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Abstract:

The thesis explores intuitive lighting for wayfinding in airport terminals. An extensive literature research and case studies led to the identification of two main problems associated with wayfinding at the airport terminals - visual noise and airport anxiety. These problems are tackled with defined concepts of ambient communication, nature centric design and futuristic approach of the airports where intuitive passenger processing and a positive experience are assumed to ease the anxiety associated with airports. The four-step method is proposed for the design and testing of the lighting concept – it includes a description of the site analysis, an experimental method for assessing and measuring of the visual noise, design development, and testing. The proposed concept was a generative dynamic lighting pattern with addressable parameters and was tested using online questionnaires and VR environment. Findings from the tests revealed that some addressable parameters such as color could suggest intuitive information, however, the VR tests did not give clear results. Nonetheless, the overall process gave a clear indication for improvements for the method which was concluded to be a useful tool, with the potential to be applicable in other areas of lighting design.

AMBIENT COMMUNICATION WITH LIGHT FOR THE AIRPORT TERMINAL WAYFINDING

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May, 2019

Abstract

The thesis explores intuitive lighting for wayfinding in airport terminals. An extensive literature research and case studies led to the identification of two main problems associated with wayfinding at the airport terminals - visual noise and airport anxiety. These problems are tackled with defined concepts of ambient communication, nature centric design and futuristic approach of the airports where intuitive passenger processing and a positive experience are assumed to ease the anxiety associated with airports. The four-step method is proposed for the design and testing of the lighting concept – it includes a description of the site analysis, an experimental method for assessing and measuring of the visual noise, design development, and testing. The proposed concept was a generative dynamic lighting pattern with addressable parameters and was tested using online questionnaires and VR environment. Findings from the tests revealed that some addressable parameters such as color could suggest intuitive information, however, the VR tests did not give clear results. Nonetheless, the overall process gave a clear indication for improvements for the method which was concluded to be a useful tool, with the potential to be applicable in other areas of lighting design.

***Keywords*:** lighting, ambient communication, airport wayfinding,

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Motivation

A thought of an airport terminal brings up memories of exciting travel time on one hand, and rather stressful experience on the other, usually preceded with a time-sensitive journey to the airport and a check-list of travel necessities and documents.

Interestingly, the commodity that stands out immediately and causes stress is the orientation inside terminals. Many times we have found ourselves in a position of running back and forth the terminal building looking for clues of where to proceed further. From personal experience, the relief only came after reaching the gate and realisation that there is still plenty of time before departure.

So why is this experience so familiar? What are the methods and factors influencing the wayfinding in the airport terminal? Is there a way to make the process more "user-friendly"? With this project, we aim to analyse the link between lighting, airport design, and wayfinding. We want to investigate the possibility of using lighting design as a tool to improve the existing conditions.

1. Introduction

Nowadays, more and more people travel by air, exploring and experiencing the world in ways that were not possible just a century ago. Air travel has become normalized and is treated as a commodity rather than a novelty. Over the last decade, airplanes have become a popular way of transportation which resulted in a number of new terminals built worldwide with the enormous 8th-fold increase in air traffic over last 50 years (International Civil Aviation Organization, 2019). A growing number of passengers resulted in the creation of hyper-airport infrastructures all over the globe with millions of passengers served daily.

"Size and internal complexity have made the terminal of the future (the design for Heathrow Terminal 5 is a good example) into megastructures, where activities are housed as self-contained villages surrounded by open space." (Edwards, 2005 pp.261)

The airports are interesting places to be in, still quite a novelty in the history of architecture with the first international commercial airport dating back only a century to 1919 (AQT Solutions, 2017). The infrastructure of an airport can be compared to a small town with increased security - size, complexity and population wise. While some airports are innovative and with a modern design approach, there are others that are complex architectural structures combining old terminals with new extensions added due to the increase in the airborne travel. Airports have a set of fixed functionalities, while essentially being designed as transit spaces meant to be passed through, filled with passengers from different time zones, cultures, contexts and travel itineraries.

Navigating large crowds through these structures creates a challenge in efficient design. Being such a complex space with so many different layers, it can potentially create an anxious and unpleasant experience for travellers. Long queues, slow and thorough security checks, visually heavy commercial spaces, uncertainty in orientation, delays, and lack of reassuring information are just some of the few challenges travellers might be experiencing. In a pejorative way, this de-humanizes the experience. However, awareness of these experiences and processing procedures suggests that airports are places with a lot of potential for improvement.

There is a new shift in the way airports are being constructed and perceived with the focus on the customer and newly available technologies. The CEO of Dubai airports - one of the busiest in the world with around 90 million passengers served yearly(Reuters, 2018) - Paul Griffiths, shares his outlook on the future of air travel (Reuters, 2019):

"The objective is to design an airport from the ground up that uses the latest technology to speed people through airports and reduce the modal shift between ground and air."

This futuristic perspective could potentially call for new ways on how airport systems are designed. How can an architect or a designer aid a person in navigating in these spaces? Is there enough guidance provided throughout the experience? Could the lighting be a solution to some of the problems the travellers are facing? In this project, we will analyse these processes and experiences from the perspective of a lighting designer. We will investigate whether light can be used as a successful tool for improving the efficiency of wayfinding and at the same time contribute to creating a less anxious, fluid and intuitive airport experience.

1.1 Initial problem statement

Therefore, the initial problem statement arises:

How can lighting improve the existing standard wayfinding tools and contribute to delivering a stress-free travel experience?

1.2 Project process model

The process model below shows how the project is constructed and gives an overview of different phases.

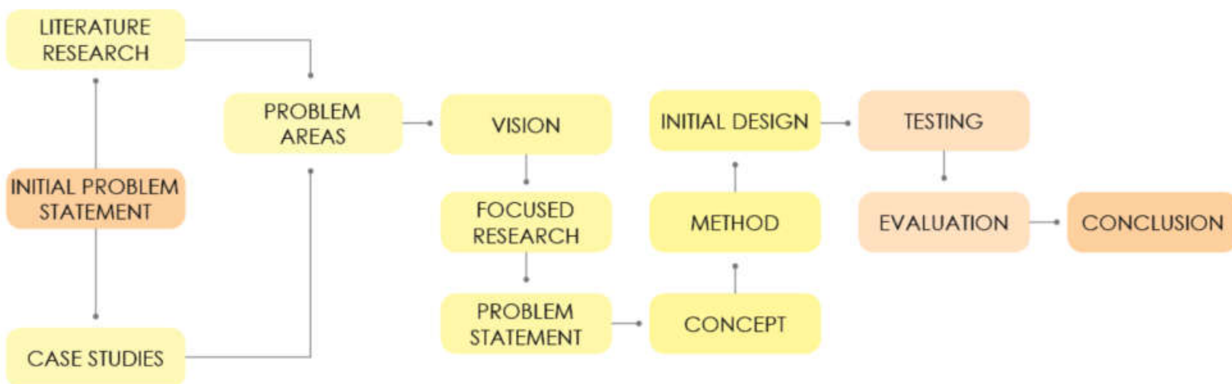


Figure 1. Process model

1.3 Structure and methodology

The introduction of this project is followed by an extensive literature analysis, which is divided into five parts. It identifies the main problems experienced at airport terminals by passengers and throughout the design processes. Identification of these problems allows to define the vision for the project and gives an insight into further research with a focus on specific aspects to be solved. The focused research builds the foundation for the final problem statement and success/design criteria of the project. Once the statement is clear, the concept for the project is introduced. In order to create the design proposal meeting the criteria and fulfilling the concept a step by step method for the design and testing procedures is described and executed. Evaluation of the design and the proposed method is followed by discussion and conclusion.

2. Analysis

2.1 Architecture of terminals and general lighting practice

2.1.1 The architecture of terminals

The infrastructure of any airport is made for accommodating airplanes, not people – people are guided to find the airplanes and not the other way around. Airport terminals are buildings made to connect the two and allow a smooth transition between the land and the air.

Terminals throughout the world share the same essential functionalities but are all different buildings. The bigger the airport, the more complex and convoluted the infrastructure and paths get, especially in the case of extended terminal or airports with multiple terminals. It is no surprise that the wayfinding process can be a challenge, especially being a first time traveller. As a general summary, terminal architectural design styles can be put into one of the configuration categories represented below (Neufert & Neufert, 2002, pp.446-451), (Ashford, Mumayiz, & Wright, 2011, pp. 420–424):

- Pier/finger terminal (see Fig. 2.)- Centralized passenger processing terminal connected with piers ('fingers') with departure gates. A popular choice due to the economic use of land and resources. Wayfinding challenges - orientation in centralized passenger hub and possible irregular pier arrangements. Example of pier terminal can be found in Copenhagen Airport.

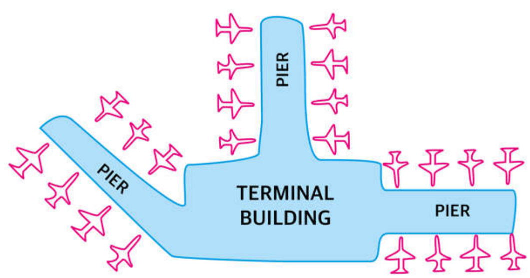


Figure 2. Illustration of pier/finger terminal

- Linear (see Fig. 3.) - Departure gates alongside the linear and long building. Simple and intuitive design, however not practical in case of larger airports due to inefficient use of aircraft parking space and large duplication of necessary airport amenities and facilities due to the length of the terminal building. Example of a linear terminal is Terminal 1 at Munich Airport.

Figure 3. Illustration of linear terminal

- Satellite (See Fig. 4)- Terminal, where all the facilities are centralized in the main building and passengers are transported to satellite buildings with departure gates. Usually ina circular arrangement where aircraft completely surrounds the satellite building. Example of satellite terminal arrangement is Tampa International Airport in Florida, USA.

Figure 4. Illustration of satellite terminal

- Transporter (see Fig. 5) - Passengers are transported from departure gates to the aircraft with vehicles. In terms of architecture, there is no need for accommodation of aircraft alongside the building (thus lack of fingers), therefore the terminal is usually easy in navigation. Transporter terminals are unpopular due to high traffic on the air ground, long turnaround process and poor passenger service. This type of terminal is a good example of how the architecture of airports is still developing, where some trends – such as the transporter terminal – are already being dropped due to changing environment and passenger processing challenges.

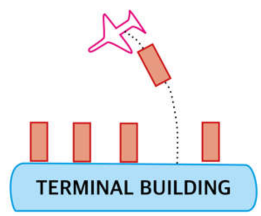


Figure 5. Illustration of transporter terminal

- Hybrid airport (the unit terminals concept) is a configuration of different types of terminals - can be either functioning as separate terminals connected with a transportation system or indoor passages. Usually adjusted to the context of the site and required functionality. Here the wayfinding can be challenging due to the irregular shape and spatial organization of the different terminal buildings. An example of a hybrid airport is Paris CDG, France, with multiple terminals.

2.1.2 Lighting practice at the airport terminal

According to the Phillips Lighting webpage (Philips Lighting, n.d.), careful and considerate lighting in airport terminals can contribute to creating spaces and order. It is important to mention, that the requirements might differ depending on local codes, certifications or even the specific airport design guidelines. Terminals usually consist of areas with different functionalities and purposes, whether it is to help the travellers feel comfortable and oriented or to ease the tasks carried out by staff at security checkpoints and customs. Furthermore, lighting has a huge role in the CCTV monitoring of the environment for security reasons. Below is the list of typical terminal areas to be considered as an individual space, and their individual focus areas and needs for lighting (Philips Lighting, n.d.):

Arrival and departure halls - these areas are considered to be the busiest parts of the airport. Most times passengers can find it unfamiliar and chaotic. It is reasonable to assume that a sense of timelessness and placelessness is particularly likely to be experienced by travellers in transit, involved in international travel between distant places with different time zones. (Jennifer Rowley, 2006). Passengers need to orient themselves in these, particularly chaotic and unfamiliar surroundings. Carefully planned lighting can ease the burden of wayfinding, waiting and orientation by creating calm and comfortable surroundings.

Check-in and information desks - The lighting is important in the process of staff interacting with travellers and in the efficiency of checking passports and documentation. Appropriate lighting ambiences makes the experience more time efficient and less taxing. This leads to collected and calm passengers in the waiting lines.

Connection areas and travellators - Airports are open 24 hours a day, where connection areas and travellators act as so to say "arteries" of the airport helping people to move from one space to another, linking them together logistically. Lighting can help indicate clear routes and ease the effort of passengers getting from A to B. Research suggests, lower light levels create a sense of calm and tranquillity in busy connection areas, whereas brighter ambiences can increase the feeling of efficiency and speed of travellators.

Retail - Airports are filled with various retail spaces. It ranges from a general department store layout to shopping centre areas. Most lighting in these areas have to comply with existing regulations, but tenants are the ones who propose the final solution, the main goal of this lighting is to enhance the product in the best possible manner.

Customs and passport control - Lighting at customs and passport control can ease the face recognition, reduce the hassle and aid to a successful and quick procedure.

Security check areas - The security procedures are more intense than ever before, where passenger checks and body scans have to be conducted in a respectful way. Well-planned lighting provides vigilant staff with clarity.

Baggage claim area - The experience of waiting for your baggage after a flight can be an anxious time for passengers. A natural lighting solution that mimics daylight will enhance guidance and comfort for the traveller to quickly find the right baggage carousel and collect its baggage as fast as possible.

Luggage handling and air traffic control - are so to say back of house areas, where typically passengers are not allowed to enter. Nonetheless, lighting in these areas is important for the comfort and wellbeing of workers, whose work shifts vary from day to night. Best solution is to introduce sensitive daylight mimicking lighting solution. For airport traffic control it is important to aid concentration and make interpreting complex instrumentation as easy as possible – whatever the time of day or night.

2.1.3 Role of daylight at the terminal

Airport terminals are often built in open landscapes, which gives the architects a unique possibility of fully utilizing and working with daylight without much worry of shadowing form surrounding structures. Used in a correct fashion, light can be every used as an expressive material intuitively guiding travellers through the complex paths of an airport terminal during daylight hours. In the modern airport terminal, the introduction of daylight into core areas of the terminal was the single most distinguishable design shift (Edwards, 2005, p. 262). Usually, main concourse areas are designed as spacious tall volumes with a lot of daylight. From a wayfinding perspective, natural light is used to guide passengers from landside to airside - towards the spacious and tall departure concourse areas, filled with daylight (Edwards, 2005, p. 262).

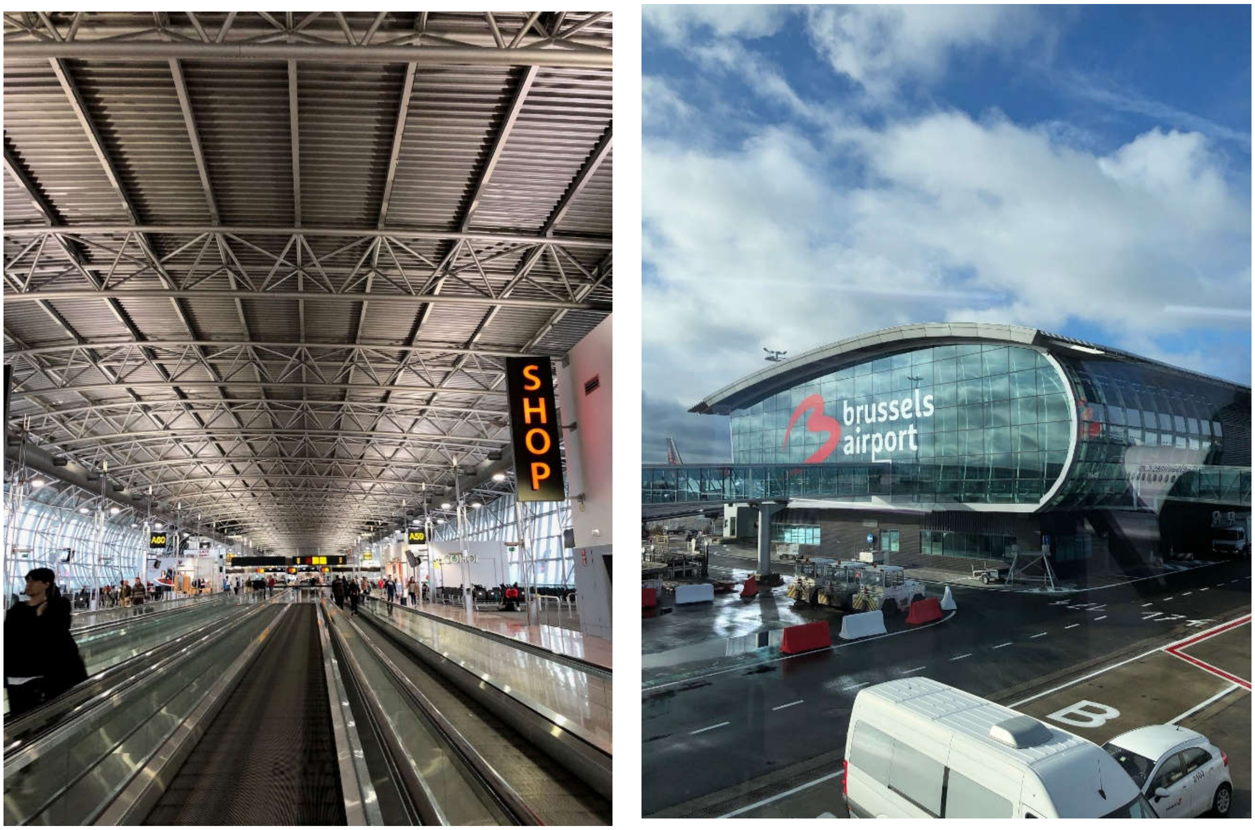


Figure 6. Departure lounge at Brussels airport flooded with daylight coming from glazed facades on both sides.

In a more direct way, paths of dynamic sunlight, arrays of skylights on the roof and large glazed facades are used along the main passages and concourses to indicate the direction of movement. This practice can also be read with a symbolic meaning – moving from a lower, narrower and dimmed areas of passages and checkpoints, into spacious tranquil zones with a view on the sky, symbolizing the upcoming airborne journey.

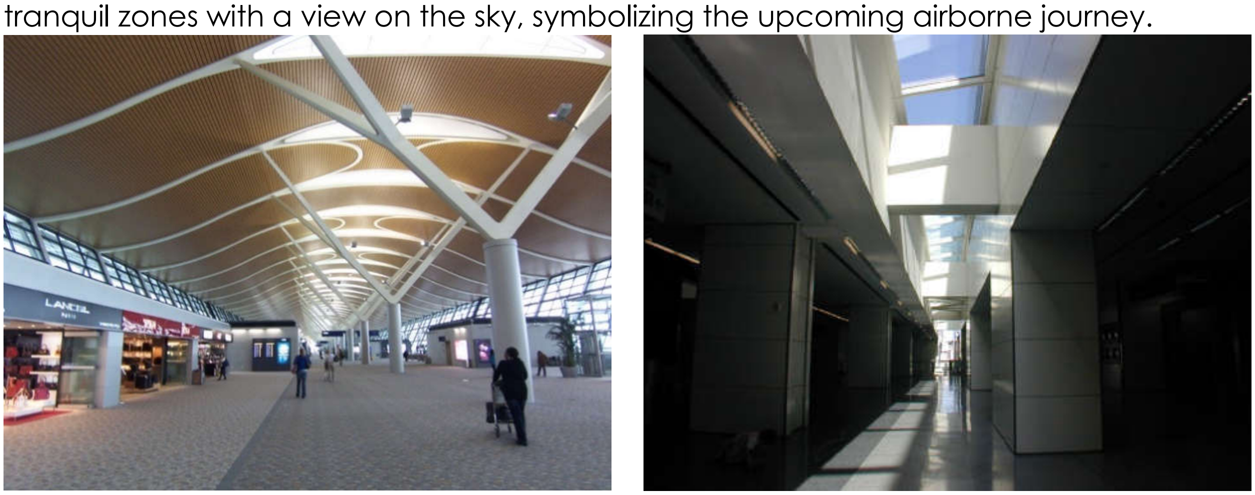


Figure 7. Daylight and sunlight animating the paths at Shanghai (left) and San Francisco (right) airports.

Furthermore, introducing daylight and dynamics of sunlight into the concourse areas has a biological and psychological significance. Firstly, by letting the daylight into deep, core zones, a new trend of having indoor gardens is becoming a popular terminal design practice (Airport Technology, 2016). Secondly, plenty of dynamic natural daylight and good view to the outside play a major role in making the lounge and waiting areas relaxing, stress-relieving and comfortable to be in, which is an important factor to consider as many of the passengers spend hours in those areas(Edwards, 2005, p. 156), (Beute & de Kort, 2018). Combined with the presence of the natural elements, modern departure lounges resemble parks, where people can relax after the stressing journey to the airport and further to their gate, and be surrounded by natural elements while still being indoors.

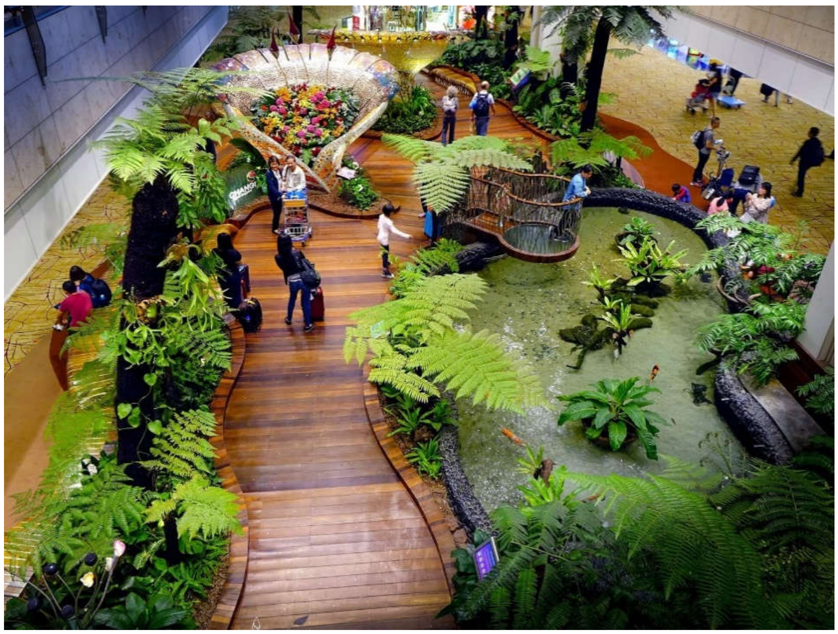


Figure 8. Indoor garden at the Changi Airport Singapore.

2.2 The wayfinding

The problem of wayfinding has progressively been given attention over the years. It is addressed in a number of literature examples, with more and more focus within the fields of architecture, service systems design, interior design, etc. The chapter below explores a thorough definition of the term, as found in the literature review of papers regarding the process of wayfinding, with a focus directed at the airport terminals. Analysed literature defines the wayfinding, investigate the components and propose classification and tools, that can be used in further design of this paper.

2.2.1 What is wayfinding?

Wayfinding has been a process accompanying humans since the dawn of ages, it is just the environment affecting it that underwent changes. The first hunter-gatherers used the natural visual environment of the forest to find the prey, the first sailors used the sun and stars to navigate the sea. In the modern context, when we talk about wayfinding, it is usually in regard to the man-made, built environments. It is also here, that a person - designer of the space - has a direct impact on these processes, as opposed to the environment designed by nature. Modern wayfinding has been defined by Fewings as ''(…) a process of finding one's way in the geographical or built environment; that is, being able to identify one's present location and knowing how to get to the required destination.''(Fewings, 2001). Now if we talk about the sub-level of wayfinding - the intuitive wayfinding - it is the capacity of getting from one place to another without obvious influences and rational or cognitive processes (Pon, 2005). Golledge (as cited in (Beecher, 2004)) proposes the following differentiation of wayfinding processes based on the complexity of actions:

First is a process of following an intended route - navigation. It is similar to a definition of a static choice problem by Fewings (Fewings, 2001)- where the choice is between predefined, known sets of options – i.e. choosing transportation modes from A to B. Second is a process of seeking information in order to decide on a route based on that information, or as defined by Fewings - the dynamic choice problem (Fewings, 2001). Here choosing the route requires acquiring information about it, or being provided with new information. This is the type of problem we encounter at airport terminals.

Fewings further elaborates the techniques of wayfinding within the dynamic choice problem as recreational, resolute and emergency:

- Recreational wayfinding - where the experience of wayfinding itself takes priority over the functionality of getting from A to B; wayfinding becomes a source of satisfaction and pleasure. A good example is a tourist wandering through an unknown city, or a person taking a bike ride in a new neighbourhood after moving in.
- Resolute wayfinding - where the purpose is strictly functional, that is: getting to the destination point in the most efficient way. In the context of airport terminals, the example would be a passenger going through the airport in a rush before the gate closes for boarding. This is the type of experience we will be focusing on in this paper.
- Emergency wayfinding - the third type of wayfinding is a more extreme version of resolute wayfinding - here the only important factor is to reach the destination quick and safe. Key factors here are to provide extremely clear instructions and visual clues so people in a stressful situation are still able to correctly recognize the right way.

Another author, A.B. Beecher brings up two additional descriptions of wayfinding by T. Todd Elvins and Arthur and Passini (Beecher, 2004). The first one described wayfinding as determining the strategy, directions, and course needed to reach the desired destination. The second one suggested a definition of wayfinding as a decision-making process with an emphasis on the availability of information in the process, where despite identical environmental conditions, the decision can still be different basing on the individual.

An important thing to understand is that wayfinding is not always affected by the information. There are moments, at which there is no available relevant information and the decision is made by chance or instinct. Moreover, the researchers point out that people use available information differently. Some use just minimum that is shown just to proceed further, while others search for more information before making a decision.

2.2.2 Wayfinding tools

The actual term *wayfinding* was already introduced by Kevin Lynch in his Image of the city (Lynch, 1960), where he described and categorized different elements of the city used both consciously and subconsciously by people, to find their way around. Those elements or visual clues are described as following:

- **Landmarks** - Physical objects standing out from an environment. Easily recognizable and solid orientation point. Good examples are city halls in most cities, Eiffel tower in Paris, big churches, etc. They can also be elements of a natural environment such as a waterfall or a hill in a city.
- **Paths** - Recognized routes along which the observer occasionally or intentionally moves - i.e. Streets, walkways, canals.
- **Nodes** - Strategic orientation points where the user can enter different districts or choose different paths. They can be junctions, stops in transportation, etc., They can also be places of concentration or assembly such as city squares, which usually are the most recognizable places of a district.
- **Edges** - Boundaries between two elements - lateral references rather than coordination orientation axes. Edges are environmental features that define the areas and districts – i.e. Buildings, railways, rivers, roads.
- **Districts** - large sections of an area with common features or themes – i.e. old town areas in major cities.

