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Abstract:
The report investigates the emerging problem of lacking integrated lighting design solutions in the built environment. Moreover, how the transdisciplinary lighting design approach can be integrated into the everyday workflow of architecture. Initially both the lighting design process model, and the architectural workflow is studied, that is resulting in the development of a research question, together with success criteria for the upcoming model. These are forming the base for the architectural-lighting model. The architectural-lighting model is a merged model, integrating the transdisciplinary lighting practice, phase by phase into the architectural workflow, simultaneously describing all services that can be expected at each construction phase. The process model is created after the principals of research-based design practices, and therefore ensures that all lighting solutions developed through the model are traceable and evaluated through academic testing. Nonetheless, the model secures a holistic lighting design solution, through its transdisciplinary layout, working over the fields of Social Science, Natural Science and Humanities and Arts. The final architectural-lighting model is tested through a case study, where the functionality of the model is evaluated. Possibilities for future work are discussed in the report as well.

AALBORG UNIVERSITY

The architectural-lighting model

Transdisciplinary lighting design integrated into the architectural workflow

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INTRODUCTION

As lighting design is a relatively new field, working practices for lighting designers are rarely established at Danish architectural companies. Lighting design is often handled in construction projects as an extra, add-on element, with the pure purpose of illuminating a space with the required lux levels of the standards. Traditionally the design of the lighting system of a building is carried out in cooperation with an electrical engineer, where the architect has a say in for the desired luminaires, and atmosphere, however this cooperation is often superficial, and the considerations made are excluding a holistic view on lighting design.

With the rapid development of lighting technologies and control systems, versatile lighting options are available on the market. On the other hand, without the understanding of human needs, functions and the new technology itself, a lighting design can do more harm, than benefit the user. Several studies are suggesting that lighting has a significant effect on both our behavioural patterns, welfare, health and even concentration and alertness (Casciani, 2016) (Robert A. Baron, Mark S. Rea, Susan G. Daniels, 1992).

Lighting designers therefore have great responsibility designing lighting systems, that are considering all angles of a lighting design. This means that lighting must be understood and worked with as a *“multidimensional design element”* (Ellen Kathrine Hansen, Michael Mullins, 2014) where the knowledge of lighting design is gathered through a transdisciplinary approach, exploring the various of angles of lighting by the crossing of academic borders. Moreover, designers must also work with lighting through an integrated lighting design approach over the entire length of a construction project. Lighting to be examined both from a technical, aesthetic and humanistic angle, nonetheless through a framework that allows a research-based approach, where the added value of the lighting design solution can be justified.

This paper investigates, how the working traditions of lighting designers can be merged and integrated into the architectural workflow. The aim is to create a working model, that helps the cooperation between lighting designers, architects, and engineers, while it ensures that a holistic view on lighting is carried through the entire construction projects. As for today, there is no established work process in for lighting design at an architectural company. This means, that important segments of lighting design are often uncontrolled, moreover conclusions and learnings can be hardly derived at the end of a design project. Which is often the result of missing quality control and user evaluation practices in for lighting. An integrated design workflow can provide with a better overview on an economical timeline, by considering details, such as installation and maintenance costs. Moreover, by choosing the exact number of luminaires with the proper technical requirements needed for the visual tasks in the building.

The architectural-lighting process model aims to be a daily working-tool, that helps to resolve the difficulties faced through a lighting design project at an architectural company. It reveals the importance of an integrated and transdisciplinary lighting design approach, nonetheless it aims to educate both engineers and architects for good quality lighting practices.

METHODOLOGY

Initially a semi-structured interview was performed, to investigate the problem, and create an initial research question for the topic of this report. Part 1 of the report is the result of an extensive literature review through scientific journals, lighting related books and websites. Through the review, the method of systematic research been used, by keywords such as, `lighting and atmospheric perception`, `effect of indoor lighting`, `social lighting`, `lighting standards`, in addition to reference and citation search. The literature analysis for this report is might not be exhaustive, the theoretical background of the investigated topics are solid, and the selected references are robust. Other than lighting design, Part 1 also investigates the working traditions of the build environment, described in the document, Description of services for Building and landscape (The Danish Association of Consulting Engineers (FRI), 2018). The literature review of Part 1, leeds to the final research question, that is the base for the architectural-lighting model developed in Part 2. Here, parallelises are drawn between the working traditions of lighting designers and architects, exploring the similarities of the two design processes, that are later on forming the final transdisciplinary and integrated architectural-lighting model. The functionality of the developed model is tested through a case-study in Part 3. The report closes with a Discussion chapter, evaluating whether the developed model fulfils the criteria of the research question, and solves the investigated problem statement. This final chapter, nonetheless, includes thoughts for future work, on topics that are reaching over the study of this report.

INVESTIGATION OF THE PROBLEM

In order to understand how the different business segments of an architectural company, are currently working with lighting, semi-structured interviews were carried at Arkitema Architects, between the time frame of November 2020 to December 2020. Business segments of learning, working, health, urban, and competition were investigated, with a total number of six participants. The participants were interviewed on an average for an hour, answering questions about their lighting practices at their specific business area. Question have been formulated to understand; how lighting design contributes to the projects at Arkitema? As an example, in which phase of the construction project lighting comes into consideration, and what these considerations are? How is the cooperation between the consultant engineer and the architect, when it comes to lighting? Who decides and on which parameters luminaires are chosen? At which depth lighting parameters are understood, and how well the technical requirements are harmonizing with the desired design outcome? How thorough is the analysis prior to a lighting concept; are the functions, visual tasks and users are taken into account?

As an overall conclusion of the interviews, there is a shared agreement, that there is a need for better understanding of lighting design. The architect participants revealed uncertainty and missing expertise, when working with lighting in a construction project. It became clear, that lighting is neither understood, nor considered through a holistic lens, and both the added architectural value, lighting could contribute to a project, and the user needs are often neglected. Although, not because of a missing desire, but because of missing professional knowledge, and a poor understanding on lighting, and how to work with it as a *"multidimensional design element"* (Ellen Kathrine Hansen, Michael Mullins, 2014). The interview participants were often unaware, how or when to consider lighting design through the construction project, or how greatly the early investigation of lighting design could contribute to their project. As an example, through the added architectural value, lighting can provide. In addition, to the security of lighting calculations, that are ensuring that the suggested design is in align with the standards. The early involvement of lighting design, moreover, provides with the understanding of the energy consumption of the lighting system, and can also result in higher rates of user satisfaction and improved health benefits, that can even result in fewer sick-leave days. All in all, the overall benefits of the early integration of lightning, and how it provides a better and holistic overview on the lighting project was unknown or very limited amongst the interview participants. However, at the end of each interview session, the participants were excited about the potentials of lighting, and been agreed, that there is a need for the up-prioritization of lighting in architecture.

Citations from the semi-structured interviews at Arkitema, are arguing on the need for a structured involvement of lighting design. Furthermore, relieving the need for a new platform that ensures a 360-degree, integrated lighting design solution.

- "I think we have a poor language when it comes to lighting" (Architect)
- "The cooperation between the engineers and architects are often difficult. It is a time-consuming process, that often ends in compromise" (Architect)
- *"Lighting* often just slips" (Architect)
- "Our best projects are the ones, that are giving a sensory experience" (Architect)
- "I am often unsure, if it fulfils the standards" (Architect)
- "We are not r*unning quality check on the lighting, the engineers do" (Architect)*

The semi-structured interviews made it clear, that it is not satisfactory to only look at a single segment of a design solution, as it is traditionally done today. It was detected, that there is a great gap between the understanding and concepts of the engineers and the understanding and desires of architects. Lighting solutions are often suffering, as only a single pillar of the lighting is considered. Instead of a holistic view on lighting, only some lighting angles are investigated, being the technical details, architectural value or user needs. However, the presence of all lighting pillars, thus a transdisciplinary solution, within a single lighting project is extremely limited. Lighting design, therefore must be studied and worked a holistic mindset.

The initial research question of this paper, is therefore the following:

How to integrate a transdisciplinary lighting design approach into the architectural workflow?

PART 1
ANALYSIS LEADING TO RESEARCH QUESTION

Study of the lighting design practice

Lighting design is a complex field, that reaches over the boundaries of numerous professions. It studies both the visual- and psychological effects, thus the biological and behavioural effects of light. The field of lighting design works with identity and added architectural value through the staging of atmosphere and impression of aesthetics in a space. It considers the needs of the users and provides high quality illumination. Meanwhile, it can influence user behaviour, wellbeing, and health. Lighting design assesses the activities of a space and illuminates surfaces, where a visual task requires that. Lighting designers are validating the qualities of all surfaces and the possible interplay between materials, textures, colours, and light. This field understands how to optimize energy requirements and follow standards and building regulations, using photometric calculations. Nonetheless, it works with a holistic view on lighting, that understands the interactions between the space, people, and lighting.

When speaking of lighting design, lighting can be categorized as daylight and electrical lighting. While there is a great tradition amongst architects to work with daylight and manipulate it through daylight-openings, the interplay between daylight and electrical lighting is less implied. The work of a lighting designer is essential in for creating a design concept, where the electrical lighting systems are complementing the daylight that penetrates the room. Moreover, the designer is fully responsible for the design of a well-functioning lighting plan, that fulfils all the needs and functions of the space, while it relates to the context of the environment, to the users, and to the lighting requirements of the building. Lighting designers must balance between the borders of architecture, anthropology, engineering and more, to be the bridge between all the professions, for a holistic lighting design solution.

The lighting design experiment model (Ellen Kathrine Hansen, Mette Hvass, 2019) from the Master of Lighting Design program at Aalborg University, is chosen to be the baseline for this paper, as it considers lighting as a transdisciplinary profession, where the knowledge in design is created through crossing boundaries. The model emphasizes the importance of starting with a problem, and then bringing various disciplines to bear on solving that problem, by searching amongst the disciplines for contribution (Meeth, 1978).

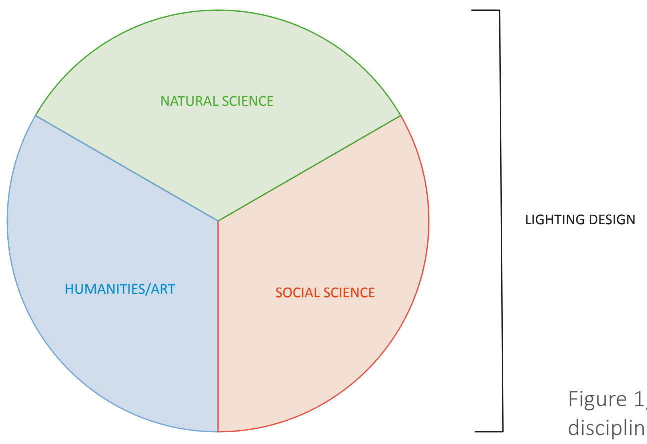


Figure 1, The three scientific disciplines within lighting design

Three primary disciplines are introduced through the model; Natural Science, Social Science and Humanities and Arts, where each scientific field represents a lighting pillar of the holistic lighting design solution. It is therefore important to point out, that the exclusion of any of the three fields, results in an incomplete design solution, where different angles of the lighting design concept are neglected.

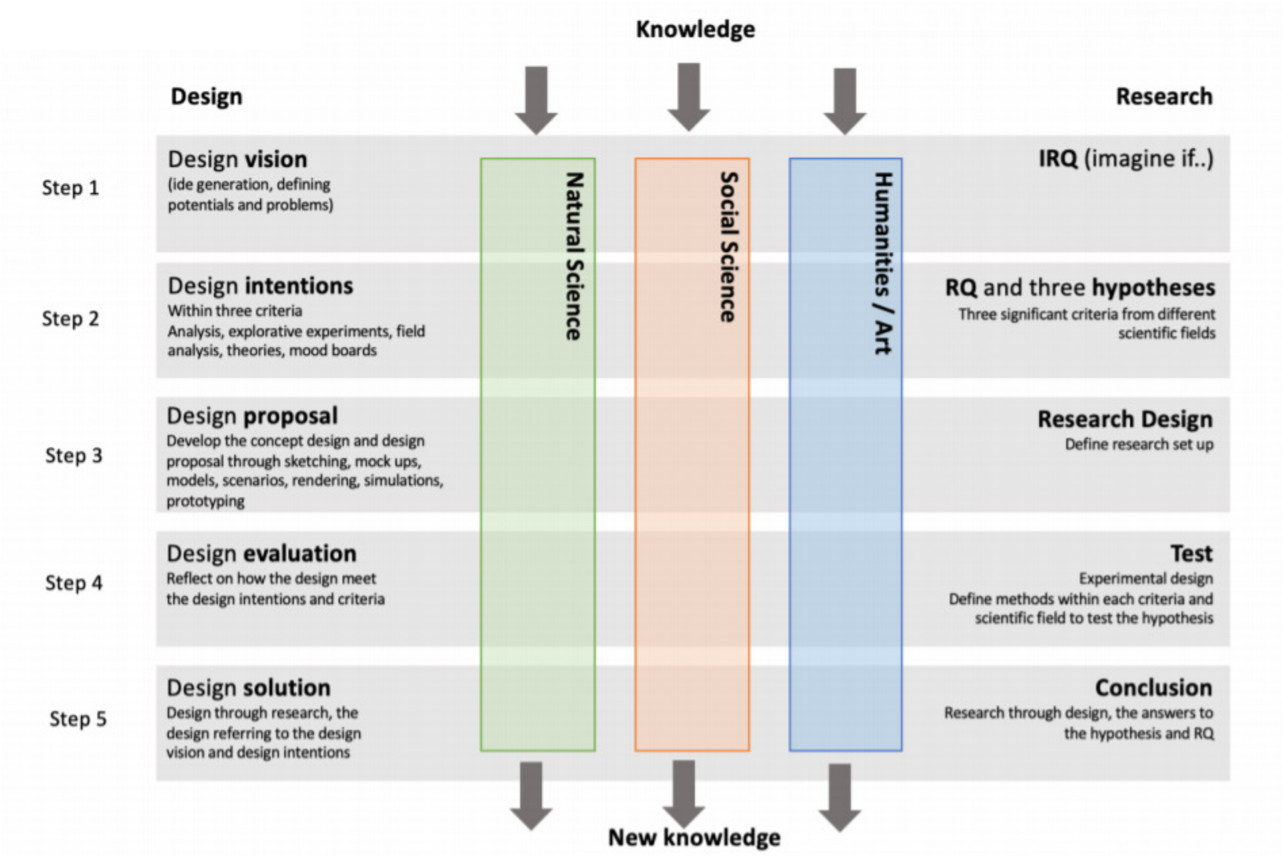


Figure 2, Design experiment model (Ellen Kathrine Hansen, Mette Hvass, 2019)

Other than the transdisciplinary layout of the design experiment model (Ellen Kathrine Hansen, Mette Hvass, 2019), the model also presents a research-based design approach, that ensures, that the design solution of each project is explicit and verifiable.

The first step of the model invites the designer to create a vision for the lighting project. Here an initial research question is formulated and the problem to be solved is identified.

Step two of the process is Design intention, where the space, its users and its functions are analysed. Based on the analysis, three separate design criteria, within each of the three scientific disciplines are created. All the criteria relate to the problem understood in the vision, and specific to the lighting critical factors, the scientific field can resolve. A hypothesis, that later, in the design project can be tested, is defined for each scientific discipline.

The design proposal, which is step three of the model, illustrates the main project. Design concepts, that are fulfilling the needs of all three hypotheses, are developed. The various concepts are realized through sketches, mock-ups, renderings and simulations.

In step four, the design concepts are to be evaluated through user testing and live-mock-ups. This step reflects on whether the design fulfils the vision and the three criteria established in the Design intention step.

The final step, Design solution is where knowledge is catalogued. After the evaluation and testing, tangible, evidence-based results are either justifying or rejecting the design solution. As the entire model lies on a research-based design method, the learnings of the design process can be categorized as explicit knowledge, and therefore can be referenced to, and applied in further projects.

The upcoming sub-chapters are exploring the lighting critical factors of each scientific discipline.

Natural Science

The field of Natural Science works with quantitative and verifiable, predictable variables. (Lotte Rienecker, Peter Stray Jørgensen, Signe Skov, 2013)

Looking on lighting design through the glasses of Natural Science, the most important to understand, are the basic photometric terms and fundamental laws. Lighting standards and regulations are demanding that certain photometric variables are within a predetermined minimum and maximum range, for various tasks and work environments. For us, to be able to design with these photometric variables, both the nature and the presence of these terms in different standards, are to be studied.

In Denmark, the Building Regulations 2018 require the fulfilment of DS / EN 124641-1 Light and lighting - Lighting at workplaces standard (Standard, 2015), therefore in practice, it has the same status as the Building Regulations and is a legal requirement in Denmark.

This European standard specifies requirements for lighting solutions for most indoor workplaces and their associated areas in terms of quantity and quality of illumination. In addition, recommendations are given for good lighting practices (Standard, 2015). The EN 124641-1 standard sets demand to visual comfort, visual performance, and safety, through parameters that are determining the luminous environment. These parameters are luminance distribution, illuminance, directionality of light, variability of light (levels and colours of light), colour rendering and colour appearance of light, glare, and flicker (Standard, 2015).

However, for us to understand these determining parameters of the luminous environment, the basic photometric terms and other fundamental lighting laws are studied toughly first. The basic photometric terms are the ones, describing the flow of light in three-dimensional space. While the fundamental laws are associated with expressions, like colour appearance, reflectance, and glare.

Basic terms	Description	Symbol	Unit
Luminous flux	Total amount of light emitted by a light source.	F or Φ	Lumen - lm (cdxsr)
Illuminance	Light (flux) incident on a unit surface.	E	Lux – lx (lm/m²)
Exitance	Total luminous flux leaving a unit area of surface.	M	Lux - lx (lm/m²)
Solid angle	Three-dimensional angle of a cone, describing the breadth of a light beam.	Ω or w	Steradian - sr
Luminance	The amount of light flowing in a particular direction from a surface. (Objective brightness)	L	Candela/square meter – cd/m²
Angle of incidence	Angle between a beam of light and the normal to the surface.	i	Degree – deg, rd
Luminous intensity	The flow of light in a given direction.	I	Candela – cd (lm/sr)
Contrast	Describes the luminance differences.	C	-
Uniformity	Ratio between minimum and average illuminance.	U	-

Table 1, Basic lighting terms (Peter Targenza, David Loe, 2014)

Lighting fundamentals	Description	Initials
Spectral power distribution	Power of the light at each wavelength in the visible spectrum (relates to light source)	SPD
Spectral reflectance distribution	Radiant power reflected from a material (relates to object)	SRD
Correlated colour temperature	The colour appearance of light, measured in Kelvin. White light with different colour temperatures. (warm – up to 3300K, cold – above 5300K)	CCT
Colour rendering index	A scale that measures the ability of light source to reproduce colours.	CRI
Reflectance	The proportion of the light being reflected from a surface. Specified as a flux ratio. Specular reflection – light leaves the surface as it hits. Diffuse reflection – light bounced equally in all directions (matte surface)	R
Flicker	Rapid variation in the light source intensity. Can be divided into electric flicker, caused by fluctuating loads on AC power distribution lines, and photometric flicker, caused by the light source itself. Flicker can be either visible or invisible. Invisible or cannot be perceived from an average of 60 Hz, referred to as CCF, critical fusion frequency.	
Glare	Excessive luminance ratios in the environment. According the EN 12464-1 standard, it is measured by the CIE glare index; UGR or unified glare rating. Disability glare can reduce visual performance, while discomfort glare can cause feelings of discomfort.	UGR

Table 2, Lighting fundamentals (Peter Targenza, David Loe, 2014)

Considering **luminance distribution**, the European lighting standard recommends reflectances for the major interior diffusely reflecting surfaces (Standard, 2015).

- Ceiling: 0.7 to 0.9
- Walls: 0.5 to 0.8
- Floor: 0.2 to 0.4

Moreover, in all enclosed places the maintained illuminances on the major surfaces shall have the following values (Standard, 2015):

- Em > 50 lx with Uo >= 0.1 on walls
- Em > 30 lx with Uo >= 0.1 on ceiling

The standard also determines the relationship and ratio of **illuminances** on task area, to in immediate surrounding, to background area.

