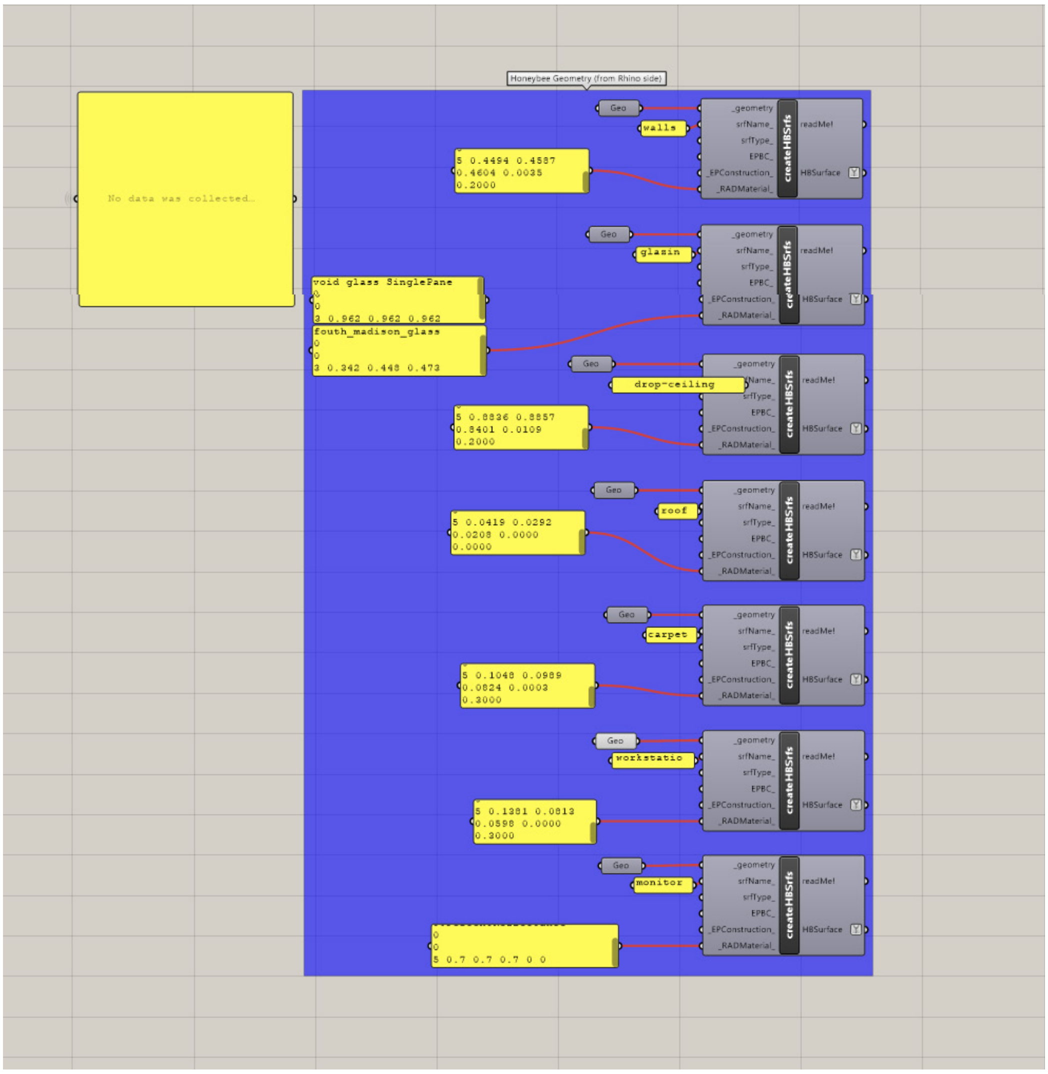
D. Lighting simulations

D.1. OWL 1: General




Generate Radiance SKY file from SPD
3CspectralSky
specify_folder
sky_name
channel_input
latitude
longitude
timeZone
sky_type
month
day
hour
dir_norm_rad
horz_diff_rad
sunAltitude
sky_material
skyDef
skyContent
skyFilePath
No data was collected...
Ladybug/Honeybee components
RADParameters
_quality
_ab_
_ad_
_as_
_ar_
_aa_
additionalP_
readMe!
radParameters
0
1
collected...
2
600
imageBasedSimulation
_skyFile
rhinoViewsName
cameraType
sectionPlane_
simulationType
imageWidth
imageHeight
radParameters
backupImages_
analysisRecipe
Toggle
True
runDaylightAnalysis
_HBObjects
_analysisRecipe
_writeRad
runRad_
numOfCPUs
workingDir
radFileName
meshSettings_
exportAirWalls_
additionalRadFiles_
overwriteResults_
readMe!
analysisType
resultsUnit
results
testPts
luminance_files
radGeoFile
studyFolder
done
FalseColor
_hdr
max_
seg_count_
legend_height_
legend_width_
legend_unit_
conversion_
contour_lines_
extrema_
color_palette_
hdr
Discretize image to View-luminance
HDR2DiscreteLumEx
HDR_file
region_mask
view_mask
folder
runIt
matrix_out
lumin_map
masked_image
region_lum
Luminance to CCT to SPD to NIF: OBSERVER SIDE
SpectralViewdome
matrix_out
lum_threshold
m_out
m_CCT
m_model
lum_threshold
450
viewCCT2SPD
CCT
SPD
Wavelength
RelativeCombinedSPD
SPD_5
luminance
Rel_comb_SPD
patch_illum
net_illum
CIES026_aopic
Rel_comb_SPD
alpha_type
net_illum
illuminance
a_opic_irradiance
a_opic_ELR
a_opic_DER
a_opic_EDI
SPD_1