Now this ‘pioneer set of tools’ was designed for the city level; however, it can be translated into indoor spaces. Wayfinding at the airport terminals involves the same visual clues, but on a smaller scale and usually on multiple levels of a building. There are predefined paths of passenger processing procedures (security, immigration, check-in, etc.), ‘districts’ of the lounge area - retail, the food court - with important areas that can be perceived as nodes - such as seating areas for passengers, or central gathering points before going to one of the piers.

“Big modern terminals are arranged in plan with streets and squares, gardens and towers, districts and neighbourhoods. When a building becomes as large and diversified as a small town (Heathrow alone employs 68000 people) then it is inevitable that the prime buildings take on civic characteristics.” (Edwards, 1998)

2.2.3 Wayfinding tools in airports

In the case of an indoor environment such as a large airport terminal, the process of decision making is much more “manipulated” than on the city level. It is necessary to make some decisions for the passengers not only to avoid overcrowding of certain areas, which is proven to increase anxiety (Tombs & McColl-Kennedy, 2003) but also to provide sufficient and full guidance in a new environment. This is especially essential in the processes that have to be sequential in a defined order, such as the traveller processing procedures.

A key principle is to think of an airport wayfinding strategy as any other building system - it needs to be maintained and treated as an integral part of the airport’s building systems (National Academies of Sciences Engineering and Medicine, 2011, p. 93). The book *Wayfinding and Signing Guidelines for Airport Terminals and Landside* define principles for airport wayfinding strategy. These can be used to evaluate the wayfinding design (National Academies of Sciences Engineering and Medicine, 2011, pp. 14–28).

Key principles for the design of a successful wayfinding strategy are:

- Continuity - the system should be continuous throughout the different architectural environment.
- Connectivity - the system should deliver the right type of information at the right time.
- Consistency - the system should be consistent in its form throughout the whole experience of wayfinding. Consistency principles should be employed in terminology and hierarchy of delivered information, visibility, and legibility, placement - where in the three dimensional terminal space are the wayfinding visual clues, typography and symbolism, format and color, etc.

Inside terminals, mostly understood method of defining a way is physical limitation and boundaries that make it impossible to choose a wrong path. In more open spaces people use several factors to find their way around, that is where it becomes a challenge. Research has shown that decision points which lead to a change in a level (multi-levelled structures) have a higher chance of negative impact on wayfinding experience compared to same-level decision points (E. S. Dada & Wirasinghe, 1999). Widely used principles and tools for wayfinding can be summarized into following, as according to the previously cited authors (Fewings, 2001; National Academies of Sciences Engineering and Medicine, 2011; Pon, 2005):

- **Visual access**. Wayfinding is simple and straightforward if the destination is clearly visible from the start. Here the landmarks play a significant role. Even if the destination is not directly visible, but a landmark associated with it is, it gives a sense of reassurance of the path and distance.
- **Maps** are universal wayfinding tools for both indoors and outdoors. They can be physically present at the place, available beforehand in an online version or as a printed leaflet. Usually, maps that are pre-aligned work best, meaning maps positioned in the space facing the same direction as a person reading it, with a clear indication of location with the You-Are-Here marker.
- **Live personal support.** Especially useful for visually impaired people or those who prefer verbal instructions.
- **Auditory information**. Audible messages act as a supplement to visual clues - they are a dynamic indicator of time-relevant events, i.e. about soon departing planes and gate information. As mentioned above – auditory information can be provided through live support, or as audio communicated through speakers. The advantage of audio communication is that the sound does not need to be found, as opposed to visual clues.
- **Architectural differentiation and interior design features**. Orientation inside a building can be eased, if different areas have distinct architectural features (could be as simple as colors) or styles. For example, experiencing the contrast between low-ceiling corridors of security check and then proceeding to the spacious and open lounge areas gives the passenger indication of reaching the new zone of the terminal.
- **Plan configuration**. If the terminal has a grid or symmetrical, predictable layout, it is more intuitive to find a way around it. This depends on the type of terminal, and

whether the terminal had an expansion. Complex structures imply complex paths which can be enhanced by the design of services and interior design of zones such as retail or lounge. Complex paths mean multiple decision points - which increases a potential challenge for simple and effective wayfinding.

- **Atmosphere**. Creating an inviting or deterring atmosphere with architecture and interior design can vastly contribute to the wayfinding process.
- **Signs**. Signage is an inevitable element of successful wayfinding strategy. Signs should provide essential information in a clear, non-ambiguous manner. The authors define three categories of signs: directional – showing the direction to the destination (usually with an arrow), identification – identifying an object or place (f. ex. Food court, bathroom, etc.), and reassurance – reassuring about correct path along the way.
- **Digital airport signage** - Modern type of airport signage - versatile digital screens, capable of dynamic display of changeable content. At the terminals they are found displaying (NanoLumens, n.d.):
  - Flight information (FIDS - Flight information display system).
  - Wayfinding - Basically the signs described above, but in a digital form. Also including interactive maps.
  - Retail and advertisement - All the screens used for displaying commercial information and advertisement.
  - Art and culture - the growing trend of displaying and promoting local culture, art, and events.

2.2.4 Lighting of the signage

To partially answer the initial problem statement, it is essential to research the existing good lighting practice for the wayfinding tools. From the tools described in the previous sections, the literature review has shown that in terms of lighting for wayfinding purposes, the important aspect is lighting for the signage. It can be categorized into following (National Academies of Sciences Engineering and Medicine, 2011, p. 154):

- Internal illumination of the entire sign, including electronic screens.
- Internal illumination of the text only with an opaque sign background.
- External illumination that uses wash lights on the signage.
- Ambient lighting inside the airport providing the visibility - here no additional lighting is considered for the signage.

Regardless of type of illumination, general guideline for sign itself is to have a high contrast - around 70% - between information and background, with black or dark blue on a yellow or white background is the best choices (Edwards, 2005, p. 162)(National Academies of Sciences Engineering and Medicine, 2011, p. 155)

However, looking at the contrast between sign and its surroundings, the designer should take into consideration the location of the signs. The general light ambience of the terminal lighting, also a visible light source in immediate surroundings of the sign should not significantly exceed the light level from the sign, so as to avoid the background glare – this is especially important to consider while positioning signs near large sources of daylight or dynamic screens.

For further glare prevention, the final luminance from the sign needs to be uniform on its whole surface, so as to avoid creating hot spots - significantly brighter areas. This is usually insured by using washing light on the surface of signs and avoiding using specular materials.

2.2.5 Wayfinding with light

Lighting has a huge role in wayfinding and decision-making process. As Blake's et al. (Blake, Hall, & Sissel, 2010) experiment concluded, more people would choose a way towards a lit corridor even though the signage pointing to another direction was provided. The signage had influence in the decision-making process but more people chose the direction towards a lit path. Both daylight and artificial light can be employed to enhance the wayfinding experience. In the context of an airport and already heavily competitive visual environment, the intended cues of wayfinding can be lost and overwhelmed by other existing features. The light should be used as a wayfinding tool to highlight key destination points such as elevators and connector bridge access points (J. Harding, 2012).

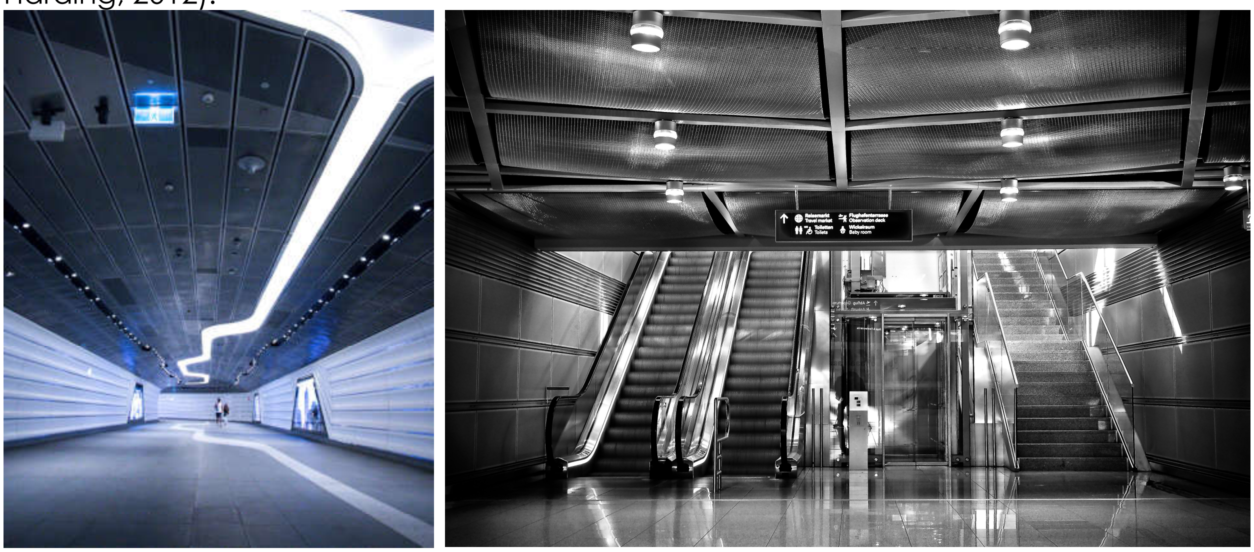


Figure 9. Examples of wayfinding with light

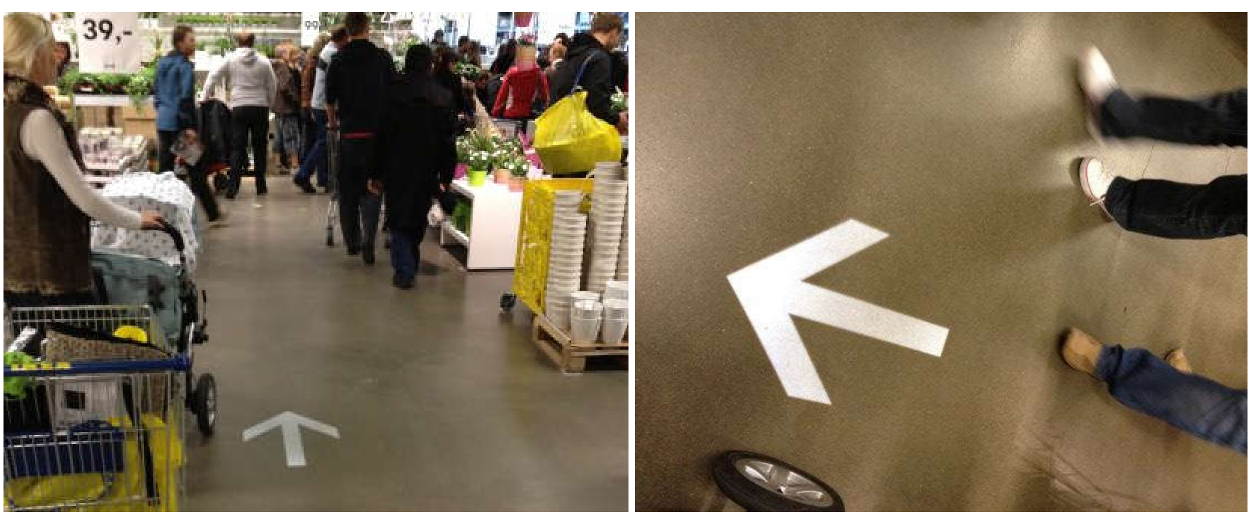


Figure 10. Example of IKEA solution for wayfinding with projections on the floor

2.2.6 Wayfinding at airport terminal - the issues

As established in the previous chapters, wayfinding in large terminals can be a challenging experience. Especially for first-time travellers, where reaching a desired primary and secondary destination point or simply knowing the exact position in the building can be overwhelming. Over the history of architectural design for the airports, wayfinding increasingly has been given more attention, however in some cases, normal practice is still to consider the wayfinding as an afterthought, rather than planning buildings with wayfinding as a building system in mind (Fewings, 2001). The previous chapters analysed the tools and design principles of good practice, and how lighting interplay with it. If these design principles are not incorporated or executed properly there is a chance of failures in the wayfinding system. Nonetheless, even in cases of a well-made and consistent wayfinding system, various authors identify two additional, yet significant problem areas such as the visual noise and impaired cognition described in more detail in the following chapters (Ezekiel Sunday Dada, 1997; National Academies of Sciences Engineering and Medicine, 2016, p. 13-15; Pon, 2005).

2.2.7 Visual noise

It all comes down to the nature of human cognition system. If there is too much information in the visual field, people tend to read only the dominant features - and abandon the attempt to look or read anything else. Likewise, if there is too little information - the eye will capture less visible clues (Arthur & Passini, 1992, as cited in (Beecher, 2004)). This added step of filtering and deciphering relevant information from the visual field adds yet another layer to the process of wayfinding, often resulting in impatient and disoriented passengers (Pon, 2005). Over-information usually occurs if it is not sufficiently delivered with only the essential and easily understandable messages. Here the principle of consistency is especially important, so as to not introduce too many variations of the same information system. Another factor causing an overload of visual information can be caused by excessive signage - which has paradoxically been reported to partly cause wayfinding problems (Ezekiel Sunday Dada, 1997). Information overload is a problem especially in multi-functional large structures, where wayfinding system is trying to show all the possible directions and functionalities from a given point. Moreover, terminals are usually rich in advertisement emitting powerful visual stimuli. (National Academies of Sciences Engineering and Medicine, 2011, p. 151)The visual input from retail areas and advertisement in modern day terminal surroundings often include dynamically changing signs with high luminance. Unfortunately, they are usually not designed in harmony with the terminal but rather added afterwards in an inconsiderate manner (Edwards, 2005, p. 151).

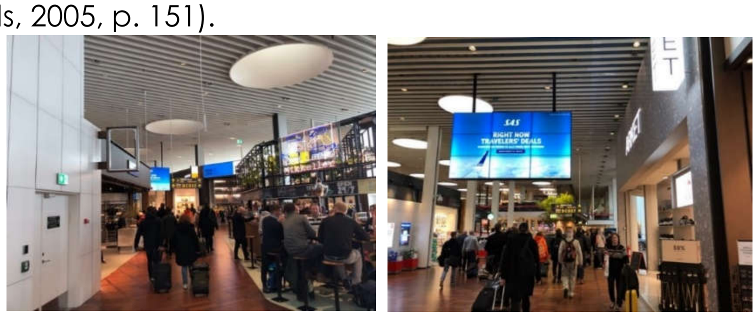


Figure 11. Example from Copenhagen Airport with dynamic screens of high luminance in the visual field which requires cognitive effort to process.

Figure 12. Example from Copenhagen airport with repeated signage, which can paradoxically cause confusion.

Figure 13. In spacious terminal lounge areas, the retail advertising competes with plentiful of signage causing visual noise. Here the wayfinding solution was to use very dominant and large signage. Example from Amsterdam Schiphol.

Another factor contributing to the overcrowding of the visual field is a choice of materials. High reflectance of some interior finishes, such as tiles, can result in mirror-like effect almost doubling the visual information to process. Moreover, reflective surfaces are susceptible to glare and can significantly reduce the visibility of important information such as signage.

Figure 14. *Example from Terminal 4 at Changi International Airport - here the large advertising screen completely dominates visual field taking the majority of passenger's attention. Floor tiles create a mirror-like effect on the floor reflecting the ceiling and screens.*

2.2.8 Visual noise - the glare issue

The architectural approach of maximizing daylight intake comes with a certain challenge of visibility - visual noise caused by the glare. The vertical window provides only about 40% of daylight a same size roof window does, however it is a major source of glare problems because of low sun glare directly in the visual field at the uncomfortable angles of viewing (Edwards, 2005, p. 167).

Another type of glare important to consider is the veiling reflections on the display screens, equally important for the wayfinding processes as they make the reading of signs and screens difficult. Discomfort glare can also be experienced due to high contrast when the passengers face the displays with glazed curtain walls behind them or roof glazing above.

The issue of daylight glare is mitigated by designers by using a number of tools such as external screenings, roof overhangs, tilting or special types of glass with surface treatment, positioning of the signage, or highly luminous screens to overpower the veiling reflections (Edwards, 2005, p. 167).

Figure 15. *Floor tiles at Barcelona airport create a tiring mirror-like effect.*

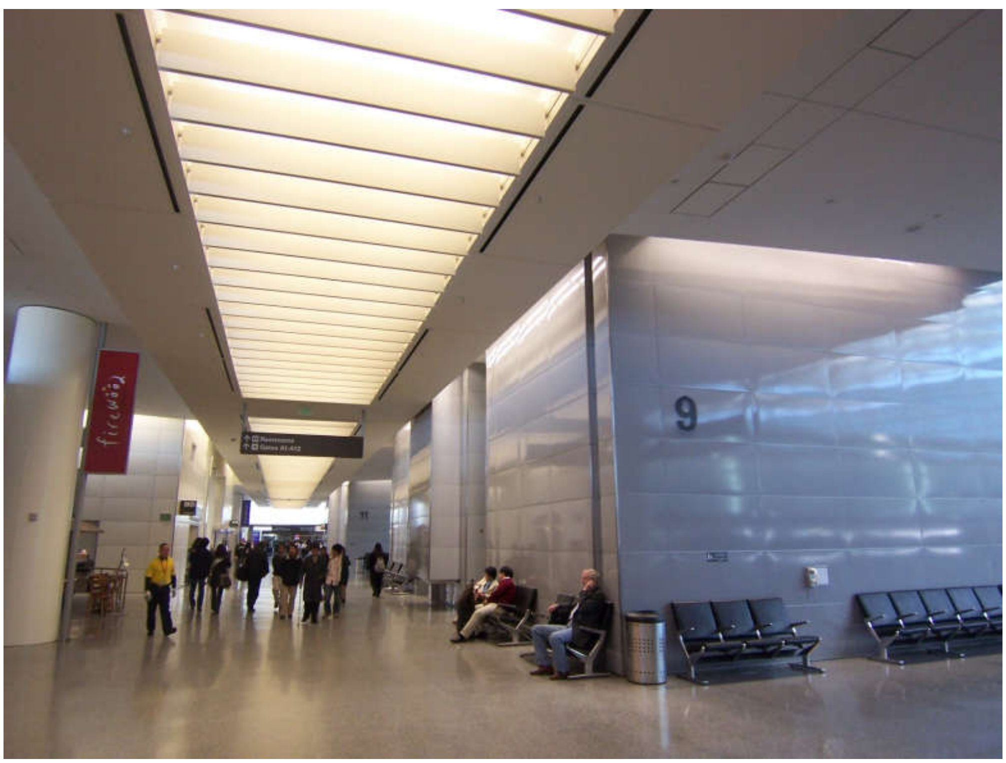


Figure 16. *Due to daylight reflections, a non-luminous gate sign can be hard to read from a distance when placed on a highly reflective wall surface. San Francisco Airport*

2.2.9 Inequality of passengers - impaired cognition

Another challenge for the wayfinding system is impaired cognition of a passenger. This can be a variety of issues - reduced vision, height, color blindness or illiteracy. Another group of impairments comes from cultural differences, which are the inability to read the language of a sign, unfamiliarity with architectural style and traditions, or unfamiliarity with graphical elements representing functionalities (Ezekiel Sunday Dada, 1997; Gärling, Lindberg, & Mäntylä, 1983).

Figure 17. Amsterdam Schiphol is a major transferring airport for intercontinental flights from Europe. For a person unable to read English, Dutch or even Latin alphabet it can be quite a challenge to orientate oneself in the environment.

2.3 The users of an airport terminal

2.3.1 The user group

Previous chapters identified and elaborated on the spatial premises of the airport terminals and type of design methods used for wayfinding. This part analysis introduces the categorizations of terminal users. There are two main groups of users identified by the way they are using the terminal and its paths (functionality), and by the response to the wayfinding tools, which connects with the level of repeated experience of an airport terminal. Airport user types are differentiated as following (J. R. Harding, Marshall Elizer, Alderman, & Frankel, 2011):

- Departing passengers - arriving at the terminal and transitioning to the air side.
- Arriving passengers - arriving with an airplane and transitioning to the land side.
- Connecting flight passengers - arriving with an airplane and transitioning to another flight without leaving the terminal.

- Non-travelling visitors – Fourth category of terminal users are the visitors, whose access is limited to the non-sterile environment.
- Terminal employees – A very well acquainted with the layout category of users of the terminal, and not paying attention to the functionality of wayfinding tools. They will, however, be affected by it in an indirect way. Any wayfinding visual element will be present in their environment for the duration of a working shift.

S. Pon suggests a more wayfinding-focused classification of passengers, depending on what type of stimuli they react to (Pon, 2005):

- Domestic and business - regular passengers, who are used to the terminal layout and existing paths. They are aware of the signals to look for and filter out information they do not need. They are confident and need little reassurance, therefore the wayfinding tools are not as essential for them as for other groups. On the other hand, in a similar manner as the airport employees, the frequent visitors will experience whatever wayfinding tools there are on a regular basis, therefore it is important to make the wayfinding design long-time sustaining and visually pleasant.
- Vacationer and personal traveller - They depend heavily on the wayfinding tools; however, they also have a more relaxed attitude and know what to look for, due to some experience in flying. They know their primary and secondary destinations - security check, departure gate, lounge, etc. - however they do not know how to get there. They are responsive to the path but need reassurance on the way.
- Transfer passenger - They experience only a part of the terminal and are usually in a rush to get near the departure gate of their next flight. For transferring passengers, the most important wayfinding element is a proper and visible indicator of the right departure gate.
- First time flyers - The most inexperienced and anxious group. They rely heavily on wayfinding tools - especially signage, as sometimes due to stress or excitement they fail to identify other environmental or less apparent visual clues. For first time travellers, the clearer the instruction, and the fewer options there are, the better.

2.3.2 Airport anxiety and stress

All of the above-mentioned types of passengers are susceptible to a particular psychological occurrence defined as airport anxiety. Targeting this issue was also the main motivation for exploring the topic of airport wayfinding, as authors, being able to identify within each of the user groups, had repeatedly experienced this phenomenon throughout their journeys.

A major factor contributing to the stress levels at the airports is time pressure. As described by AIR magazine, the gate anxiety comes from fear of not going through all the airport procedures in the time before the departure. (Baker, 2018)

Literature confirms that perceived air travel anxiety is a common occurrence (Swanson, Dempster, Power, McIntosh, & Raeside, 2006) and can be identified as a psychological concept linked to the increased stress levels and frustration of air travellers (Wattanacharoensil, Schuckert, Graham, & Dean, 2017). Another research on the airport experience concluded that there are two main factors, that can directly have a negative effect contributing to airport anxiety (Bogicevic, Yang, Cobanoglu, Bilgihan, & Bujisic, 2016):

- Functional organization. Orientation at the airport, achieved through the wayfinding strategy, such as spatial layout and comprehensible signage.
- Air and lighting conditions, affecting the physical comfort of a passenger.

Two other investigated factors were cleanliness and seating, which were interestingly found to have little impact on traveller's anxiety. The authors sum up "(...) bad signage systems, poor plan configuration, inadequate lighting, and air quality can induce anxiety in travellers and result in their dissatisfaction. Considering that air travellers are extremely time-sensitive, airports are advised to provide successful wayfinding through the facility. In ideal conditions, passengers should spend as little time as possible commuting between terminals and gates, or trying to identify information on signs."

Which is also emphasized by Susanna Pon, who concludes, that at airport terminal it is crucial that passenger who may be handicapped by stress and fatigue, has all the necessary information required to make a decision quickly (Pon, 2005).

Other research on wayfinding has shown that common emotions associated with wayfinding are fear, anxiety, or even anger (Beecher, 2004). Therefore, a successful and intuitive wayfinding strategy should work to reduce these negative emotions and thus improve the airport experience. This is an important point to stress for the airport as an institution. A stressed and disoriented passenger will have a rather negative opinion on the terminal service - which will reflect in reviews and ratings. Moreover, such a passenger is likely to spend less time and money in the retail zone or airport facilities, services, and entertainment. As summarized well in *Wayfinding and Signing Guidelines for Airport Terminals and Landside* (National Academies of Sciences Engineering and Medicine, 2011, p. 146) "(…) passengers who have a positive wayfinding experience will be confident in taking time to shop; while passenger that are lost and confused will worry about missing their flight more than shopping."

Associating certain built environment with wayfinding difficulties may lead people to avoid those places - such as shopping malls, hospitals, museums, airports, train stations, etc. It can also make people late for important events, meetings or flights, which may cause loss of opportunity and money. Moreover, research suggests that negative airport experience can potentially be a decisive factor in avoiding travelling to certain locations (Wattanacharoensil et al., 2017).

2.4 Case studies - assessment of wayfinding processes

To further validate the findings from literature study, this section presents an assessment of wayfinding strategy at two airports from different geographical and cultural contexts - Miami International Airport and Brussels Airport, which the authors had a chance to visit during the time of writing this thesis. The assessment is focused on the wayfinding process and significance of the problem areas identified through research:

- The efficiency of wayfinding tools
- Visual noise
- Airport anxiety and stress levels

2.4.1 The arrival and departure at Miami International

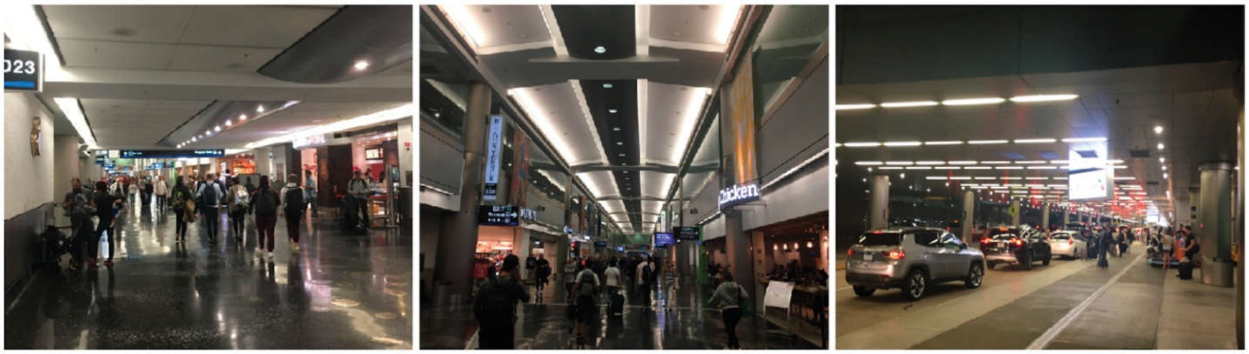


Figure 18. Arrival flow in Miami International Airport, USA.