- Illuminance on the task area to illuminance on immediate surroundings areas is; 3:2
- Illuminance on immediate surroundings areas to illuminance on background area is; 3:1

Furthermore it provides recommendations on illuminance uniformity for lighting from artifical lighting (Standard, 2015).

- immediate surroundings area: Uo>=0.40
- background area: Uo>=0.10

For the determination of discomfort **glare** the standard is using the *CIE Unified Glare rating (UGR) tabular method*. This method is based on the following formula (Standard, 2015):

$$UGR = 8 \log_{10} \left(\frac{0{,}25}{L_B} \sum \frac{L^2 \omega}{p^2} \right)$$

By increasing the background luminance (Lb) the UGR reduces, while the increasement of the luminance of the luminaires in sight (L), are increasing the overall UGR. The position of the light source in relation to the viewers sight, has also a significant part in the amount of the glare the user experiences. Further the luminaire is from the viewer, bigger the guth index, and thermal lower the UGR.

The EN 124641-1 standard describes the **colour appearance** of artificial light as well, which can be restricted for specific applications. Meaning, that certain work tasks, such as colour inspection must take place under the predetermined Correlated Colour Temperature (CCT) values, described by the standard (Standard, 2015).

Colour appearance	Correlated colour temperature
Warm	Bellow 3300 K
Intermediate	3300 to 5300 K
Cool	Above 5300 K

Table 3, Lamp colour appearance (Standard, 2015)

Nonetheless, a minimum value for the **colour rendering** properties of a light source is given in the standard, marked as Ra, where the maximum value is 100. The minimum Ra value is specified by working tasks in the standard.

Even though, the EN 124641-1 standard is not keen on setting a limit on the acceptable rate of **flicker**, it emphasizes, that lighting systems should be designed to avoid flicker and stroboscopic effects.

All in the standard sets a baseline for good lighting practices and provides with verifiable, quantitative parameters for the lighting designers to follow. Parameters such as, colour rendering, colour appearance, glare, illuminance levels and luminance distribution are values that can be calculated and validated through the methods of natural science. Parameters that can be measured through photometric meters.

Humanities and Arts

The scientific field of Humanities and Arts is probably the one, that is the hardest to grasp and understand from the three examined scientific fields. Its purpose is to understand the unique and the specific (Lotte Rienecker, Peter Stray Jørgensen, Signe Skov, 2013).

This field examines the relationship between the individuals' perception and their environment. Humanities and Arts are greatly relying on qualitative data collection, studying the perceivers' role in atmospheric perception.

The world atmosphere, already as early as the 18th century been used, for the time indescribable feeling *"in the air"* (Böhme, 2013). Peter Zumthor, Swiss architect, later on discusses overall atmosphere with the following phrase.

"I enter a building, see a room, and – in the fraction of a second – have this feeling about it" (Pallasmaa, 2014, p. 230)

The phenomenon of atmosphere is itself something intangible and indeterminate. In order to understand this phenomenon, one must experience it at expose the self to it. Even though, when the subject is exposed to a certain atmosphere, he or she *"often experiences it as something out there, something which can come over one"* (Böhme, 2013, p. 2). Therefore, it is essential to understand, that atmosphere is merely nothing without the subject.

Atmosphere is a phenomenon, something intimate between the subject and the object. Both Juhani Pallasmaa, Finish architect, and Gernot Bohme, German philosopher, are describing atmosphere as following.

"As we enter a space, the space enters us, and the experience is essentially an exchange and fusion of the object and the subject." (Pallasmaa, 2014, p. 232)

"Atmosphere is the shared reality of the perceiver and the perceived." (Bohme, 2016, p. 24)

Both in phenomenology and in architecture it is common practice, when speaking of atmosphere, to refer to *"Genius loci, the Spirit of Place"* (Pallasmaa, 2014, p. 231), which is characterizing a space through its unique identity. The phenomenon of "*Genius loci"* (Pallasmaa, 2014, p. 231) studies the visual identity, however it evolves even deeper, considering the unseen, the felt and perceived “spirit” in a room, which is also called, as the ambience or atmosphere of a space.

“The quality of a space or place is not merely a visual perceptual quality as it is usually assumed. The judgement of environmental character is a complex multi-sensory fusion of countless factors which are immediately and synthetically grasped as an overall atmosphere, ambience, feeling or mood.” (Pallasmaa, 2014, p. 230)

Even though the fact, that atmosphere is something extremely challenging to express through words, because of its complex and multi-sensory nature, we are all programmed to grasp atmosphere even before we can “*understand it intellectually”* (Pallasmaa, 2014, p. 232), as “*we perceive atmospheres through our emotional sensibility* (Pallasmaa, 2014, p. 233). This perception or understanding of the surroundings, happens through a multi-sensory experience, where an immediate judgement of the space happens through our bodily senses, a sort of embodied experience. This means, that we are exceptionally great to sense atmosphere on an unconscious level, however we often have a difficulty saying anything meaningful about it.

In order to illustrate, what this paper refers to, when speaking of atmosphere, some examples are selected. A formal atmosphere, perceived by office workers, could appear due to bright, evenly distributed/uniform illumination, where the intimate atmosphere of a home can be rendered under dim, non-uniform lighting conditions (Edensor, 2015) (Casciani, 2016).

Both formal and intimate, are atmospheric parameters, that are overreaching qualities of our environment. Nevertheless, atmosphere can be perceived as ‘*tense* ‘, ‘*light-hearted*‘ or ‘*serious*‘, ‘*oppressive*‘ or ‘*uplifting*‘, ‘*cold*‘ or ‘*warm*‘ (Böhme, 2013). Moreover, according to Vogels, atmospheres can be understood as *‘safe’*, *‘intimate’*, *‘cosy’*, *‘pleasant’*, ‘*stimulating’*, *‘lively’*, *‘terrifying’*, *‘threatening’*, *‘tense’*, ‘*oppressive’*, *‘business-like’*, ‘*formal’* and *‘chilly’* (Vogels, 2008).

As described above, atmospheres are extremely versatile, intangible, and greatly dependent on the perceiver itself. Therefore, the question arises; how a lighting designer or an architect should design after a desired atmosphere? Even taking the question further; is it possible to create or stage atmosphere?

As atmosphere in itself, is not something tangible, neither is it a “thing”, it cannot be directly created, however through confined setting of conditions, the desired atmosphere appears. These conditions that are influencing the atmospheric perception, are the atmospheric “*generators”* (Vogels, 2008).

To be able to stage atmosphere, both the atmospheric generators and human factors are to be introduced in a spatial conception. The important connection between the perceived environment and the perceiver to be once again highlighted. William Lam emphasizes the need to understand the effecting factors of our perception, as well as encourages us to rely on lighting, the powerful design element, that connects the individual to its environment.

“We do not need more technology, nor do we need more light. What we do need is an understanding of how to apply the technology already at our disposal, which can only come from an understanding of how we see, what we look at, what we perceive and why. “ (Lam, 1977, p. 12)

"Light has always been recognized as one of the most powerful formgivers available for the designer, and great architects have always understood its importance as the principal medium which puts man in touch with its environment." (Lam, 1977, p. 10)

Even though light itself is not an exclusive factor creating atmosphere, meaning that atmospheres are not exclusively shaped by light, as it is only one of the many ingredients, it is still an exceptionally powerful element, worth to be analysed. Light has the ability to transform a space, and can define what we are able to see, reveals visible colours and informs us of the shape of a space. All qualities that are greatly atmospheric and determined by the light falling upon the space and objects within it. The varying intensity of light levels, the changing patterns of dark and light, colours and levels of illumination are atmospheric generators that are contributing to the production of atmospheres (Edensor, 2015).

*"**Light** and **darkness** are particularly powerful constituents of atmospheres. […] As we move through spaces in which these levels of light shift, we continuously attune ourselves to the changing circumstances in which we are situated."* (Edensor, 2015, p. 334)

*"…the conditions in which the atmosphere appears', creating 'tuned' spaces with **tones**, **hues and shapes**, and the capacity of **illumination** and **darkness** to contribute to the ongoing production of particularly intense atmospheres…"* (Edensor, 2015, p. 335)

*"…atmospheres are most often created by specific **materiality**, **scale**, **rhythm**, **colour** or formal theme with variations. **Materials**, **colour**, **rhythm** and **illumination** are strongly atmospheric"* (Pallasmaa, 2014, p. 241)

Summarizing the above citations, materiality, rhythm, illumination, light, darkness, and colours, are found to be generators that are influencing perceived atmosphere.

In conclusion, we are armoured to grasp atmosphere effortlessly, however the creation of this phenomenon is much more difficult. It occurs only in the presence of a perceiver, a subject who experiences the space through a "*fully embodied sensation*" (Pallasmaa, 2014, p. 243).

As atmosphere is not an object in its being, the creation or making of it happens through atmospheric generators. Factors that are shaping the conditions for the atmospheric phenomenon to appear, in the presence of the observer.

The identified effecting factors or generators, that designer can manipulate in order to provoke atmosphere are, light, dark, rhythm, illumination, intensity, colour, temperature and spatial light distribution (Edensor, 2015) (Pallasmaa, 2014) (Vogels, 2008).

Elaboration of the atmospheric generators, through the design theory of Richard Kelly
Because of the intangible nature of atmosphere, and as it extremely hard to grasp and describe, the above definitions of the atmospheric generators are studied through an application plan. The aim is to show, how the generators can be applied in an everyday work situation.

Factors such as light, dark, rhythm, illumination, intensity, colour, temperature, and spatial light distribution are elements that are well considered in the lighting theory of Richard Kelly (1910 – 1977), a today world-famous lighting designer from the United States. Kelly has established a great tradition in for using light as an architectural element, and values qualitative lighting design.

Moreover, he stands for the holistic understanding of light used in architecture. His well-known illumination principles, “*focal glow”* (highlights), “*ambient luminescence”* (indirect light) and “*play of brilliance*” (sharp details) (Kelly, 1952),are based on a qualitative approach, focusing on human perception. An approach that is reaches beyond the pure functional and the decorative uses of light, mimicking the transdisciplinary design approach studied through this paper.

By taking a closer look on the three principles of Richard Kelly, the atmospheric generators can be easily associated with his lighting principles. The bellow walkthrough of Kelly’s lighting elements is illustrating, how these generators can be used in everyday design, by focusing on the lighting design principles, with the generators in mind, and by that enhancing the desired atmosphere of a space.

Ambient luminescence (indirect light) – light and dark + general illumination

Ambient luminescence provides balanced light levels, through a uniform light distribution. Under ambient luminescence, shadows are soft, and contrast levels are low. This illumination with its indistinct colours contributes to enough brightness for the visibility of the surroundings.

Giving this element a great influential effect on both light and darkness, thus the general illumination of the room. (Kelly, 1952) (lys, n.d.)

Focal glow (highlights) – focused intensity, spatial light distribution, rhythm

The element of focal glow, functions as highlights. This type of illumination fulfils the need of various functional and visual tasks. It is the second layer on top of ambient luminescence, and it is bright enough to create contrast with the background. Focal glow is expected to cast hard shadows, moreover its varied light distribution and focused intensity is creating a rhythmic pattern in space, contributing greatly to atmospheric perception. (Kelly, 1952) (lys, n.d.)

Play of brilliance (sharp details) – rhythm, colour

Play of brilliance is an evocative and playful element, the last layer of Kelly’s lighting design principles. As an example, it can be associated with an art piece or a special component, such as a crystal chandelier in a space, casting a mesmerizing light show over the entire room. Usually, it is bright, as it stands out from the rest of the elements. This discrimination from the other elements, can also be, due to an introduction of a new light colour to the element of play of brilliance. This element has indistinct shadows; however, its strong reflections can create possible glare. All in all, an element, that with its varying colours and light distribution, generates playfulness in the space. (Kelly, 1952) (lys, n.d.)

In conclusion, the correct application of Richard Kelly’s lighting design principles, with a focus on the revealed atmospheric generators, namely, light, dark, rhythm, illumination, intensity, colour, temperature and spatial light distribution, the atmosphere of a space can be staged and manipulated after the desire of the lighting designer. An application allowing the designer to create an atmosphere, matching the function and context of a space.

Social Science

The field of Social Science works with the understanding of social interactions and relationships, in relation to a given environment, and provides knowledge on social inequality (Lotte Rienecker, Peter Stray Jørgensen, Signe Skov, 2013).

In this chapter social practices in a social space are studied, with focus on the crucial role of lighting, in forming interactions. In a world the *"social aspects of light"* (Dr Elettra Bordonaro, Dr Joanne Entwistle, Dr Don Slater, 2019, p. 3) are investigated, through different social groups and social contexts.

Through the study of the two fields, Natural Science and Humanities and Arts, it become clear that a lighting designer can stage a certain scene, and ensure good quality lighting in a space, by fulfilling the listed lighting critical factors and criteria. Through those fields the designer can manipulate the perception of the space using lighting. However, the design only becomes complete, when the observer, the social group take it into use. For that reason, the study of the social circumstances is critical. Social Science makes it possible for the designer to personalizes the lighting design for its users, actives, and space.

Anthropological studies, when studying the use of a space, are often asking the questions, *"how many, who, where, what happens in it"* (Dr Elettra Bordonaro, Dr Joanne Entwistle, Dr Don Slater, 2019, p. 5). Therefore, lighting designers must ask similar question to succeed with a holistic lighting design solution. Issues that lighting designers must address, specific to a space can be categorized into four segments, according Bordonaro. These categories are *"diversity, practices, places and connections"* (Dr Elettra Bordonaro, Dr Joanne Entwistle, Dr Don Slater, 2019).

"Diversity" refers to the actors of the space. All the user that can interact within and with the environment. This segment is probably the most import to understand, together with *practices*. The mapping of the user needs is crucial for a successful lighting design. User needs and perception can vary according, age, gender, personality, memory, culture, social class, as well as general health conditions. Consequently, the wellbeing of the individuals in a group are critical for the success at a social level.

"Practices" are related to the actives within the space, focusing on the different functions lighting must help to facilitate. This segment ensures that the visual tasks within the space are understood, and the lighting is sufficient, as so the user can get all the visual information needed for carrying out the task effortlessly. As an example, the task of reading, requires different lighting conditions, than the task of relaxation.

"Places and connection" are connected to the identity of the space, and the context in within the space exists. Moreover, the individuals understanding of these circumstances.

Numerous studies through the years have been investigated the social effects of lighting, and how it influences behaviours, experiences and even emotions. Nonetheless, what kind of lighting settings are preferred for different activities. As an example;

- Higher lighting levels are preferred for demanding visual task and lower lighting levels for non-visual activities (Casciani, 2016)
- Lower lighting levels and warm white light induce calmer and more relaxed feelings (Casciani, 2016)

- The feeling of publicness and formal environment are often the result of higher lighting levels (Casciani, 2016)
- Impression of relaxation and intimacy are connected to warm and non-uniform lighting distribution with lower levels (Casciani, 2016)
- People prefer the combinations of warm-dim and cool-bright light (Robert A. Baron, Mark S. Rea, Susan G. Daniels, 1992)
- Blue-enriched light is found to increased improvement in self-reported alertness and ability to concentrate (Antoine U Viola, Lynette M James, Luc Schlangen, Derk-Jan Dijk, 2008)
- The willingness to volunteer increased under warm-white light compared to cool white (Robert A. Baron, Mark S. Rea, Susan G. Daniels, 1992)

It is inevitable, that Social Science cannot be excluded, when a holistic lighting design solution is the aim. The user preferences, the space, and corresponding activities, are all circumstances that are influencing the lighting concept, and therefore to be taken into consideration through the entire design process. Understanding the users of the space, their needs, activities and environment are crucial.

The knowledge gained through Social Science is leading how the lighting design concept evolves through a design project. Both the staged atmosphere and the desired lighting quality is greatly dependent of the findings of Social Science. As the different users, actives and spaces are requiring unique solutions, the one-size fit all concepts, way too often applied in construction projects, when it comes to lighting, must be stopped. The criteria set through Natural Science and Humanities and Arts must rely on the findings of Social Science, and ensure a lighting design that fits both the user needs and the unique environment it is placed in.

Identified design factors of the three scientific disciplines

As the literature study of the three scientific disciplines been performed, their main topic of interest has revealed themselves. Table 4 describes the lighting critical factors, or in other words, lighting tools, available at a specific scientific field, as well as the aim the different segments are to achieve.

Research based method	**Humanities and Arts**	**Natural Science**	**Social Science**
Lighting critical design factors/tools	• Illumination • Intensity • Rythm • Etc. → application: Richard Kelly`s lighting theory	• Glare • Flicker • CCt • Etc. → application: Lighting standard	• Diversity = users • Practicies = activities and functions • Places and connections = identity and context → application: manipulating lighting settings after needs
Aim of segment	Staging atmosphere for added value	Ensuring good quality lighting practicies	Pleasing observer experience and perception of lighting that matches, tasks, context, and activities

Factors → Circumstance

Table 4, Lighting critical factors within the three scientific fields (Ellen Kathrine Hansen, Mette Hvass, 2019)

Humanities and Arts are greatly concerned with the atmospheric perception of the space, through the observer's experience. In the world of architecture, this discipline ensures that there is an added value to the architecture, that the building and the urban surroundings are perceived sensual and memorable. Humanities and Arts are filling the space with identity and are often unconsciously suggesting a mood, as well as influencing different behavioural patterns. From a lighting point of view, atmosphere can be staged through atmospheric "*generators"* (Vogels, 2008), such as, light, darkness, rhythm, intensity, distribution, and illumination. In a real-life application, easiest to realize, when the "*generators"* (Vogels, 2008) are combined with the three-layered lighting design theory (Kelly, 1952) of Richard Kelly.

The main function of Natural Science in a design project is to provide with verifiable quantitative data. In a lighting design project, Natural Science must ensure good quality lighting practices, by assessing the parameters of the space, its users' needs and the visual tasks of the environment. This assessment, as an example considers, whether the visual task is demanding, and therefore requires higher illuminance levels, or an elderly user is more prone to experience glare, and therefore the glare rating to be adjusted accordingly. In practice, the DS / EN 124641-1 Light and lighting - Lighting at workplaces standard (Standard, 2015) defines the acceptable minimum and maximum lighting parameters for various applications, and through lighting calculations these parameters are justified in a design process.

Even though, in the lighting design experiment model (Ellen Kathrine Hansen, Mette Hvass, 2019) the three scientific disciplines are illustrated as three columns, side by side, the findings of this paper suggest, that these fields are having a more complicated interaction. Humanities and Arts and Natural Science can be categorized as factors, which through the lighting design can be manipulated after a preference. However, Social Science is rather a circumstance the designer must assess, and design after. Through Social Science the users of the space, their activities and expected functions of the space are studied, as well as the context in within the space is placed.

From a practical point of view, Social Science must be understood thoroughly at the first place (Ellen Kathrine Hansen, Michael Mullins, 2014), then through the introduced lighting critical factors of the other two disciplines, namely Humanities and Arts and Natural Science, must be designed after. Figure 3 illustrates, how these scientific fields are interconnected, and how these disciplines together are forming a holistic lighting criteria and strategy for the design intention. The vision of each project defines, what to achieve, while Social Science reveals the circumstances the design must fit to. Humanities and Arts and Natural Science are the tools the designer have available to accomplish the vision within the framework provided by Social Science.