a_opic_type
5
SPD_graph
Toggle
True
SPD_graph
Rel_comb_SPD
skyORview
folder
runIt
SPD_graph
cicadLight
Rel_comb_SPD
net_illum
CLa
CStim


Edit these locations!
Folder
EPW File
DASHBOARD
No data was collected...
Item
Binocular Mask
masks/binocular_mask.mat
Human Vision Mask
masks/Human_Vision_mask.mat
Fisheye Mask
masks/Fisheye_mask.mat
masks/tregenza_circular.mat
Join
Analysis Days
No data was collected...
DiscreteLum
True
View 4
Rhino View name
collected...
Analysis Period
Hour of Day 15
Day of Month 4
Month of Year 5
Mask 1
View-mask [bino,human,fish]
Region-mask [patches]
Radiance Sky-type
3
Image scaling factors
0.5
0.5
NIF@Sky
Illuminance
Melan-Irrad
Melanopic ELR
Melanopic DER
Melanopic EDI
Circad_Light
Circad_Stim
collected...
NIF@view
Illuminance
Melanopic Irradiance
Melanopic ELR
Melanopic DER
Melanopic EDI
Circad_Light
Circad_Stim
Relative combined SPD from Sky
Region-aver
imagePath_
coordinates_
scale
imagePath
values
GIF
Please use a valid image file path.
HDR, TIF, PNG, GIF, or JPG image
No data was collected...
0.5
0.66
0.6
Sky SPD
View SPD
No data was collected...



```
No data was collected…
```

```
walls
```

```
5 0.4494 0.4587
0.4604 0.0035
0.2000
```

```
glazin
```

```
void glass SinglePane
0
0
3 0.962 0.962 0.962
```

```
fouth_madison_glass
0
0
3 0.342 0.448 0.473
```

```
drop-ceiling
```

```
5 0.8836 0.8857
0.8401 0.0109
0.2000
```

```
roof
```

```
5 0.0419 0.0292
0.0208 0.0000
0.0000
```

```
carpet
```

```
5 0.1048 0.0989
0.0824 0.0003
0.3000
```