Arrival - *Being a domestic flight within the USA the terminal was really simple to leave after the flight landed. The baggage claim in the US airports is usually located in the non-sterile area of the airport. The only issue I have faced as a traveller was to find my way out to the correct floor of the arrivals. I ended up waiting for a ride-sharing car service in the wrong area without being aware of it. After a few attempts, I had to go back inside the airport and look for cues to where I might need to go. After an intense few minutes, it was clear that the pick-up area was located one floor below. The signage was poor and my intuition led me straight outside as there were a lot of people and cars believing this is the right place, but it was misleading.*

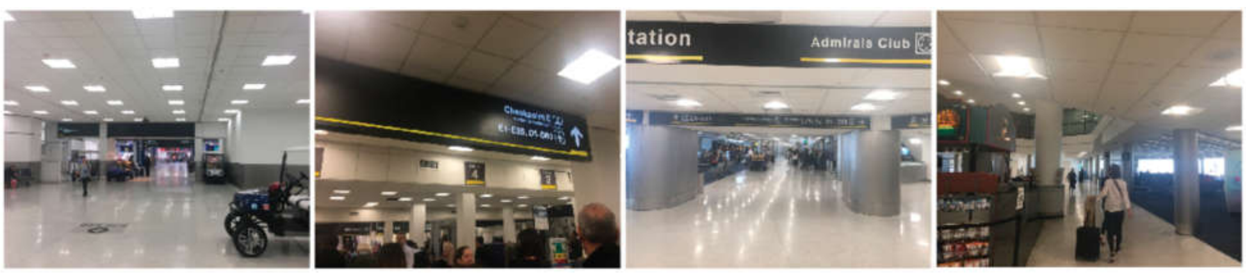


Figure 19. Departure flow in Miami International Airport, USA.

Departure - *The departure was a little stressful due to the fact that only the gate, not the terminal was provided prior to the flight. I was dropped off by the airline check-in desks to make sure I can find the right terminal and gate. I had to go through two terminals and ask the people working there which terminal my gate is at, after that, it was easy to follow the signs, but the security check was located at the floor above and the only available wayfinding tools were signage that I passed initially.*

All in all, the airport is easy to navigate, but the change in the level of the environment should be indicated better. Another reason why the experience might have been a little stressful is the cultural differences. Airports in the USA are similar to Europe but still have minor differences that were easy to notice. For example the public transportation is not as advanced.

2.4.2 Transfer at Brussels Airport

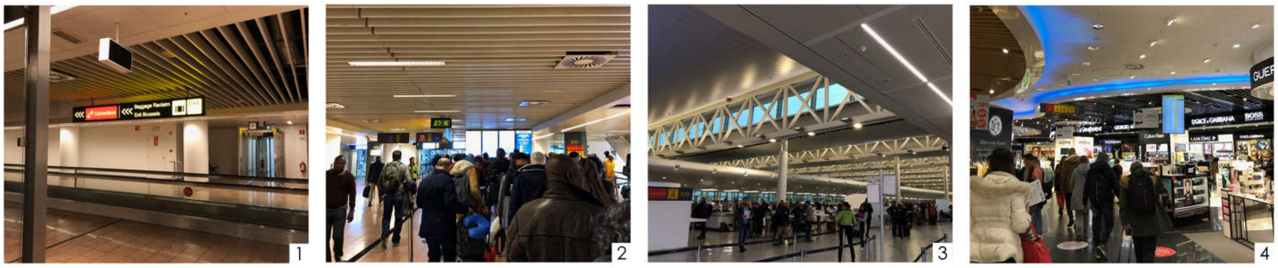


Figure 20. Transfer flow in Brussels Airport, Belgium.

From the start, the traveller is met with wayfinding instructions and a color theme to follow (1). Relaxing reassurance is countered with an increased stress level caused by a large amount of queuing transfer passengers (2). Information displays dominate the visual field creating the main point of attention and reassuring with the flight information. After the transfer security screening passenger is passing on the left the main building security screening area (3). Notice how the array of windows and structural elements are aligned to the passenger paths from the entrance hall through security screening.

As a transfer passenger, the path is straightforward with physical limitations and reassuring signage eliminating the risk of any hesitation along the way. In the retail area, the visual field is exposed to plentiful of advertising and branding, creating a lot of visual noise (4). Here the blue light lines on the ceiling provide a good indicator of the path, distinguishable from surroundings. Stress and cognitive effort to filter the information in shopping areas is countered with the pleasant wave of blue light easier to focus on along the path.

Figure 21. Transfer flow in Brussels Airport, Belgium.

Further into the airport, the passenger is led to the food court lounge with a tall and glazed ceiling. There is also a landmark (5) - restaurant sculpture - attracting from a distance. Moreover, the blue light pattern is continued along structural beams leading towards the passage to the next pier (5,6). The departures pier is organized in a straightforward way, with architecture being the main indicator of the flow with well-organized signage (7,8). Here the blue light pattern did not continue.

Overall, transferring at the Brussels Airport was a pleasant experience with well-executed wayfinding strategy at every stage of the journey. As a tired (after 8 hours of night flight from completely different climate) passenger with increased levels of stress and anxiety, the author did not experience a feeling of being lost or confused at any part of the journey. In terms of lighting, using a distinguishable color on the ceiling areas was a pleasant, reassuring add-on. However, if it's continuity was preserved throughout the buildings it could have had more effect.

2.5 Summary of problem areas

Literature research and examining examples of terminals from around the world led to identifying the main problem area that can be associated with airport terminals – poor wayfinding. Key factors include visual noise, impaired cognition, time pressure, and disorientation in the space. A consequence of these factors contributing to poor wayfinding can be identified as airport anxiety of the users. Furthermore, self-made case studies confirmed the validity of the problem areas. Figure 22 below shows a summary of the problem areas and is a foundation for the vision of the project.

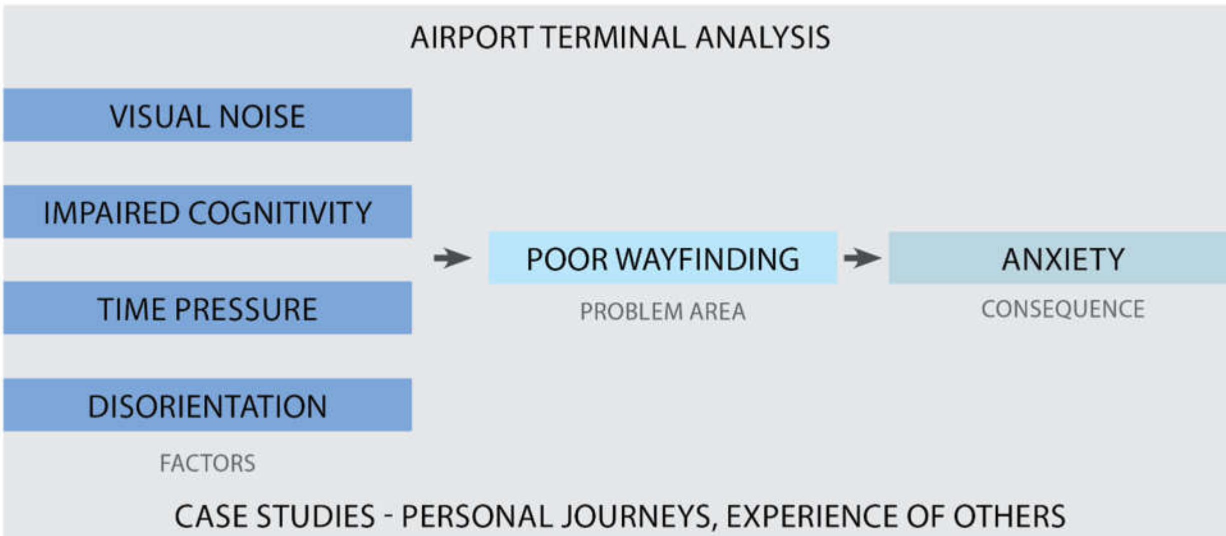


Figure 22. Summary of problem areas generally found in airport terminals based on the literature analysis

3. Vision

Imagine if a new approach to wayfinding experience in airport terminal could be intuitive and stress-free.

The vision is focused on easing the experience of people affected by airport anxiety. The idea behind it is to create a lighting system which could help intuitively orient people in the terminal environment. This does not mean that signage should be eliminated completely, but theoretically, less of signage could be used. Therefore, this could contribute to less visual noise. An intuitive system would also help people with impaired cognition, such as people from other cultures, visibility issues or those who do not speak languages signage is provided. This would allow reducing the possible time pressure, by ensuring a traveller that he/she is following the right direction towards their designated gate. Being sure you know where to go could potentially increase the travellers time spent in recreational zones such as retail or dining. Moreover, the concept could be implemented in the future designs of airport wayfinding systems.

The literature review has shown that lighting of the existing wayfinding tools (utilizing daylight and open spaces to guide and attract people, lighting signage in a correct way) is already a well-described and commonly considered practice, therefore with the design, we will explore an option of a more innovative, modern approach. Further chapters of focused research explore the design methods and visions that could potentially aid while creating the concept and solving the problems described in the previous chapter.

3.1 Focused research

This chapter focuses on finding the right tools that can be used to tackle the identified problem areas, and how they can be implemented in the design. At first, a comparatively new concept of ambient communication is introduced. Then the principles of nature centred design, as a starting point for the concept and a way of addressing the stress-reduction factor. Last part of this chapter discusses the future of the airport design and passenger processing.

3.1.1Ambient communication

In the search of a tool which could contribute to easing the traveling experience for already visually overwhelming and crowded airports, a concept of ambient communication could be potentially used. The idea of ambient communication is comparatively new and has its roots in a widely accepted definition of ambient intelligence (AmI). Defined by the EC Information Society Technologies Advisory Group (ISTAG) in a vision of the Information Society dating back to 2001(Ducatel, Bogdanowicz, Scapolo, Leijten, & Burgelman, 2001). ISTAG introduced the concept as a part of the technological growth of interfaces:

"People are surrounded by intelligent intuitive interfaces that are embedded in all kinds of objects and an environment that is capable of recognizing and responding to the presence of different individuals in a seamless, unobtrusive and often invisible way." (Ducatel et al., 2001)

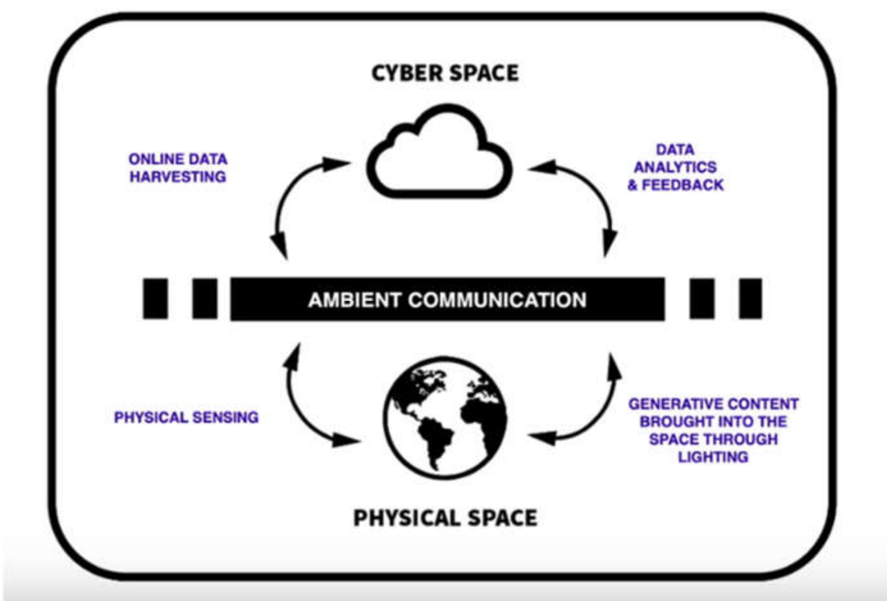


Figure 23. Model showing the principles of ambient communication.

The ability of carefully design everyday objects to interact and influence the users without them being aware is based on **peripheral awareness** defined as, "our ability to maintain and constantly update a sense of our social and physical context." (Pedersen & Sokoler, 1997). This means that most of the ambient information systems are focused on providing the intended information to the periphery of the users' attention. In this manner, users are able to receive the information without even being aware of it while still maintaining the primary tasks in the foreground (Davis et al., 2017).

"(…) information is moved off the screen into the physical environment, manifesting itself as subtle changes in form, movements, sound, color, smell, temperature, or **light**" (Yarin et al., 1998).

Lighting is a subtle and easily available tool for encoding and displaying the intended information. The information can easily be encoded to lighting by using the four most common parameters: colour, brightness, position and a pulse, according to Mankoff J., & Dey, A. as cited in (Davis et al., 2017). These parameters are then implemented into a peripheral display which is not meant to be the primary focus of users' attention and can deliver the necessary intended information. These displays can be divided into two categories - ambient and emergency (Mankoff & Dey, 2003). This project will focus on ambient displays. Where a successful ambient display is defined as a system able to modify users' "(…) awareness of certain information and potentially change one's behavior with respect to that information." Mankoff, J., & Dey, A. (2003)

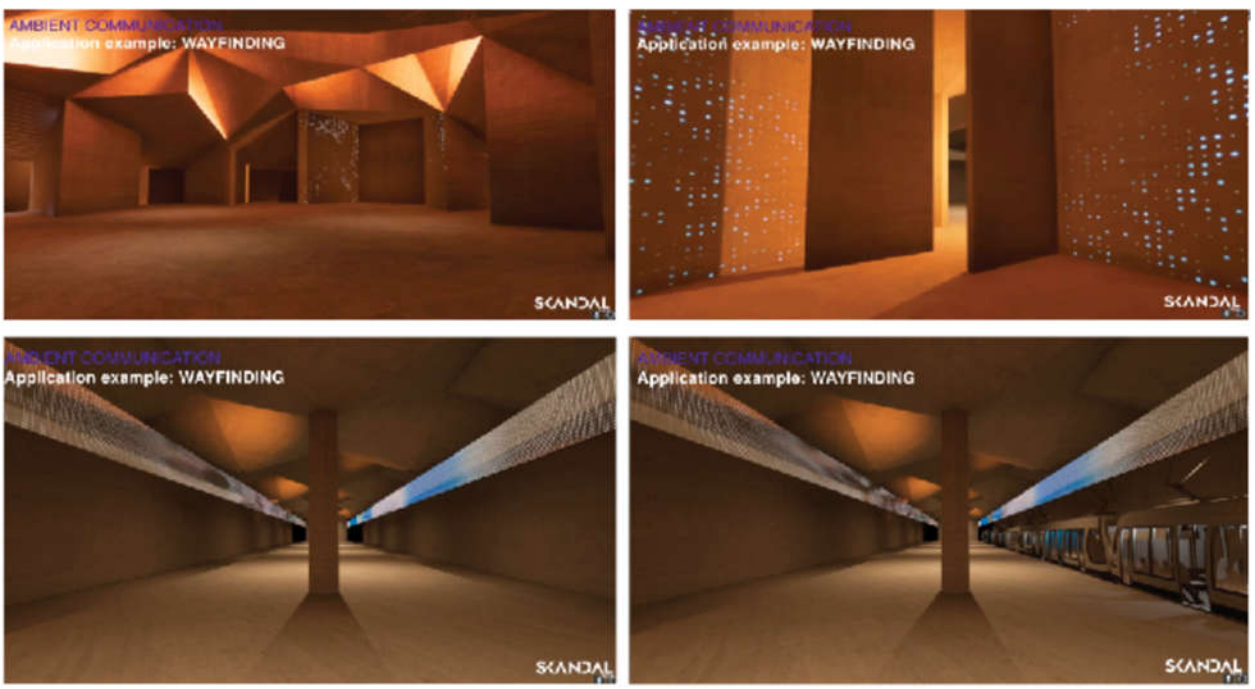


Figure 24. Example of ambient communication in the train platform by Skandal Technologies.

A company based in Helsinki - Skandal Technologies - have already introduced some design concepts with ambient communication for influencing behaviour and enhancing wayfinding. This conceptual example can help us understand the design principles better and introduce the wayfinding with ambient communication to the airport terminals. The example above (Figure 24) shows how persuasive technology could possibly improve the distribution of people on the metro platform. The blue light shows the sensor data from the arriving train and indicates the carriages with fewer people so that the waiting passengers could intuitively distribute themselves more evenly throughout the platform. The goal is to improve the people distribution only by 3-5% which could provide a vast amount of savings corresponding to the train operation. (The New School, 2018).

3.1.2 Nature centred approach (bio-design)

It is proven that the aspect of nature in built environments contributes to advancing people's well-being, physical and mental health (Kellert & Calabrese, 2015, p. 4). A practice of biophilic design described by Stephen R. Kellert and Elizabeth F. Calabrese breaks it down to 3 categories:

- Direct experience of nature includes attributes such as light, air, water, plants, animals, weather, natural landscapes and ecosystems, fire.
- Indirect experience of nature can include images of nature, natural colors, simulation of natural light and air, nature inspired forms and shapes, natural geometries, biomimicry.
- Experience of space and place contains attributes such as organized complexity, integration of parts to wholes, transitional spaces, mobility and wayfinding, prospect and refuge, cultural and economic attachment to the place.

Using an indirect aspect of nature in the wayfinding practice by focusing on nature inspired forms and shapes, naturally occurring colors, geometries and biomimicry could potentially contribute to improving the anxious travel experience. Furthermore, the sense of space and place can be enhanced by the integration of parts to wholes, for example, connecting different areas of the airport such as retail and a connector area, with a more fluent, intuitive and continuous wayfinding tool.

Figure 25. Natural phenomena of northern lights.

3.1.3 How can nature be translated into lighting?

One of the ways to translate nature into technology and intuitive lighting design could be by using a generative content that can be communicated to the user through an ambient communication system. A well-known and widely used realistic CGI algorithm Perlin Noise was introduced by Ken Perlin in 1985. The algorithm can mimic water, clouds, marble, etc. (Perlin, 1985). Introducing an algorithm like that or a similar one would allow creating a lighting system for wayfinding design providing an aspect of nature. There are a lot of parameters that can be edited such as the speed, intensity, size of the particles, etc.

A good example of an installation using ambient communication and generative patterns is an award winning lighting installation in Helsinki - Silo 468 by Lighting Design Collective. Where the old and unused oil structure was transformed into a day and night art piece. The installation is using a generative pattern based on the way birds move in the area, the speed of the pattern movement is based on the prevailing wind direction to illuminate the LEDs at night. During the day reflective material pieces move inside the perforated surface to extend the movement of the sea surface on to the walls of the silo. The piece became a landmark and a civic space for the public. It is visible from various locations throughout the city. This is a good example of how nature mimicking lighting can be incorporated into the design. Please see Figure 26 below.

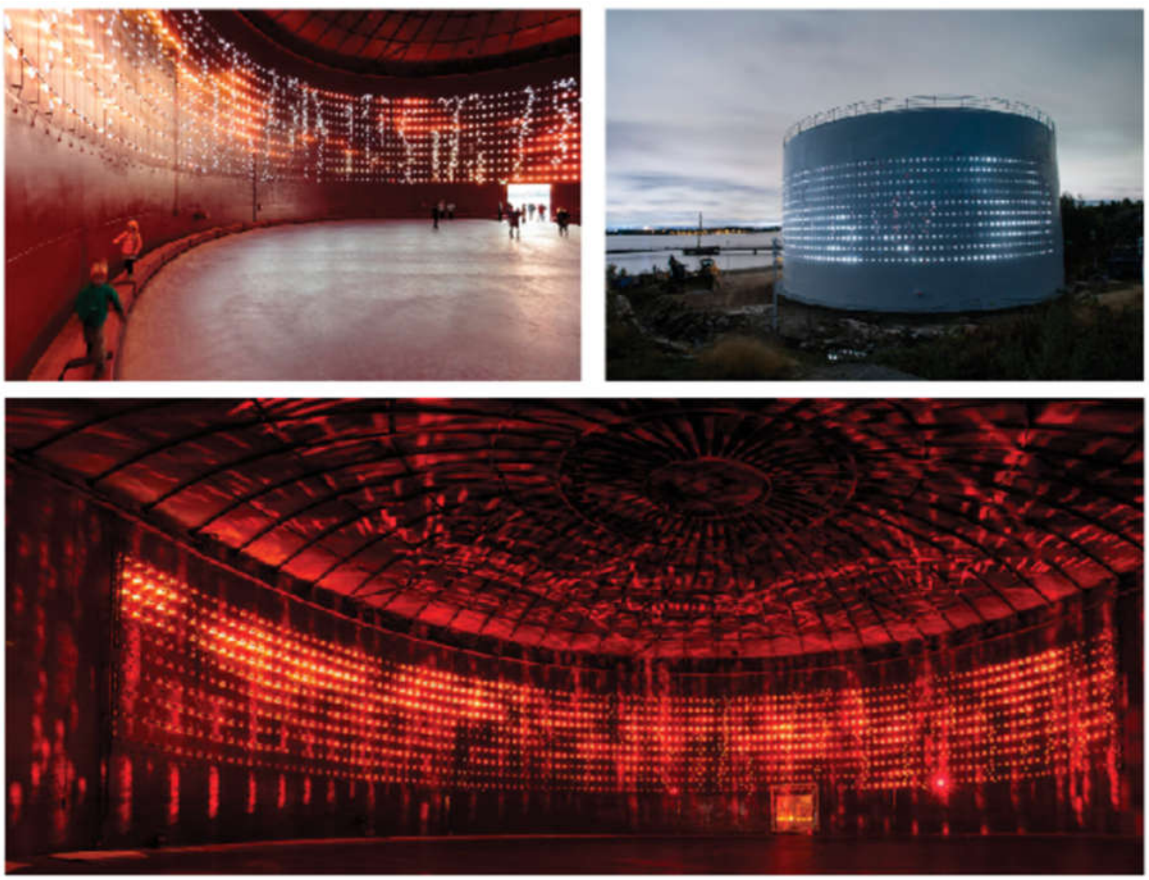


Figure 26. Silo 468 by Lighting Design Collective. An award winning installation using generative patterns and ambient communication in Helsinki.

3.1.4 The future of airports

In order to design in a dynamic environment such as an airport, it is important to understand that it evolves and changes. Not only the technology is evolving fast, but the ideas of the way airports are being built is also changing. How design for a lighting wayfinding system can be forward thinking and used in the future? To find out how the future of the airport looks like, the Reuters series of The Business Debate Global Thought Leadership interviewed Dubai Airports CEO Paul Griffiths and gave an insight into how the not so far future of the airport can be redefined. One of the main points stressed by Mr. Griffiths was that the current design approach is based on the convenience of the designers and operators, not the convenience of the customer. The fact is most people want to spend as little as possible time in the airport. The latest technology is being implemented in Dubai's airport in order to speed the processing of passengers and reduce the time spent at the airport. The future technology includes the usage of biometric tokens, shortening ques and reducing waiting time while being able to support the growth of passengers without expanding the existing infrastructure. Furthermore, he mentions the idea of all the parties involved in the operation of the airport and customer experience to work together to deliver an experience focusing on customer satisfaction (Reuters, 2019). These points are greatly connected with the main problems of anxiousness and wayfinding experience in the airports. The idea of having an intuitive wayfinding would highly contribute to the time people spend while transitioning through the airport towards their destination.

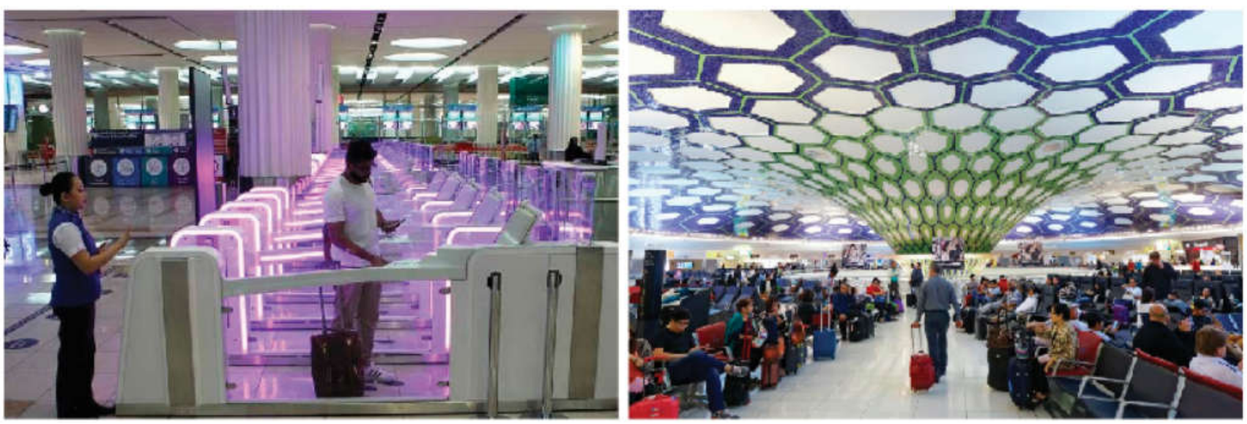


Figure 27. Pictures from Dubai's International Airport.

4. Problem statement

Through focused research the approach for fulfilling the vision was identified, therefore the problem statement and success criteria for the design is as follows:

*An **intuitive lighting system** can **improve the wayfinding** at the airport terminal, and as a consequence **reduce the airport anxiety** experienced by travellers.*

Design/Success criteria:

Intuitive system:

- The design is intuitive and understandable for all user groups.
- The design informs the user with intended information through ambient communication principles.
- Customer-centred lighting system helps the user to orient in the complex structures of an airport.
- Securing success in this criterion can be tested by evaluating if the intended suggestive information is perceived correctly.

Improved wayfinding:

- The designed system is incorporated throughout different architectural environment found at the terminal – continuity.
- Designed system indictes the way at all times – connectivity.
- The coherence of the design, good visibility, fluidity of colors – consistency.
- Reduction of visual noise.

Anxiety reduction:

- A consequence of improved wayfinding.
- Research-proven layers (such as previously mentioned bio-mimicking, peripheral design) are consciously implemented into the design.
- Organic shapes, forms, geometries, and biomimicry to benefit the health and wellbeing of the users.

5. Concept

5.1 Initial concept model

The concept model is created to reflect the main tools and concepts that are used in order to meet the design criteria described in the chapter above. Initial concept model below can be used as guidance throughout the design process. The model is divided into 3 parts which are described further in this chapter. Usage of ambient communication principles allows creating a lighting system designed for users' peripheral awareness which targets passengers with suggestive information without engaging them into a cognitive process. Further, an element of nature centric approach is introduced which will help to add a layer of natural experience in an indirect way by using organic forms, shapes, biomimicry through the usage of computer generated patterns and connects the different existing structures into one. Based on the focused research, this layer should positively influence the users' experience. Last part of the initial concept model focuses on customer-centric airport design principles, where the satisfaction of the customer and a smooth and fast, transition throughout the terminal is prioritized. Please find the concept design model below in Figure 52.