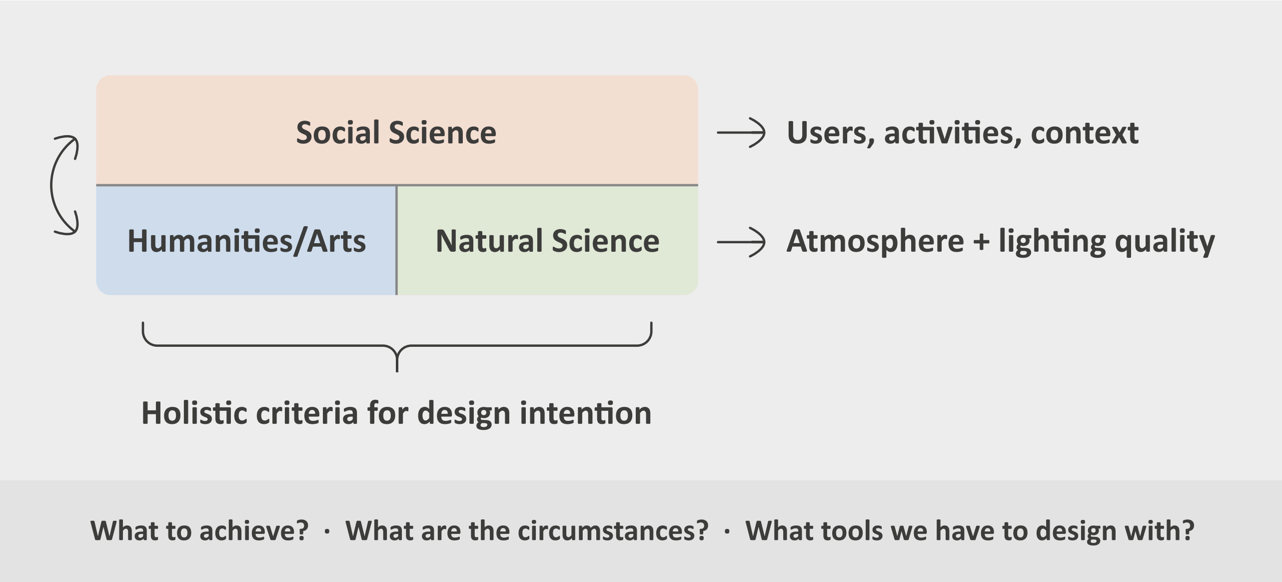


Figure 3, Interconnectivity of the three scientific fields, forming the base for a holistic design criteria

The recognition of the interconnectivity of these three scientific fields are thoroughly essential, to work transdisciplinary and integrate the holistic understanding of lighting into the workflow of architecture. With the help of the design factors of Natural Science and Humanities and Arts, the unique challenge of the social circumstances of a given space can be solved. By conducting the Social Science study prior to the other two fields, the vison and the success criteria are customized to the specific project. This results in, that all the investigations of Natural Science and Humanities and Arts are focusing on filling the success criteria of the specific and unique architectural project. As all the three disciplines are an active part of the design process, both the transdisciplinary and holistic nature of the project is secured. In other words, lighting is investigated from all angles, where all the known lighting pillars of the lighting design profession are taken into consideration through the entire length of the construction project.

Figure 4 is an extended version of Figure 3, additionally including the identified lighting design factors of the various disciplines.

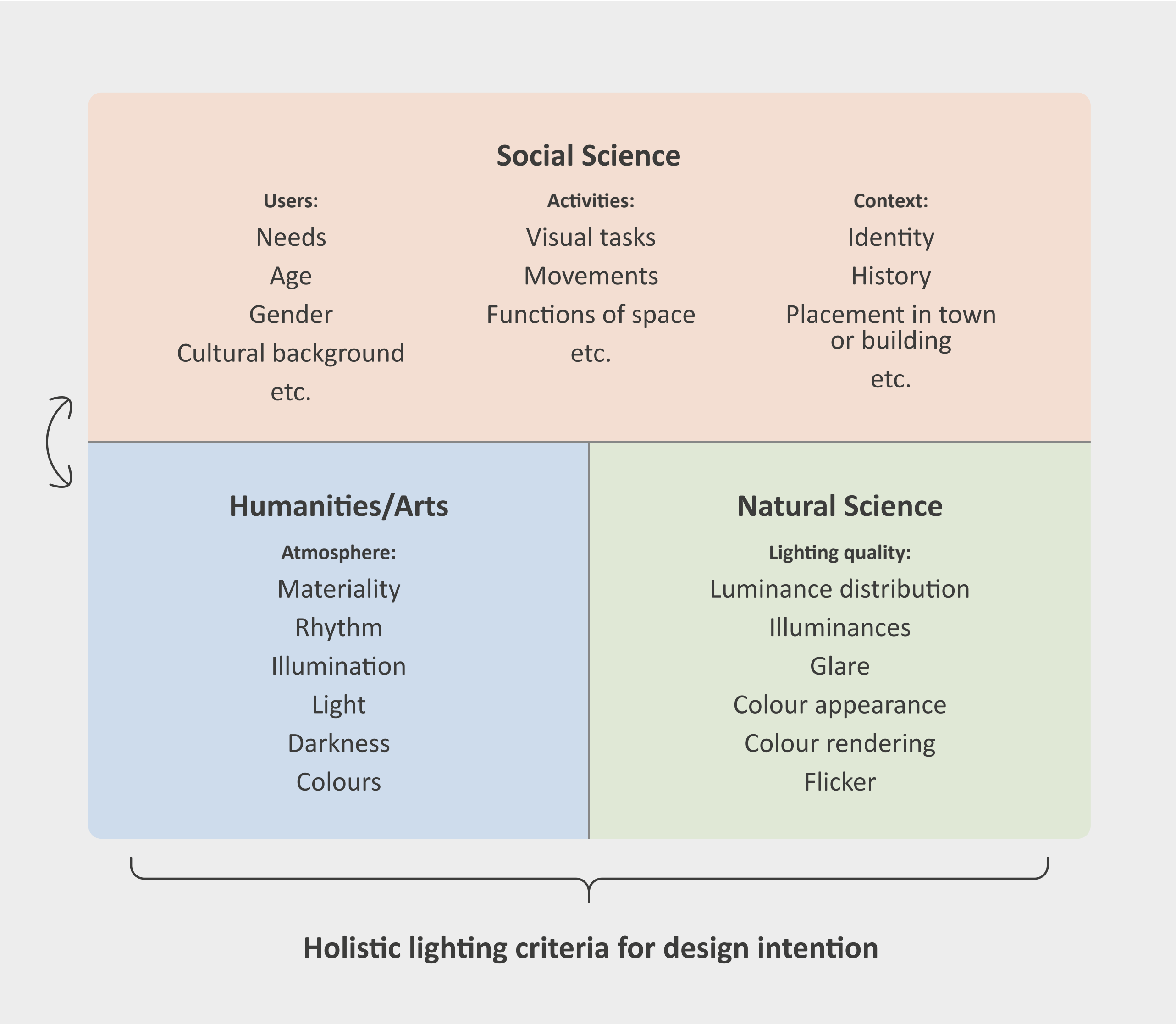


Figure 4, The interconnectivity between the three scientific fields, including the lighting critical factors of each discipline

Study of the architectural workflow

The Description of services for Building and landscape (The Danish Association of Consulting Engineers (FRI), 2018), in Danish often referred to as, YBL18; Ydelsesbeskrivelse for byggeri og landskab 2018, is the baseline for the architectural workflow explored in this report. The content of the entire document was studied thoroughly; although, the presented construction phases are not exhaustive of the Description of services for Building and landscape. The selected descriptions bellow are limited to the construction phases relevant to lighting. Table 5 is describing these phases.

Construction phase		Overview of construction phase
Initial consultancy		• Client`s requirements summarized in a report • Registration of ´existing conditions´ • User involvement and ´analysis of needs and functions´ • Expectations towards sustainability and energy requirements • List of ´necessary conditions for the further development of the project´ • Specifications of health and safety during operation and construction • Special requirements ´contained in the Danish Building Regul*ations and other legislation*´, such as optical indoor climate **SUMMARY:** Analysis of existing conditions, specific to building site, user needs and required functions. Understanding of the client`s requirements, and how to align that with the developing project.
Proposals	Outline proposal	• ´P*roposal*, including its architectural concept, functions, proposals for the general choice of materials, design and installation principles´ • Basis design specification regarding architecture, function and construction method • Preliminary studies and analysis • Well-crafted sketch proposal **SUMMARY:** Initial concepts with visuals
	Project proposal	• ´T*he basis upon which the client makes its decisions on th*e aesthetic, functional, technical and financial solution of the project´ • All registrations are completed and a thorough analysis is carried out of the needs and functions • Detailed concept proposal that relies on the approved outline proposal and analysis • *´Description of the overall architectural approach´,* materials and structures • *´Description of main design principles´* • Basis calculations, principal plans and construction drawings **SUMMARY:** A well-described concept proposal that focuses on the general design idea. Little technical details are included; however, the overall design idea and principles of the concept are clear. Function as the base for the tender design.

Main project	Tender design	• Precise description of the project, supported with detailed technical drawings, digital building models and quality control plans from consultant experts and contractors • Consultants provide information on ´energy requirements, indoor climate, statics, fire safety, etc.´ • ´Proposal for a *construction contract and building project specification´* **SUMMARY:** Basis for construction project, with detailed technical descriptions from contractors.
	Construction project	• Based on accepted tenders and obtained offers from contractors, that will form the final project • Basis for contractor purchases and execution of the construction • Finalized and reviewed project documentation, including technical drawings, design guidelines, building model simulations and calculations **SUMMARY:** Final clarification of the project, with detailed and coordinated project documents, construction plans and building schedules of contractors.
Construction phase		• The actual construction of the project, based on the final project specifications of the construction project • Site supervision, project follow up and inspection • Solving of problems encountered during the construction • ´Monthly budget for the financial framework´ • ´Quantitat*ive and qualitative control in the form of random supervision´* **SUMMARY:** Trouble-shooting, quality control, site supervision and the actual execution of the construction
Delivery		• Delivery of the project • Site-supervision and follow up in connection with delivery • Collection of defects list • Evaluation of the success-rate of the project **SUMMARY:** Evaluation and delivery of the final project

Table 5, Description of the construction phases in an architectural workflow. Descriptions adapted from the Description of services for building and landscape 2018 (The Danish Association of Consulting Engineers (FRI), 2018)

From a lighting design point of view, the limitation of the Description of services for Building and landscape is, that lighting is mentioned spares. It is either mentioned under, optical indoor climate, or as a part of electrical instillations, taken care of an electrical engineer. The challenge of integrated lighting design therefore arises, as the description, that forms the baseline for the everyday architectural workflow, is leaving little space for the actual practice and development of a lighting design concept.

In the first relevant construction phase, namely Initial Consultancy, lighting appears indirectly under optical indoor climate, however, only if the client demands it, and it is described as a specific requirement.

In the project proposal phase, lighting is mentioned as the responsibility of the electrical engineer, as the description of the lighting systems is required in this phase (The Danish Association of Consulting Engineers (FRI), 2018).

Under tender design, lighting once again falls under the description of indoor climate. In this phase the only demand is, that the responsible consultant provides information on the area (The Danish Association of Consulting Engineers (FRI), 2018). Nevertheless, the depth of this information is undescribed.

According to the Description of services for Building and landscape, at the construction project phase, the electrical engineer has the responsibility of creating drawings, with 2D symbols, representing the location and type of electrical components, here including luminaires as well (The Danish Association of Consulting Engineers (FRI), 2018).

Practices for site supervision and quality control in connection to quality lighting are not established in the Description of services for Building and landscape, therefore the evaluation of the final lighting design is often missing. Which might be one of the leading causes of the frequently experienced poor lighting quality in buildings.

Even though the fact, that lighting is mentioned spares, under the different construction phases, and therefore a holistic lighting design solution remains premature in a construction project, the Description of services for Building and landscape is providing an opportunity for the client to choose it as an additional service. Under the chapter, other services, lighting indirectly appears in five categories, namely under chapter "*9.9 Special visualisation",* chapter *"9.30 Optical indoor climate",* chapter *"9.39 Standard fittings, fixtures and equipment",* chapter *"9.40 Special fittings, fixtures and equipment",* and chapter *"9.42 Artistic decoration"* (The Danish Association of Consulting Engineers (FRI), 2018).

9.9 Special visualisation

"This service may comprise photorealistic visualisation, 3D visualisation, architectural photos, animations, video and interactive presentations. This service may also comprise the preparation of physical models on the basis of the above (The Danish Association of Consulting Engineers (FRI), 2018)".

NOTE: Allows for lighting simulations, calculations, and mock-ups.

9.30 Optical indoor climate

"Calculations or simulations or measurements of optical indoor climate in addition to the provisions of the Danish Building Regulations, including:

- *Calcu*lations of incoming sunlight and sunlight protection
- Calculations in terms of lighting technology (The Danish Association of Consulting Engineers (FRI), 2018)*".*

NOTE: Allows for daylight and electrical lighting simulations and calculations.

9.39 Standard fittings, fixtures and equipment

- *"The* consultant may assist in specifying fixed/non-fixed standard fittings, fixtures and equipment.
- The consultant may prepare furnishing plans.
- The consultant may prepare a time schedule for purchasing, delivery and installation and coordinate such activities against the main time schedule.
- The consultant may prepare a budget for purchasing, installation, etc (The Danish Association of Consulting Engineers (FRI), 2018)*".*

NOTE: Allows for the purchase of special luminaires, and luminaire plans

9.40 Special fittings, fixtures and equipment

- *"The c*onsultant may assist in the design of special fittings, fixtures and equipment.
- The consultant may prepare layout plans etc.
- The consultant may prepare a time schedule for purchasing, delivery and installation and coordinate such activities against the main time schedule.
- The consultant may prepare a budget for purchasing, installation, etc" (The Danish Association of Consulting Engineers (FRI), 2018)*.*

NOTE: Allows for custom-made, and special designed luminaires, and luminaire plans

9.42 Artistic decoration

"The consultant may assist in connection with the organisation and negotiation related to artistic decoration (The Danish Association of Consulting Engineers (FRI), 2018)*".*

NOTE: Opportunity for lighting installations

The final Research Question

The aim of the above analysis of the transdisciplinary lighting design process (Ellen Kathrine Hansen, Mette Hvass, 2019) and the architectural practice (The Danish Association of Consulting Engineers (FRI), 2018) is to understand the barriers and similarities of the two workflows. The overall goal of this investigation is, to integrate the today disconnected daily architectural workflow and lighting process.

The holistic and transdisciplinary working tradition from the world of lighting design must find a place in the everyday workflow of architecture. As earlier described, the challenge of the architectural process is, that it considers lighting as an “add-on” element, rather than a multidimensional tool, the designer must include through the entire length of the construction project. The limitation of the lighting design model is, that it however does not include the construction phase of a design project, which is a major phase of the architectural process, together with delivery. Therefore, to secure that the real-life construction project is traceable and can be evaluated, the stages of the two process models are be assimilated the best possible way.

Therefore, the goal of the upcoming chapter must be to create an architectural-lighting design model, that integrates lighting design practices, into the daily practices of the architectural workflow, defined by the Description of services for Building and landscape (The Danish Association of Consulting Engineers (FRI), 2018). The model must aim to describe a design process, that secures good quality lighting practice, through the entire length of the construction project. Moreover, it must ensure, that the lighting design solution is research-based, and the choices made through the design process are traceable and a result of academic validation and testing.

The final research question:

How to create a process model that integrates the transdisciplinary lighting design practice, into the daily workflow of architecture, defined by the Description of services for Building and landscape?

Success criteria of the model:

The lighting design solution developed through the architectural-lighting model must be both holistic and integrated. Nonetheless, research-based, thus traceable, and should be a result of academic validation and testing.

PART 2
DESIGN OF AN INTEGRATED ARCHITECTURAL-LIGHTING MODEL

The architectural-lighting model chapter investigates, how the desired integrated model can be developed. The developed designed model must function as a quality working-checklist for the lighting designer, meanwhile it should provide an overview for the architect, on the services to be expected at each phase of the construction project. The architectural-lighting model must also accomplish the success criteria stated for the model and fulfil the requirement of the research question of Part 1.

The first layer of the model matches the various phases of the lighting design and the architectural workflow. Here, parallelises are drawn between the working practices, exploring the similarities of the two design processes. The core of the architectural-lighting model are the five established design phases, that are reflecting on the phases found at the architectural approach. The function of initial consultancy assimilates with the design vision of the lighting design approach. Proposals can be matched with design intention. Main project represents the core design, which corresponds with the design proposal at lighting design practices. The construction phase known from architecture, can cover the evaluation phase known from lighting design. Lastly delivery matches well with design solution.

Table 6 visualises, how the phases known from architecture and lighting design can stand side-by-side, at the same time, on the right-hand side, introducing an initial process model that focuses on merging the research-based design techniques, known from the lighting design method, into the model. The initial model aims to integrate an academic design approach, where all three scientific fields, namely Social Science (SS), Humanities and Arts (H/A) and Natural Science are represented at each phase of the design process.

<table>
<tr><th>Lighting design model</th><th colspan="2">Architectural workflow</th><th colspan="3">Process model</th></tr>
<tr><td>Design vision</td><td colspan="2">Initial consultancy</td><td colspan="3">General vision and registration of circumstances – Social Science</td></tr>
<tr><td rowspan="6">Design intention</td><td rowspan="6">Proposals</td><td rowspan="3">Outline proposal</td><td colspan="3">SS</td></tr>
<tr><td colspan="2">H/A</td><td>NS</td></tr>
<tr><td colspan="3">Many ideas that do fit the vision. The concepts are derived from the analysis of SS, while the lighting critical factors of H/A and NS are taken into account. User involvement is key at this phase. Brainstorm and bold ideas.</td></tr>
<tr><td rowspan="3">Project proposal</td><td>SS</td><td>H/A</td><td>NS</td></tr>
<tr><td>?</td><td>?</td><td>?</td></tr>
<tr><td colspan="3">Few selected ideas that do match the 3 x hypotheses created in project proposal. Still not in detail, but well-crafted sketches and descriptions. Targeted concepts.</td></tr>
<tr><td rowspan="4">Design proposal</td><td rowspan="4">Main project</td><td rowspan="3">Tender project</td><td>SS</td><td>H/A</td><td>NS</td></tr>
<tr><td>test</td><td>test</td><td>test</td></tr>
<tr><td colspan="3">More detailed drawings and ideas, in a depth, that can be tested through a mock-up session or simulation. Lines up to the selection of the final solution. All 3 x hypotheses to be proved in order to move forward. Own quality control of the lighting designer.</td></tr>
<tr><td>Construction project</td><td colspan="3">Main/final project
Detailed description of the selected project solution. Lines up to construction. Interdisciplinary control of the solution, in cooperation with architect, electrical engineer and lighting designer.</td></tr>
<tr><td rowspan="2">Design evaluation</td><td colspan="2" rowspan="2">Construction phase</td><td>SS</td><td>H/A</td><td>NS</td></tr>
<tr><td colspan="3">Evaluation of the whole, through the three scientific fields. User evaluation.</td></tr>
<tr><td>Design solution</td><td colspan="2">Delivery</td><td colspan="3">New knowledge, that to be catalogued.</td></tr>
</table>

Table 6, An initial process model that parallelises the various design phases of the architectural and the lighting design model

Initial consultancy

The initial consultancy phase allocates time for the architect and the lighting designer to understand the circumstances of the design to be developed. Here the requirements from the contractor, the registration of the environment and the mapping of the user groups and needs are weighted and are forming the base of the initial concept proposals.

This phase questions the overall goal and the vision of the project and sets the line for what to achieve with the lighting design. The vision created at this phase of the design project, is highly dependent of the findings of the Social Science studies, including the analysis of the surroundings, context, users to design for, actives, visual tasks, and functions.

Proposals

Outline proposal
During the phase of the outline proposal numerous concepts are developed, that are focusing on the vision of the project, while keeping the findings from the initial registration and analysis in mind. At this stage the concepts are at a draft stage and are including little of detail. The circumstances studied through various methods of Social Science, as an example, observation, are greatly influencing the outcome of the final design solution, and therefore, the initial concepts are already highly dependent on the constraints derived from the users, activities and the context of the space. The two other scientific fields, Humanities and Arts and Natural Science are factors that are helping to achieve and fit the lighting design with the overall vision. These two fields are allowing the lighting designer, to through the lighting critical factors, explored in the previous chapters, form their design after the needs established through the field of Social Science. Both the atmosphere of the space, and the lighting quality is fitted after the needs of the users, the expected visual tasks, and the context of the space.