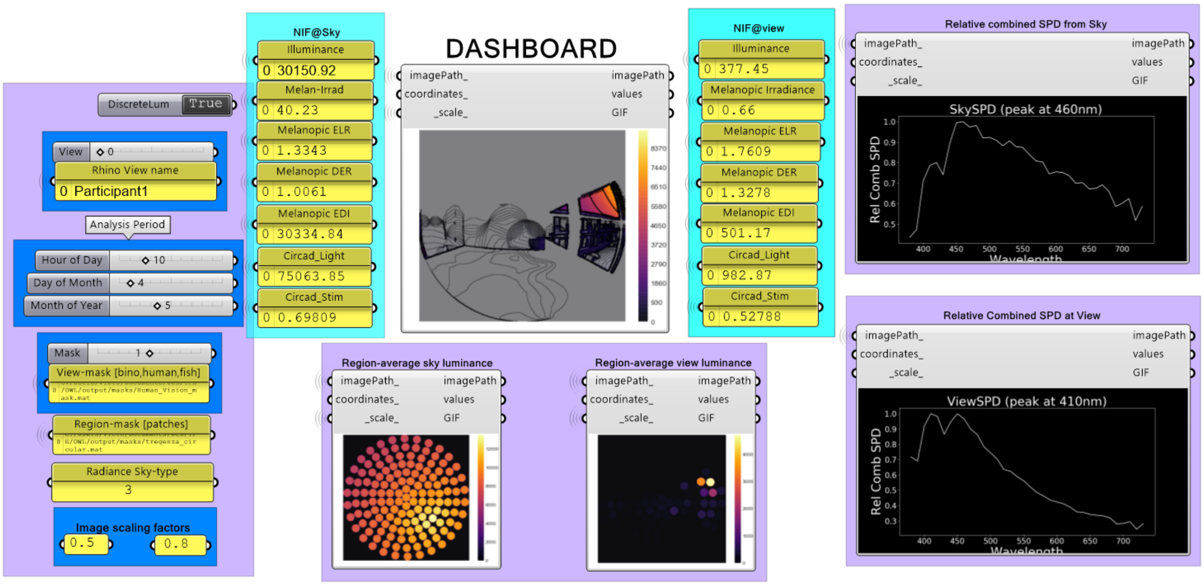
```
workstatio
```

```
5 0.1381 0.0813
0.0598 0.0000
0.3000
```

```
monitor
```

```
0
0
5 0.7 0.7 0.7 0 0
```

D.2. OWL 1: Participant 1



DiscreteLum: True

View: 0

Rhino View name: 0 Participant1

Analysis Period

Hour of Day: 10

Day of Month: 4

Month of Year: 5

Mask: 1

View-mask [bino,human,fish]

Region-mask [patches]