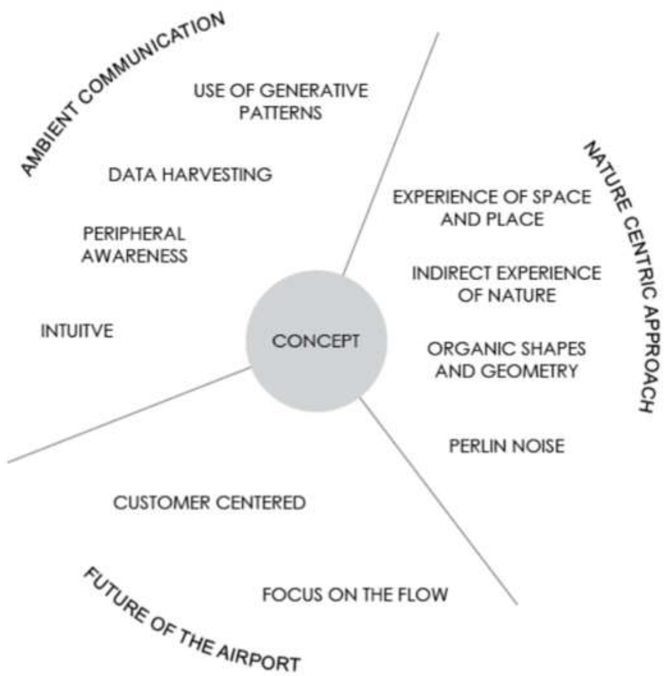


Figure 28. Concept model used to design an intuitive wayfinding system.

5.2 Inspiration works/Reference projects

While researching the concept of wayfinding and sterile terminals it was challenging to find other projects that compliment the shopping centre-like airport environments. Lighting installations at airports are not an uncommon practice, but functionality is not always the case. Although three inspiring cases were found and are shortly described below.

Inside – Shopping and business centre in Volketswil, Switzerland. The centre opened its doors in December 2014. I Art have designed a special feature interior ceiling lighting, where in specific areas LED stripes were mounted above the cylindrical aluminium ceiling system. Dimming the lights up and down creates a wave like paths serving the visitors as guidance throughout as well as reflecting the visitor flow. This project is inspiring in terms of simplicity and functionality that serves the users.

Figure 29. A wayfinding system subtly mounted into the ceiling in a shopping centre in Switzerland.

The Journey – Located at the San Diego airports' second terminal a lighting installation of 37 000 single LED pendants to create a path guiding and entertaining the passengers. Single LED's are used as pixels and displays birds, silhouettes of people swimming and varies in height throughout. This seemingly floating installation is biggest to date by a well-known lighting artist Jim Campbell. This installation is a good example of a consistent and interesting design throughout a large terminal space with different ceiling typologies.

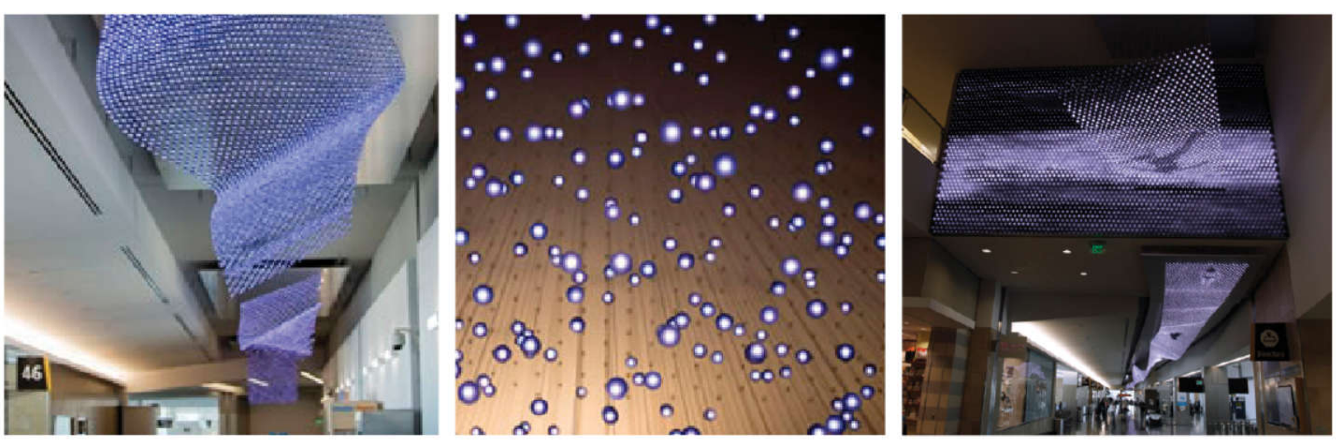


Figure 30. Lighting installation by Jim Campbell at the San Diego Airport.

In Transit – a lighting installation in a transitional temporary corridor placed in Copenhagen Airport by Kollision. The installation on the walls tries to change the uniform transit area that is designed only for one purpose – the transition. The installation evokes curiosity and creates constantly changing and mysterious environment. It is a rather simple solution of using individually controllable low-res LED panels. What we can take away from this lighting installation is the simplicity, where a subtle and rather low-scale project can have a positive effect in usually dull and boring transition corridor.

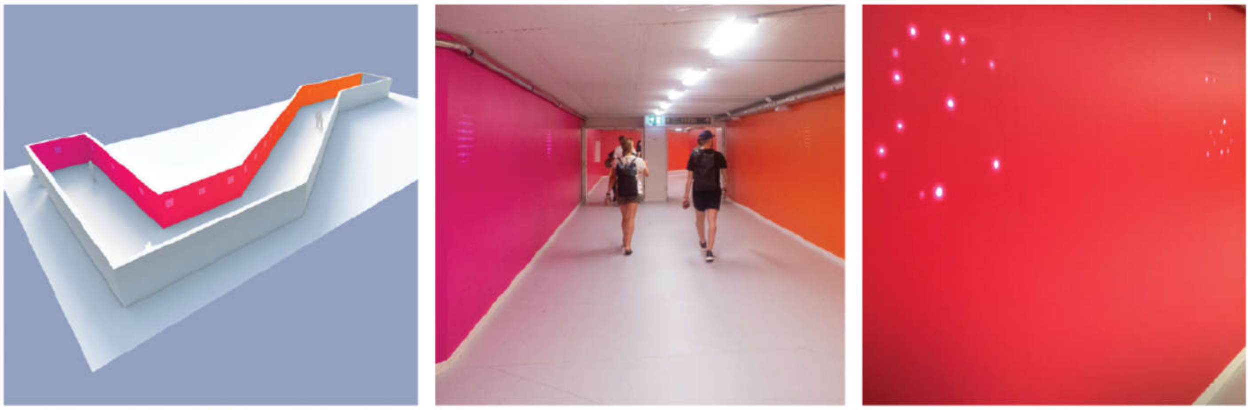


Figure 31. Lighting installation by Kollision in Copenhagen Airport transitional corridor.

5.3 Concept development

The idea of incorporating a nature aspect into the design clearly leads to the association of any airport terminal with sky and clouds. Airborne travel and the uplifting freedom of it can symbolise the dynamic movement, shapes and organic patterns of the ever-changing clouds. Clouds can extend the natural colours of the dawn and sunset. A conceptual layer of clouds and sky can easily introduce the previously discussed aspect of indirect nature in the highly commercial and structured airport environment, allowing to feel the excitement and joy of getting up in the air.

Figure 32. Illustration of the clouds.

As the passenger tries to find the path towards the designated gate or exit suggestive lighting resembling shapes of the clouds and naturally occurring sky colors lead the way. An airborne journey includes the changes in the atmospheric pressure (high on the ground level, low in the air, then high again). This can be compared to the time pressure, experienced while moving towards the gate/exit. The take-off moves from high stress caused by time pressure in the beginning, towards a relaxed mood and lowered time pressure at the gates, with the anticipation of soon being lifted in the sky. This can be translated into the path of the clouds, which in the same way are pushed by the wind and travel from high to the low (atmospheric) pressure. The arriving passenger moments after landing feels relaxed and secure, but only for a few moments. After leaving the airplane, thoughts of all necessary procedures, such as passport security, baggage, mobile network, etc., increase the pressure again. Here, the smooth and reassuring breeze of a cloud path leads towards the low pressure and a safe feeling of being back on the ground, to the feeling of relief and freedom after exiting to the city.

We sum up the concept metaphor by giving the design a name – The Cloud Trail.

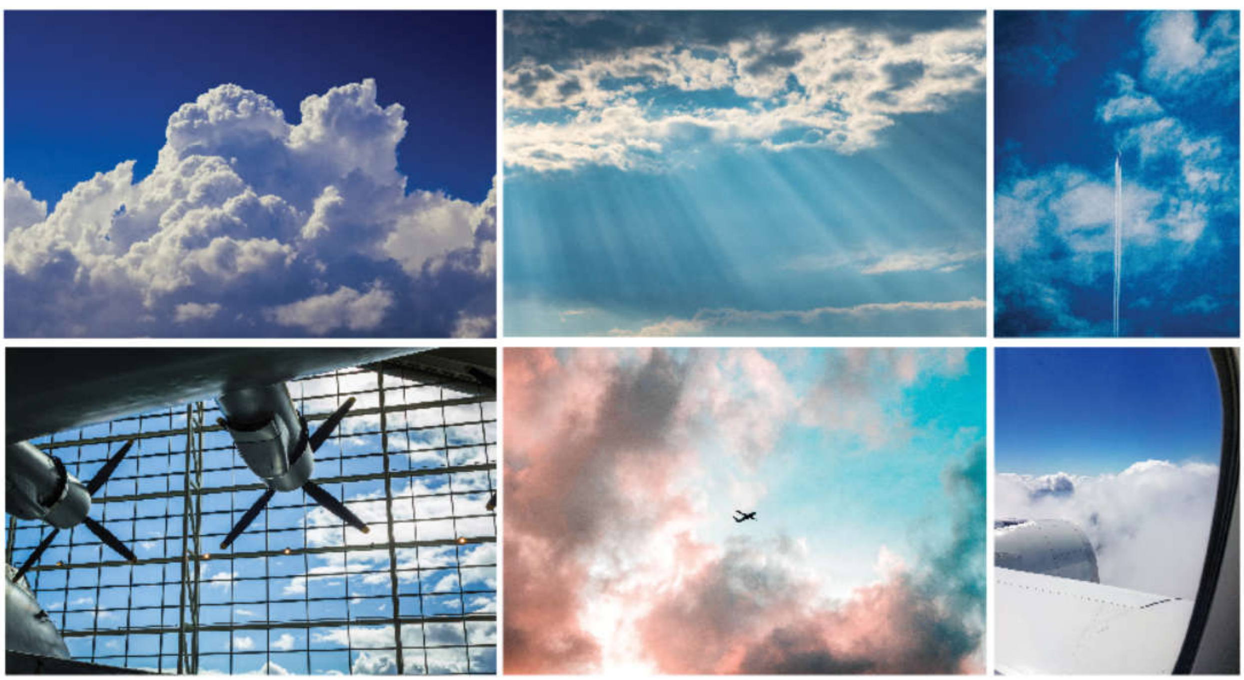


Figure 33. Illustration of the clouds.

6. Method proposal

This chapter introduces a method assessment and testing of a lighting scheme for wayfinding in the airport terminal environment. The method consists of gradual steps that consist of: analysis, visual noise assessment, design development, and testing. The method includes the usage of various digital tools, such as a variety of digital cameras with adjustable parameters (exposure) allowing for taking high dynamic range pictures, spherical pictures and videos, VR equipment, and access to image and video processing softwares (i.e. Adobe Photoshop, Premiere Pro, etc.).

1. The analysis is crucial to gain an understanding of the functional and architectural (spatial) context of the site. This will allow determining site specific challenges and problems. While analysing the space, it is of great importance to document each step in order to gather a library of pictures and videos, that can later be used as a visual map. This will allow coming back to space at any point in time if necessary. Documentation of the space can include:

- Collection of media – videos, pictures, spherical pictures.
- Collection of light measurements, such as luminance of environment, illuminance levels, CCT measurements.
- Acquiring all available drawings (upcoming design, as built drawings, sections, lighting plans, etc.).
- Insight – An interview with Client (Airport) could give great insights into the existing problems, future vision, design approach, energy limitations in the space, etc.
- A more qualitative approach is to analyse the passengers' behaviour in the space, determining the wayfinding decision-making points and gain an insight into what a traveller is seeing while actively immersed in the space. Flow can be determined by observations, interviews, analysis of the airport maps, etc.

2. In order to introduce a new lighting element to the existing space, it is important to understand that the addition of a new lighting element does not always contribute visually. Therefore, visual noise analysis and a possibility to reduce it is necessary. While using the material gathered during the site analysis the further proposed reduction approach allows establishing a background for enhancing existing wayfinding tools such as signage, information screens, and a new lighting system. The steps are as following:

- The atmosphere of the space is perceived by the traveller. It is important to understand how it is perceived by the user in order to improve for the customer.
- The sources of visual noise might differ from site to site, and vary in different areas throughout the site. It is important to determine what are the sources and if they are luminous (such as glare caused by fixtures and/or daylight, high contrasts, excessive daylight) or spatial (such as specular materials, design choices, etc.). It is important to consider what are the main sources of visual noise, occupying the immediate visual field of the person and if these sources are affecting the wayfinding. Quantitative measurement of visual noise in relation to the whole visual field of a person. The proposed method is to calculate how much of the visual field is occupied by visual noise. The proposal is to use pixel calculations from a hemispherical HDRI picture of a scene. The method is explained further with examples.
- To evaluate how the visual noise affects the space, images of the analysed scenes are edited using image processing software where the visual noise sources are

removed, then compared with the original. This will allow understanding how much visual noise is present in the space.

3. Developing the design allows to implement findings and focus on defined problems. Existing conditions and present problems can be improved, with the application of gained knowledge from research and analysis of the site.

4. Testing comes after the definition of the new background and design where visual noise is identified and minimised. The concept and initial design is tested with two types of procedures:

- **Tests to acquire quick feedback on a concept** where simple design decisions have to be made, it can also be used for insights and feedback in order to adapt the design. Best tools for quick assessment of ideas are simple online questionnaires, as well as mockups to evaluate the integration method, luminaire, etc.
- **Testing for the evaluation of the design**. These steps can help to evaluate the design proposal and see if the intended solutions for the wayfinding problems work. Virtual Reality goggles with sounds of the airport environment to increase the level of immersion is the testing tool proposed. Important design criteria can be tested, by playing 360° videos, 360° pictures or even engaging the test subjects in a game-like environment of an airport. The test tasks can vary depending on the design, criteria, and solutions, but parameters measured could be time, the decision making processes (path choice), etc. Testing should be followed up by a questionnaire for the evaluation of the method and an open comment section to get full feedback of the subjects.

Tools needed for the design to be tested in this step of the method are:

- A platform for online questionnaires. (Various platforms can be used depending on the test context, the free and easily accessible platform, for example, is Google Forms).
- VR equipment for the immersive testing.
- Image processing software such as Adobe Photoshop.
- Other content-creating software such as 3D Studio Max, Vray, etc.

STEPS	WHY?	HOW?
1. SITE ANALYSIS	Spatial understanding →	**drawings, media, videos**
	Functionality of the space →	**light measurements**
	Flow of terminal traffic →	**observations, maps**
	Insight to site specific problems →	**interviews, airport data**
2. VISUAL NOISE ANALYSIS	Understand the atmosphere →	**perception, interviews**
	Identification of visual noise sources →	**luminous (glare by fixtures and/or daylight, high contrasts, excessive daylight) or spatial (materials, design choices)**
	Measuring visual noise →	**ratio of occupied visual field**
	the space without visual noise →	**comparison of before and after pictures**
3. THE DESIGN	Improve existing conditions Solve problems Provide new approach →	**applying methods, research and knowledge**
4. TESTING	Acquire quick information →	**Online questionnaires, mockups**
	Evaluate the design →	**Immersive Virtual Reality test**

Figure 34. Table illustrating the four steps for the design of a wayfinding lighting in the airport terminal.

7. The site - Copenhagen airport

In order to create a design for an airport environment, a specific site for the design process has to be chosen. The closest and most familiar is the Copenhagen Airport, Kastrup (CPH). CPH airport is one of the first civil airports in the world dating back to 1925. Today it is the busiest airport in Scandinavia with 30 million passengers transferred yearly (2018) and covers an area of 11.8 square kilometres. It has two terminals (terminal 2 and terminal 3) that are connected and share common areas. The airport is constantly expanding with the current expansion of pier E.

Figure 35. Map of Copenhagen with the indicated location of Copenhagen Airport.

With high hopes, the authors tried to make contact with the airport directly by filling out a form provided at the Airport webpage and indirectly through a person who was familiar with the architecture department of the airport. Both attempts were unfortunately unsuccessful. Therefore, the resources of the site were limited to less graphical drawings and limitations of carrying out the measurements and interviews. Due to the security reasons, the site access was limited and due to lack of cooperation, the permissions to carry out certain measurements were not attained. Nonetheless, as frequent travellers, the authors are familiar with the CPH airport and were able to travel through it during the process of this project so it was possible to make an analysis of existing conditions.

To start with, the main flow of departure and arrival passengers was identified. There are 3 floors that a passenger might have to orient themselves if initially arriving with the train as it is located in the underground level, all the check in and information desks, as well as arrival gate, are located on the ground floor level, and security check a well as all the other publicly accessible areas in a sterile environment are located on the 1st floor of the airport with a rare necessity to access the ground floor due to the gate position.

Figure 36. A map showing typical passenger arrival flow at Copenhagen Airport.

Figure 37. A map showing typical passenger departure flow at CPH airport.

The architecture of the airport varies from narrow to wide spaces and from low to high ceilings depending on the context and purpose of the area, the fact that the airport has been constantly expanding throughout the years created not necessarily a consistent design look throughout. Each pier has a distinct design of its own. Examples of different areas are shown in the following figures 38-41.

Figure 38. A diagram showing the general layout and flow of Copenhagen airport.

Figure 39. A change in the ceiling height from high and wide space before the security check to low and narrow space right after.

Figure 40. A difference in pier A (left and centre) and pier B (right) A big difference in ceiling heights, transit corridors have the gates on the sides, different use of daylight.

Figure 41. Other retail and dining areas are somewhat consistent but there is a high variance in ceiling types and heights.

CPH airport is a huge infrastructure and due to the size of it, specific scenes for the design will be chosen and analysed in a more thorough way depending on the context.

7.1 Establishing the design framework

In order to reduce and refine the scope of the concept, the decision was made to only focus on the sterile airport environment – area after the security check - where most wayfinding decisions for departure and arrival have to be made in order to find the intended destination. To further reduce the extent, one low ceiling area, one high ceiling and one gate location are chosen as an initial design framework. Due to the limitations of accessing the airport the flow of transfer passengers is not be analysed further and can be picked up as an extension of this project.

8. Visual noise analysis

Before introducing a new lighting concept to any existing or new location, it is necessary to establish a framework for the design. This means **that the design can be a useful addition to the environment only if space allows it.** Therefore, this chapter provides general rules for the reduction of visual noise and a toolset for assessment of it in a specific environment. As identified in the analysis - visual noise is a problem at airport terminals. During the initial phase of analysis, it was identified that various elements can contribute to the visual noise and create an overwhelming sensation of too much visual stimuli and overload of information. To narrow down the framework, visual noise based on the aforementioned analysis can be divided into spatial and luminous visual noise, where both are still closely interconnected. Spatial factors contributing to visual noise include elements of design choices, advertisement locations, excessive signage, etc. Whereas luminous elements are inconsiderate daylight systems, placement of luminaires, usage of specular materials, dynamic screens – all of which can cause discomfort glare and produce high contrast that can be considered as a part of visual noise.

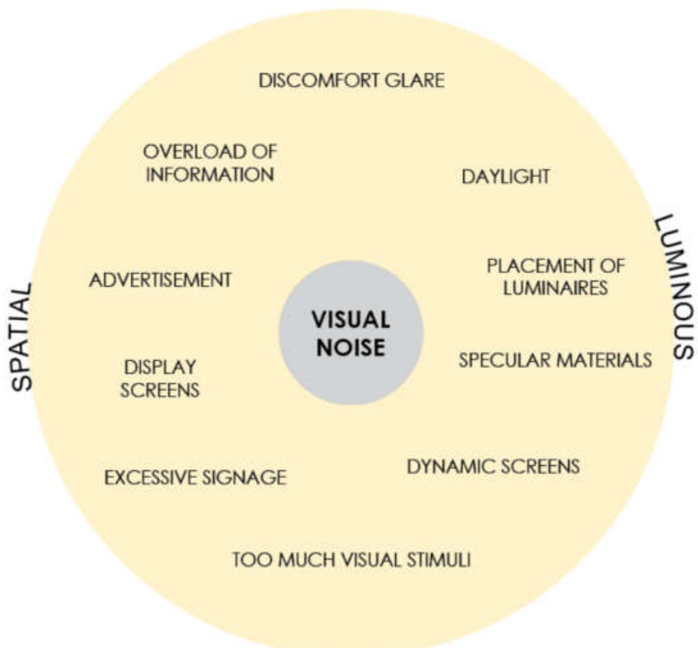


Figure 42. A model illustrating spatial and luminous visual noise sources.

To justify that the new lighting system does not contribute to the increase of visual stimuli in the environment, there is a need to look into the existing case study of Copenhagen Airport and find examples of environment where visual noise is present. As identified in the previous analysis, the main source of visual noise can be encountered in the retail areas from advertisement, the specific layout of the stores, dynamic screens, etc. These findings were confirmed during the site visit. Pictures below show the immersive path through a visually noisy retail environment. It is the initial area the passengers walk into right after the clean and organized security check zone as shown in Figure 43.

Figure 43. The Duty free rea in Copenhagen Airport with various sources of visual noise.

Another example is a comparison of two paths from different parts of the Copenhagen Airport as shown in Figure 44. A clear difference is in terms of visual noise is visible between an area with more conventional stores (left) and high-end stores (right). A path on the left has a lot of sources that can be considered as visual noise such as a dynamic screen for commercials, illuminated advertisement on the walls, products placed on the path, etc. The high-end stores are subtler in their advertising and provide a clear path without overloading the visual field. This is a good example of how the retail areas should be designed providing an option of choice for the passenger to be immersed inside the shops by choice, and not by force.

Figure 44. Two paths in retail areas of Copenhagen Airport.

The reduction of visual noise can be described as a set of qualitative guidelines while designing or refurbishing the indoor environment of the terminal. Clear paths and visibility should be provided so there are no doubts between the distinction of a path and retail areas. This would provide clarity for the passenger and improve the poor functional organization, which is one of the main factors that have a negative effect contributing to airport anxiety (Bogicevic et al., 2016). Moreover, the reduction of the visual noise would establish a background for adding a new lighting layer for the improvement of the wayfinding as a new addition to the functional organization. An introduction of rules/guidelines for reduction of visual noise especially towards commercial spaces is necessary. As the site analysis suggests, if not restrained, the ways of merchandising can get out of hand (see Figure 43 above). Furthermore, these rules could also be a great asset if customer satisfaction is to be the main goal in modern airports. Essentially, the guidelines come down to making the visual environment less crowded with various elements and more uniform in terms of luminance, and as a result, tackling issues of contrast and glare. Therefore, we propose a set of guidelines as the following:

- Highly-luminous advertising screens should generally be avoided in the main passage areas so as to not dominate the visual field, obstructing the view, architecture of the space and most importantly signage.
- Use of multiple pendants for different merchandise and colorful light installations in open areas should be limited.
- Reducing the general level of ambient illumination in the retail areas.
- Wayfinding signs should be dominant in their immediate visual field. This can be achieved by using luminous signage, spot lights, adequate general illumination and providing clear visual field.
- Specular materials causing glare should be avoided.

8.1 Identification of visual noise

Firstly, an analysis of two visually heavy areas in Copenhagen Airport Is presented, where a reduction approach is used in order to visualize how an environment like this could be changed. This initial analysis is a qualitative approach based on the felt perception of the space. Below are examples of spaces where the limitations could be applied.

Scene 1. The busy path through the retail area with a sketched-over representation of how it could look after applying the proposed limitations (Figure 45 and Figure 46 below):

1. The general level of illuminance in shops could be limited if the whole visual environment was dimmed down.
2. The shop has a very bright, standing out logo, luminosity could be limited. Moreover, it also has a hanging sculpture above its stall taking the ceiling space and adding more elements.
3. Highly luminous advertising screen takes most of the attention, causes glare and blocks visibility.
4. Less specular materials could be chosen (now the big advertising screen is mirrored).
5. Advertising screens could be limited to the inside of the shop, or their luminance limited.

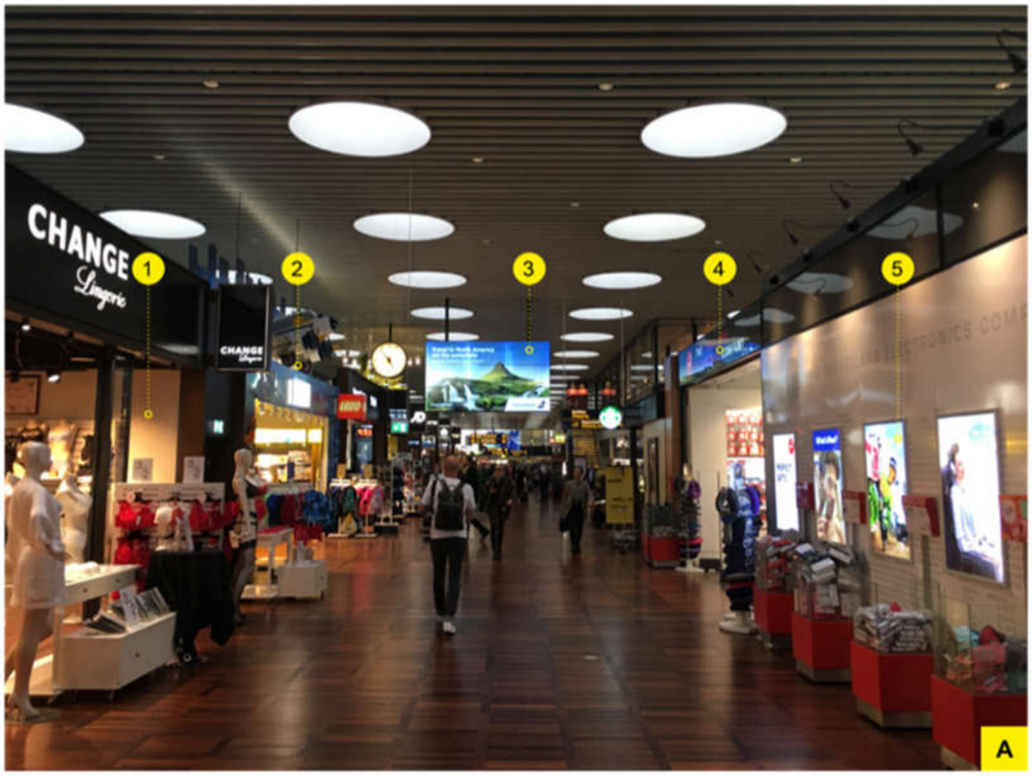


Figure 45. A scene from Copenhagen airport with sources of visual noise identified.