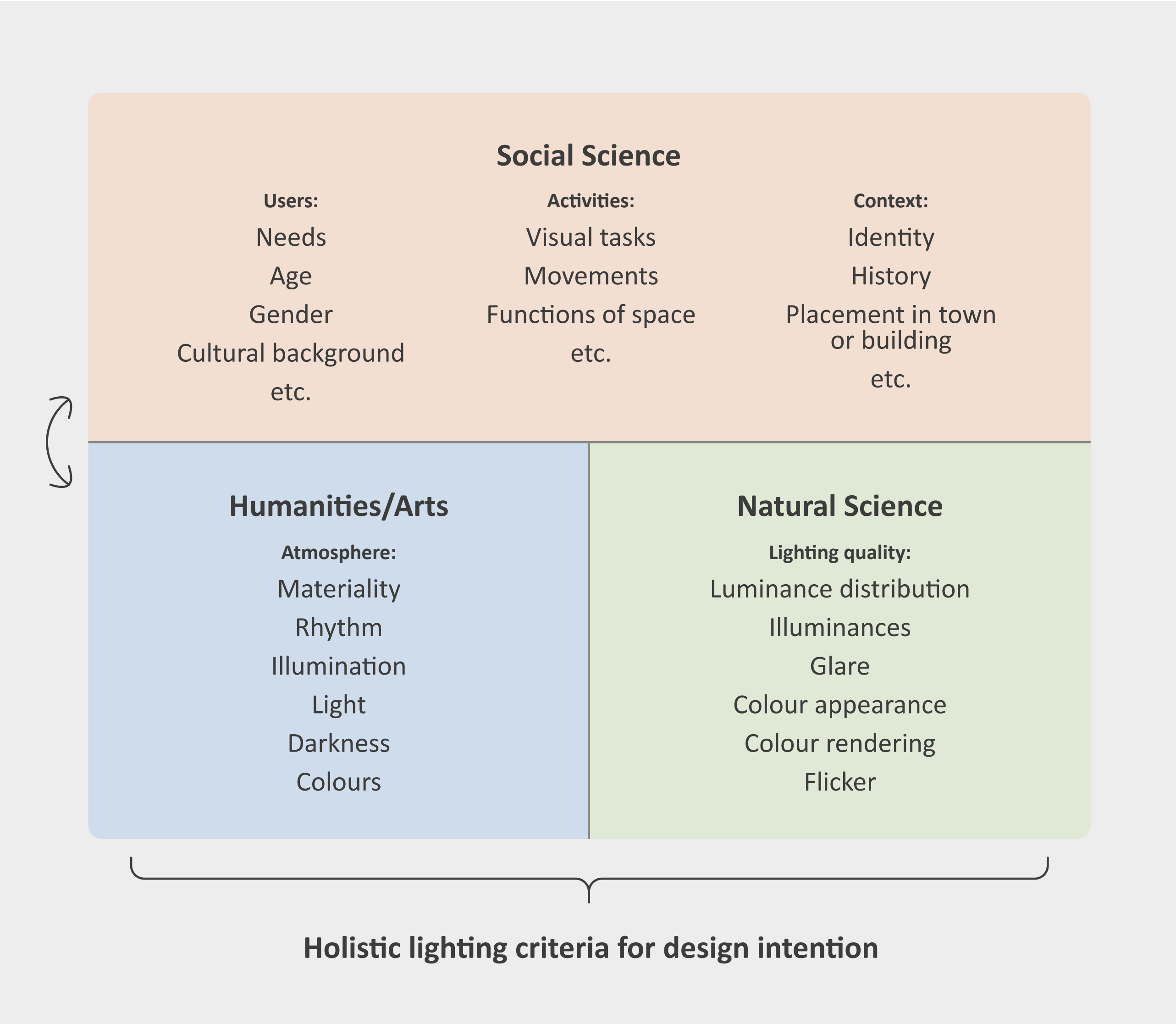


Figure 5, Caption of the architectural-lighting model, illustrating the outline proposal phase

Project proposal
The project proposal phase already works with more mature concepts, that has the potential to fulfil the criteria of all three scientific fields. To be able to validate, whether the design idea matches the criterium of a specific field, hypotheses are developed within each discipline.

Natural Science focuses greatly on the lighting quality, in relation to visual comfort and the visual tasks in the space. Nonetheless, the needs of the different user groups are taken into account. As an example, an elderly user group at a nursery home often requires uniform lighting distribution, with higher illumination levels, due to the degradation of the eye and its decreased ability to accommodate (S M Salvi, S Akhtar, Z Currie, 2006). While office workers often require focused task lights for demanding visual tasks, such as reading and writing. Therefore, the designed lighting must adapt to the needs and tasks of the space. Within the field of Natural Science, the lighting designer can work with parameters, such as, illumination, intensity, glare, colour temperature, colour rendering index and flicker. And by the manipulation of these lighting parameters adjust the lighting design to fulfil the hypothesis of the field, and the requirements of the lighting standards.

Humanities and Arts aims to stage a certain atmosphere within the space. The goal is not only to support a specific task, but to also strengthen the perception of the space, through the eyes of the user, enhance the context, and emphasize the architectural details through added value, created by lighting. This value creation can happen through the careful use of the identified atmospheric generators, merged within the lighting design theory of Richard Kelly (Kelly, 1952). Within this discipline, the perception of the space is manipulated through lighting critical factors, such as, distribution, rhythm, colour, intensity, and illumination, adjusted to the different layers of light, ambient luminescence, focal glow and play of brilliance (Kelly, 1952). This staged atmospheric perception contributes to nudging, by emphasizing the characteristic feel of an activity, unconsciously helping the user to grasp the function and the mood of the space.

Social Science within the design proposal phase ensures that the various activities, visual tasks, user groups and their needs are accounted during the design process. The knowledge gained from the Social Science study is making sure of that each concept developed is suited into the contextual framework of the space and fits the identified and required functions. Thus, this field guarantees, that each lighting design concept is unique and developed after the exact circumstances of a given space.

The project proposal phase narrows down the many ideas and concepts developed during the outline proposal, through three hypotheses created, each corresponding to a specific scientific field. The aim of the screening is to alone allow holistic concepts to pass, in other words, lighting ideas that are having the potential to fulfil all the three criteria created.

The criteria, or hypothesis of each discipline must be therefore interrelated and add up to a holistic lighting design concept. Examples for the three hypotheses can be seen in Figure 6.

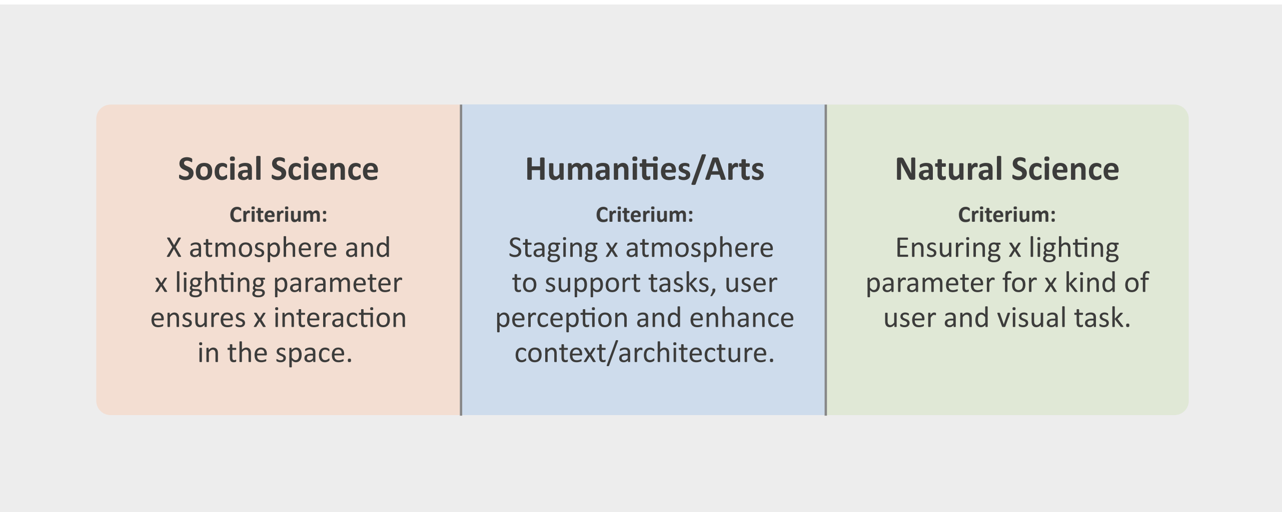


Figure 6, Caption of the architectural-lighting model, illustrating the three hypotheses created at the project proposal phase

Main project

Tender project
While during the project proposal phase, target concepts has been selected, with the potential to fulfil all three criteria of the scientific fields, the tender project phase tests, whether the selected concepts can actually meet the set criteria. Until the proposal phase, the concepts are working with little of details, often based upon an overall idea, and sketches; however, during the main project, these ideas are taking form, and detailed, testable drawings, and simulations are constructed.

The tender project phase functions as the intern quality control of the lighting designer. Each concept, selected during the project proposal, is tested within the three scientific fields, leaving the best fitted concept to become the final lighting design solution. The tests within the three fields are carried out through live-mock-up sessions, computer simulations and lighting calculations, studying the real-life application of the idea. In order for a concept to become the final lighting design, it must fulfil each of the three criteria, moreover, has the potential to work as a holistic lighting design solution.

As mentioned earlier, the tender project phase is the first phase, where evaluation and quality control come into play. At this phase of the architectural lighting design model, the lighting designer has the opportunity to review his or her own decisions and check up on all the details of the concepts. Nonetheless, this phase is the first phase for new knowledge creation as well, where the until now, research-based design, becomes design-based research, through the academic testing of the individual hypothesis. New explicit knowledge is created within each scientific field, knowledge that is traceable, tested and evidence-based, as it builds up on already established academic knowledge. The knowledge gained from the testing can be catalogued and used as a reference for further projects.

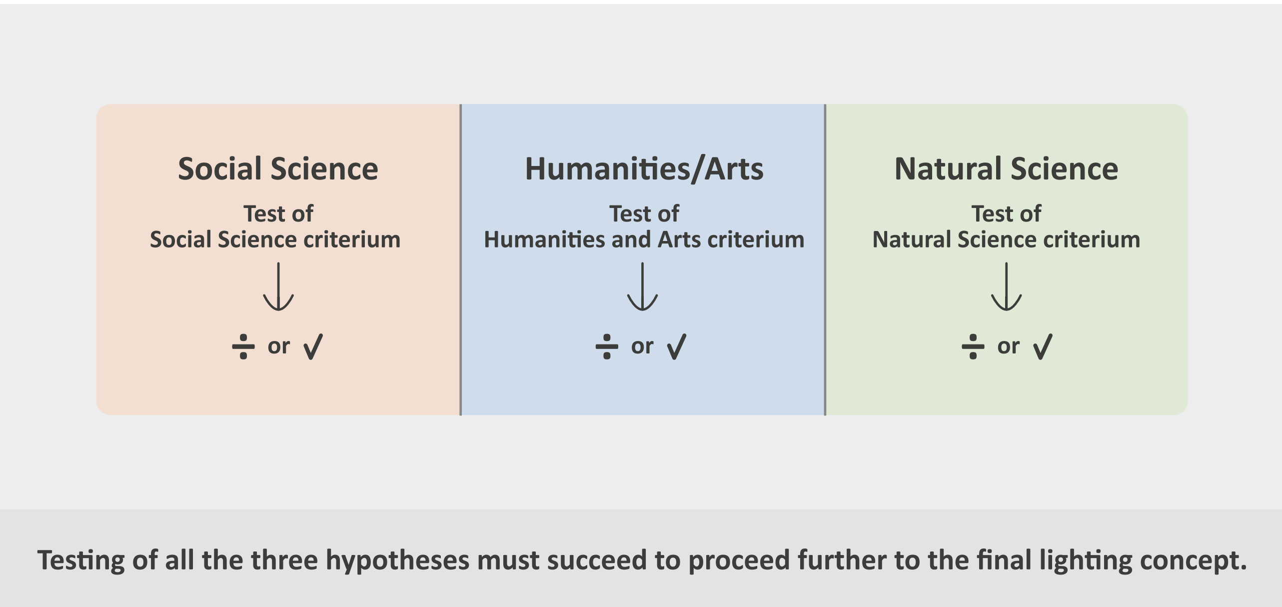


Figure 7, Caption of the architectural-lighting model, illustrating the tender project phase

Construction project
The construction project describes the final lighting design solution. Detailed descriptions of the lighting design, supported with drawings and calculations are prepared. Ceiling plan, luminaire list, mounting instruction, calculations that are fulfilling the requirements of the standards, and a description of the control system are attached documents that can be expected from the lighting designer.

At this phase, an interdisciplinary review of the lighting design is carried out. In cooperation, the lighting designer, the architect, and the electrical engineer are revising the solution, moreover the border areas within the tasks are set. The interests of each participants are aligned, and a common understanding between the partners are set. Lighting details are concluding both aesthetic, functional, and technical parameters.

Construction phase

Under the construction phase the luminaires are mounted after the approved ceiling plan, and the lighting system is fine-tuned to be ready for use. The angles of the different luminaires are adjusted, and possible disturbance from glare is minimized. The control system is tested, and the overall lighting design is evaluated.

As the final design has already been evaluated through the individual scientific segments, during the tender project phase, the focus is on the evaluation of the whole, during the construction phase. The holistic design is judged by the overall function, visual perception, visual comfort and user satisfaction. Even though the fact, the design is evaluated as a whole, the different scientific fields are taking a considerable part in the process. Visual perception is analysed through methods related to Humanities and Arts. Here evaluation tools are used, such as word cards, based on the atmospheric terms developed by Ingrid Vogels (Vogels, 2008), or the visual-physical lighting theory developed by Anders Lijefors and Jan Ejhed (Liljefors, 1999) (Ute C. Besenecker, Foteini Kyriakidou, 2020). When visual comfort is judged, practices known from Natural Science are applied. As an example, glare, contrast ratios and illumination levels are measured and evaluated against the recommendations of the lighting standards. Lastly, the segment of Social Science can help to assess the overall user satisfaction and the added value created by the lighting design. This can be achieved by a user survey or a semi-structured interview, based on the topic; success rate of the final lighting design.

At the end of this phase minor details based on the results of the evaluation can be adjusted, such as intensity, or the sensitivity of the control system.

Figure 8, Caption of the architectural-lighting model, illustrating the evaluation process of the construction phase

Delivery

Delivery is the phase, where the learnings from the evaluation of the construction phase is catalogued. The delivery phase is the second phase at the architectural-lighting model, where new knowledge is born. As the final lighting is assessed the research-based design, is one more time transformed to be design-based research and provide with new explicit knowledge. This time with new knowledge on a transdisciplinary and holistic lighting design solution. Because of the academic set-up of the testing and evaluation process, meaning that the methods used for the evaluation are based on scientific reports, approved by the lighting design community, the knowledge gained through the process model is traceable, and can be used as a reference for further projects.

The architectural-lighting model

The final product, called the architectural-lighting model is a process model, assisted with an expected services table. In the process model the research-based, transdisciplinary lighting design practices are merged into the architectural workflow, in a way that lighting can be effortlessly integrated into the everyday working practices of an architectural company. Moreover, the model ensures research-based value creation, thus that the lighting design solution to be implemented for a construction project, is uniquely designed, and fits the criteria of the building and its users. In other words, holistic lighting solutions are developed through the transdisciplinary design process, where each three pillars of a lighting design are considered, by the three scientific fields implemented into the model.

The expected services table functions as a "hands-on menu", for the cooperation between architects, engineers, and lighting designers. The table describes which services to be expected from the lighting designer, and in which phase of the construction project. As an example, suggestions are included in what depth a concept is described, and if hand-sketches or detailed simulations to be expected at a certain phase of the project.

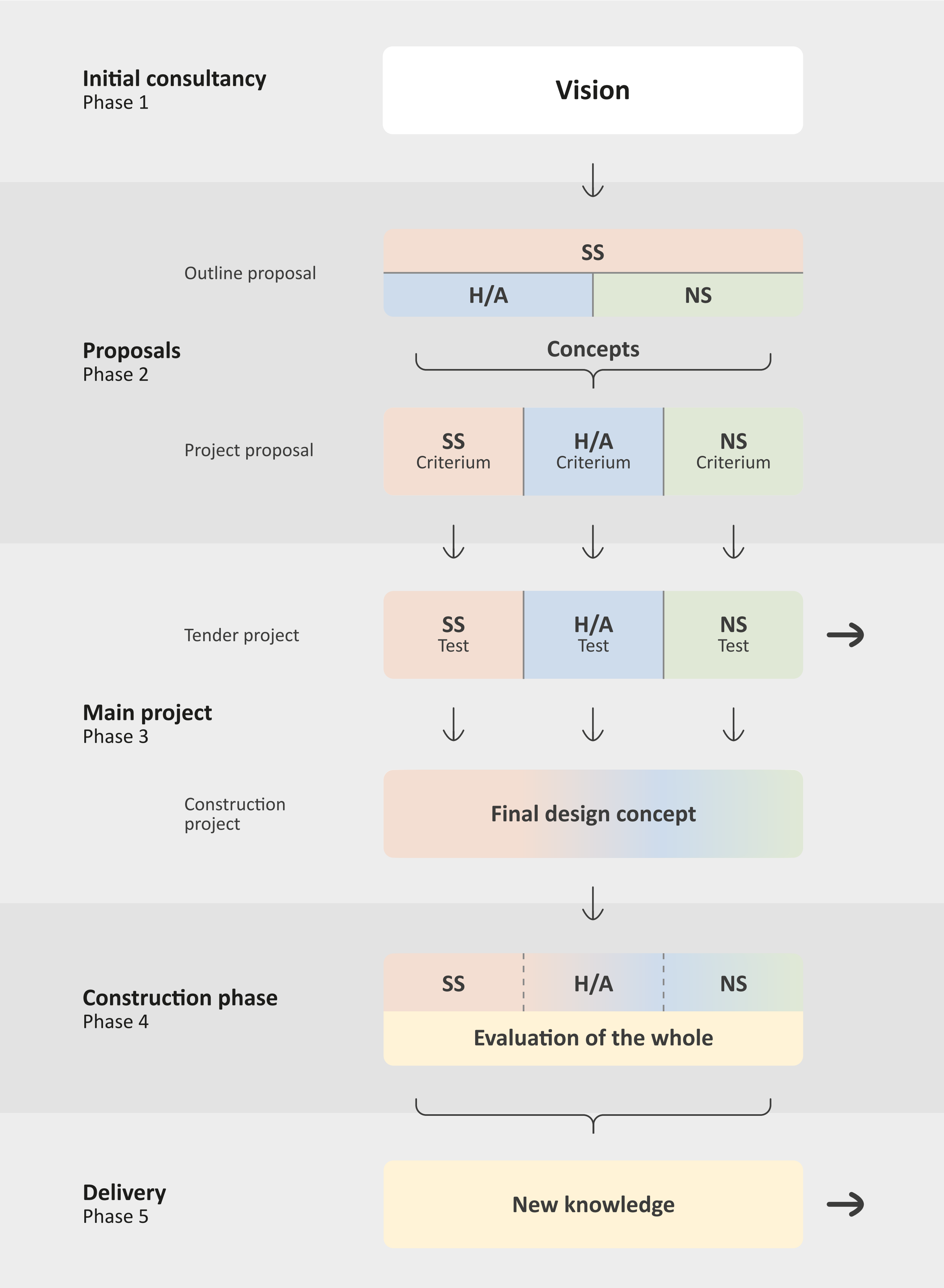


Figure 9, The final architectural-lighting model

Initial consultancy Phase 1	• Reading the design specifications of the contractor • Study of the initial registrations of architects • Social Science studies concerning context, users and activities • Participation in design meetings • Creation of an overall lighting vision for the projects
Proposals Phase 2	• Well-crafted sketch proposals • Participation in user involvement meetings • Simple daylight studies (Velux daylight visualiser) • Basic light simulations and renderings on a conceptual level (Dialux)
Main project Phase 3	• Detailed ceiling plan • Luminaire list • Mounting description • Lighting calculation • Plan for lighting control • Detailed renderings of the lighting proposal • Testing through live-mock up sessions
Construction phase Phase 4	• Overviewing the mounting of luminaires • On-site adjustments for minimizing glare • Visual perception and user satisfaction evaluation
Delivery Phase 5	• Sharing learnings and cataloguing knowledge for the benefit of further projects

Figure 10, Description table of the expected services at each phase of the architectural-lighting model

PART 3
TEST OF THE MODEL THROUGH A CASE STUDY

The upcoming chapter facilitates the discussion of the integrated architectural lighting design model through a case study. The selected case for this purpose is the transformation project of the Northern Copenhagen University-library reading hall, in danish called as, Københavns Universitetsbibliotek Nord, therefore often referred to as KUB Nord. The transformation project been carried out by the architectural firm, Arkitema, where the firm`s role can be described, as a full-service consultant, totalrådgiver in Danish. The case has been previously introduced by the author, in the report, Lighting as an integrated part of architecture (Thorup, 2020), however the current use of the case is specialized to illustrate, how the architectural-lighting model can be used on a real-life project.