Radiance Sky-type: 3

Image scaling factors: 0.5 0.8

NIF@Sky

Illuminance: 0 30150.92

Melan-Irrad: 0 40.23

Melanopic ELR: 0 1.3343

Melanopic DER: 0 1.0061

Melanopic EDI: 0 30334.84

Circad_Light: 0 75063.85

Circad_Stim: 0 0.69809

NIF@view

Illuminance: 0 377.45

Melanopic Irradiance: 0 0.66

Melanopic ELR: 0 1.7609

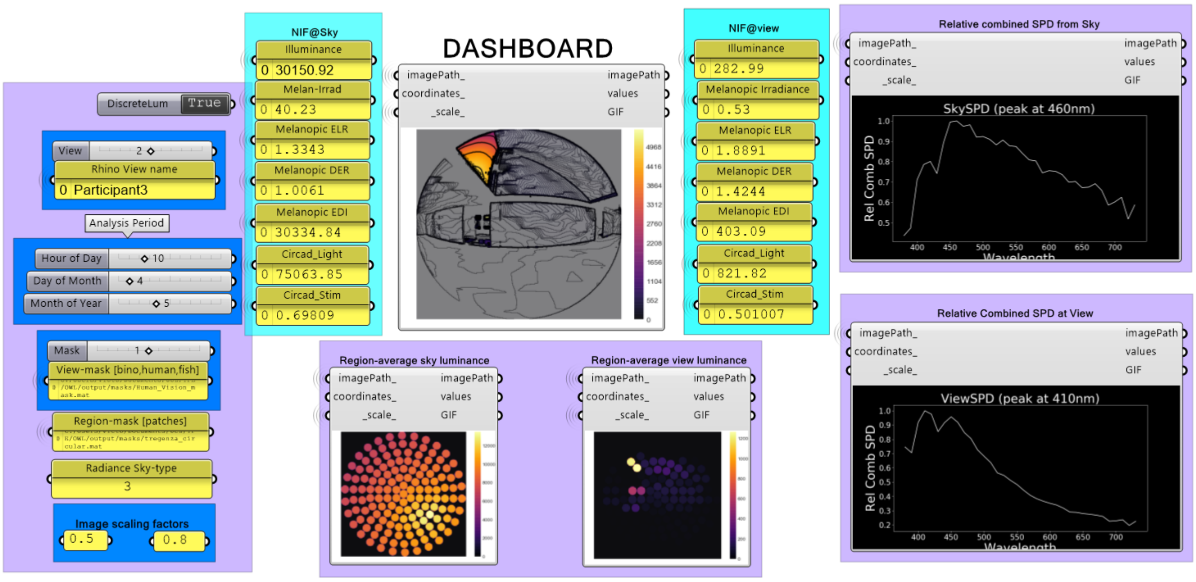
Melanopic DER: 0 1.3278

Melanopic EDI: 0 501.17

Circad_Light: 0 982.87

Circad_Stim: 0 0.52788

D.3. OWL 1: Participant 3



DiscreteLum: True

View: 2

Rhino View name: 0 Participant3

Analysis Period

Hour of Day: 10

Day of Month: 4

Month of Year: 5

Mask: 1

View-mask [bino,human,fish]

Region-mask [patches]