Figure 46. A scene from Copenhagen airport with sources of visual noise removed.

Scene 2. Duty free retail area, the description of the pictures is in the following page:

Figure 47. A scene from Copenhagen airport with identified sources of visual noise.

Figure 48. A scene from Copenhagen airport with reduced visual noise.

1. A playful lighting installation with various colors highly contributes to visual noise. Such lighting should be considerate and placed in locations where it can be appreciated and would not contribute as visual noise as it does here.
2. Luminous retail signage should only be employed in cases where visibility is really poor. In this case, it overwhelms the wayfinding signage on the right.
3. General illuminance in different merchandise areas should be limited to not stand out as the main feature.
4. Luminous commercials should be subtle.
5. Considerate lighting for signage to stand out should be employed.

8.1.1 Retail and reduction of visual noise

A point to stress out is the obvious necessity in the reduction of merchandise marketing. One might argue that this could result in loss of revenue for the airport, however for a number of reasons we hypothesize that this would not affect the revenue as much. One on-site passenger survey revealed that, while there is evidence of impulse purchasing brought about by affective responses to the airport context, much of the browsing and purchasing behaviour is planned in advance of the airport visit and is seen as a component of the trip/holiday (Baron & Wass, 2007). Also, people are aware that at airport stores, prices tend to be noticeably higher (Tymkiw, 2017). Furthermore, travellers are limited to the amount of merchandise they can purchase at the airport, due to increasingly tight regulations on carry-on items. Most airlines restrict carry-on baggage to one personal item and one carry-on bag, while budget airlines have even tighter constraints (Gavin, 2016 as cited in (Tymkiw, 2017)).

As discussed earlier, the future airport approach where the goal is to increase the number of passengers by improving the flow of people without spatial expansion means more revenue for the airport. Another argument for reducing the marketing caused visual noise is the stress reduction factor. As further discussed by Tymkiw, emotions connected with shopping, contribute to the shopping behaviours where for example consumers tend to buy more items when they experience positive moods. This knowledge allows us to believe, that customers with awareness of wayfinding towards the gate, understanding of the space and remaining time are more likely to explore the retail and restaurant areas and spent their money there.

Moreover, creating a unique, modern system could become a symbol of any airport, generally bringing more people to it - and thus increasing the overall revenue while creating a brand and identity. This would allow the airport to stand out and give a memorable experience for the passengers rather than be experienced as just another shopping centre-like airport. Considerate lighting can create a memorable experience and identity by means of distinctive design and mood setting.

8.2 How to measure visual noise?

Assessment of the visual noise using proposed guidelines in the previous pages is qualitative and based on the felt perception of specific scenes in Copenhagen Airport. To further investigate the possible methods of how visual noise can be identified and measured, authors propose a method to measure the ratio of visual noise in the visual field of a person for a specific scene. The method proposes the usage of hemispherical HDR picture, as a photographical tool for estimated representation of a visual field of a person, where the angular distance and radial angles can be mapped. Then the use of a false-color image from a grayscale version of the picture for assessing the contrast of luminance (based on the pixel values), and thus enabling the evaluation of glare, which can contribute to the overall visual noise. Furthermore, to be even more specific about the visual field of a person we can use the visual field limitations described by Kim & Jeong, 2011 where the extension for Guth's calculation method for glare was proposed. This study has come to the conclusion that there is not a big difference between the left and right eye sensations of discomfort glare, whereas the lower visual field is more sensitive to it than the upper visual field. This could further help indicate the limitations for the placement of not only glare causing luminaires, but also define the area of the picture that can be perceived as having a high risk for the visual noise perception based on the fact that the person is looking straight (Kim & Jeong, 2011). Please see the visual field of a person graph from the paper below.

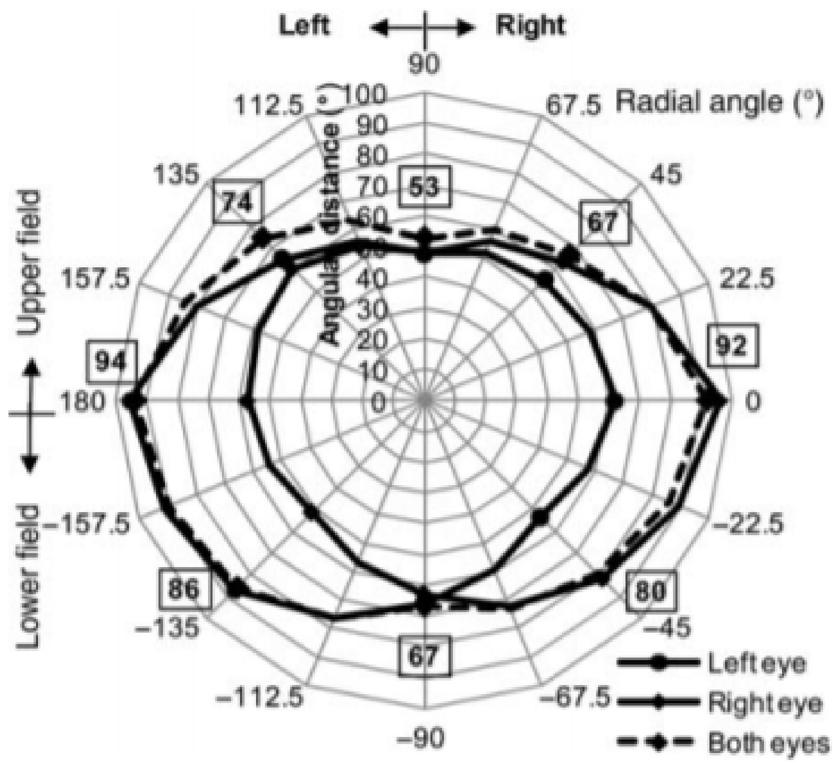


Figure 49. Illustration of visual field limits of both and single eyes (Kim & Jeong, 2011).

8.3 Calculation of the noise ratio

Unfortunately, due to security limitations of the airport, it was not possible to take luminance measurements inside the sterile airport environment. Therefore, a complete assessment of luminance and contrast ratios was not possible. The picture, however, still gives a valuable input in the representation of the general contrast in luminance while using the number of pixels that can be interpreted as a solid angle from the field of view.

8.3.1 High visual noise example

Figure 50. The first analysed scene: retail environment with a high level of perceived visual noise.

1. Risk areas for visual noise. Previously mentioned visual field model can be applied to the fish-eye lens picture to define the areas of high risk for visual noise by identifying the visual field of a person in the selected scene. This can be done by mapping the angular distance and radial angles on top of the hemispherical picture and then identifying the visual field as an area with increased risk for visual noise (Figure 51).

2. **False-color of the picture.** In the first step, the gamma of the picture was corrected to linear, as the camera took the picture with 2.2 automatic corrections. Then the corrected image was de-saturated to **obtain a grayscale image**, from which it was possible to extract pixel values to **estimate the contrasts**. See Figure 52 below.

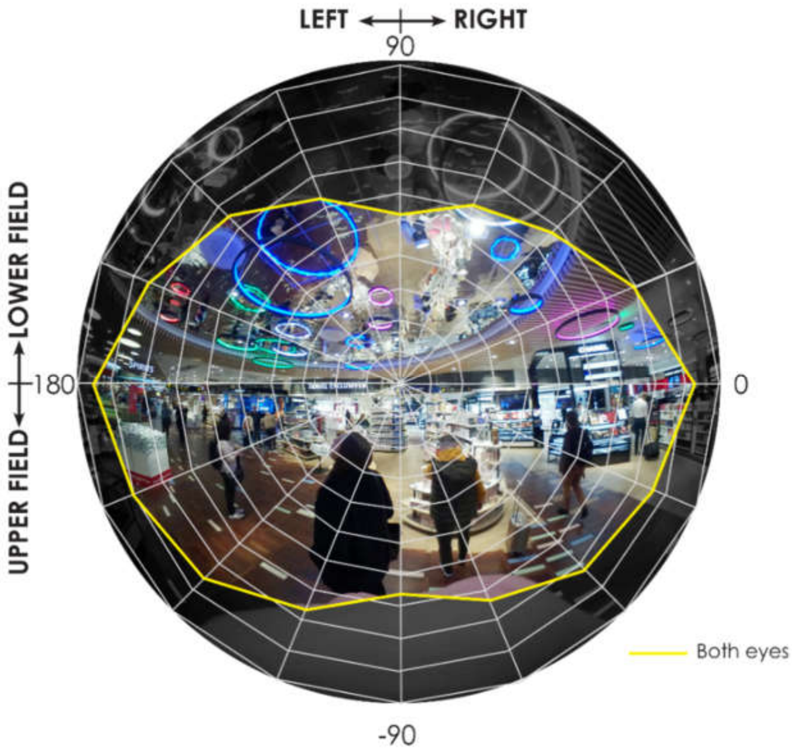


Figure 51. Definition of the visual field in the hemispherical image of the scene.

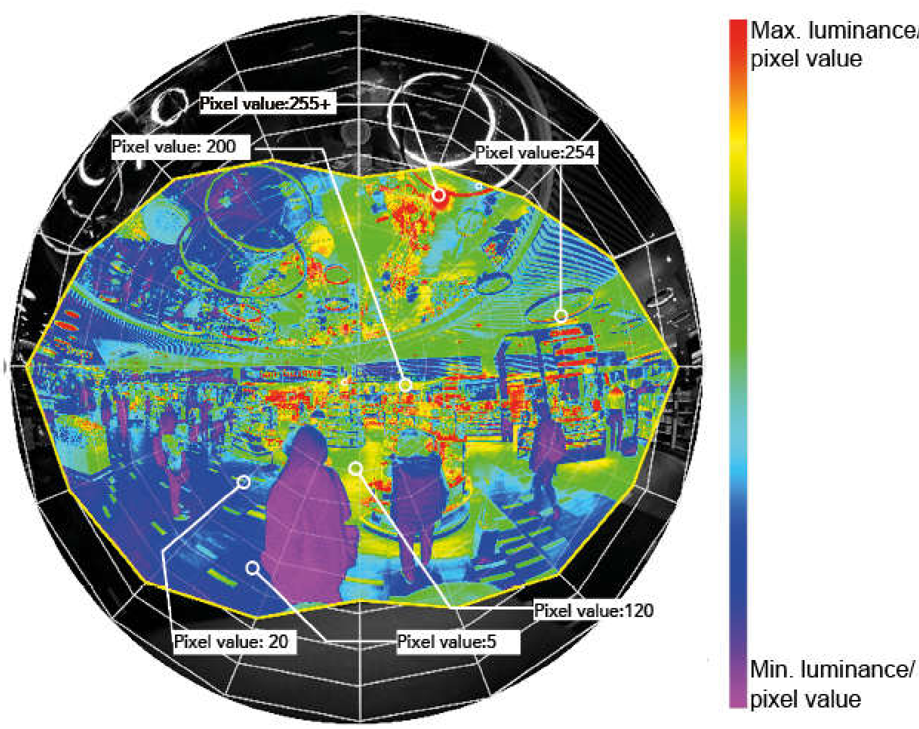


Figure 52. False-color representation of the analysed first scene.

3. **Evaluation of luminance.** As seen in figure 52 it is clear that the retail zone stands out with generally higher luminance in contrast to the path. What is interesting is that there are only a few spots with very high pixel values (luminance exceeding the maximum), therefore space can be evaluated as not glary once a person is inside it. This proves that evaluating glare and contrast does not form a holistic approach, as it does not take into consideration other elements of visual noise, such as for example a huge color variety or the general crowding of the elements in the visual field. The next paragraphs describe an attempt of creating a simple quantitative approach to the proposed qualitative assessment of visual noise from the previous section.

Figure 53. 180-degree fish-eye lens picture of the analysed scene with high perceived visual noise.

4. **Calculate the ratio.** In this step, the goal is to evaluate the estimated percentage of the perceived area (expressed in steradians of the visual field), that can be considered as visual noise. For visulisation purposes, Figure 53 is shown in grayscale with reduced brightness, the elements considered as visual noise with normal colors and opacity. It is assumed that the pixel values are representing three dimensional steradians. The total amount of pixels considered as visual noise 24810 pixels is divided by a total amount of pixels located in the defined visual field 60332 pixels. Pixel values were calculated using Adobe Photoshop CC2019, see Figure 54 below.

Element	**Pixels**
(1)Lighting installation	19542
(2) Retail stands with screens	1054
(3)Highly luminous signs	278
(4)The general ambience of the retail zone (20%)* marked with green perimeter	3936
Total:	24810
Noise ratio:	24810/60332 = 41.1%

*General ambience of the elements retail zone was estimated to be around 20% too much, therefore, for the calculation a 20% of the total amount of pixels in that area was taken into the ratio calculation.

Figure 54. Table illustrating the calculation of the visual noise.

From the proposed analysis it was concluded that an estimated 41.1% of the visual field can be considered as a source of visual noise. To further investigate the relevance of the method, the next example is a scene from the airport with a perceived acceptable level of visual noise.

8.3.2 Low visual noise example

Figure 55. The second analysed scene – retail zone with low perceived visual noise.

The chosen scene is the beginning of a passage with high end shops, where the initial retail area (the high visual noise scene) is present on the left side. This area has a similar function to the first scene. However, in this scene merchandise is subtle, and does not overwhelm the passenger with too much visual information.

1. Risk areas for visual noise. Mapping the angular distance and radial angles on top of the hemispherical picture, and then identifying the visual field as an area with increased risk for visual noise.

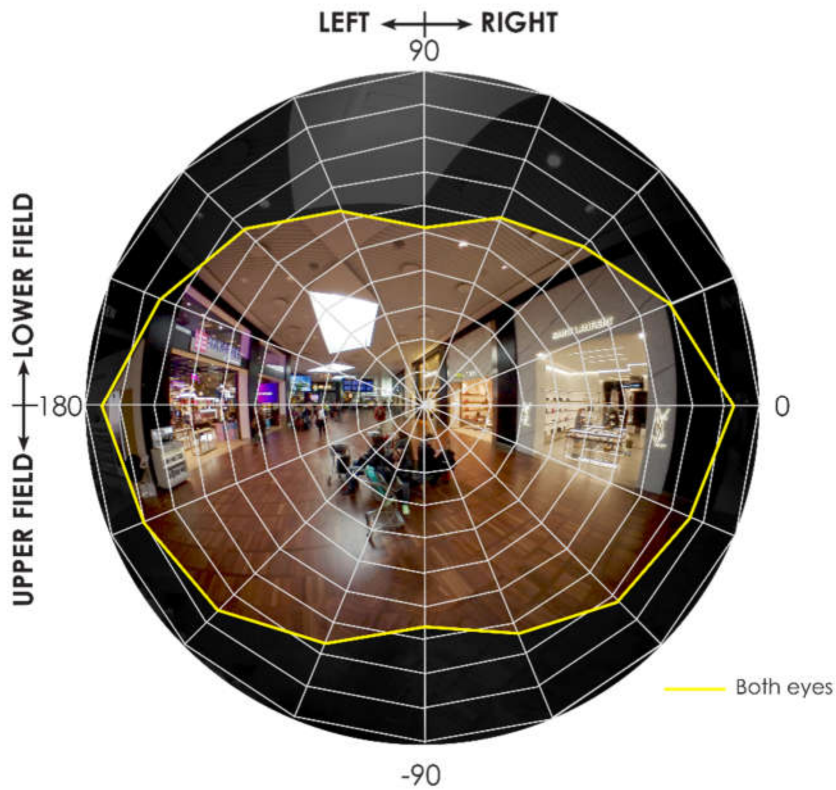


Figure 56. Definition of the visual field in the hemispherical image of the scene.

2. False color of the picture shows again that glare is not a big issue. There are few focal points of high luminance coming from the retail and from the daylight coming through the roof. Generally, the zones - corridor and the retail - have quite uniform luminance. The skylights in this area are not considered as part of visual noise, due to the fact that a high cut-off angle allows the openings to act as luminaires only providing the light that bounced back from the white surface. Furthermore, it provides ambient lighting for the space during day hours.

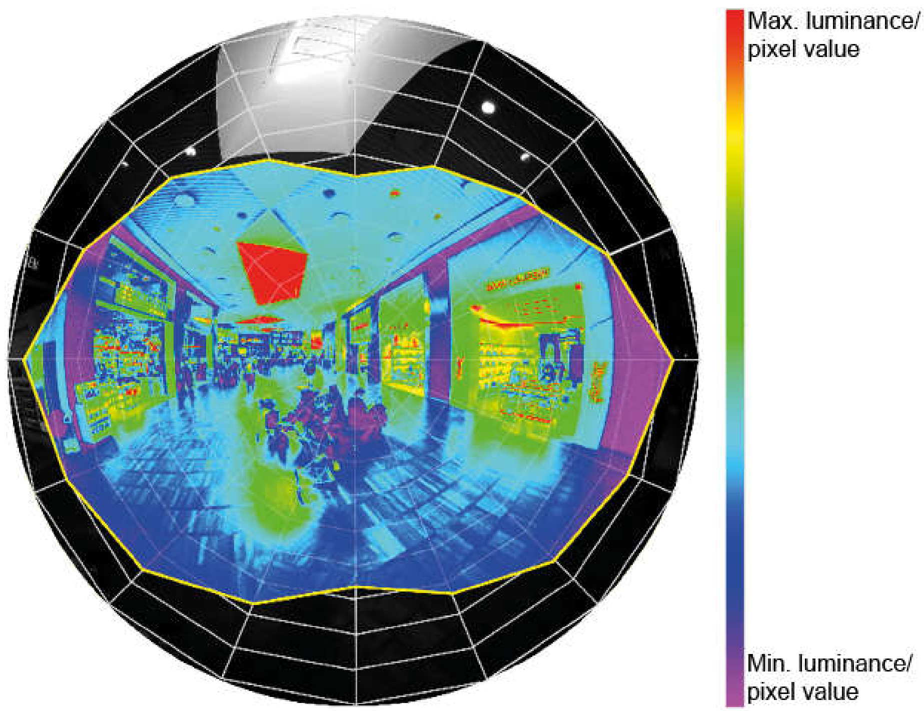


Figure 57. A false-colored version of the image of the second analysed the scene.

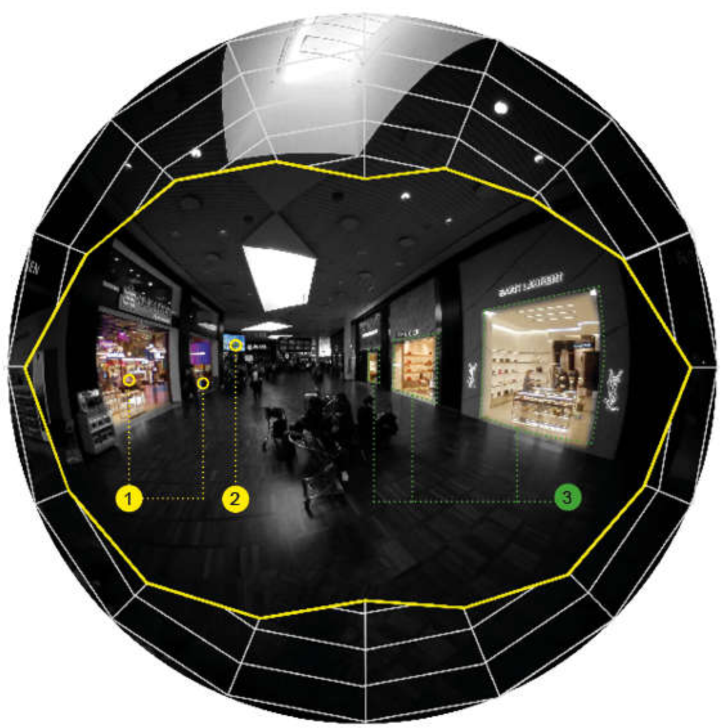


Figure 58.

3. For the visual noise assessment using the proposed guidelines, it was possible to identify three issues. Firstly, despite being in a significant distance, the entry retail area still produces visual noise, being rich in color and possibly glaring luminance points. Secondly, the big advertising screen in the back is considered as visual noise, blocking the view and contrasting with the environment. Finally, a percentage of visual information from the high-end shops on the right side is considered as noise, due to possibilities of glare and possibly unnecessarily high general illuminance inside the shops.

4. **Calculating the ratio.** Shops on the right side of the corridor have increased luminance, but are consistent in style and lighting language. In general, as described during the on-site assessment, *space feels comfortable, like there is room to breathe*. The ratio is calculated in the same manner, where the total amount of pixels (3245 pixels) considered as visual noise is divided by the total amount of pixels in the defined visual field of a person (58695 pixels).

Element	**Pixels**
(1) Entry retail area	2156
(2) Advertisement screen	99
(3) High-end shops (20%)*	990
Total:	3245
Noise ratio:	3245/58695 = 5.3%

*Despite their uniform lighting and coherent color theme, for the calculation 20% of the visual field coming from inside of the high-end shops was considered as noise.

Figure 59. Table illustrating the calculation of the visual noise

Analysis of the second scene using the proposed visual noise assessment method the ratio is ca. 7.5 times lower than in the first scene. This suggests that for a space to be considered visually comfortable levels of visual noise have to be kept minimal and not be placed in the immediate visual field. For further implementation into the design, the proposed visual noise analysis method gave a valuable understanding about what elements should be limited before the introduction of new additional elements in the space. This can be a challenging task, as introducing a subtle functionality within a lighting element can be perceived only as decorative (no perceived functionality), therefore possibly adding to the visual noise.

8.4 Visual noise method biases and possible improvements

The main bias of the method described above is the extent of visual noise that is considered for calculation. Definition of the visual noise comes from a qualitative assessment of space. An improvement could be a proposal of quantitative criteria for the visual noise, such as limitations of luminance based on the histogram values, color range, the geometry of objects, dynamic screens with limited brightness and contrasts, etc. The two scenes were also different in the architecture; therefore, a more telling result would be achieved when comparing the same scene with different interior design setups. Moreover, the estimated 20% reduction of luminance of the general retail ambience in the calculations was based on the trials in brightness reduction of that area of an image. To make a better assessment, actual site measurements would have to be taken.

Another improvement could be further narrowing the field of view considered for analysis, by differentiating the extent (percentage) to which the visual noise is a problem in the different areas of the field of view. The method proposed defining risk areas for visual noise based on the actual visual field of a person, however further research and development could propose different hierarchy of visual noise in different areas of the central and peripheral vision (defining a steradian cut-off of the visual field, after which the visual noise could be considered as less significant).

Thirdly, as the visual noise assessment considers a phenomenological approach to space (being and moving within it), rather than a single scene, the method could introduce a uniformity indicator, i.e. that at any given measurement point (scene) in the given space, the visual noise should not exceed a certain percentage.

In general, proposed visual noise assessment method had a goal in producing argumentation that in some spaces in the terminal it is necessary to impose certain limitations on visual information - especially before introducing a new lighting element. Due to time limitations and scope of this thesis, the method was not further developed.

9. Initial design

In an attempt of a holistic approach to the design, it was divided into two parts with their own characteristics as shown in the design model (see Figure 60 below) and described further in this chapter.

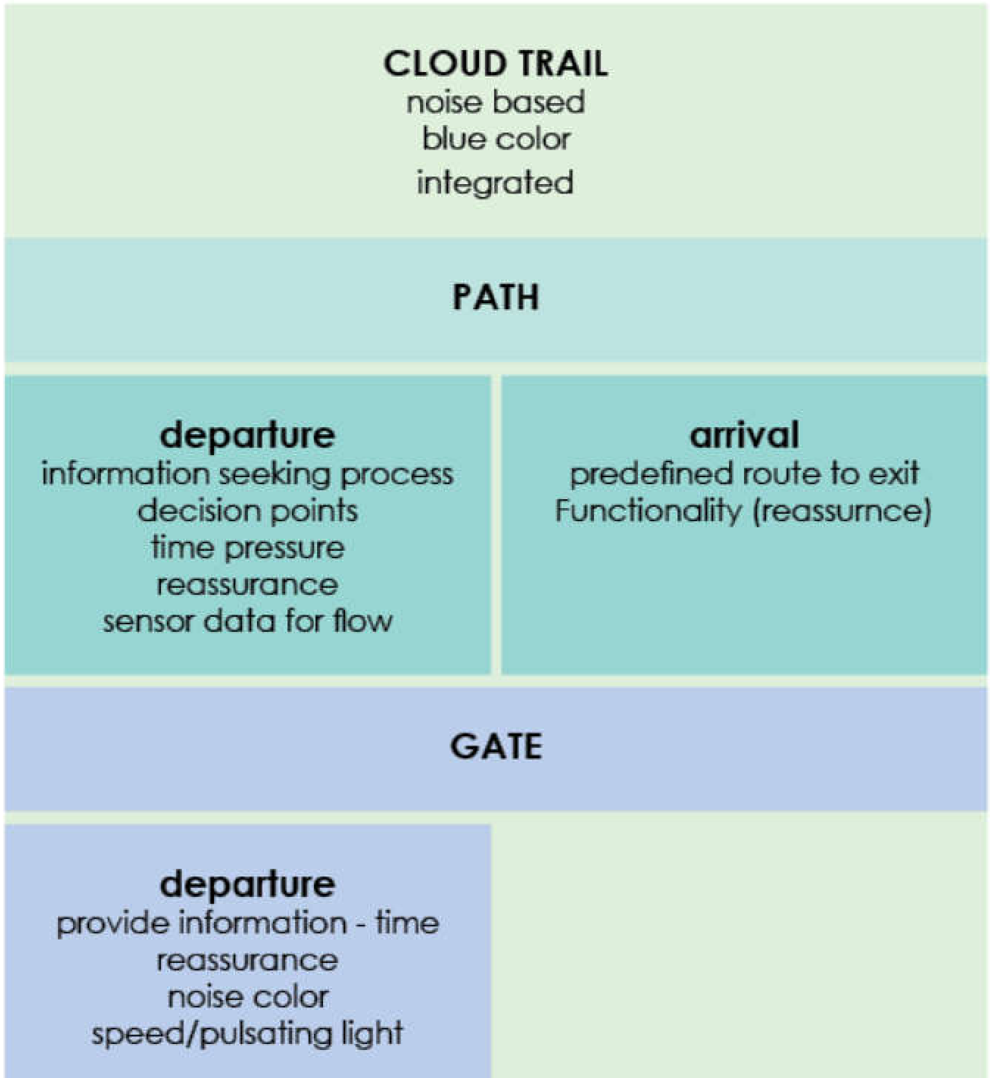


Figure 60. Design model indicating two main aspects of the design of the intuitive lighting for wayfinding in the airport.

9.1 The path

The path is a first element of the design, it is continuous throughout the terminal. The path is either from the aircraft to exit, or from security to the departure gate. The same path leads arriving passengers towards the exit to the baggage claim and later to the non-sterile environment. Here a good practice is to implement the principles of successful wayfinding design, as described in the literature review chapter previously:

- Continuity means the designed system is incorporated throughout different architectural environment found at the terminal.