From a lighting design point of view, this form of consultancy is highly beneficial, as it provides the deepest insight into the project and the greatest opportunity for the integration of lighting design. Opposing to a total-enterprise, full-service consultancy means, that the architectural company has a direct contract with the contractor (bygherre) itself, and therefore has substantial influence on the outcome of the project. Nonetheless, the architectural firm can emphasize the importance of architectural details and express it with the help of quality lighting.

Initial consultancy

Prior to the first lighting concepts, the initial consultancy phase ensures that the requirements of the contractor are well understood, and the registration of the space is carried out. At KUB Nord, especially the cultural and historical values are examined, as the contractor wishes to re-establish the core values of this heritage.

Based on the earlier described three points of a Social Science study, the analysis and registration of the space is divided into three sub-parts.

Context
The reading hall is allocated in the west-wing of the Northern Copenhagen University, a precious construction with a memorable history, dating back to 1938, when the building been brought to use for the public. At that time the building was referred to as a book palace, benefitting the scientific community. Back in the days, the double height reading hall was associated with knowledge and built with high quality materials.

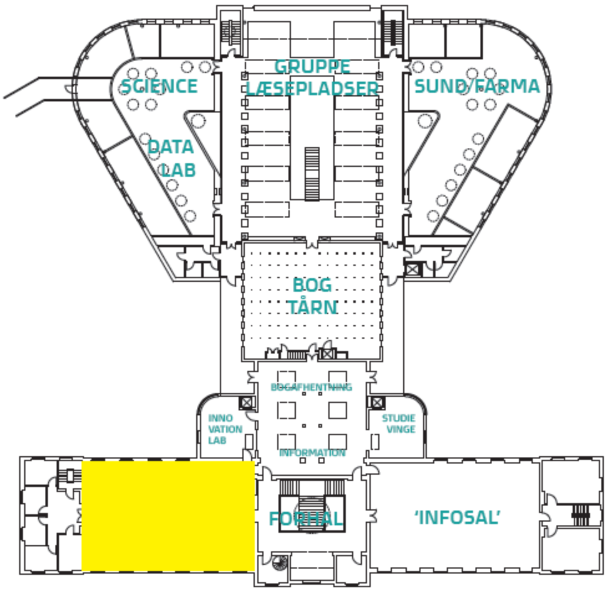


Figure 11, Layout drawing of the Copenhagen University library by Johan Grud Bjerregaard

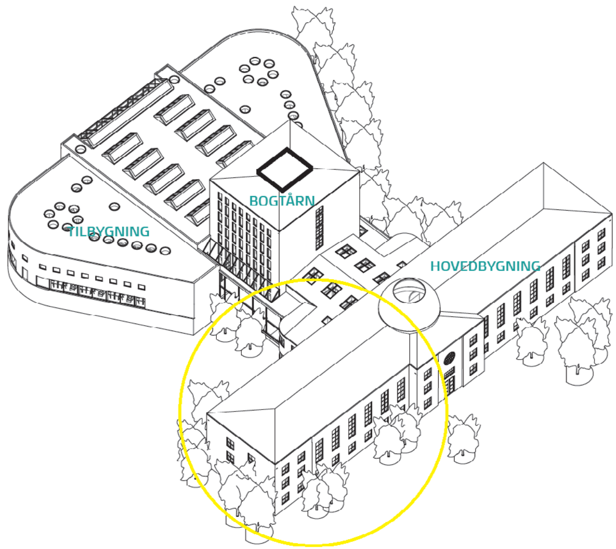


Figure 12, Isometry drawing of the Copenhagen University library by Johan Grud Bjerregaard

Figure 13, KUB Nord photo of the old reading hall.
Archive photo, provided by Lene Wendelboe/KUB Nord

Figure 14, Inaguration1938 – Berlingske

In addition to the historical background of the reading hall, the existing conditions are studied as well. Here amongst other details, the current luminaires of the room are registered. The space is primarily illuminated with ceiling hanged linear fluorescent pendants, accompanied with surface mounted table lamps.

Figure 15, Picture of the Copenhagen University library reading hall from KUB Nord Facebook site

Figure 16, Picture of the Copenhagen University library reading hall from KUB Nord Facebook site

The geographical location and orientation of the building is analysed through an online available sun chart generator, called SunCalc.org.

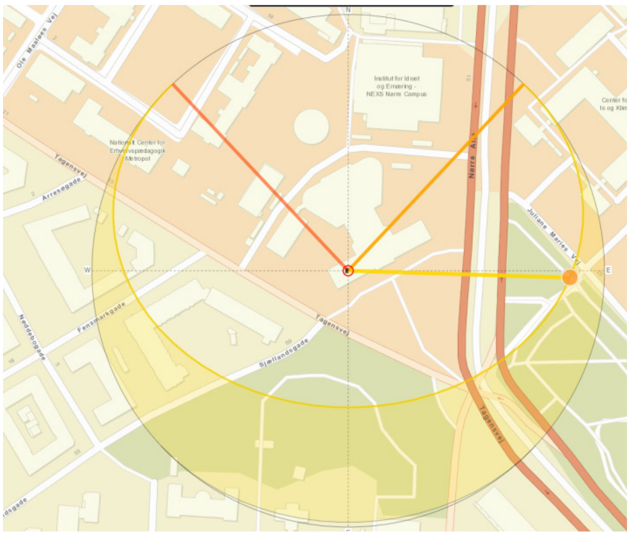


Figure 17, KUB_Nord Sunchart 21.jun_sommer solstice

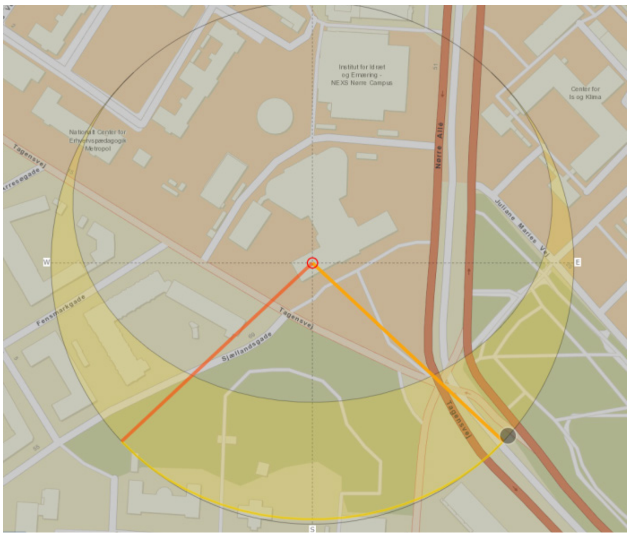


Figure 18, KUB_Nord Sunchart 21.dec_winter solstice

Users
Even though the fact, that the library is open for the public, the primary users of the space are the students of the Copenhagen University. A mixed demographics, where the majority of the users are within the age range of 18-35, excluding the librarians.

Activities
Both the placement of the tables, and low noise levels of the reading hall are encouraging individual study activities, and immersion. The leading function of the room is studying and reading, as it is also stated in the name of the hall. Therefore, the most important visual task, lighting must support is reading.

Concerning the encountered movements of the space, user must only commute between the two exits and one entrance of the space.

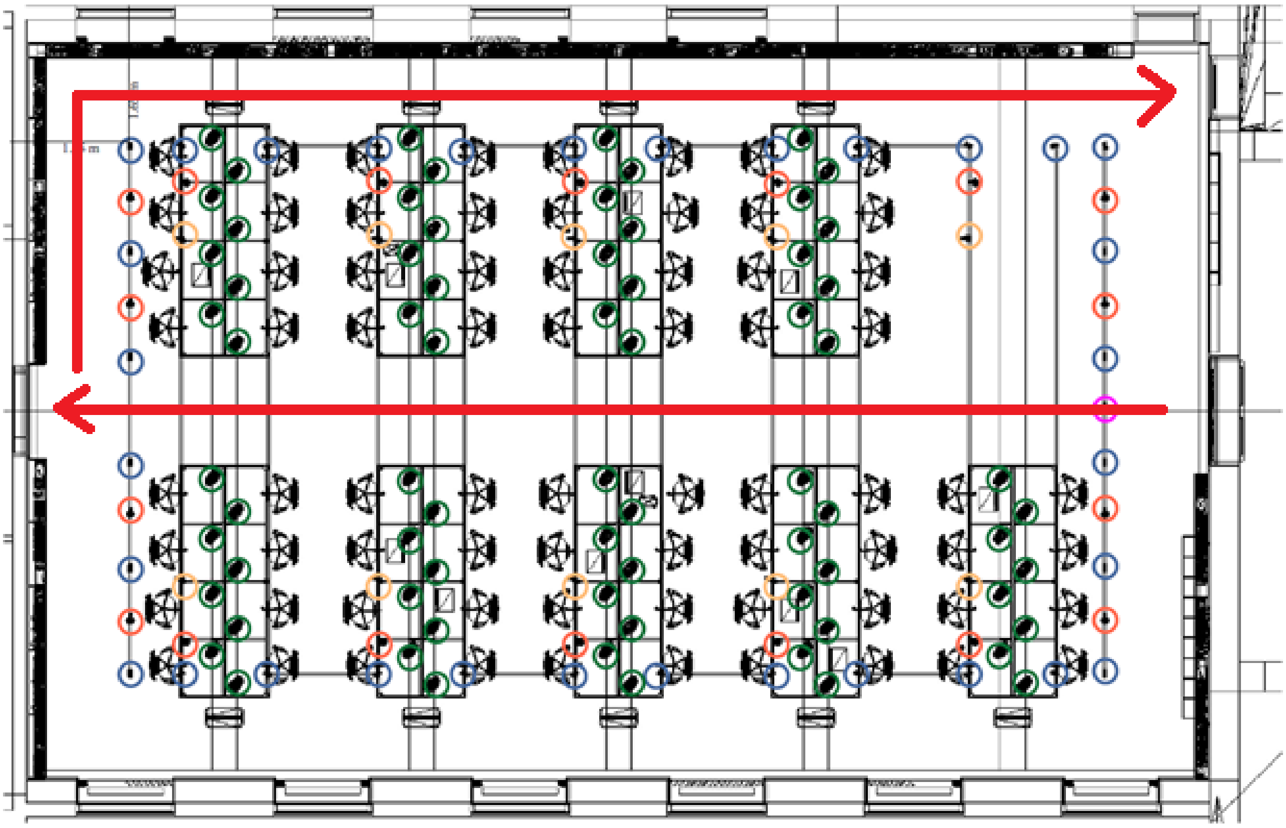


Figure 19, Observed movements of the reading hall

Based on the requirements of the contractor and the findings of the Social Science studies, the overall vision of the project is created.

Imagine if lighting can bring back the atmosphere of the "old" reading hall, while it encourages immersion and learning.

Proposals

Outline proposal

The transdisciplinary design process truly starts at the phase of the outline proposal. The vision that is born from the observations of Social Science is now the base for the design process. The field of Natural Science and Humanities and Arts are contributing to the completion of the initial concepts. These two fields are helping to fulfil the vision of the initial consultancy, using the available lighting critical tools explored in Part 1.

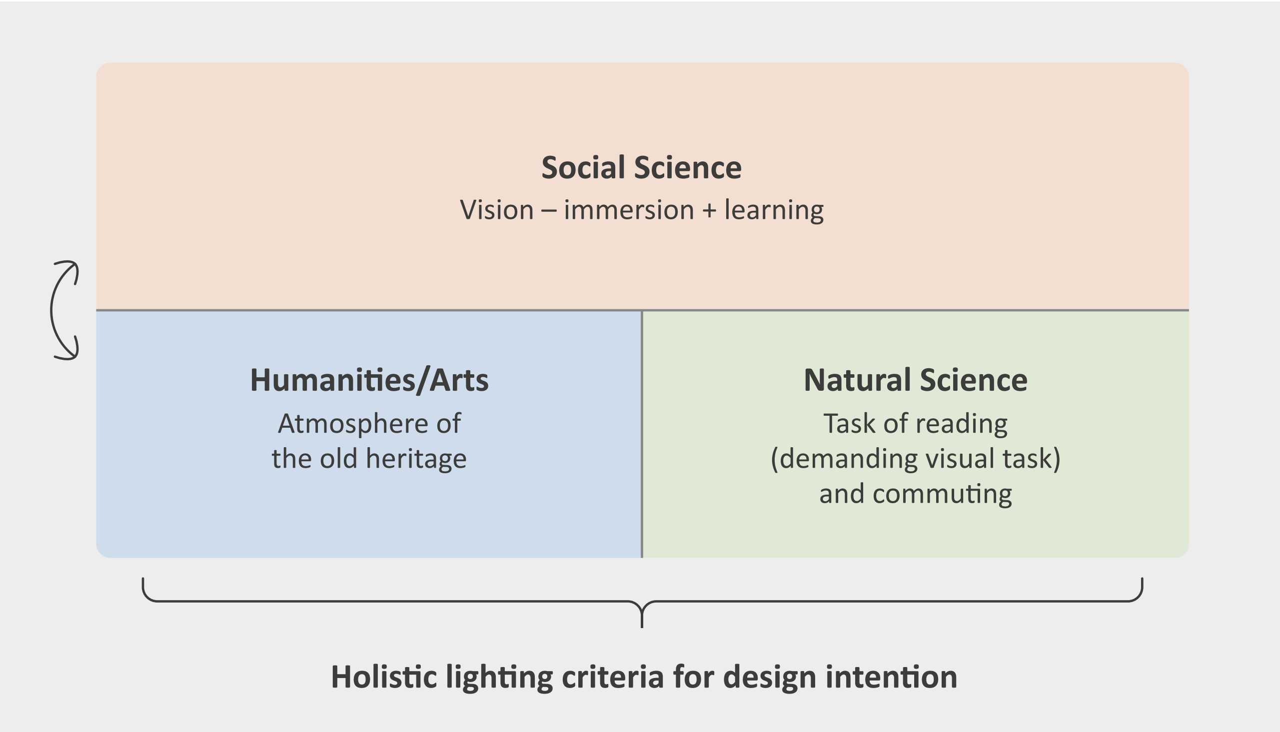


Figure 20, A caption form the outline proposal phase of the architectural-lighting model, with filled examples from the case study

Concepts are gathered, where the discipline of Humanities and Arts focuses on staging an atmosphere that recalls the historical heritage of the reading hall, and Natural Science ensures good quality lighting for the visual task of reading, and wayfinding.

For the sake of illustrating, how the architectural-lighting model works simultaneously through the different scientific disciplines, the various concepts analysed and studied are divided into areas, based on their most relevant scientific field. However, it is important to understand, that the studies of the various fields, must together add up to a holistic lighting design concept, already at this early stage of the design.

Natural Science – reading and commuting/wayfinding

At first, the daylight condition of the reading hall was analysed, in order to be able to design for an electrical lighting-, shading- and control system. The daylight analysis of the room illustrates well, how great of an influence the south-facing double-height glazing has on the daylight intake of the room. Moreover, the analysis points out the need for a shading system, and a control system that is regulated based on the daylight penetration into the room.

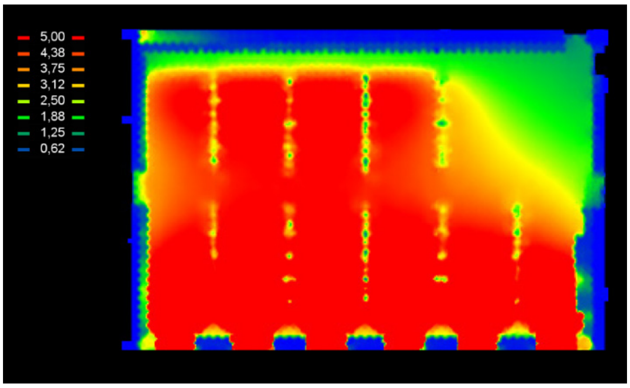


Figure 21, Daylight factor calculations in Velux Daylight Visualizer

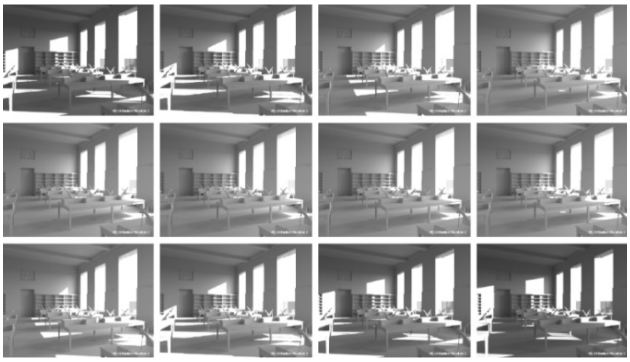


Figure 22, Luminance simulation in Velux Daylight Visualizer

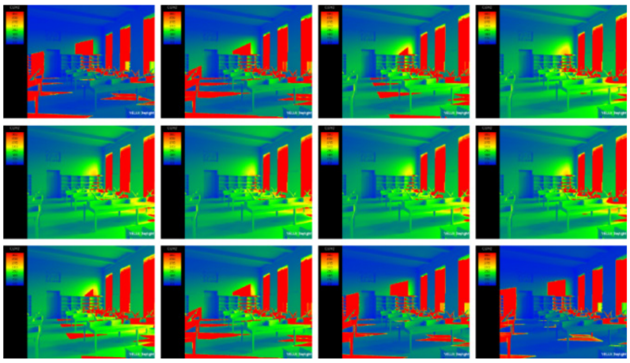


Figure 23, Luminance simulation in Velux Daylight Visualizer

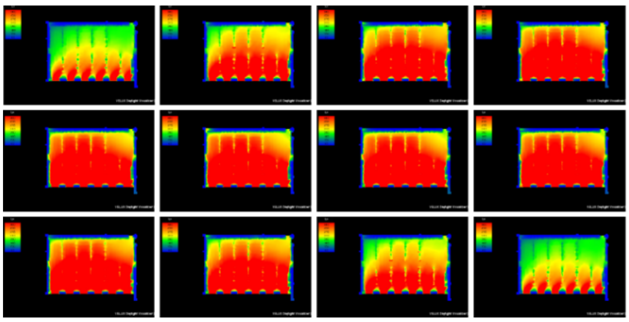


Figure 24, Illuminance calculation in Velux Daylight Visualizer

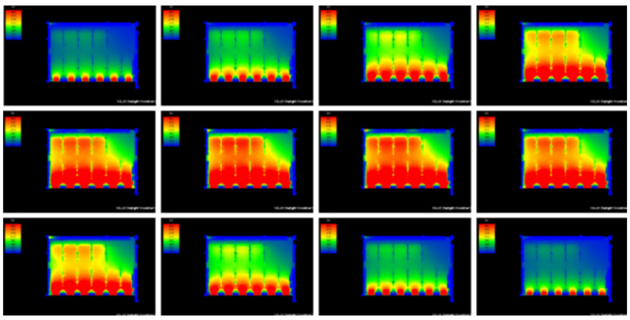


Figure 25, Illuminance calculation in Velux Daylight Visualizer

As the circumstances, thus the daylight conditions of the hall are assessed, basic light simulations and renders of the initial concepts are created. These simulations, created in Dialux, are equipped with simple lighting calculations, that can verify whether the proposed concept has the potential to fulfil the requirements of the European lighting standard, concerning both the unified glare rating (UGR) and the lux output of the luminaires.