Radiance Sky-type: 3

Image scaling factors: 0.5 0.8

NIF@Sky

Illuminance: 0 30150.92

Melan-Irrad: 0 40.23

Melanopic ELR: 0 1.3343

Melanopic DER: 0 1.0061

Melanopic EDI: 0 30334.84

Circad_Light: 0 75063.85

Circad_Stim: 0 0.69809

NIF@view

Illuminance: 0 282.99

Melanopic Irradiance: 0 0.53

Melanopic ELR: 0 1.8891

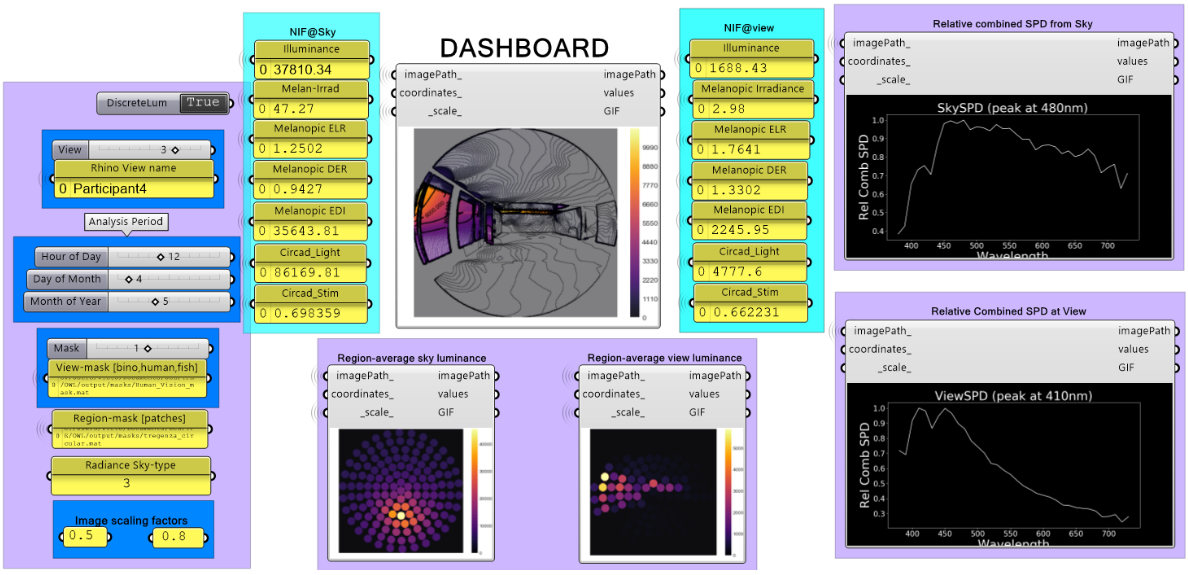
Melanopic DER: 0 1.4244

Melanopic EDI: 0 403.09

Circad_Light: 0 821.82

Circad_Stim: 0 0.501007

D.4. OWL 1: Participant 4



DiscreteLum True

View 3

Rhino View name: 0 Participant4

Hour of Day 12

Day of Month 4

Month of Year 5

Mask 1

View-mask [bino,human,fish]

Region-mask [patches]

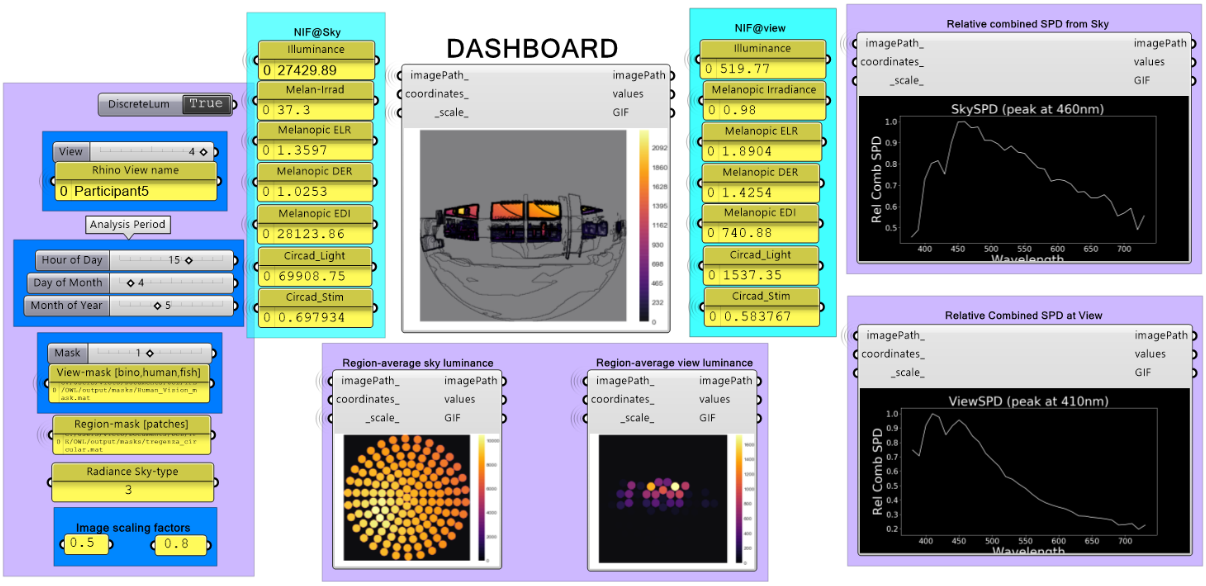
Radiance Sky-type: 3

Image scaling factors: 0.5 0.8

NIF@Sky
- Illuminance: 0 37810.34
- Melan-Irrad: 0 47.27
- Melanopic ELR: 0 1.2502
- Melanopic DER: 0 0.9427
- Melanopic EDI: 0 35643.81
- Circad_Light: 0 86169.81
- Circad_Stim: 0 0.698359

NIF@view
- Illuminance: 0 1688.43
- Melanopic Irradiance: 0 2.98
- Melanopic ELR: 0 1.7641
- Melanopic DER: 0 1.3302
- Melanopic EDI: 0 2245.95
- Circad_Light: 0 4777.6
- Circad_Stim: 0 0.662231

D.5. OWL 1: Participant 5



DiscreteLum True

View 4

Rhino View name: 0 Participant5

Hour of Day 15

Day of Month 4

Month of Year 5

Mask 1

View-mask [bino,human,fish]