- Connectivity imposes the designed system shows the path at all times.
- Consistency provides coherence of the design with good visibility, the fluidity of colors, etc.

The design criteria for the lighting of the path is to provide *reassurance* and feeling of safety to the passenger when moving towards the gate. Increased reassurance would improve wayfinding and reduce orientation induced stress. As shown in the design model, the lighting design for the path is divided into two sub elements:

The departure path - corresponds to the *information seeking process* (as identified in the research chapter 2.2.1). Here the necessity of gathering new information on the multiple decision points along the way determines the choice of path. The departure path branches out at decision points, therefore the challenge here is to find the way to the right pier. The differentiation of paths to the piers has to be cleverly incorporated while keeping the continuity of the design as well as connecting the different functional zones and design approaches (i.e. low ceilings/high ceiling spaces) into a whole system.

The *arrival* path - where the passengers from different flights follow the intended predefined route and in the end all gather at one place - the baggage claim and further exit. This path should lift the stress and reassure passengers, as well as symbolise safety of being on the ground and be welcoming. Due to time constraints, this thesis will not be focused on the arrival or transfer paths, which are subjects for future development, research, and design.

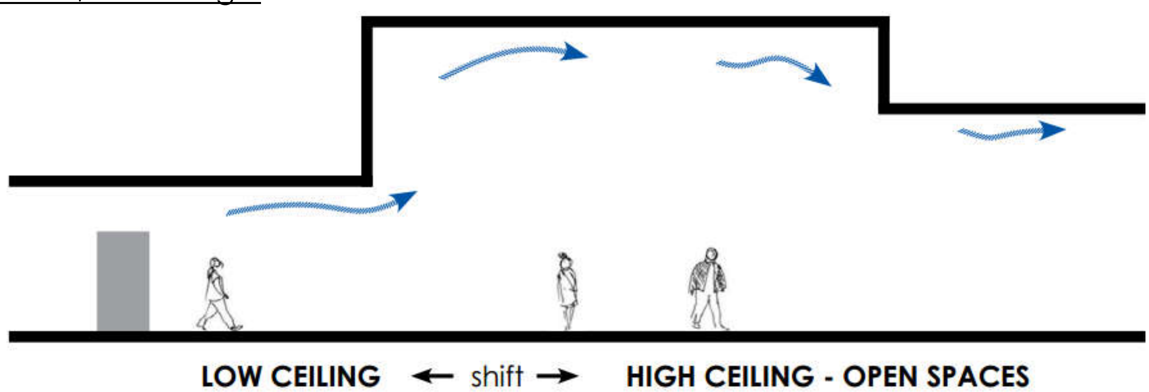


Figure 61. Conceptual section representing the shift between different environments in the terminal.

For the design implementation, a general rule is that the lighting system is placed the above-head spaces throughout the terminal in order to be consistent and not to interfere with various existing elements. The placement decision might be different based on another site and concept. In the case of Copenhagen Airport, it was possible to differentiate two contextual areas for the proposal of lighting design. It is a shift between height in the spaces as shown in Figure 61 above. For the low ceiling option, it is observed that a certain repetitive architectural feature is reoccurring throughout the terminal – ceiling with suspended baffle lamella system. A proposal is to cleverly incorporate lighting into it, as per Figure 63 below. For the high ceiling scenario, three options of the media-luminaire were proposed as per Figure 65 in the following pages.

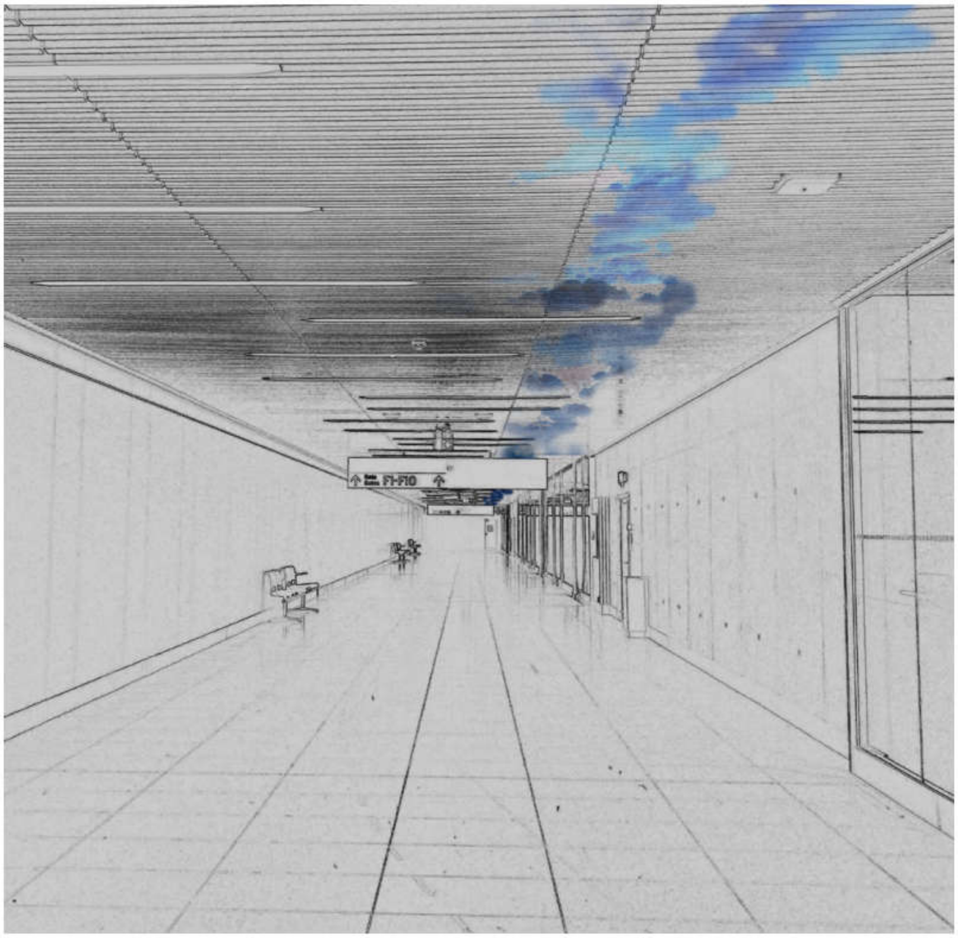


Figure 62. Conceptual sketch for the low ceiling environment.

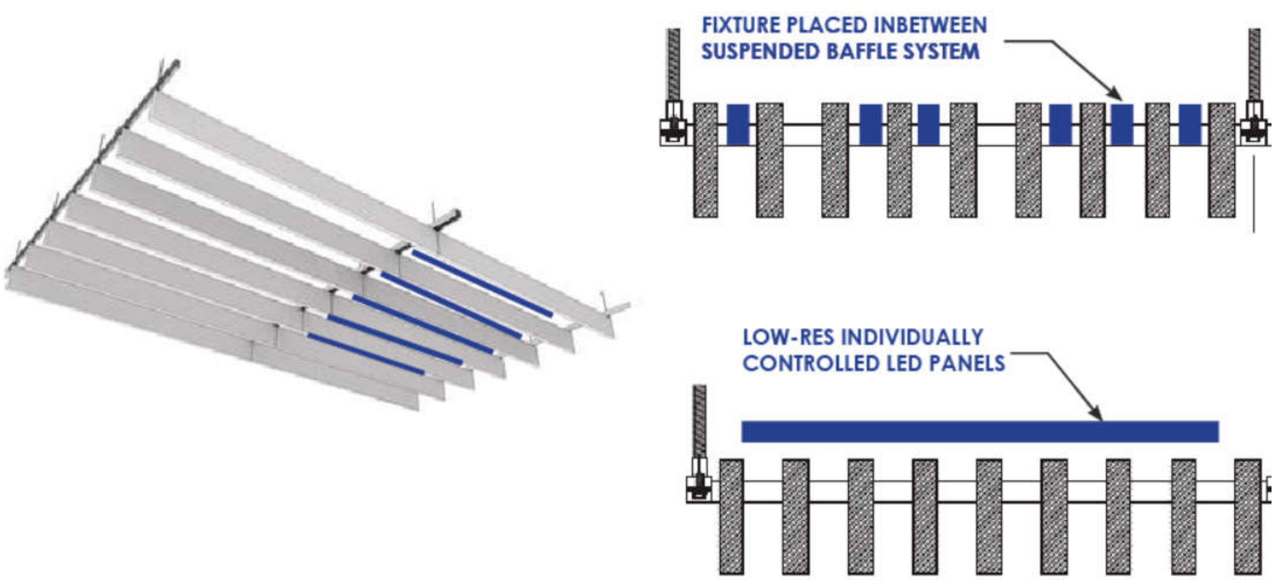


Figure 63. Different integration options for the low ceiling environment.

Figure 64. Conceptual sketch for the high ceiling environment.

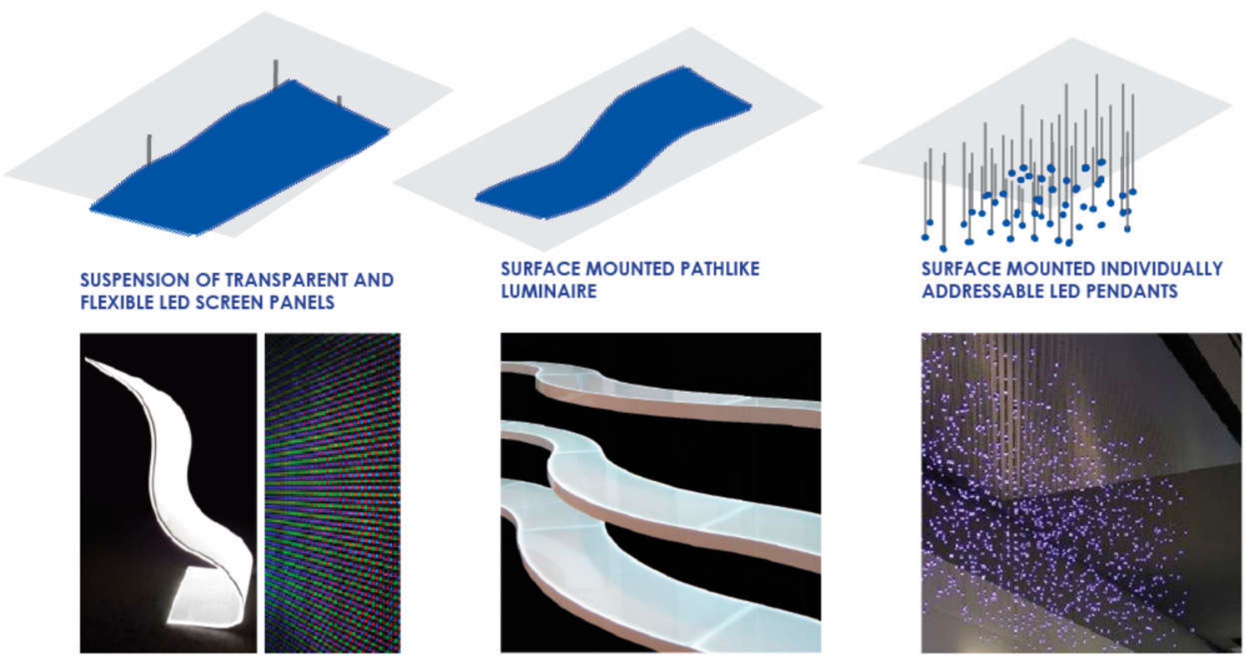


Figure 65. Different integration options for the high ceiling environment.

The lighting scenario for the path, which is present throughout the whole terminal area and has a functionality of giving passenger reassurance about moving throughout the terminal. The difficulty here is the process of finding the path to the right terminal. The initial idea was to create a color or pattern differentiation for each of the piers as shown in Figure 66 below. Eventually, this idea was dropped as it would result in a visually heavy element that contradicts the low visual noise approach described previously. Instead, the cloud trail on the path is acting as a general reassurance of being on the right path and not wondering away from it. As mentioned earlier, the path is not a tool to replace the signage, but rather to compliment it with subtly communicated information through the element that is consistent and continuous throughout sterile airport environment as shown in Figure 67 below. Furthermore, to communicate that the cloud trail is a part of the wayfinding system to the unaware traveller, it is continuously connected with the flight information screens.

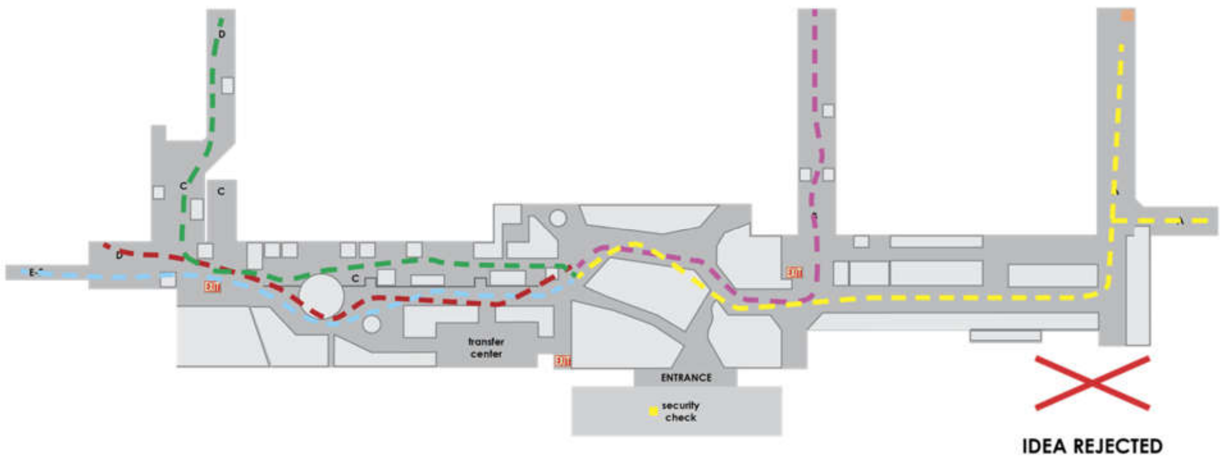


Figure 66. The idea of having a different color/type of pattern for each pier was rejected due to risk of introducing too many different elements - adding the visual noise.

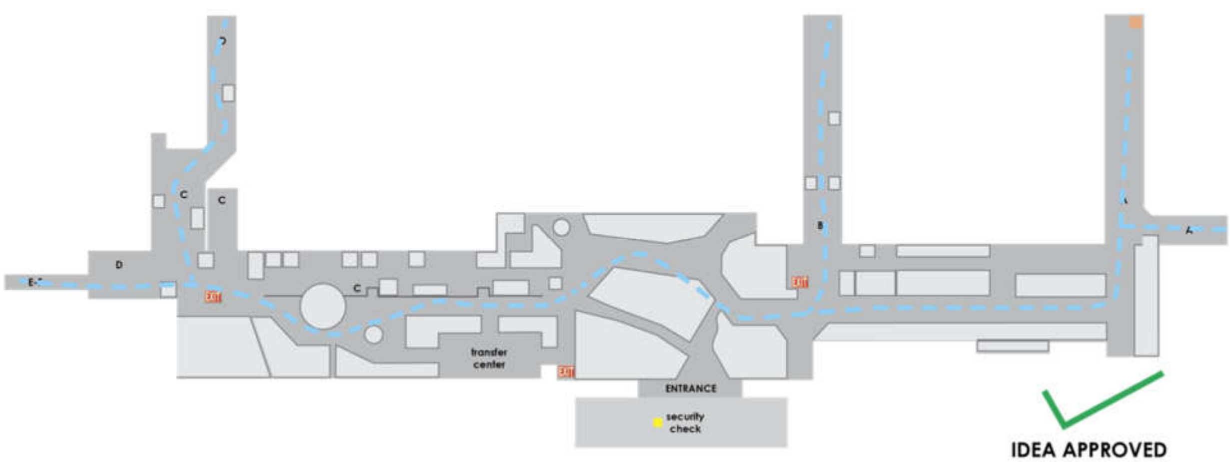


Figure 67. Lighting design for the path was chosen to be consistent in color and pattern to all gates.

9.2 The gate

The departure gate is where a traveller comes, with the reassurance of the cloud path. However, seeing the gate from afar does not inform if the boarding has started or how much time is left before the gate is closed. Even if the passenger found the gate already, and is waiting there patiently to start the journey, it is usually hard to understand how much time is left before the gate is closed. Factors such as a language barrier, hearing difficulties or cultural differences may not allow understanding the vocal information and some visual clues. Furthermore, a phenomenon such as silent airport is gaining more success throughout the world, where only emergency announcements are made and general vocal information is avoided, leaving passengers calmer in a silent environment but constantly looking for visual reassurance for boarding status.

Introduction of ambient communication at the gates could provide the information of remaining time visually, and be visible from different focal points around each gate. For example, while approaching the gate from afar and while sitting close to it. This would benefit travellers with reassurance about the remaining time without having to find the departure information screen or asking an employee as such information is not always provided on the screen.

Moreover, the design can be useful in situations when a person already found a gate, realized there is a significant amount of time left before departure and then went back to explore the pier. Pier area can be big and wide offering various shopping and dining experiences. Usually it is hard to be able to see what is displayed on the screen next to the gate, however, a dynamic lighting pattern with color could communicate remaining time information from afar. To better understand the concept - imagine having a snack before the flight in one of the pier cafes where seeing the light from of the gates informs you about the remaining time until the gates are closed, without having to approach it.

Figure 68 below shows a conceptual section sketch for the gate information. The clouds change their color corresponding to the remaining time of the specific. A new color pallet to alert travellers is introduced – colors of the sunset ranging from yellow, orange to red. Figure 69 introduces the conceptual sketch for the pier environment with ambient communication providing remaining time information with color.

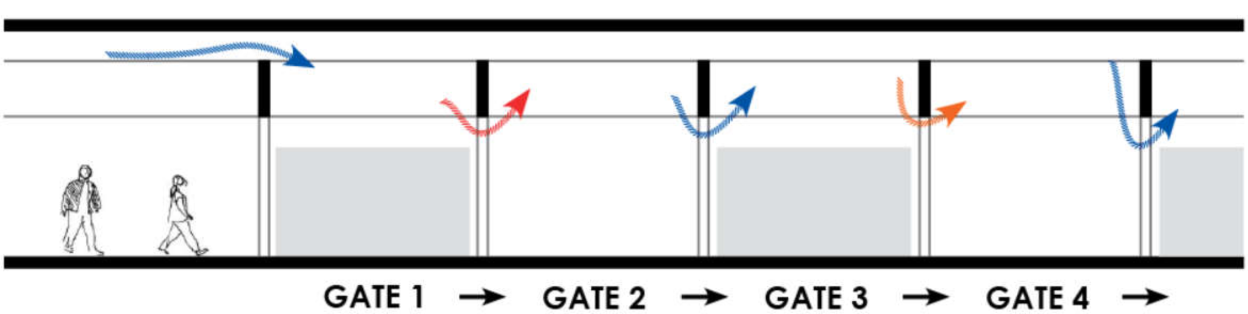


Figure 68. Conceptual section representing the cloud path at the pier with multiple gates.

Figure 69. Conceptual sketch for the pier environment.

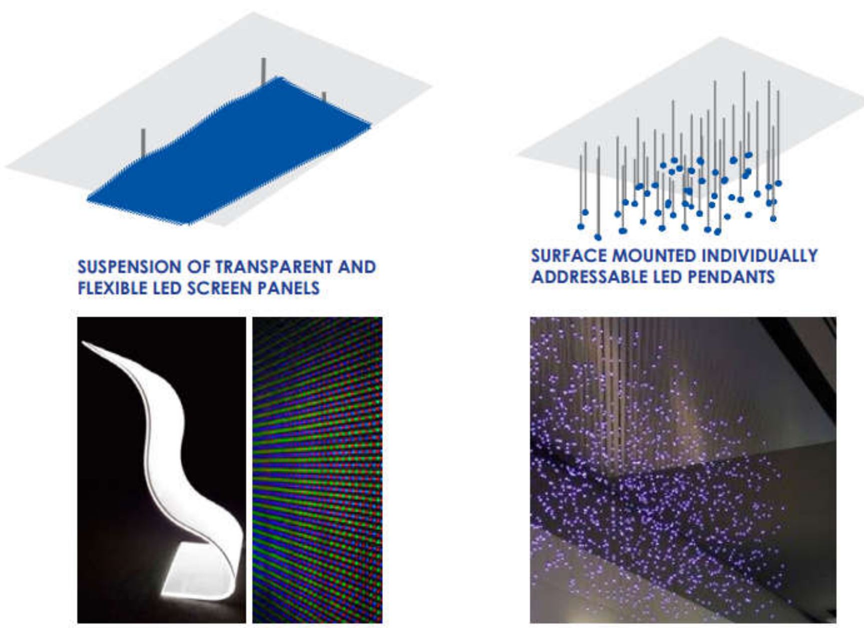


Figure 70. Different integration options for the gate environment.

9.3 Materializing the concept

In order to materialize the concept of dynamic clouds that could be implemented into parameters of lighting or visuals, a generative Perlin Noise algorithm is chosen as a starting point for the development of the pattern. Perlin noise, as discussed in the focused research chapter, is an algorithm that was proven to successfully simulate natural occurrences such as clouds, water, etc.

To determine the appearance of the conceptual pattern, a number of parameters inside the algorithm such as color, dynamic speed and size of the particles had to be defined. The choice of a specific pattern is thoroughly explained and determined in the following 10. Testing chapter.

9.3.1 Color

Focused research suggested the use of natural colors can be a part of the indirect experience of nature implemented into the design. In order to define a color that is associated with sky and travel, a study from the University of Georgia showed that 79.6% of participants had a positive emotional response to blue color, described it mostly as relaxing, calming and associated it with ocean or the sky. (Kaya & Epps, 2004)

Another research into color association describes the ecological valence theory (EVT; Palmer & Schloss, Proceedings of the National Academy of Sciences 107:8877–8882, 2010), this theory suggests that (…) people generally like colors to the degree that they like the objects associated with those colors (Taylor & Franklin, 2012). The study by Taylor and Franklin (2012) investigated the EVT further and confirmed the theory with supporting findings of a link between color preference and color–object associations. These findings can help us to build a firm foundation of the use of natural colors of the sky such as blue and sunset colors (yellow to red for the gate). The EVT theory allows us to directly associate the blue color with the sky, clouds and yellow/red hues with sunset or dawn without having a chance of it to be misunderstood due to the cultural background of users as colors of the skies are universal all over the world. Furthermore, another study compared colored lighting presence after a stress session with conventional white light and found that blue lighting accelerates the process of stress level reduction (Minguillon, Lopez-Gordo, Renedo-Criado, Sanchez-Carrion, & Pelayo, 2017). As the reduction of airport anxiety has a great value for the success of the design, this is a turning point to using the blue light as the main design color.

9.3.2 Technological framework

The dynamic pattern of Cloud Trail is generated with a moving image as an output, therefore the device has to be either displaying the whole generated video pattern (projection mapping, display screen), or be made of individually addressable pixels with each diode as a pixel (an array of light emitting diodes acting as a low-res display), see Figure 71 below.

The latter option could be a LED panel or freely hanging strings with LEDs. They have a major advantage over projection mapping or a high-resolution display – lower energy consumption while still being able to communicate the designed dynamic pattern. Lower energy consumption is due to the actual number of LEDs per square meter (pixel density) that has to powered, compared to a high-resolution display screen or a constantly operating projector. In addition, projection mapping highly depends on the material it is being projected on and requires unobstructed space between the projection canvas and projector. Therefore, even though it offers a high-quality displayed image, it was concluded to be the least attractive option.

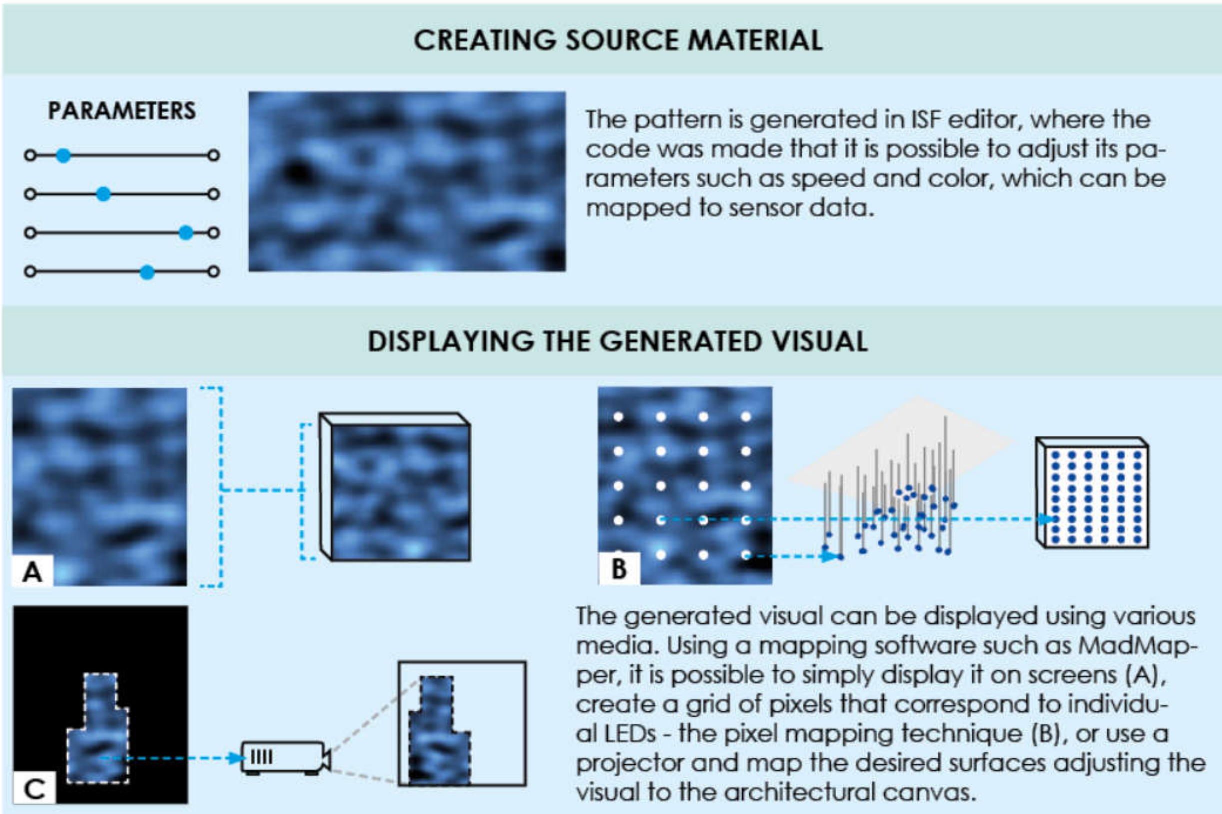


Figure 71. An illustration of the technological framework for the concept of explaining how a dynamic generative algorithm can be translated into lighting.