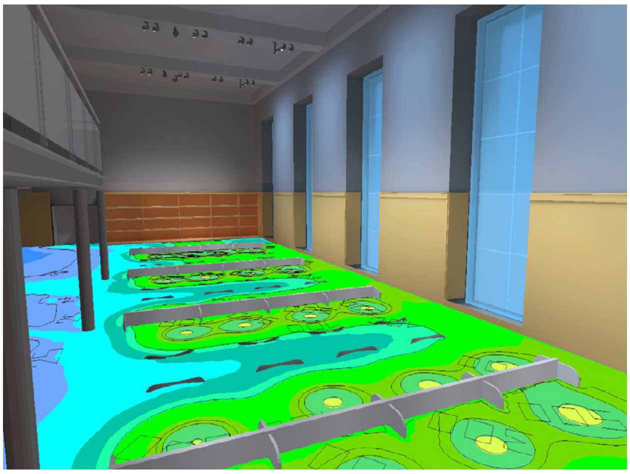


Figure 26, Simple lighting calculation on the lux levels at the level of task surfaces (Dialux)

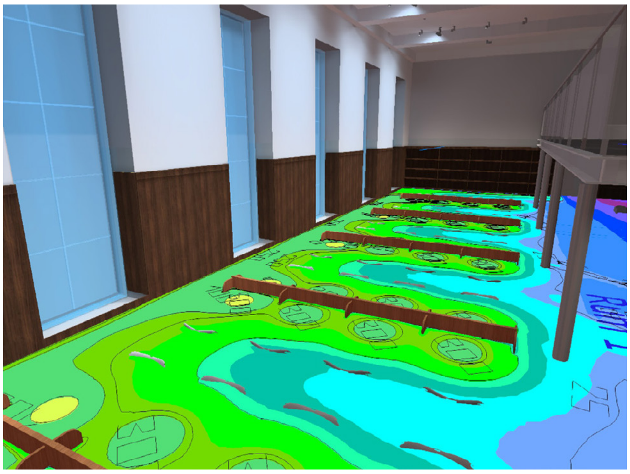


Figure 27, Simple lighting calculation on the lux levels at the level of task surfaces, materials included (Dialux)

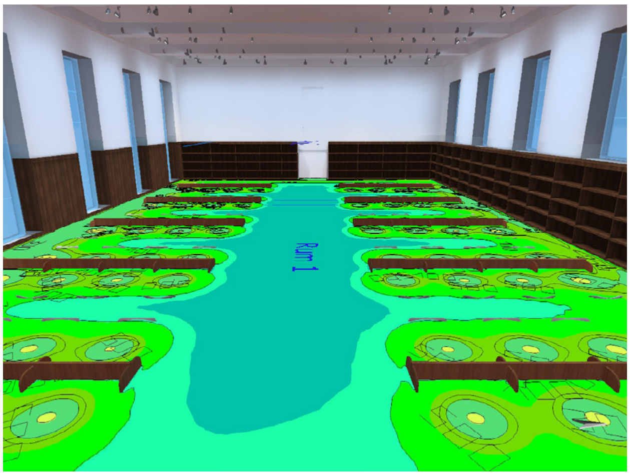


Figure 28, Simple lighting calculation on the lux levels at the level of task surfaces, materials included (Dialux)

Humanities and Arts – atmosphere of the old heritage
Concepts that have the potential to emphasize the architecture of the space, especially the momentous feel of the double height room and windows, are explored through Humanities and Arts. Initial concept renderings from Dialux are studying the different opportunities for the vertical illumination of the walls. The various concept proposals are investigating the possible placement of luminaires and their lighting parameters, such as colour temperature and light distribution, also known as beam angle.

Figure 29, Simulation of light distribution and perceived atmosphere (Dialux)

Figure 30, Simulation of light distribution and perceived atmosphere, with materials (Dialux)

Figure 31, Simulation of light distribution and perceived atmosphere, with materials (Dialux)

Figure 32, Simulation of light distribution and perceived atmosphere, with materials and cool colour temperature (Dialux)

Figure 33, Simulation of light distribution and perceived atmosphere, with materials and warm colour temperature (Dialux)

Figure 34, Simulation of light distribution and perceived atmosphere, with materials and warm colour temperature (Dialux)

Figure 35, Simulation of light distribution and perceived atmosphere, together with table lamp (Dialux)

Figure 36, Simulation of light distribution and perceived atmosphere, together with table lamp (Dialux)

Project proposal

The phase of the project proposal focuses on narrowing down the numerous ideas explored through the outline proposal. Target concepts are selected that has the potential to later on fulfil the three criteria created in this phase. Individual hypothesis within each scientific field is developed, in order to ensure, that each of the pillars of the lighting design discipline are utilized and are supporting a holistic lighting design concept that fulfils the overall vison of the project. Another aspect of the hypotheses is to secure the research-based design approach, as so, that the criterium of each field can be tested and be justified.

Social Science	Humanities/Arts	Natural Science
Criterium: The semi-unformal atmosphere together with the individual task lighting supports immersion and learning.	**Criterium:** The vertical illumination of the walls is emphasizing the momentous scale of the reading room, and by that strengthening the atmosphere of the old heritage.	**Criterium:** The combination of the task lighting and general lighting ensures proper illumination levels, combined with appropriate luminance ratios, are ensuring good quality lighting for the visual task of reading.

Figure 37, A caption form the project proposal phase of the architectural-lighting model, with filled examples from the case study

Based on the three criteria of the project proposal phase, two promising concepts were selected for this project, as target concepts, concepts that are also presented to the contractor. These two projects are progressing into detailed design concepts, assesing possible luminaire choices, colour temperatures and lighting schemes.

Concept A is suggesting ceiling mounted spot lights, as task lights, combined with the vertical illumination of the walls, and the illumination of the hallway between the tables.

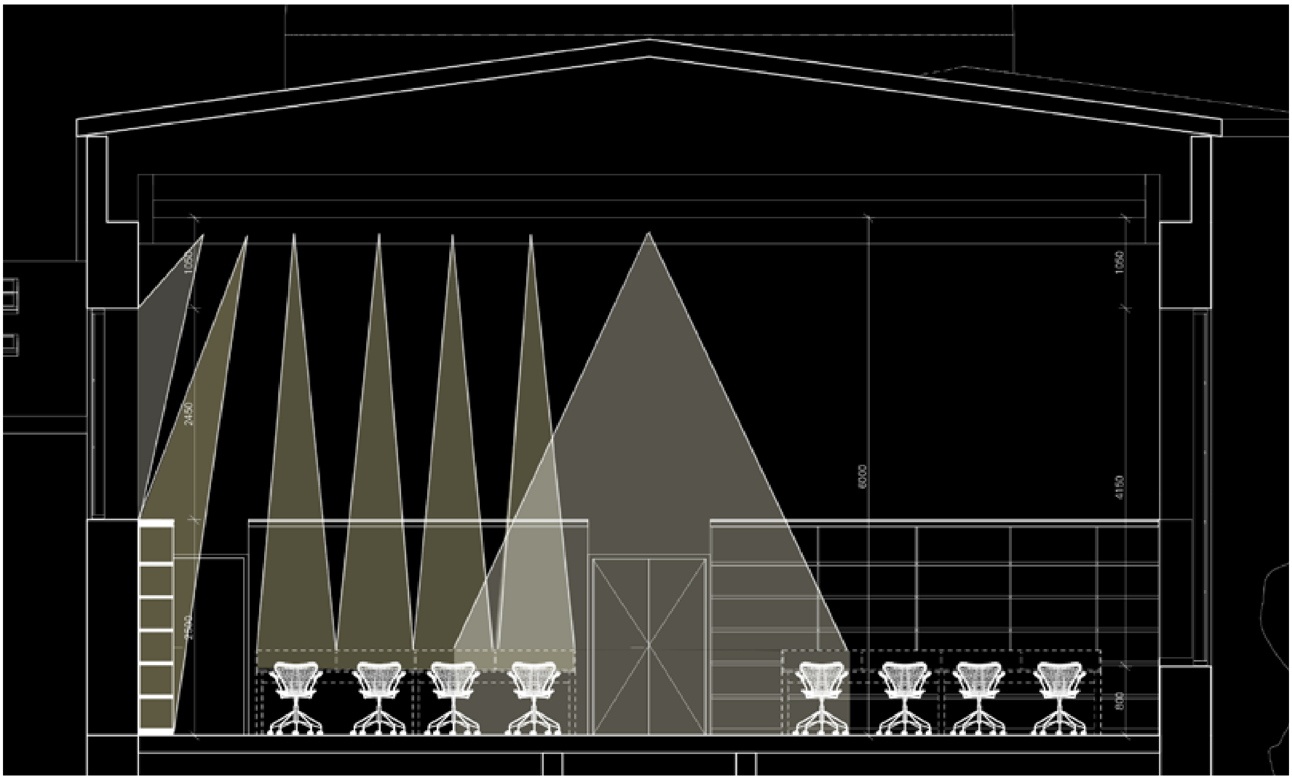


Figure 38, Cross-section of the lighting principals (Concept A)

Figure 39, Placement and distribution of the ceiling mounted luminaires (Dialux)

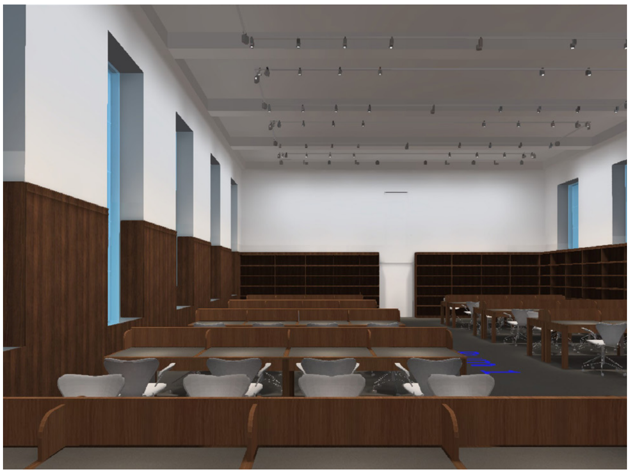


Figure 40, Rendered light at the task surface (Dialux)

Figure 41, Atmosphere of the combined lighting system (Dialux)

Figure 42, Atmosphere of the combined lighting system (Dialux)

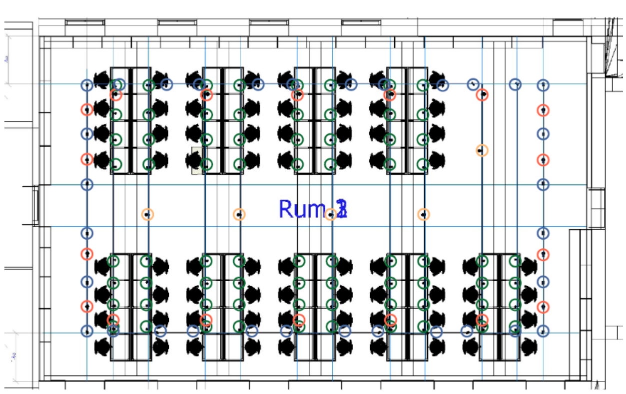


Figure 43, Luminaire placement of Concept A

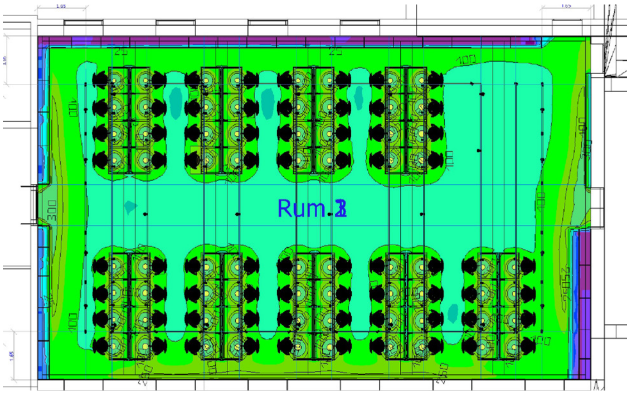


Figure 44, False colour illustration of illumination (lux) in Dialux

Φ_{Samlet}	P_{Samlet}	Lysudbytte
76988 lm	1311.0 W	58.7 lm/W

	stk.	Fabrikant	Artikel-nr.	Artikelnavn	P	Φ	Lysudbytte
	32	ERCO	24277000	Pantrac Lens wallwasher 1×LED 12W neutral white	15.0 W	783 lm	52.2 lm/W
	72	ERCO	58501000	Optec Spotlight 1×LED 3W warm white	5.0 W	251 lm	50.2 lm/W
	18	ERCO	58549000	Optec Floodlight 1×LED 19W warm white	22.0 W	1569 lm	71.3 lm/W
	5	ERCO	58762000	Optec Floodlight 1×LED 12W neutral white	15.0 W	1130 lm	75.3 lm/W

Figure 45, Luminaire list of Concept A

Concept B on the other hand, suggests table mounted reading lights, as task lights, combined with the vertical illumination of the walls, and ambient illumination of the reading hall, including the hallway between the tables.

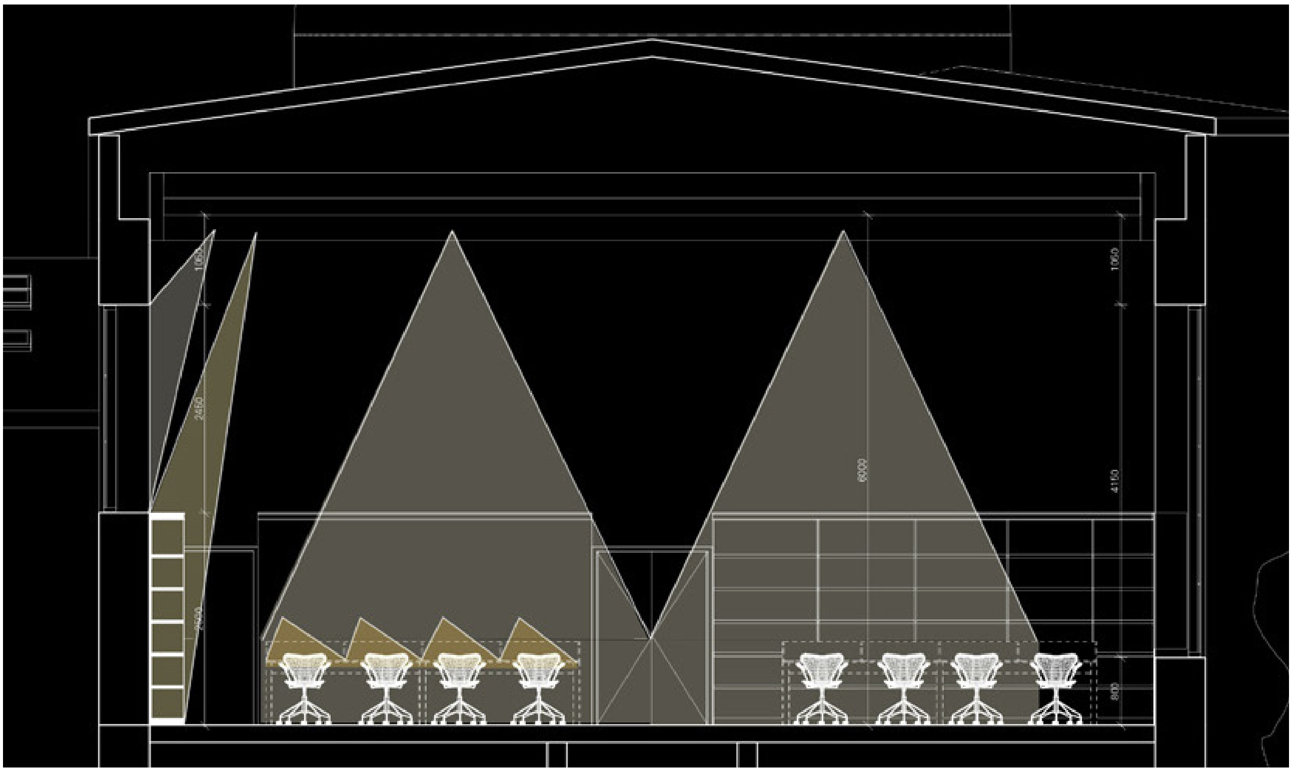


Figure 46, Cross-section of the lighting principals (Concept B)

Figure 47,Placement and distribution of the ceiling mounted luminaires (Dialux)

Figure 48, Rendered light at the task surface (Dialux)

Figure 49, Atmosphere of the combined lighting system (Dialux)

Figure 50, Atmosphere of the combined lighting system (Dialux)

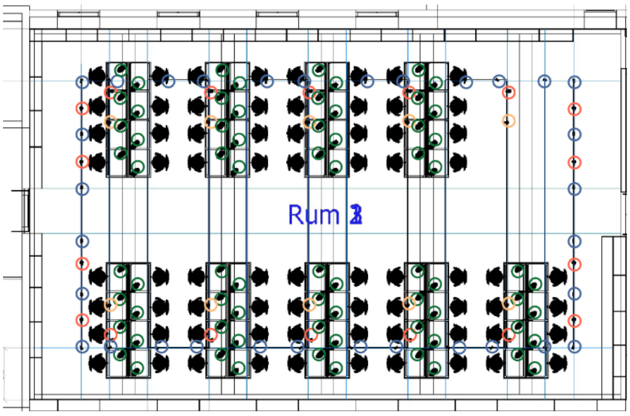


Figure 51, Luminaire placement of Concept B

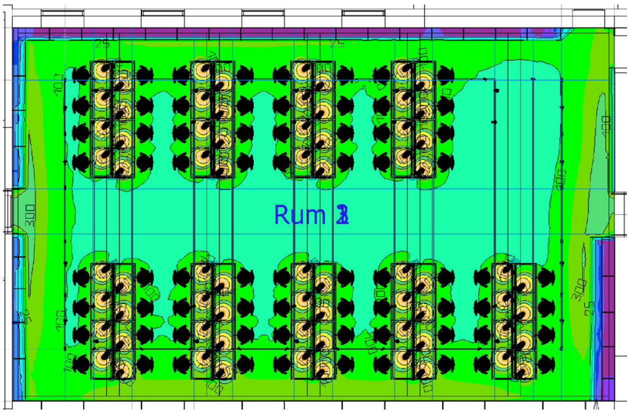


Figure 52, False colour illustration of illumination (lux) in Dialux

Φ_{Samlet}	P_{Samlet}	Lysudbytte
104742 lm	1566.0 W	66.9 lm/W

stk.	Fabrikant	Artikel-nr.	Artikelnavn	P	Φ	Lysudbytte
32	ERCO	24277000	Pantrac Lens wallwasher 1×LED 12W neutral white	15.0 W	783 lm	52.2 lm/W
18	ERCO	58549000	Optec Floodlight 1×LED 19W warm white	22.0 W	1569 lm	71.3 lm/W
10	ERCO	58762000	Optec Floodlight 1×LED 12W neutral white	15.0 W	1130 lm	75.3 lm/W
72	LOUISPO ULSEN	57441660 69	AJ Bord E27 LED 7,5W 2700K	7.5 W	558 lm	74.4 lm/W

Figure 53, Luminaire list of Concept B

Main project

Tender project

During the tender project phase, various testing procedures were conducted, to justify whether the proposed lighting solutions and luminaires can fulfil the criteria and overall vision of the project.