Region-mask [patches]

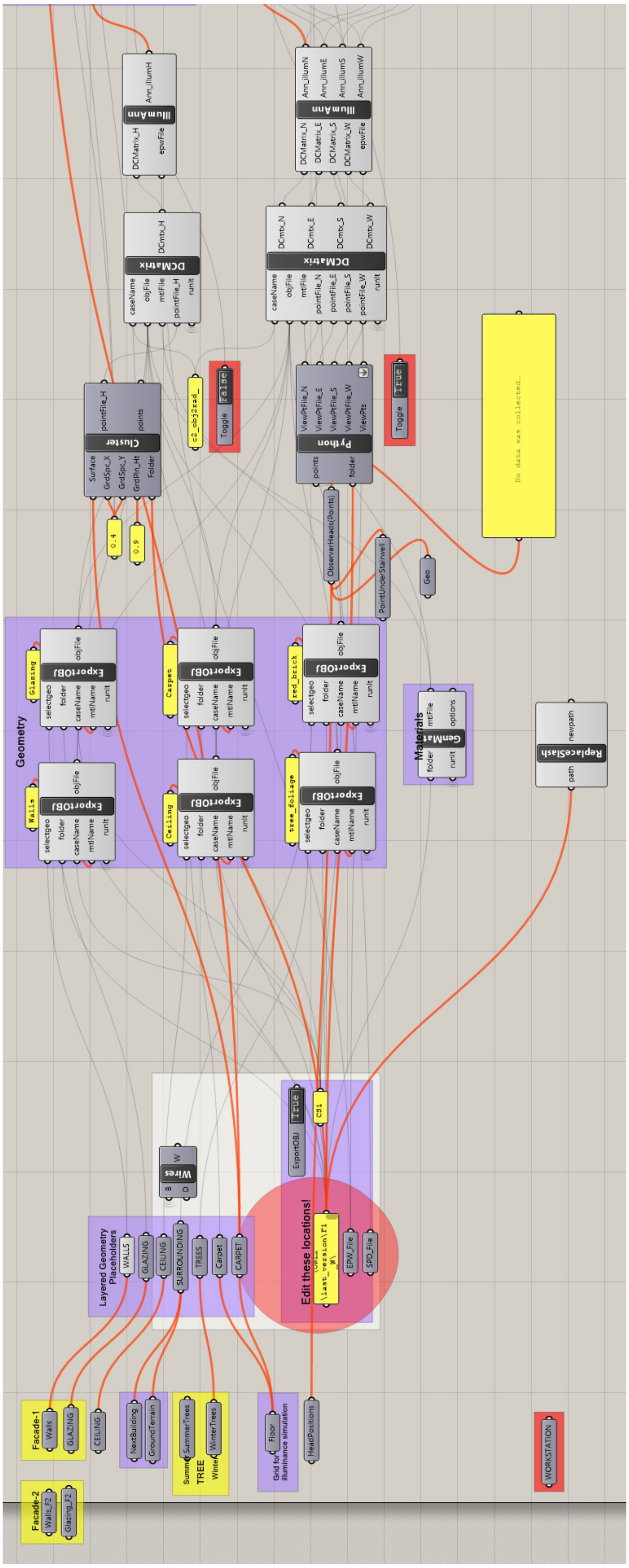
Radiance Sky-type: 3

Image scaling factors: 0.5 0.8

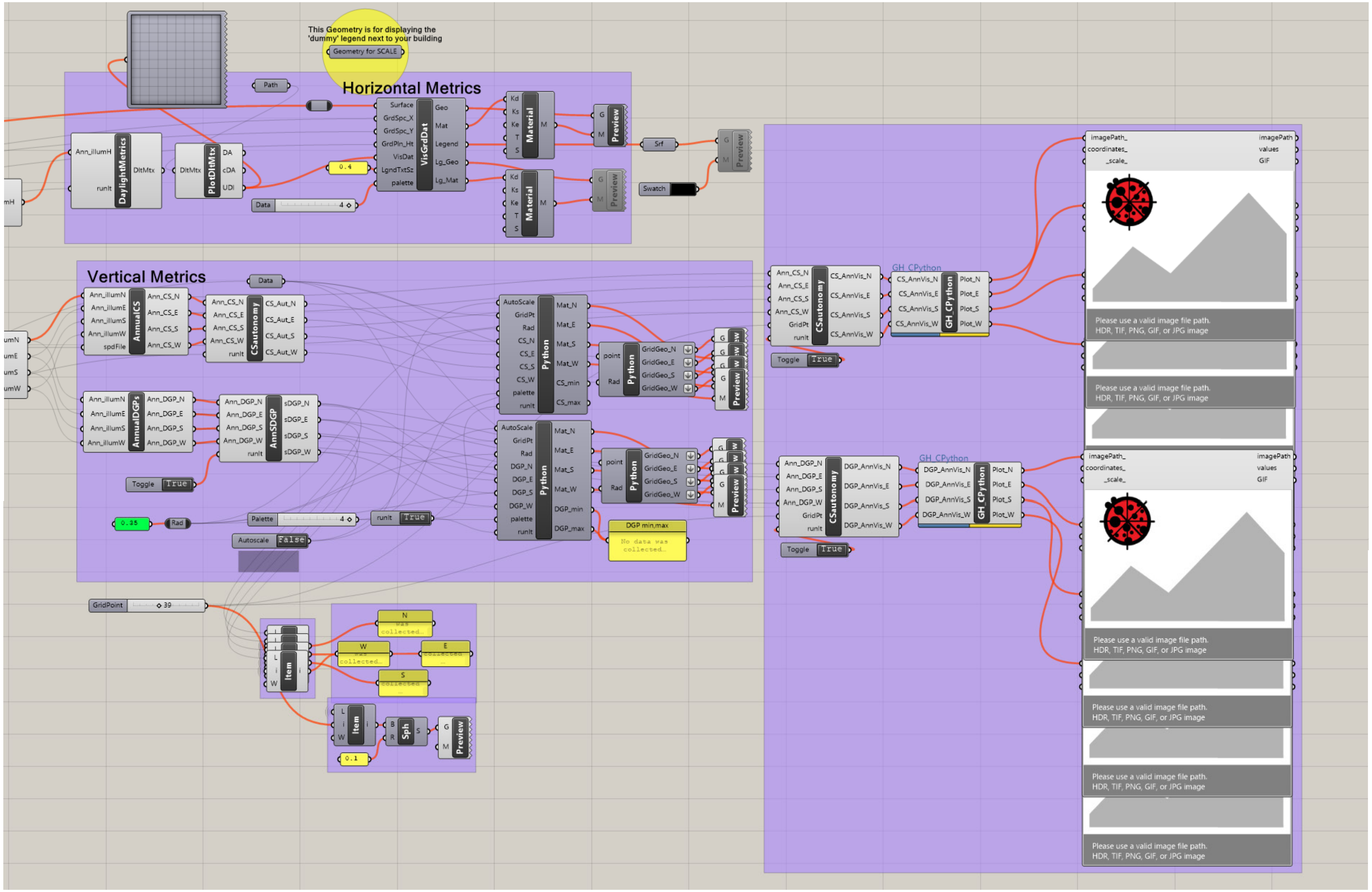
NIF@Sky
- Illuminance: 0 27429.89
- Melan-Irrad: 0 37.3
- Melanopic ELR: 0 1.3597
- Melanopic DER: 0 1.0253
- Melanopic EDI: 0 28123.86
- Circad_Light: 0 69908.75
- Circad_Stim: 0 0.697934

NIF@view
- Illuminance: 0 519.77
- Melanopic Irradiance: 0 0.98
- Melanopic ELR: 0 1.8904
- Melanopic DER: 0 1.4254
- Melanopic EDI: 0 740.88
- Circad_Light: 0 1537.35
- Circad_Stim: 0 0.583767