10. Testing

10.1 Pretest. Choosing the pattern

To define the most nature resembling pattern a questionnaire was carried out with five different visualizations. Having the base criteria of using blue as the default color and generative nature-resembling algorithm, we created 5 different options based on Perlin and Worley noise algorithms. Five patterns differed in the speed of change, size of particles and nature of their movement. Patterns were created using ISF editor based on OpenGL Shading programming language. The base for the codes for Perlin and Worley noise were acquired from shadertoy.com website.

In order to choose the preferred option, a test was performed which displayed the conceptual patterns in the context of the site (Copenhagen Airport), overlaying the moving animation of patterns over a picture of a corridor at the airport by using the Adobe Premiere Pro. The corridor was chosen due to the visual clarity of the space. See Figure 72-76 below, where patterns in the software environment are shown on the left (black color represents transparency) and conceptual interpretation of the design on the right side of illustrations.

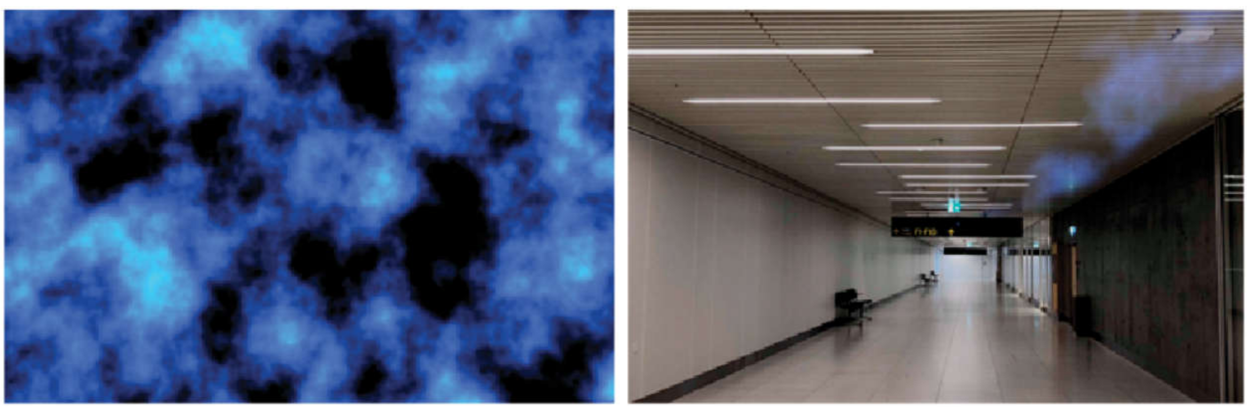


Figure 72. Pattern 1

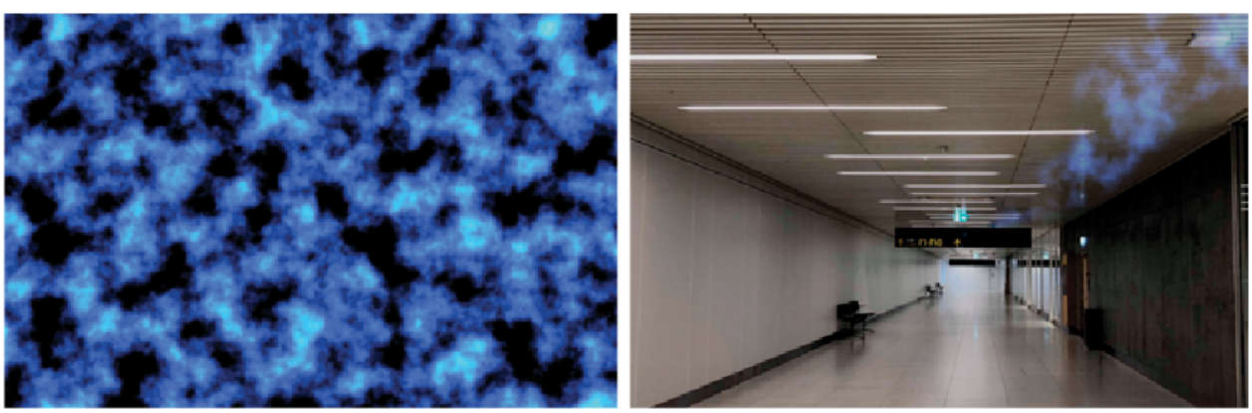


Figure 73. Pattern 2

Figure 74. *Pattern 3*

Figure 75. *Pattern 4*

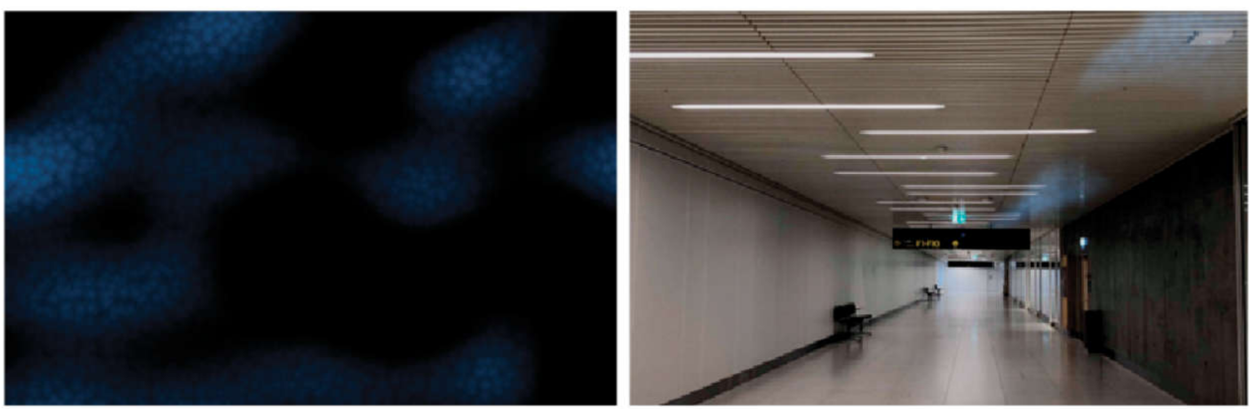


Figure 76. *Pattern 5*

10.1.1 Procedure

The viewers were presented with 5 animations and asked to assess each animation individually evaluating the statements about dynamic lighting pattern using the 5-point Likert scale method (Sullivan & Artino, 2014). Each question had a 5-point scale, varying from 1 - strongly disagree to 5 - strongly agree. The statements were as following:

1. The dynamic pattern resembles nature
2. The dynamic pattern is artificial
3. The dynamic pattern is calming
4. The dynamic pattern is disturbing

10.1.2 Results

The test results of 35 participants have shown a slight but clear preference for pattern number four as per Figure 75 above. It scored high in the nature-resemblance and it was also perceived as the most calming and least disturbing. All of the patterns were scored very similarly in the artificial aspect (for results see Appendix B). Therefore, pattern number 4 is taken intothe further design and testing phases.

10.1.3 Further design and testing

After establishing a background for introducing a new element (limiting the visual noise), defining the initial design principles and having the pattern - next step is to test the lighting for the path and the gate. Both of the components have specific test parameters described below.

10.2 Testing the path

This test is carried out to evaluate if the lighting design for the path is intuitively suggesting which direction to proceed to reach the designated. Participants were immersed in a VR environment located at a decision point as indicated in Figure 77 below. The participants were informed that their destination is Paris and asked to find the necessary information (gate indicated on the screen) and choose the direction they would proceed further in order to reach the gate. As a consequence, they had to seek information to find out which gate (A15) the plane is taking off and then to seek further information provided in the space in order to make a decision. There were two possibilities – the right and the left path, both of which were indicated by the airport signage. The lighting design was applied to only one of the paths, with the goal of testing whether participants would choose one way over the one without the cloud trail. To be able to compare the results there were two scenarios – a control scenario, with the existing situation, and the new enhanced scenario with reduced visual noise and conceptual lighting design for wayfinding added. In addition, the time that it took for a participant to make the decision was measured, in order to assess whether the decision-making process was faster in the edited environment.

Figure 77. Location of test02 and the possible choices to take – left or right path.

The test hypothesis was the following:

The dynamic lighting influences the decision of taking a direction and reassures about the right path.

Two different scenarios were created. A control scenario with existing situation of the scene during peak hours of airport operation and a design scene. In order to create a significantly different scene for the design scenario the measures taken are described below:

- Design scenario scene was taken at night time, therefore no daylight coming from the skylights.
- Fewer people present in the scene.
- Most of the shops were closed therefore less luminous visual noise.
- Layers with luminous signage of the shops, restaurant environment, and the floor had their overall brightness and contrast reduced using the Adobe Photoshop levels tool, which allows modifying the image histogram. The output levels have been set to maximum 210 in those layers, which toned down the brightest points in the areas.
- Animation of the dynamic lighting concept was added to the ceiling using image and video processing tools of Adobe Photoshop and Adobe Premiere Pro.

10.2.1 Procedure:

Before the test, all participants were immersed in a VR environment with an example scenario from another location of Copenhagen airport. This was done in order to familiarize test subjects with the equipment, procedure, and the VR experience in general. Afterwards, the participants continued to the actual test. First 11 participants participated in the control group scenario as shown in Figure 78-80. The scenario was a picture of the existing scene condition with enhanced information screen and signage (due to poor 360° image quality). The other group of 21 participants was introduced with conceptual design scenario, as per Figure 81-83. A scene consists of a spherical picture of the same location taken during night hours with changes as per description in the previous chapter. After the decision of direction was taken and time measurement documented, participants were asked to answer two questions assessing whether the design had a role in their decision-making process or if they had any additional comments. The questions were as following:

1. Which visual clues did you use to make the decision?
2. Do you have any other comments?

Figure 78. Spherical picture of the control scenario with enhanced information screen and signage.

Figure 79. Control scenario view towards the information screen.

Figure 80. Control scenario view towards the signage and two available paths (left AB and right A) towards gate A15.

Figure 81. Spherical picture of the design scenario with reduced visual noise, enhanced information screen signage, and added design.

Figure 82. Design scenario view towards the information screen.

Figure 83. Design scenario view towards the signage and two available paths (left AB and right A) towards gate A15.

10.2.2 Results

Before discussing the results, it is important to mention the technical framework of the tested content. The maximum resolution of the spherical pictures taken by the available camera was 15MP, which corresponded to a produced image of 5472×2736 pixels. While displayed in a VR headset, very close to the eyes, the images had a blurry appearance. This reduced the immersive factor of the experience.

The immersion was also affected by the monoscopic characteristic of tested images. The available camera was not able to shoot stereoscopic pictures which would have been a better alternative, as they provide a better perception of depth in the VR environment. (Rowell, 2015)

The control scenario included 11 participants from various age groups with the majority between 25 and 34 years. The average time for the decision was 27,28 seconds with scores ranging between 5,56 to 52,82 seconds. The tendency was to choose the path to the right with a 64% to 36% ratio (see Figure 80). The participants used the standard process of decision-making by using the wayfinding tools: gate information on the departure information screen, looking for the signage indicating paths towards the gate, and then choosing one of the two options - either path marked with "AB" sign or only with "A" sign. Generally, participants expressed choosing the right option mostly because it was marked with only to "A" gates, therefore it seemed like a safer choice. Moreover, some participants expressed that the right path seemed like a better choice because of good overview (visual access) and skylights indicating the path, which both can be identified as types of architectural wayfinding tools, as found in the literature review.

Interestingly, the scores for the enhanced design scenario did not reveal a significant difference. The time for decision making was quite similar to the control scenario - an average of 29,17 seconds with scores ranging between 8,21 and 74 seconds. This might be interpreted as an indicator that generally the decision-making process was not affected by the environment because the main wayfinding tools were well executed (in both scenarios the board and signage were delivering a clear message). As for the choice of the direction, the right path (with the added design) was a more popular choice, however, the responses were quite evenly distributed - with 57,10% going to the right, and 42,9% going to the left. In the question about used visual clues, most participants expressed relying on the screen and signage. Nonetheless, a number of responses also listed the added lighting design as a decision factor. Therefore, despite very even distribution of the scores, it can be concluded that the added lighting in a low visual noise environment partially did its function of suggesting the path. However, a larger sample of participants would have to be tested to extract a noticeable tendency. Nonetheless, it is essential to mention that the choice of direction was mostly affected by the signage indicating only the "A" gates, as it appeared less confusing than the sign with "AB". Therefore, it can be argued that the tested scenario was not fully appropriate to assess the path choice (it would have been better if both directional signs were identical). Nonetheless, the goal of this design test was to incorporate it in the real airport environment, as an add-on to the existing wayfinding tools.

Interestingly, findings from the last question revealed a lot of comments about the lighting dynamics. Participants expressed that they have noticed the added lighting design dynamics only after making the decision (and stopping the time measurement) and after immersing longer in the VR environment. The general response was that a more dynamically changing pattern could be more noticeable. This gives a useful input for the further refinement of the design and the testing procedure, i.e. further testing could be on the speed of the pattern with a more parametric approach to the test.

10.2.3 Test summary

The major conclusion drawn from this test was that the proposed visual noise reduction and the addition of dynamic lighting did not significantly affect the speed of the decision-making process. The direction choice was also not greatly affected by the installation according to the participants. However, it could be argued that with a goal of lighting system being an intuitive and ambient communication tool, the design should not necessarily be noticed by the users, yet still affect their choice. In order to assess whether this is the case, further testing on a larger number of participants is necessary. This can also be backed by an argument, that many of the participants said they noticed the dynamic lighting after being in the VR environment for a longer while.

Basing on the gathered data, the hypothesis cannot be proven without further testing and adjusting the pattern. Moreover, a different and more extreme scenario (for example with the absence of signage, or signage in an unknown language) could be considered to better answer the hypothesis of reassuring and intuitive design. However, the aim of this test was also to make the assessment of designed lighting in the actual context of Copenhagen Airport. Another idea for the further testing would be a more immersive experience where the viewer would immerse in a simulation where he/she would be able to move in the space, and thus experience "the path" from a more "storytelling" perspective. For example, starting from a more distant point and approaching the decision point.

Further test improvements could include identical signage, where "AB" option is converted to "A" only. If the goal to test in the existing environment the user group could be not familiar with the language of the signs. This test would also check the intuitiveness factor of people with impaired cognition, as one of the design focus groups.

To sum up, even though the results did not provide a clear answer to reassurance and intuitiveness, it was possible to extract hints that the lighting was partially fulfilling its purpose. Still, the majority of participants relied only on the classic wayfinding tools - signage and the information board. A valuable contribution came from the participants' comments, where the conclusion is that lighting design needs further refinement and testing. As for the hypothesis, based on test results only, it was concluded that designed dynamic lighting pattern had only a small effect on the decision-making process.

Detailed scores of the path test can be found in Appendix B.

10.3 Testing the gate

In the third test, the dynamic pattern was put in the spatial context of pier B in Copenhagen Airport as shown in Figure 84 below. The test consisted of five scenes, where each scene had the same background picture with overlaid animation of a generative pattern. The color parameter was different for each scene. The objective of this test was to assess whether different colors intuitively provide information about the remaining time before the departure/closing of the gate. Test subjects were not given clear instructions or explanationws of functionality or purpose of the colored pattern. The test was performed as a form of an online questionnaire, with a goal of gathering a large number of responses and reaching out to various age and user groups. After viewing each of the videos, participants were asked to fill in a survey with ten questions. The majority of participants were in the age group of 25-34 years.

Figure 84. Illustration indicating the location of the test in Copenhagen Airport pier B.

The tested hypothesis was as follows:

The color in the dynamic lighting pattern at the gate can inform the passenger about remaining time for departure and influence their decisions.

10.3.1 Procedure

The test questions were assessing two main dimensions of the design and were made in a simple format with a YES – NO – I DO NOT KNOW response options. The third part of the test was an open end question for the indication of time. The dimensions and questions were as following:

1. Functionality. Intuitive communication:

- Question 1: I could understand that dynamic lighting has a function
- Question 2: The dynamic lighting made me decide to approach the gate immediately
- Question 3: The dynamic lighting suggested that I still have some time to go to the shop
- Question 4: The dynamic lighting suggested that I have a lot of time to go to the shop
- Question 5: The dynamic lighting suggested that no plane is leaving from this gate anytime soon

2. Assessment of lighting as a useful tool:

- Question 6: I find the added lighting as a useful add-in in the terminal space
- Question 7: I find the added lighting as an unnecessary component
- Question 8: The dynamic lighting confused me
- Question 9: The dynamic lighting was pleasing

3. Time indication (open end question):

- How much time do you think there is before departure?

Figure 85. Snapshots from 5 scenes with different colors, the scenes were shuffled for randomization after every 10th subject.

10.3.2 Results

Findings from the questions about the suggestions given by patterns with different colors and whether they intuitively communicate the time, were as anticipated. The color mostly triggering the reaction of approaching the gate immediately was red, and afterwards respectively orange, yellow, blue and green. Colors suggesting that there is some or a lot of time before the departure were green and blue. Here the interesting finding was that about the green color, which in other lighting situations is generally read quite otherwise. For example, green at the traffic lights suggest movement or green and red signalizing free and taken parking spaces. It could be concluded here, that positioning it against other colors, including the "transitional ones" such as yellow and orange, affects the response and scoring. A suggestion here would be to perform another set of tests with each of the dynamic patterns assessed individually, by different participants.

In the last questions, the participants were asked an open-end question. The very interesting finding was that despite being an open question, a lot of answers were largely similar - 15 out of 41 participants answered 01:00:00 to the scenario with a blue pattern. By asking this question, the goal was not only to further facilitate the hypothesis but also to utilize the user-designer, co-design approach. Having recorded the answers, it was decided to use the median as a data extract to further take into consideration the design (due to some very far-off answers such as 45 hours which would distort the score if the average was taken). The results were as following from the highest to lowest times, also illustrated in Figure 86 below:

- Green - 1hr0min0sec
- Blue - 00hr45min00sec
- Yellow - 00hr20min00sec
- Orange - 00hr10min00sec
- Red - 00hr05min00sec

Figure 86. Illustration of results for the color association and time in the proposed scenes.

The scores from the test also revealed several tendencies. The function of the lighting was generally understood, with the least understanding of the scenario where both the gates had the same - default - blue color. In this scenario, the 15 out of 41 participants responded NO or I DO NOT KNOW to a question whether they understood that lighting has a function. This could be due to the fact that there was no difference between the two visible gates, therefore it could have been hard to have a reference point for the viewer. In other scenarios, where the colors were different the functionality was well understood.

Another general finding was that in questions 6, 7 and 8, the participants positively assessed the design as being a useful added tool (with the lowest positive response of 63% of the votes for the blue and green patterns). The biggest confusion was associated with the "transitional colors" which are orange and yellow and can be interpreted as a comment to the test itself. Perhaps a video showing the transition gradient would have been better understood, or perhaps these colors themselves do not evoke a straightforward response. Nonetheless, the ratio of those negative responses was still quite low (11 out of 41 responses for both orange and yellow pattern evaluated as "confusing").

The design of the pattern with different applied color was judged positively in question no 9 as ''pleasing'' with the highest scores (75% of 'yes' votes for each of the patterns) for blue and green, which can also be interpreted as a positive argument for the default blue color of the installation - and lowest for orange - at 61%.

The last open question about the general comments gave valuable input for further design development. There were several comments pointing out that the functionality is only understandable after seeing the second video, and that it would have been more understandable if it was seen in the context of the whole airport. This observation could be implemented to refine the design in the further testing, where more gates would be in the field of view and the whole experience could involve moving in the space as opposed to a static point of view.

Another set of comments was about the speed of the patterns - a number of participants expressed that they would have liked speed/frequency of pattern to be indicating the time as well. This could also be checked with further pattern refining tests.

10.3.3 Test summary

The test can be concluded as successfully proving the hypothesis that a simple gradient of colors can be used to intuitively communicate the time left for the gate closure. Nonetheless, only one dynamic pattern was tested, which can be considered as a bias. From the two open questions with the user-designer co-design approach, it was possible to extract suggestions for the time that each of the colors will represent and also possible areas for further testing to refine the design – the parameters of the dynamic pattern.

To sum up, findings that can be taken into the further design are that colors can intuitively suggest the information and that the patterns were positively judged, therefore this is the right design direction to take. However, the dynamic pattern should be further refined with more tests regarding the visual, its speed and frequency. Finally, from the open question about the time assessment, it was possible to extract the most intuitive timeframes, in which different colors of the design would be displayed.

It is important to emphasise that this testing approach puts a layer of technological difficulty or bias because it was not possible to ensure that participants' display screens had the same sizes and color calibration, therefore the colors and the general judgement of the scene could have been affected by it.

11. Evaluation

11.1 Evaluation of the design

The proposed lighting concept was tested using the developed method for the terminal wayfinding lighting. Therefore, the findings from the overall process assess both the dynamic wayfinding lighting system and the method itself. This chapter evaluates the lighting concept for the wayfinding system and discusses possible future tests, works, etc.

As introduced before the conceptual Cloud Trail development is divided into two categories, corresponding to the two elements as described previously in the concept – The Path and The Gate. Both categories have been tested with different tests:

11.1.1 The path

Evaluation of the proposed concept for the path did not result in a clear direction the design should take. It was concluded that for further refinement of communication of the proposed concept, there is a need for a number of design tests to define the following parameters:

- The lighting effect – Following a number of responses from test participants, the parameter of the speed for the designed pattern should be tested.
- Type of integration – Only one type of integration was visualized in the test – the light installation with individually addressable pixels. As defined before, using the chosen software allows mapping designed pattern with other types of media. Testing the parameter of lighting integration would give a great insight if the communication tool would influence the design.
- Also, testing the parameter of the positioning of the lighting in the space, such as different height options, or planes (for example, walls and floor).

Another approach for fulfilling the design criteria for the path – which is reassurance and improved wayfinding – could be to follow a principle of "less is more". By actually putting more focus on the visual noise reduction, in an attempt of emphasizing the already existing wayfinding tools. This concept could be further developed by adding a subtler ambient communication strategy (as opposed to the approach in Cloud Trail - the dynamic generative lighting patterns) and investigating the influence of more traditional lighting qualities on the improvement of wayfinding (such as for example color temperature or illuminance levels of different spaces). This is a topic for another concept development, however, it can be argued that the workflow of the proposed method is still applicable.

Generally, it was not possible to conclude whether the proposed design of the path was or was not fulfilling the design criteria. This could be an indication that the concept itself was not the best fitting, however, it could also be an indicator that the method needs to be improved.

11.1.2 The gate

Evaluating the testing of the intuitive communication of the gate design gave a very comprehensive, applicable data. Firstly, following a positive response of the test and data from the research, it was decided that using a dynamic generative pattern with changeable colors is a well-working approach for fulfilling projects' intuitive communication and anxiety reducing design criteria.

It was decided to apply the findings from the test question about the times to the design, and map the color gradient from the default blue (being displayed at all times when there is no leaving plane up to 45min before gate closes) to red corresponding to time before departure starting 5 minutes before, when the pattern starts to change from blue to red, with intermediate stops at 20min (full yellow) and 10min (orange), as visualized below:

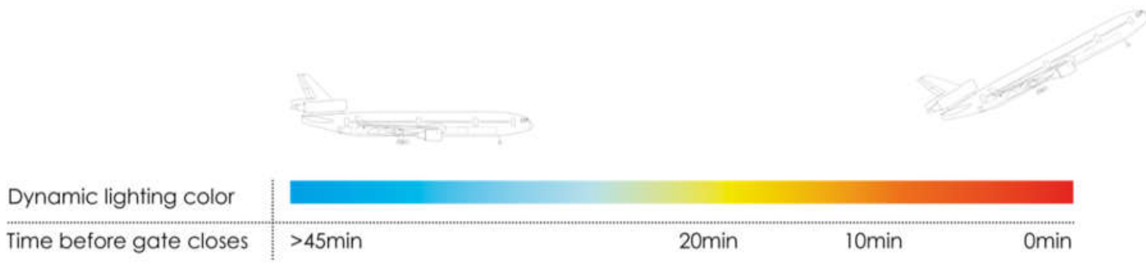


Figure 87. Illustration of the gradual color change of the pattern based on the time left to the closing of the gate.

For further design, it is necessary to gather airport data on departure times from one pier on a busy day. This data would be then mapped to the proposed design and simulated in computer software, in order to assess whether there are times at the day, where the multiple gate lighting would become disturbing (a lot of departures, too frequently changing lighting). In this case, the design proposal is to remove the default blue pattern at all times, and only turn it on when the gate is open indicating the time of 45 remaining minutes with blue, to yellow - 20 minutes, orange - 10 minutes and a gradual change to red when the time is 5 minutes or less.

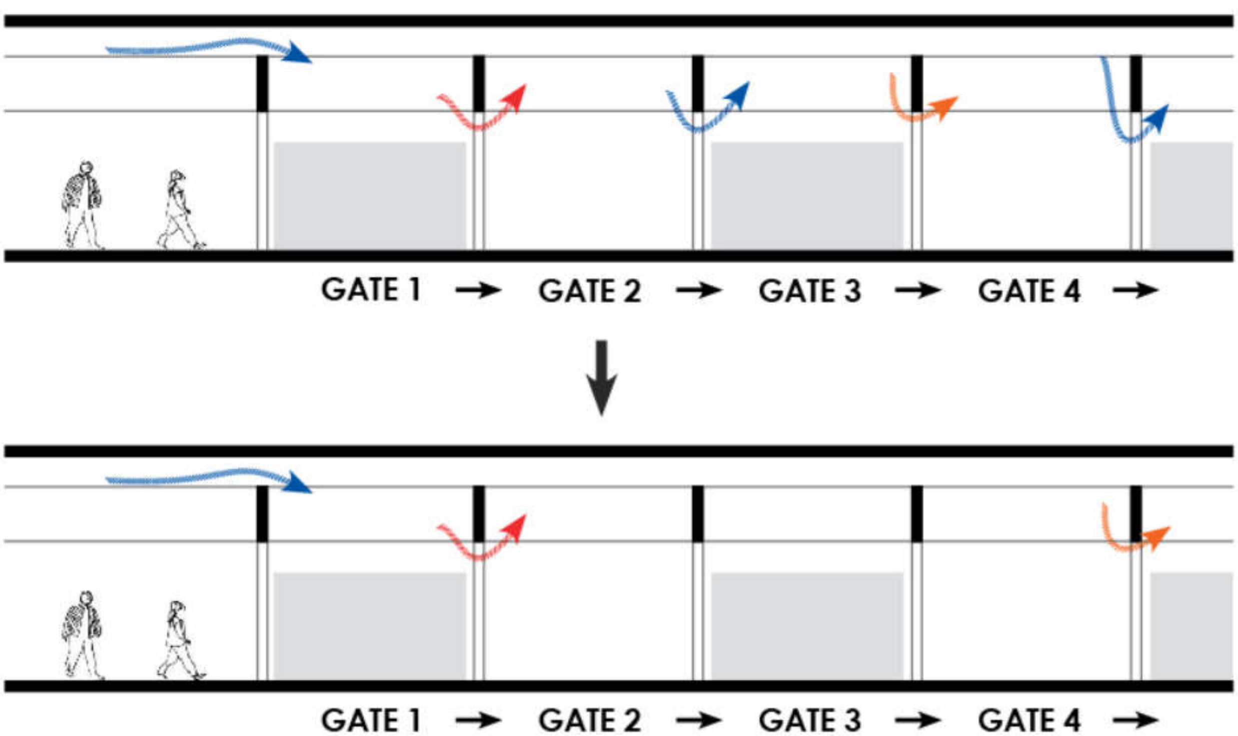


Figure 88. Illustration of reducing the lighting visual from the initial concept idea.