Testing from the field of Natural Science evaluated the lighting quality, especially for the visual task of reading. A 1:1 model of the desk was built in the office, where the beam angle, intensity and glare rating of the reading lamp was tested. The glare evaluation of the ceiling mounted task lights took place under an on-site mock-up session, together with the assessment of the luminance ratios, and overall intensity of the ambient lighting.

Figure 54, 1:1 mock-up testing of the integrated table lamp

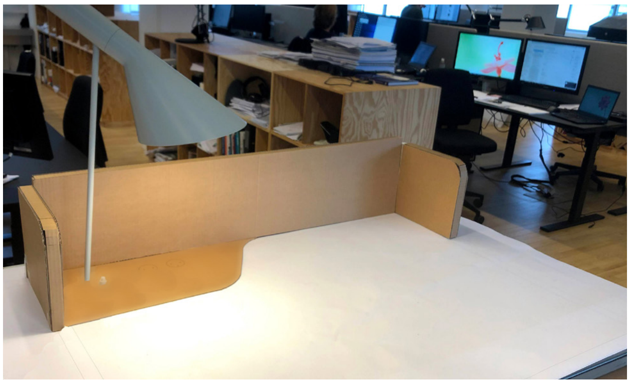


Figure 55, 1:1 mock-up testing of the integrated table lamp

Figure 56, 1:1 mock-up testing of the integrated table lamp

During the on-site mock-up session, the atmosphere of the space (Humanities and Arts) was evaluated, together with the selected colour temperatures of the luminaires, in regard to the various materials and surfaces of the room. Nonetheless, the ability of the vertical wall illumination was evaluated in relation to the enhancement of the momentous feel of the double height reading hall. The participants of the mock-up session also got the chance to test, how the new lighting system can support the desired user activities (Social Science) of the room.

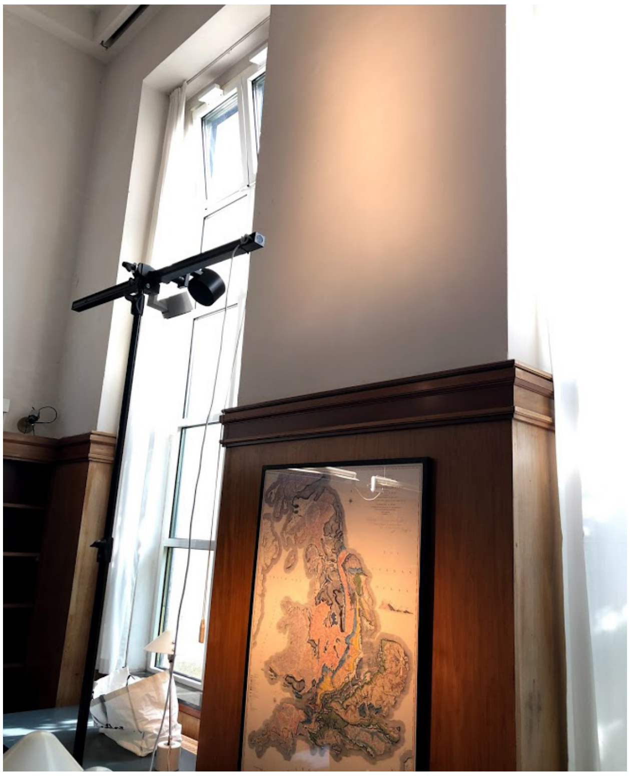


Figure 57, Mock-up session at the Copenhagen University Library reading hall

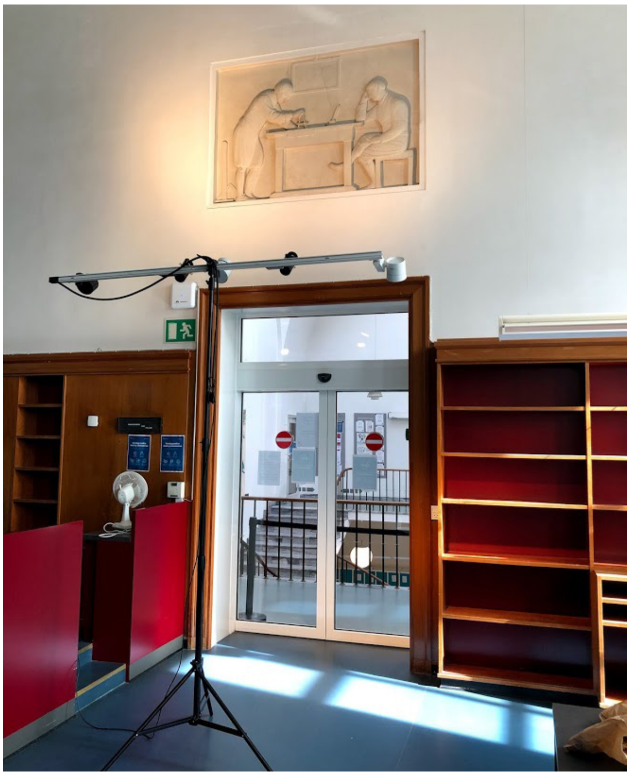


Figure 58, Mock-up session at the Copenhagen University Library reading hall

Figure 59, Mock-up session at the Copenhagen University Library reading hall

Figure 60, Mock-up session at the Copenhagen University Library reading hall

Figure 61, Mock-up session at the Copenhagen University Library reading hall

Figure 62, Mock-up session at the Copenhagen University Library reading hall

Construction project

As the phase of the tender project ended with the testing of the target concepts, Concept B was selected as the final lighting solution. Concept B provides good quality lighting for the various ac-tives and visuals tasks, supports learning and immersion, moreover it elevates the atmosphere of the reading hall, to a level, similar to the old heritage of the room. The concept was selected, as the table mounted reading lights are providing a better reading experience, in addition to, that the lamps are creating an individual light-room for the user, supporting immersion. The table mounted lights are also adding to the overall atmosphere and aesthetics of the room, mimicking the style of many traditional reading halls.

At the construction phase, Concept B, or now called, the final lighting solution, is described in detail. Final renders of the lightning solution are created, together with detailed ceiling- and mounting plans. Simulations of the control-system are conducted. Furthermore, datasheets of the selected luminaires are saved, and all lighting calculations are finalized, and measured against the lighting standards.

In addition, the function of each lighting layer is concluded, based on the lighting principles of Richard Kelly (Kelly, 1952). The wall washers, also known as the vertical illumination of the wall, to-gether with the ceiling mounted wide floods are forming the layer of ambience luminescence. The table mounted reading lights are representing focal glow. Lastly the daylight that penetrates room, through the double-height glazing is the element of play of brilliance.

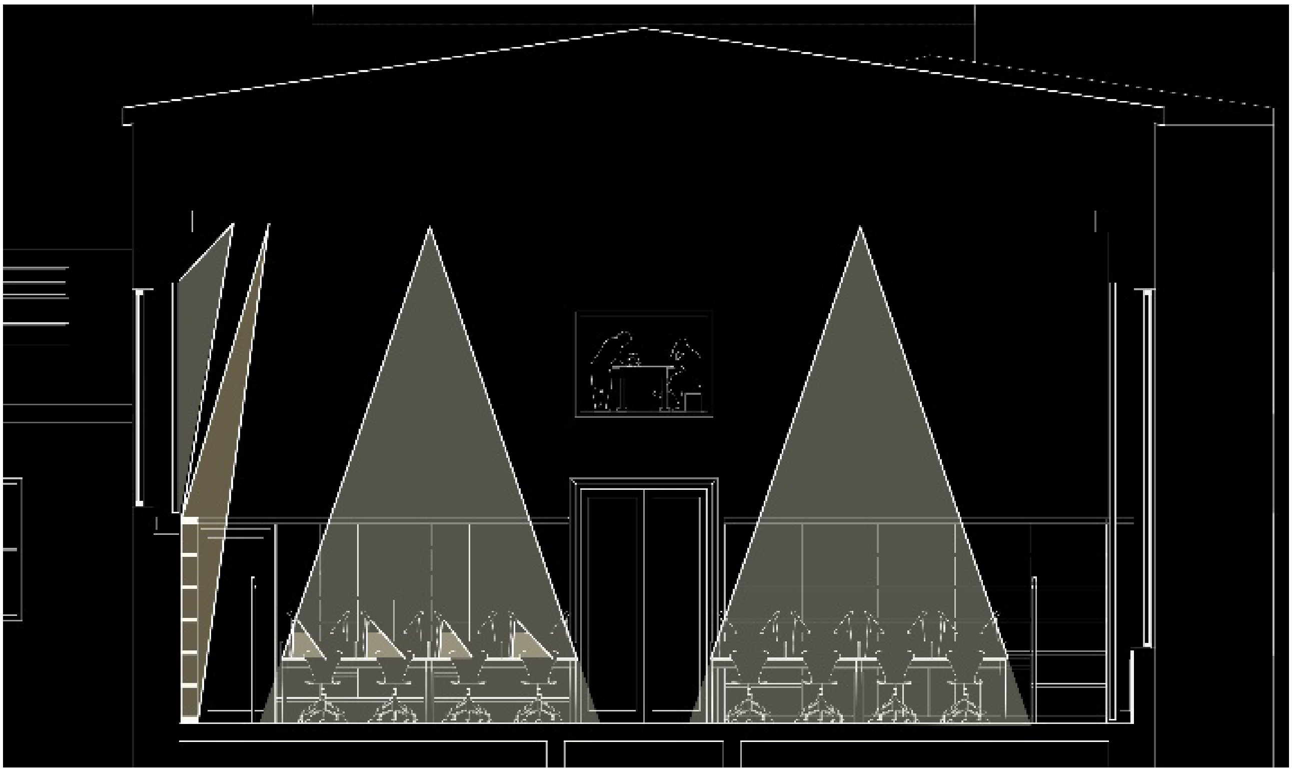


Figure 63, Cross-section of the lighting principal for the final solution

Figure 64, Render of the final lighting solution (Dialux)

Figure 65, Render of the final lighting solution (Dialux)

Figure 66, Render of the final lighting solution (Dialux)

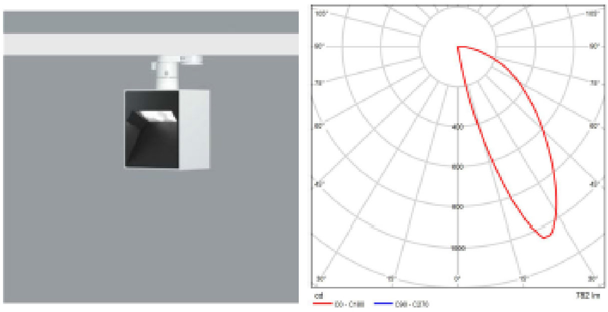
Figure 67, Render of the final lighting solution (Dialux)

Figure 68, Render of the final lighting solution (Dialux)

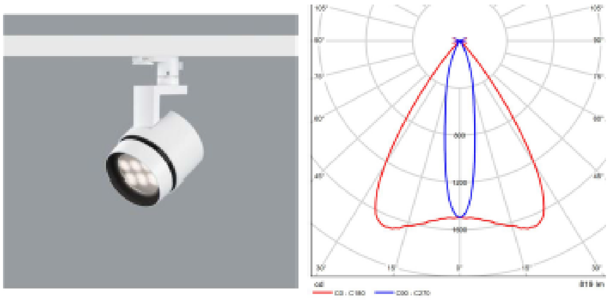
Φ_{Samlet}	P_{Samlet}	Lysudbytte
105561 lm	1581.0 W	66.8 lm/W

stk.	Fabrikant	Artikel-nr.	Artikelnavn	P	Φ	Lysudbytte
32	ERCO	24277000	Pantrac Lens wallwasher 1×LED 12W neutral white	15.0 W	783 lm	52.2 lm/W
1	ERCO	57683000	Parscan Zoom spotlight 1×LED 12W warm white	15.0 W	819 lm	54.6 lm/W
18	ERCO	58549000	Optec Floodlight 1×LED 19W warm white	22.0 W	1569 lm	71.3 lm/W
10	ERCO	58762000	Optec Floodlight 1×LED 12W neutral white	15.0 W	1130 lm	75.3 lm/W
72	LOUISPO ULSEN	57441660 69	AJ Bord E27 LED 7,5W 2700K	7.5 W	558 lm	74.4 lm/W

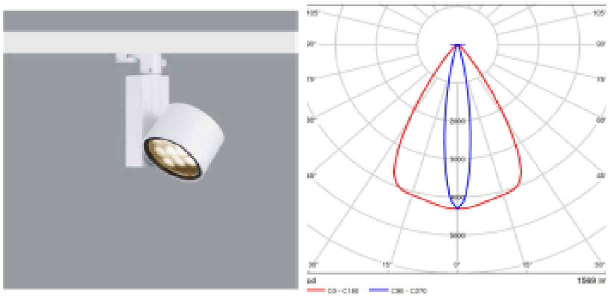
Figure 69, Luminaire list of the final lighting solution



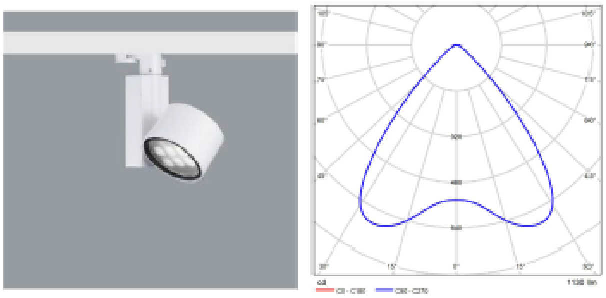
ERCO Pantrac Lens wallwasher 1×LED 12W neutral white



ERCO Parscan Zoom spotlight 1×LED 12W warm white



ERCO Optec Floodlight 1×LED 19W warm white



ERCO Optec Floodlight 1×LED 12W neutral white

Figure 70, Luminaire specifications of the final lighting soltion

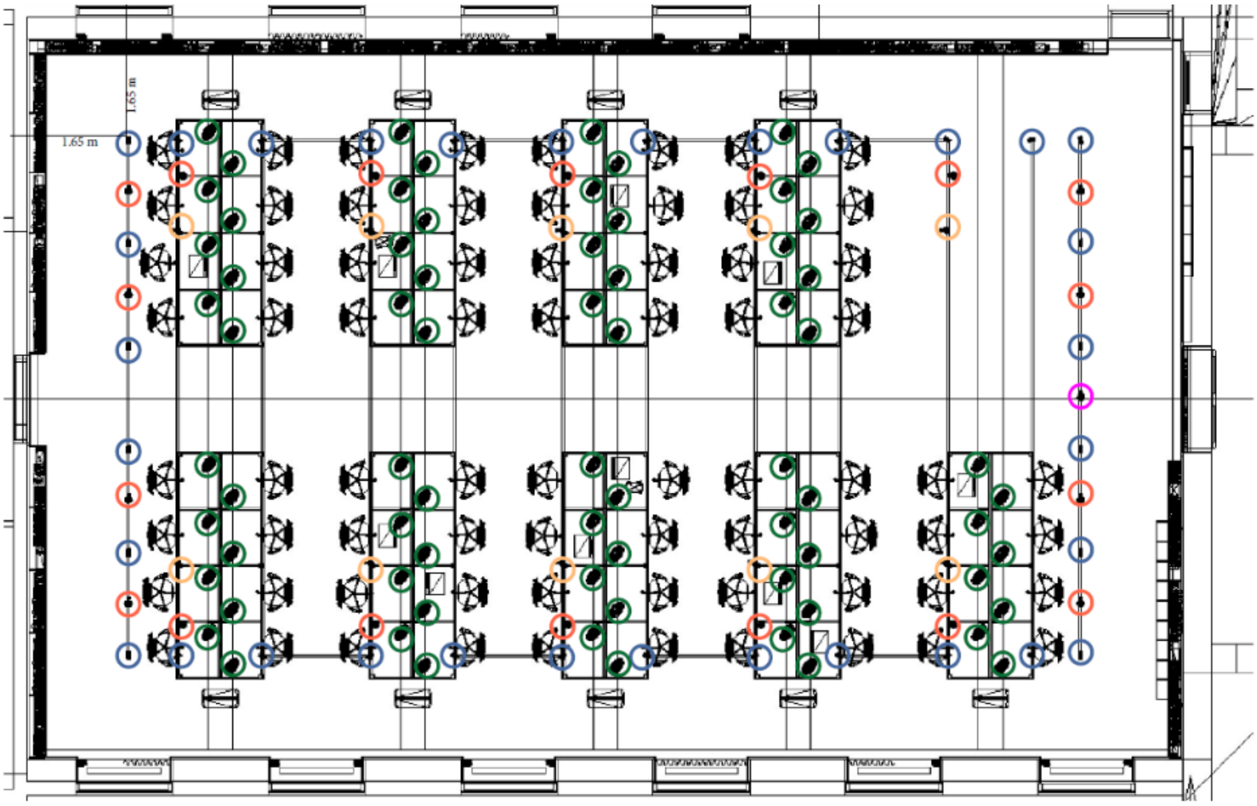


Figure 71, Placement of luminaires at the final lighting solution

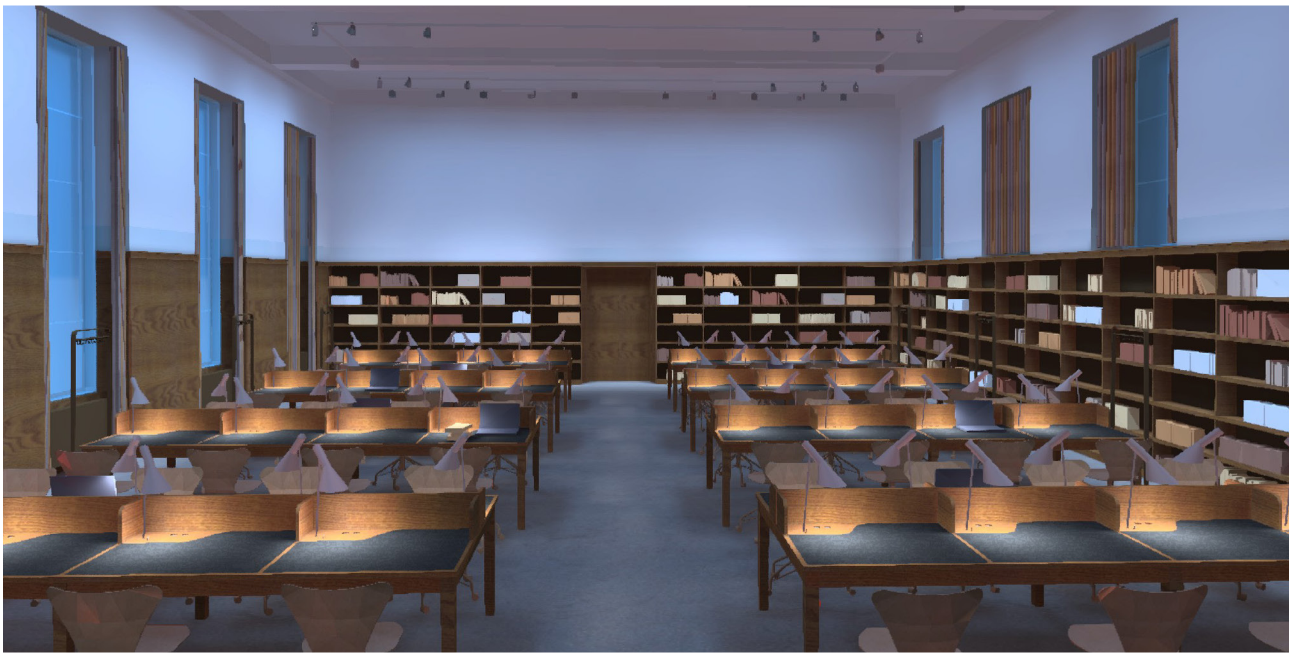


Figure 72, Simulation of the control-system (Dialux)