D.6. OWL 2



IllumAnn
DCMatrix_H
epwFile
Ann_IllumH
DCMatrix_N
DCMatrix_E
DCMatrix_S
DCMatrix_W
Ann_IllumN
Ann_IllumE
Ann_IllumS
Ann_IllumW
DCMatrix
caseName
objFile
mtlFile
pointFile_H
runIt
DCmtx_H
pointFile_N
pointFile_E
pointFile_S
pointFile_W
DCmtx_N
DCmtx_E
DCmtx_S
DCmtx_W
Cluster
Surface
GrdSpc_X
GrdSpc_Y
GrdPln_Ht
Folder
points
c2_obj2rad_
Toggle
False
Python
folder
ViewPtFile_N
ViewPtFile_E
ViewPtFile_S
ViewPtFile_W
ViewPts
True
No data was collected...
0.4
0.9
ObserverHeads(Points)
PointUnderStairwell
Geo
Geometry
ExportOBJ
selectgeo
caseName
mtlName
Glazing
Walls
Carpet
Ceiling
red_brick
tree_foliage
Materials
GenMat
options
ReplaceSlash
path
newpath
Wires
ExportOBJ
C91
Edit these locations!
EPW_File
SPD_File
Layered Geometry Placeholders
WALLS
GLAZING
CEILING
SURROUNDING
TREES
Carpet
CARPET
Facade-1
Walls
GLAZING
CEILING
NextBuilding
GroundTerrain
SummerTrees
WinterTrees
TREE
Summer
Winter
Floor
Grid for illuminance simulation
HeadPositions
WORKSTATION
Facade-2
Walls_F2
Glazing_F2


This Geometry is for displaying the 'dummy' legend next to your building
Geometry for SCALE
Horizontal Metrics
Path
Ann_illumH
runIt
DaylightMetrics
DltMtx
PlotDltMtx
DA
cDA
UDI
0.4
Data
Surface
GrdSpc_X
GrdSpc_Y
GrdPln_Ht
VisDat
LgndTxtSz
palette
VisGrdDat
Geo
Mat
Legend
Lg_Geo
Lg_Mat
Kd
Ks
Ke
T
S
Material
M
G
Preview
Srf
Swatch
Vertical Metrics
Ann_illumN
Ann_illumE
Ann_illumS
Ann_illumW
spdFile
AnnualCS
Ann_CS_N
Ann_CS_E
Ann_CS_S
Ann_CS_W
CSautonomy
CS_Aut_N
CS_Aut_E
CS_Aut_S
CS_Aut_W
AnnualDGPs
Ann_DGP_N
Ann_DGP_E
Ann_DGP_S
Ann_DGP_W
AnnSDGP
sDGP_N
sDGP_E
sDGP_S
sDGP_W
Toggle
True
0.35
Rad
Palette
Autoscale
False
AutoScale
GridPt
CS_N
CS_E
CS_S
CS_W
Python
Mat_N
Mat_E
Mat_S
Mat_W
CS_min
CS_max
DGP_N
DGP_E
DGP_S
DGP_W
DGP_min
DGP_max
point
GridGeo_N
GridGeo_E
GridGeo_S
GridGeo_W
DGP min,max
No data was collected...
GridPoint
39
Item
L
i
W
N
E
S
Sph
B
R
0.1
CS_AnnVis_N
CS_AnnVis_E
CS_AnnVis_S
CS_AnnVis_W
GH_CPython
Plot_N
Plot_E
Plot_S
Plot_W
DGP_AnnVis_N
DGP_AnnVis_E
DGP_AnnVis_S
DGP_AnnVis_W
imagePath_
coordinates_
scale
imagePath
values
GIF
Please use a valid image file path.
HDR, TIF, PNG, GIF, or JPG image

UNIVERSITÉ CATHOLIQUE DE LOUVAIN
Faculté d'architecture, d'ingénierie architecturale, d'urbanisme
Rue du Levant, 1 bte L5.05.02, 1348 Louvain-la-Neuve, Belgique | **www.uclouvain.be/loci**