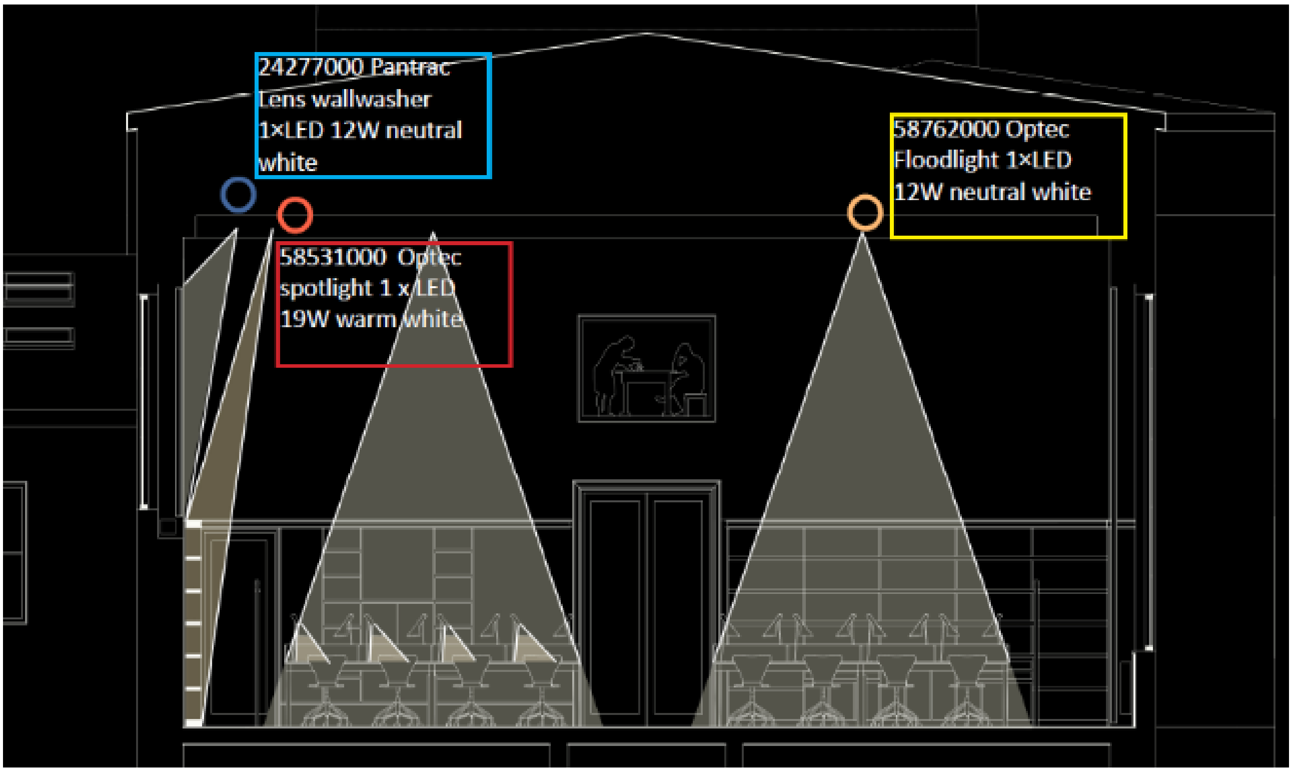


Figure 73, Placement and mounting principals of the luminaires

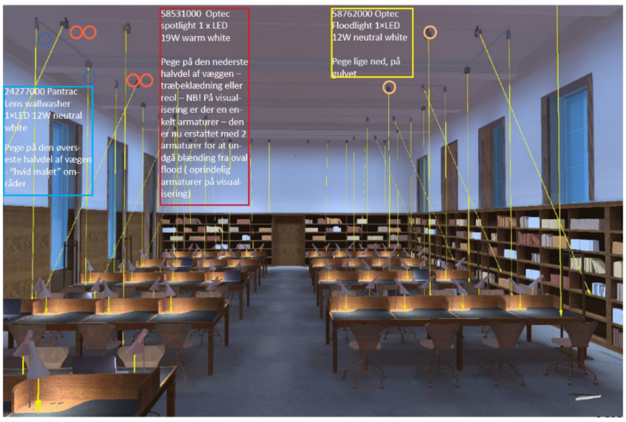


Figure 74, Placement and mounting principals of the luminaires

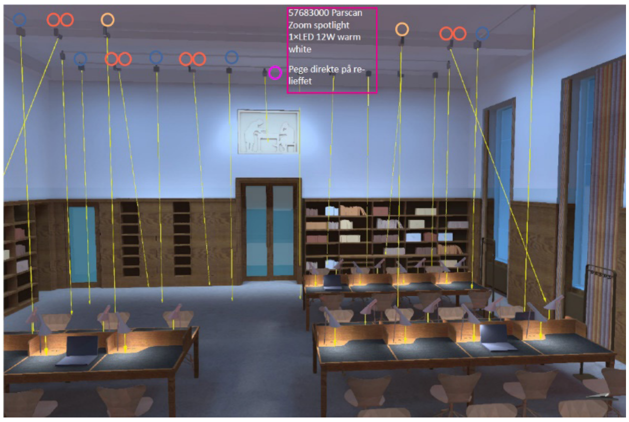


Figure 75, Placement and mounting principals of the luminaires

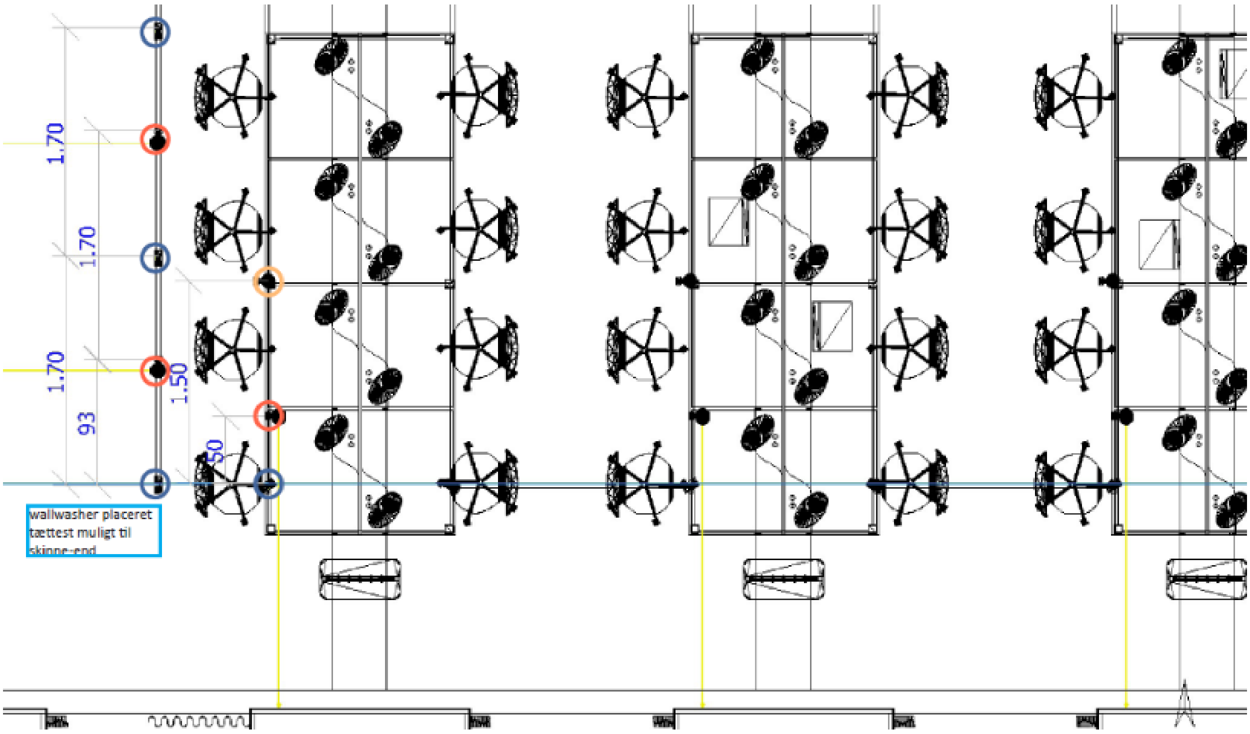


Figure 76, Placement and mounting principals of the luminaires

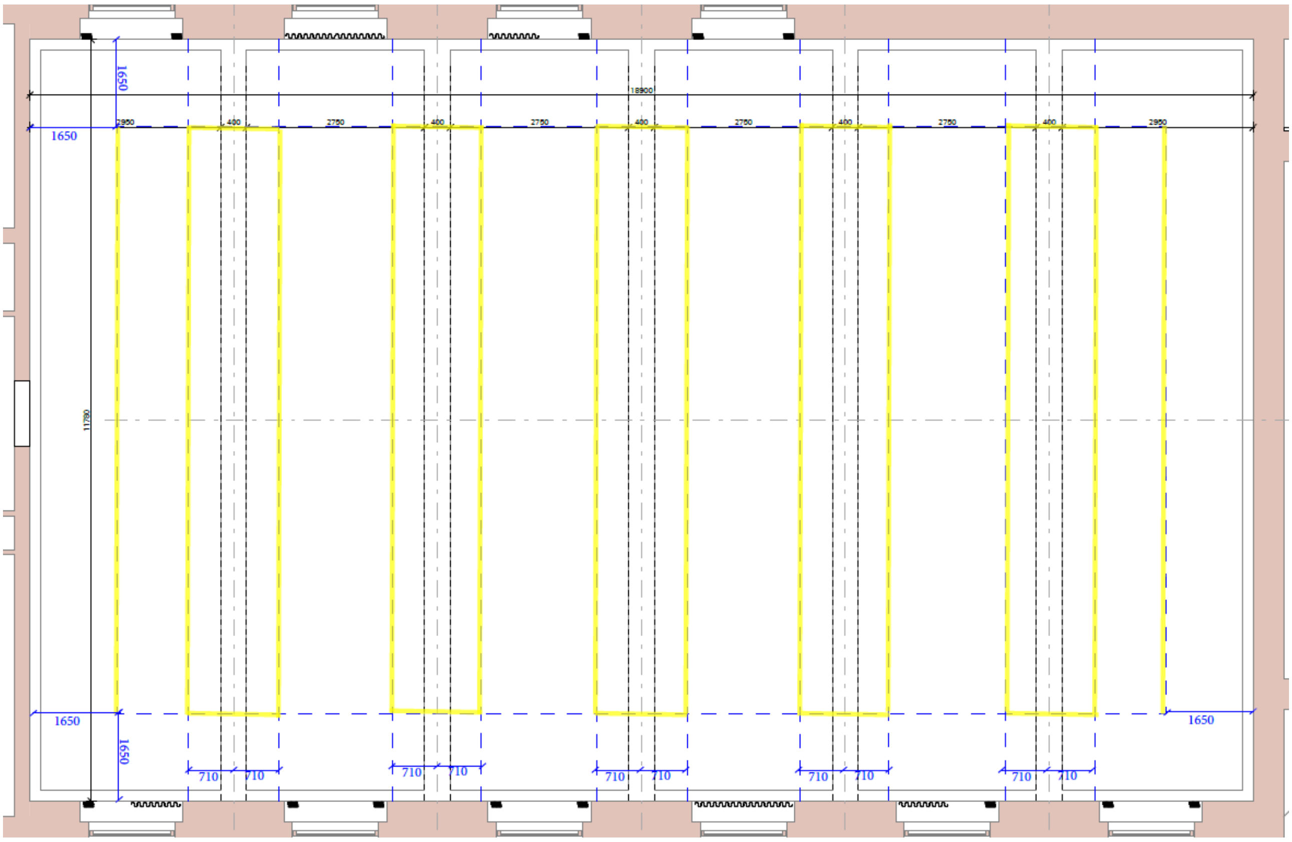


Figure 77, Placement of ceiling tracks

Construction phase

Under the construction phase the luminaires are mounted after the guidelines of the mounting instruction, and the lighting control system is adjusted on site. Due to COVID-19 restrictions, the lighting designer have not had the opportunity to participate in the mounting of luminaires at this project, however it is highly suggested, as an on-site visit, during the construction phase, provides with the perfect circumstances to evaluate the final lighting solution as a whole. Moreover, it allows for the necessary adjustment and fine-tuning of luminaires, in case the instructions of the mounting instructions are deficient or misunderstood. An on-site visit during the construction phase provides the last opportunity for quality control in forehand to delivery.

From a Natural Science aspect, the evaluation starts with on-site measurements of illuminated surfaces, that can justify that the lighting design overholds the requirements of the standard. Followed by the registration of possible glare issues, that can be adjusted under construction.

Figure 78, Construction in progress at the Copenhagen University Library reading hall

Figure 79, Construction in progress at the Copenhagen University Library reading hall

Figure 80, Adjustment of the luminaires in cooperation with the electrical engineer and manufacturer

The success of a holistic lighting design solution is evaluated through a user survey, that is constructed of a mixture of evaluation practices known from Vogels (Vogels, 2008) and Liljefors (Liljefors, 1999). The aim of the user survey is to assess the final lighting solution from the widest angle possible, including the various pillars of a holistic lighting design; visual perception, visual comfort and atmosphere.

The evolution of the perceived qualities of the reading hall is essential, in order to understand, how people perceive lighting in the space, whether the users like or dislike the lighting and if the lighting design made a difference to them. All in all, the assessment helps to determine, whether the lighting design succeeded, and can provide with an added value to the construction project and the overall architectural goal of the project.

The user survey used for the evaluation of this specific project can be found in the Appendix of the report. It is a two page assessment, starting with an open-question questionnaire, followed by a word-card, including a selection of words that identify as atmospheric metrics (Vogels, 2008), and closing with the V/P theory evaluation (Liljefors, 1999) (Ute C. Besenecker, Foteini Kyriakidou, 2020).

The result of the evaluation survey shows that the contractor of the project is satisfied, and that the lighting design is satisfactory for the visual task of reading and commuting. The atmosphere of the reading hall is evaluated to be safe, pleasant, and relaxed, in addition to that it is described to be inviting for learning and immersion. The wallwashers over the upper half of the room are emphasizing the momentous architecture of the double height reading hall, bringing back the values of the old heritage. Meanwhile, the warmer-toned spots over the wooden shelves are strengthening the feeling of a home-like and balanced atmosphere, by creating a personal workplace. The evaluation scheme reveals that the lighting is glare free, and generally received well by the users.

Delivery

All in the lighting design solution is a success. The proposed concept fulfils the user needs, while it provides with high quality and glare free lighting. The installed lighting fits the activity of reading and through a balanced and pleasant atmosphere invites for long-time work, and immersion. As the lighting fixtures are installed at ceiling height, the double height feature of the room is emphasized. Nonetheless, the different colour temperatures selected for the vertical illumination of walls and shelf systems are working well, in terms of staging the momentous atmosphere. The colder colour temperature over the upper half of the hall invites the feeling of daylight and openness to the room, while the warmer illumination of the wooden shelves is providing a personal, intimate, and pleasant atmosphere for study activities.

Learnings from the Copenhagen University Library reading room, summarized:

- The vertical illumination of the walls emphasizes the double height architecture.
- Wallwashers, thus indirect lighting minimizes glare.
- Warmer tones over the lower part of the reading hall are creating an intimate and pleasant working atmosphere, that invites for immersion.
- The colder colour temperature over the upper height of the room mimics daylight and contributes to the feeling of openness and height.
- The combination of the different colour temperatures is contributing to a balanced lighting solution.
- The non-uniform distribution of luminaries is helping to create an intimate and pleasant atmosphere.

Figure 81, The final lighting solution after delivery

Figure 82, The final lighting solution after delivery

Figure 83, The final lighting solution after delivery

Figure 84, The final lighting solution after delivery

DISCUSSION AND CONCLUSION

This report challenges how lighting can be, or even to go as far, should be worked with at an architectural company. The initial chapters of the report are exploring the challenges of the current lighting design practices at an architectural company and are describing an image of the missing integrated design process, where lighting design is often an add-on element, disconnected from the construction project and the core values of the architecture. One-to-one interviews with architects have also revealed the missing understanding of lighting as a holistic, and *"multidimensional design element"* (Ellen Kathrine Hansen, Michael Mullins, 2014), that is further contributing to the current problem of lighting design involvement at a construction project.

The research question of this project therefore stresses the importance of an architectural lighting design model, that integrates lighting design practices, into the daily model of the architectural workflow, defined by the Description of services for Building and landscape.

A thorough analysis of the Lighting design practice of Aalborg University (Ellen Kathrine Hansen, Michael Mullins, 2014) in part 1, points out the importance of the transdisciplinary workflow, when designing with lighting, and forming the base for the integrated and transdisciplinary architectural-lighting model. The final model, described in part 2, merges the transdisciplinary and research-based design theory of lighting design, into the five phases of the architectural workflow, ensuring that lighting design is worked with on a holistic plan, through the entire length of the construction project. Moreover, part 3 of the report, tests the functionality of the model on a case study.

The outcome of the tested case study shows great potentials using the architectural-lighting model. Using the model, the workload of the lighting design project can be structured and coordinated with the main timetable of the construction project. The services of the lighting designer are clear, and the delivered lighting design provides with a holistic and transdisciplinary solution.

The potential impact the architectural-lighting model can have on the build environment is substantial as well. First and foremost, the model secures good quality lighting for the users of the space, by setting a set of success criteria for the construction project, early in the design phase. This means that a vison is formed, that is customised for the specific space and project, allowing to focus on the added value, lighting must contribute with to the overall architectural experience. Because of the fact that both success criteria and vision are formed, the communication of the overall goal of the lighting project becomes also easier towards the contractor. As success criteria are set, the project later on can be measured up against that and evaluated whether it lives up to the project`s exactions. From the contractor`s point of view this means, that the design can be verified, and set in the perspective of measurable "value for money".

Another advantage of the developed model is, that it can build a bridge between the various professions involved in the lighting design process, as the model helps to create a common language for architects, lighting designers and electrical engineers. The architectural-lighting model can be used as a daily guideline, or checklist, listing what tasks to be expected and achieved in which phase of the construction, making the daily coordination tasks between the numerous professions more effortless.

Lastly, the academic research-based design approach that is integrated into the model, ensures that the developed lighting design solution can be traced, evaluated and justified. This means that new shareable explicit knowledge is born after each developed lighting design project, that can be catalogued and used for further projects.

Summary of the potentials of the architectural-lighting model
• Customised lighting solution aligned with the user needs and context of the space • Holistic lighting design achieved by the transdisciplinary approach • Improved communication towards the contractor by ensuring quality • A bridge between various professions – structured and coordinated list of services • Shareable research-based knowledge for further lighting projects

Table 7, Summary of the potentials of the architectural-lighting model

Future works, considering the improvement of the architectural-lighting model, must include new cases to test the functionality of the model. With time, it is expected that the list of services, describing the expected workload delivered by the lighting designer at the different phases of the construction project will be improved with further details. As an example, templates for mounting instructions and evaluation schemes can be developed, in order to structuralize the design process even further, minimalizing the risk of errors of the everyday workflow.

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APPENDIX

The user evaluation survey

Evaluation of the Copenhagen University Library Reading Hall

Name of participant	
Date and time of evaluation	
Weather condition under evaluation	

What is your overall impression of the space?

Would you prefer sitting here to work? Why/Why not?

Do you find that the conditions of the room are appropriate for reading and learning?

Do you find that the lighting is satisfactory for your activity?

Is there anything you would like to change if you could?

Choose three words that describe the reading hall.

Intimate	Stimulating	Cosy	Relaxed
Formal	Spacious	Exciting	Hospitable
Safe	Pleasant	Inspiring	Lively
Luxurious	Uncomfortable	Personal	Hostile

Evaluate the lighting conditions of the reading hall. Place your mark on the scale between the two lighting qualities. Do you perceive this quality good or bad in the space?

Level of light	dark						bright	good	bad
Spatial distribution of light	uniform						varied	good	bad
Shadows	sharp						diffuse	good	bad
Reflections	soft						clear	good	bad
Glare	tolerable						disturbing		
Colour of light	cold						warm	good	bad
Colour of surfaces	natural						distorted	good	bad