Following the responses from the performed test, another parameter for further refinement is the frequency of the pattern. Next test could be to investigate the effect of changing the speed of the patter along with the predefined colors – if it has a more powerful communication than only the color itself. Furthermore, testing the threshold at which the frequency of change would become disturbing might also be necessary to limit the parameter.

In the final stages of concept development, an idea could be perhaps to take it into a context of a less busy airport and test on the site over time.

11.1.3 Further design tests

After refining the concept and dynamic lighting parameters, the next step is a series of technical design tests, possibly with mockups. Firstly, a major challenge with incorporating artificial lighting at the terminals comes from the daylight. In this case, the lighting should be functional during both, day and night hours. As thoroughly described in the first chapters and confirmed with analysed cases, modern terminals are often flooded with daylight, and Copenhagen Airport is no different. Therefore, a number of visibility tests using mockups of the proposed lighting effects would have to be performed before the implementation in the actual space in order to confirm that the lighting is still functional when the daylight is present. A variety of prototypes would have to be carried out in a specific architectural environment simulating the actual space. This would result in a choice of the specific luminaire, then later adjustments of the luminous output, which would define the visibility thresholds during the most daylight hours. Figure 89 shows examples of visibility testing.

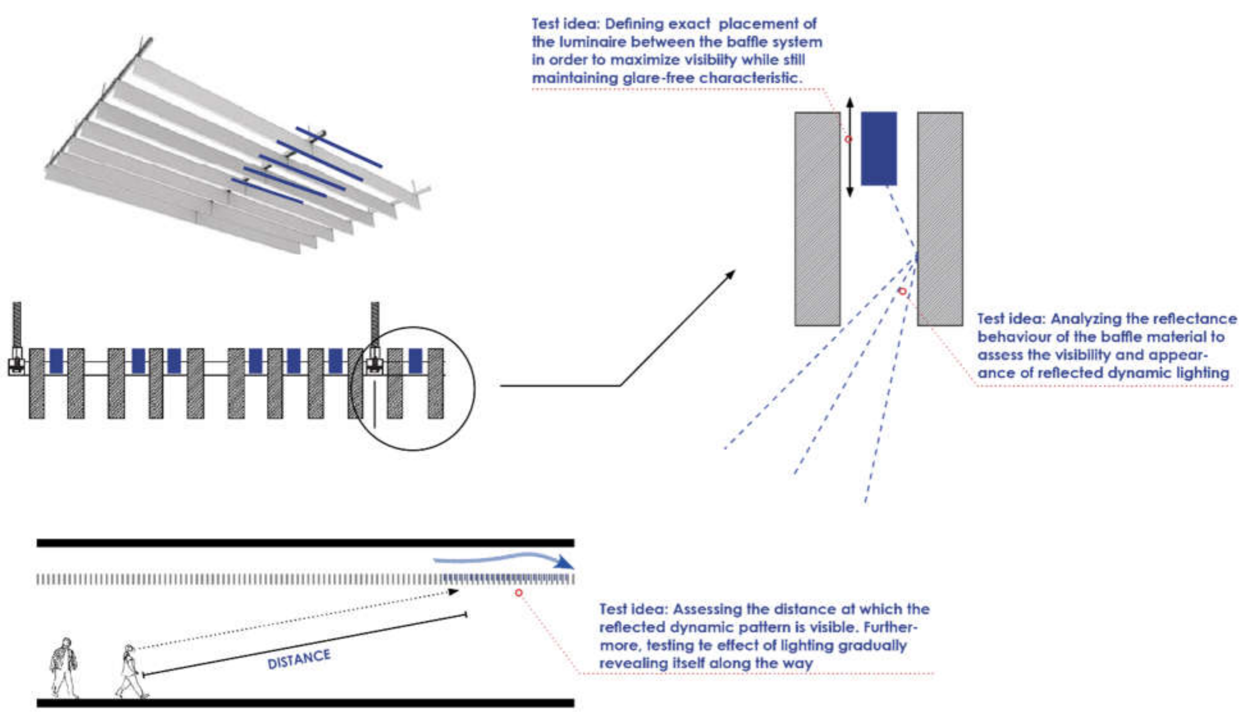


Figure 89. Examples of further testing.

11.2 Evaluation of the method

Generally, the aim of the proposed method was to make it universally usable for analysing the airport environment and then later assessing lighting concept for improvement of wayfinding. After the application of the method, it was clear to see that some aspects of it worked well and are good to apply, while others need further development.

The first step of the method – analysis of the site – generally gave a good understanding of the relevant context for the project. However, a big improvement here would be the acquisition of passenger processing data from the airport, technical architectural drawings (for quick assessment of possible design integrations and limitations), and ideally digital model of the space. An observation that came after the process was that video time-lapse at the decision points would be helpful in order to assess the efficiency of existing wayfinding strategy and path preferences and choices of passengers.

For the documentation aspect, the major improvement should be a series of luminance and illuminance measurements in different areas of the terminal, and also the behaviour of daylight over time in different seasons. As found in the analysis, airport terminals are structures significantly relying on the natural light, therefore observations of its behaviour would greatly benefit the quality of the designed lighting. What was also found through the process, a higher quality of images should also be taken if the goal is to later utilize them in Virtual Reality tests content preparation.

Visual noise – the experimental method for assessment and calculation of Visual noise has proven itself to be a relevant tool. As discussed earlier, there is a number of biases, mainly for determining the extent to which parts of the visual field are visual noise. A priority for development here should be putting more quantitative figures on the different aspects that area counted as visual noise. For example, the number of pixels considered as sources of glare in the scene could be more defined by establishing a pixel value threshold from the image's histogram. Another limitation that could follow, is establishing maximum luminance and size of the dynamic advertising screens which currently visually compete with the wayfinding tools. In general, the next steps would be to pick selected major visual noise factors and attempt to put quantitative thresholds on them in order to make the method more universal. Nevertheless, despite the necessary developments, the proposed visual noise assessment and reduction method can be a good starting point for establishing a good background for adding a new lighting design to the terminal space. Its' functionality, however, needs to be further assessed with a number of tests – which could be in the same format as the performed tests, but just with a comparison of the existing airport environment, with the one with reduced visual noise (without the added new lighting effect).

Testing the lighting concept itself in terms of the defined design criteria for lighting for wayfinding gave a number of valuable observations. Firstly, the proposed time-measurement test for the criteria of the improved flow of passengers did not give easy-to-process findings. An observation here was that perhaps a better format of VR test would have given more hands-on results. Therefore, the proposal for further development is to create a test in which the content would allow the participant to move in the space and try to find the way. In such a format, the time measurement and preference choice (which way would they take?) throughout the whole experience would give better results. This is also due to the character of the wayfinding process, which is something by definition associated with a longer immersion and movement through space. Another factor that could contribute to the immersion is the addition of the sounds from the airport environment. Furthermore, by recreating the dynamic experience (with the possibility of movement) in virtual reality, the reassurance factor could have been tested as well, and response to the conceptual lighting as a whole system present throughout the terminal. Here a great help would be the 3D model of the space or architectural drawings which would allow quick recreation of the space in a 3D digital environment (for example in 3D Studio Max software and later in Unreal Engine to create an interactive 3D environment of the terminal).

This observation is also relevant for the intuitive communication test. With more interactive and immersive content, ambient communication could have been better understood by the participants. The topic of ambient communication is quite challenging on its own, as by definition it should not be something heavily perceived. The tested lighting concept was dynamic and with changing colors – a concept consisting of subtler parameters - for example, the effect of different levels of ambient lighting on wayfinding - could require a more immersive content. Nevertheless, performed testing procedure with a comparison of images/videos has proven itself to be a valuable tool for quick assessment of conceptual ideas by a broad panel of observers.

Generally, the main observation from the testing was that the VR approach is a good method of lighting design assessment. With the availability of modern digital tools, the lighting qualities can also be very much specified and controlled. Though for testing the success criteria for lighting that enhances wayfinding, the content should be more immersive and interactive.

However, the conflict here is with the processing of the participants – VR testing is an enduring process and requires the presence of the participants. As found through the online-based test, concept assessment performed through online questionnaires gives a rather fast and high response rate. Here the designer should be careful not to test qualities that are too technical, due to possible differences in the procedure and personal display screens of participants which would be a significant bias if a test was to assess for example perception of very specific CCT or luminance.

12. Discussion

Looking through the scope of the whole thesis, a major discussion point would be the exploration of the ambient communication with lighting field. There could be limitless possibilities of suggestively communicating information within the lighting system with utilisation of a variety of parameters such as CCT, luminance, dynamic dimming, etc. Moreover, ambient communication could also refer to other functionalities within the wayfinding, such as suggestively indicating the location, distance, atmospheric qualities, etc. Therefore, it was decided to put more focus on the design method rather than the lighting itself, and then use the created concept as an example design to evaluate the method.

The proposed method was developed with the goal of being universally applicable to other lighting concepts within the wayfinding area. The established 4-step workflow has proven itself to be well functioning, however with a need of several improvements as discussed in the previous chapter. Here a major discussion point is the visual noise assessment proposal. The authors are aware, that the proposed pixel-count based quantitative measuring method is at an early stage of development. However, it was created in an attempt to put numbers behind the qualitative assessment - which can still be argued to be a solid analysis tool backed by research and authors' personal experiences.

Outside the improvement of wayfinding with light, the method could find further application within other fields of lighting. The visual noise aspect deals with a wide topic of and could be addressed towards other areas. For example, time of recognition in visually heavy environments, luminous advertising in an urban or retail environment, pixel-count based glare assessment, assessment of materials reflectance and so on. Furthermore, proposed testing procedures – online based questionnaires and virtual reality tests – are powerful assessment tools as their combination provides both wide ranges of responses for extracting trends, and also detailed observations about the design by immersive engagement in the environment. The latter is especially significant, as it offers much more insight into the "real thing" as opposed to a more traditional comparison of rectangular images. Off course, preparation of content and testing procedure is more time and resource taking (one participant at a time), which can be an issue in some projects.

Going back to the wayfinding lighting design proposal, it was partially evaluated as a good add-on to the terminal space. It utilized the color of lighting and programmed dynamics parameters which were both tested. The suggestive communication of remaining time to departure has been positively evaluated and it could be implemented for prototype testing. However, the universal application of the design can be questioned, as it requires a more thorough analysis of architectural context before implementation. As seen in the site analysis, some piers of the Copenhagen Airport (for example a large section of gates A, with the exposed structural steel roof structure) would be challenging to integrate the pattern in a same, delicate manner. To tackle this issue, a number of implementation techniques have been proposed, with the general principle of mapping the generated lighting through different integration methods.

13. Conclusion

To conclude, the wayfinding experience at airport terminals can be vastly improved by the usage of intuitive lighting. However, as the thesis suggests, the success of intuitive lighting would require a lot of changes in the way airports are structured these days. This would include the necessity of change in priorities of organizational systems, such as providing adequate signage with appropriate lighting, plus control and management of visual noise. Lighting management is of great importance when considering these functional systems at terminals. Furthermore, as hypothesized and supported by literature research, simple methods such as the introduction of indirect nature elements implemented in lighting could contribute to the wellbeing of travelers. Another important aspect to mention is prioritizing the experience of a passenger rather than the revenue from retail tenants. When the passenger experience is the main theme, a modern, suggestive lighting system for wayfinding can contribute to the image of the airport, through the creation of identity and memorable brand.

Interestingly, while trying to solve the main problem question derived from the analysis, a step by step method for lighting design in the terminal was developed. The idea was to describe the procedure for the design process of intuitive lighting design system at the airport environment. This method, however, could be broadly applicable for other lighting design systems in the airport terminal environment. It involves four gradual steps, which can guide a designer along the process. Firstly, the analysis of the site context to investigate the existing conditions. Further on, an identification, analysis, and measurement of the extent of visual noise in the space in order to reduce it. Afterwards, implementation of the concept ideas and design of the lighting system. Finally, a two-level testing phase which includes using digital tools such as online questionnaires and VR equipment to assess if the concept and design decisions address the main design problems and criteria

Bibliography:

Airport Technology. (2016). Flying in tune with nature: the cleanest, greenest airport spaces. Retrieved March 20, 2019, from https://www.airport-technology.com/features/featurethe-airport-worlds-cleanest-greenest-spaces-4809435/

AQT Solutions. (2017). What Was the World's First Airport? Retrieved March 20, 2019, from http://www.aqtsolutions.com/what-was-the-worlds-first-airport/

Ashford, N. J., Mumayiz, S., & Wright, P. H. (2011). *Airport Engineering: Planning, Design, And Development of 21st-century airports* (4th ed.). JOHN WILEY & SONS, INC.

Baker, J. (2018, May). GATE ANXIETY: THE HOT TOPIC FOR 2018. *AIR Airport Industry Review*. Retrieved from https://airport.nridigital.com/air_may18/gate_anxiety_the_hot_topic_for_2018

Baron, S., & Wass, K. (2007). Towards an understanding of airport shopping behaviour. *The International Review of Retail, Distribution and Consumer Research*. https://doi.org/10.1080/09593969600000026

Beecher, A. B. (2004). *Wayfinding Tools in Public Library Buildings: a Multiple Case Study*. University of North Texas. https://doi.org/10.1017/CBO9781107415324.004

Beute, F., & de Kort, Y. A. W. (2018). The natural context of wellbeing: Ecological momentary assessment of the influence of nature and daylight on affect and stress for individuals with depression levels varying from none to clinical. *Health and Place*, *49*(February 2017), 7–18. https://doi.org/10.1016/j.healthplace.2017.11.005

Blake, S., Hall, J., & Sissel, S. (2010). Using Lighting to Enhance Wayfinding. *Syntax*.

Bogicevic, V., Yang, W., Cobanoglu, C., Bilgihan, A., & Bujisic, M. (2016). Traveler anxiety and enjoyment: The effect of airport environment on traveler's emotions. *Journal of Air Transport Management*, *57*, 122–129. https://doi.org/10.1016/j.jairtraman.2016.07.019

Dada, E. S., & Wirasinghe, S. C. (1999). Development of a New Orientation Index for Airport Terminals. *Transportation Research Record: Journal of the Transportation Research Board*, *1662*(99), 41–47. https://doi.org/10.3141/1662-05

Dada, Ezekiel Sunday. (1997). *Quantitative measures of orientation in airport terminals*. University of Calgary. https://doi.org/10.16953/deusbed.74839

Davis, K., Owusu, E., Marcenaro, L., Feijs, L., Regazzoni, C., & Hu, J. (2017). Evaluating Human Activity-Based Ambient Lighting Displays for Effective Peripheral Communication. *Proceedings of the 11th International Conference on Body Area Networks*, (December). https://doi.org/10.4108/eai.15-12-2016.2267663

Ducatel, K., Bogdanowicz, M., Scapolo, F., Leijten, J., & Burgelman, J.-C. (2001). ISTAG Scenarios for Ambient Intelligence in 2010. *Society*, 58. https://doi.org/10.1111/jvh.12555

Edwards, B. (1998). *The modern terminal□: new approaches to airport architecture*.

Edwards, B. (2005). *The modern terminal□: new approaches to airport architecture*.

Fewings, R. (2001). Wayfinding and airport terminal design. *THE JOURNAL OF NAVIGATION*, *54*, 177–184. Retrieved from https://www.cambridge.org/core/journals/journal-of-navigation/article/wayfinding-and-airport-terminal-design/91DB680F65F3A20FFD47A29A08EB843E

Gärling, T., Lindberg, E., & Mäntylä, T. (1983). Orientation in buildings: Effects of familiarity, visual access, and orientation aids. *Journal of Applied Psychology*, *68*(1), 177–186. https://doi.org/10.1037/0021-9010.68.1.177

Harding, J. (2012). How to tell if your airport has a wayfinding problem. *Journal of Airport Management*, *6*(3), 231–242. Retrieved from https://www.ingentaconnect.com/content/hsp/cam/2012/00000006/00000003/art00006

Harding, J. R., Marshall Elizer, J., Alderman, J., & Frankel, M. J. (2011). *Wayfinding and Signing Guidelines for Airport Terminals and Landside*. https://doi.org/10.17226/13640

International Civil Aviation Organization. (2019). Air transport, passengers carried. Retrieved from https://data.worldbank.org/indicator/IS.AIR.PSGR

Jennifer Rowley, F. S. (2006). The retail experience in airport departure lounges: reaching for timelessness and placelessness. *International Marketing Review*, *16*(4/5), 363–376.

Kellert, S., & Calabrese, E. (2015). The Practice of BioDesign. Retrieved from http://www.bullfrogfilms.com/guides/biodguide.pdf

Kim, W., & Jeong, T. K. (2011). A position index formula for evaluation of glare source in the visual field. *Indoor and Built Environment*, *20*(1), 47–53. https://doi.org/10.1177/1420326X10389267

Lynch, K. (1960). *The Image of The City*. Massachusetts Institute of Technology.

Mankoff, J., & Dey, A. (2003). From conception to design: a practical guide to designing ambient displays. *Public and Situated Displays*. https://doi.org/10.1055/s-2008-1067188

NanoLumens. (n.d.). Airport Digital Signage Solutions: We've Got 'Em All! Retrieved from https://www.nanolumens.com/blog/airport-digital-signage-solutions-weve-got-em-all/

National Academies of Sciences Engineering and Medicine. (2011). *Wayfinding and Signing Guidelines for Airport Terminals and Landside*. *Wayfinding and Signing Guidelines for Airport Terminals and Landside*. https://doi.org/10.17226/13640

Neufert, E., & Neufert, P. (2002). *Neufert-140814092159-Phpapp01.Pdf*. (B. Baiche & N. Walliman, Eds.) (3rd ed.). Wiley-Blackwell.

Pedersen, E. R., & Sokoler, T. (1997). AROMA: Abstract Representation of Presence Supporting Mutual Awareness. *Proceedings of the International Conference on Human Factors in Computing Systems (CHI'97)*, 51–58. https://doi.org/10.1145/258549.258584

Philips Lighting. (n.d.). Creating space and order with light. Retrieved from http://www.lighting.philips.com/main/systems/system-areas/airports/terminal-side

Pon, S. (2005). *Planespotting. Wayfinding in architecture. An airport terminal*. University of Calgary. https://doi.org/10.16953/deusbed.74839

Reuters. (2018). 90 million passengers seen using Dubai International airport in 2018. Retrieved March 20, 2019, from https://gulfnews.com/business/aviation/90-million-passengers-seen-using-dubai-international-airport-in-2018-1.1542105368680

Reuters. (2019). Forward Thinking – Designing the Airport of the Future. Retrieved from https://www.reuters.com/brandfeatures/business-debate/forward-thinking-designing-the-airport-of-the-future

Rowell, M. (2015). Stereo vs Mono 360° Video for VR. Retrieved from https://360labs.net/blog/stereo-vs-mono-360-video-vr)

Sullivan, G. M., & Artino, A. R. (2014). Analyzing and Interpreting Data From Likert-Type Scales. *Journal of Graduate Medical Education*. https://doi.org/10.4300/jgme-5-4-18

Swanson, V., Dempster, C., Power, K. G., McIntosh, I. B., & Raeside, F. (2006). Anxiety and Health Problems Related to Air Travel. *Journal of Travel Medicine*, *5*(4), 198–204. https://doi.org/10.1111/j.1708-8305.1998.tb00507.x

The New School,(2018). Light for Ambient Communication | Parsons School of Design. Retrieved from Youtube: https://www.youtube.com/watch?v=rjp6ne7EaU0&t=3766s

Tombs, A., & McColl-Kennedy, J. R. (2003). Social-servicescape conceptual model. *Marketing Theory*, *3*(4), 447–475. https://doi.org/10.1177/1470593103040785

Tymkiw, A. D. (2017). Emotions Involved in Shopping at the Airport. *The Catalyst A Multidisciplinary Review of Undergraduate Scholarship at The University of Southern Mississippi*, *4*(1), 4–17. https://doi.org/10.18785/cat.0401.02

Wattanacharoensil, W., Schuckert, M., Graham, A., & Dean, A. (2017). An analysis of the airport experience from an air traveler perspective. *Journal of Hospitality and Tourism Management*, *32*, 124–135. https://doi.org/10.1016/j.jhtm.2017.06.003

Yarin, P., Ishii, H., Gorbet, M., Dahley, A., Ullmer, B., Wisneski, C., & Brave, S. (1998). Ambient Displays: Turning Architectural Space into an Interface between People and Digital Information, 22–32. https://doi.org/10.1007/3-540-69706-3_4

List of figures:

Appendixes

Appendix A – The chosen dynamic pattern code

Below is a code for the dynamic lighting pattern that was chosen through test 01. It was based on the code ''Worley – Perlin noise'' by author identifying himself as w450468524 (www.shadertoy.com\/view\/MdGSzt). The added parameters to the code were the color (red, green, blue sliders), size of particle 1, size of particle 2.

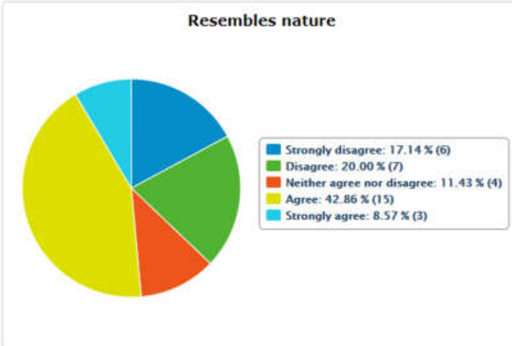
The code:

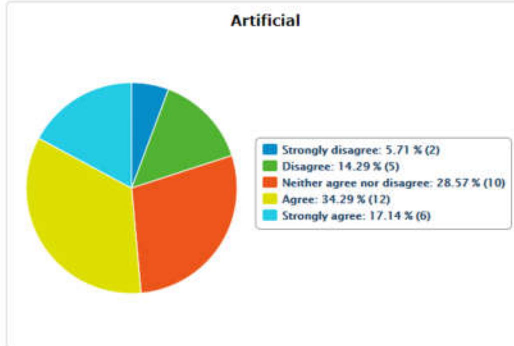
```
/*
{  "CATEGORIES" : [
    "Automatically Converted",
    "Shadertoy"],
   "INPUTS" : [
    { "NAME" : "red",
      "TYPE" : "float",
      "MAX" : 5,
      "DEFAULT" : 5,
      "MIN" : 0},
    {"NAME" : "green",
      "TYPE" : "float",
      "MAX" : 5,
      "DEFAULT" : 3.8599999999999999,
      "MIN" : 0},
    { "NAME" : "blue",
      "TYPE" : "float",
      "MAX" : 5,
      "DEFAULT" : 2.7999999999999998,
      "MIN" : 0},
    { "NAME" : "size1",
      "TYPE" : "float",
      "MAX" : 1,
      "DEFAULT" : 0.02,
      "MIN" : 0},
    { "NAME" : "size2",
      "TYPE" : "float",
      "MAX" : 100,
      "DEFAULT" : 10,
      "MIN" : 1},
    { "NAME" : "cellsize",
      "TYPE" : "float",
      "MAX" : 5000,
      "DEFAULT" : 20,
      "MIN" : 1}
  ],
  "ISFVSN" : "2"
}
*/ // copy from https://www.shadertoy.com/view/4l2GzW
float r(float n)
{
                              return fract(cos(n*89.42)*343.42);}
vec2 r(vec2 n)
{
                              return vec2(r(n.x*23.62-300.0+n.y*34.35),r(n.x*45.13+256.0+n.y*38.89)); }
float worley(vec2 n,float s)
{
    float dis = 92.0;
    for(int x = -1;x<=1;x++)
    {for(int y = -1;y<=1;y++)
        {   vec2 p = floor(n/s)+vec2(x,y);
            float d = length(r(p)+vec2(x,y)-fract(n/s));
            if (dis>d)
            {dis = d;}
```

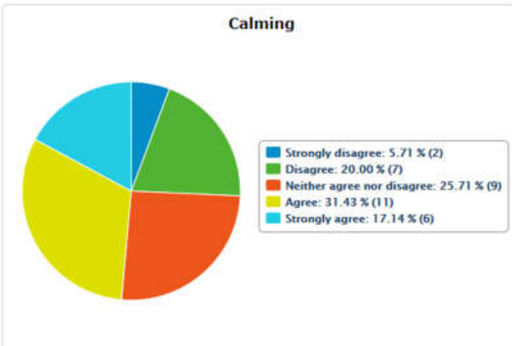
```
        }
    }
    return 1.0 - dis;
}
// copy from https://www.shadertoy.com/view/4sc3z2
#define MOD3 vec3(.1031,.11369,.13787)
vec3 hash33(vec3 p3)
{
                p3 = fract(p3 * MOD3);
    p3 += dot(p3, p3.yxz+19.19);
    return -1.0 + 2.0 * fract(vec3((p3.x + p3.y)*p3.z, (p3.x+p3.z)*p3.y, (p3.y+p3.z)*p3.x));
}
float perlin_noise(vec3 p)
{
    vec3 pi = floor(p);
    vec3 pf = p - pi;

    vec3 w = pf * pf * (3.0 - 2.0 * pf);

    return          mix(mix(mix(dot(pf - vec3(0, 0, 0), hash33(pi + vec3(0, 0, 0))),
              dot(pf - vec3(1, 0, 0), hash33(pi + vec3(1, 0, 0))),
                w.x),
                mix(dot(pf - vec3(0, 0, 1), hash33(pi + vec3(0, 0, 1))),
              dot(pf - vec3(1, 0, 1), hash33(pi + vec3(1, 0, 1))),
                w.x),
                w.z),
                    mix(
             mix(dot(pf - vec3(0, 1, 0), hash33(pi + vec3(0, 1, 0))),
              dot(pf - vec3(1, 1, 0), hash33(pi + vec3(1, 1, 0))),
                w.x),
                mix(dot(pf - vec3(0, 1, 1), hash33(pi + vec3(0, 1, 1))),
              dot(pf - vec3(1, 1, 1), hash33(pi + vec3(1, 1, 1))),
                w.x),w.z),w.y);
}
void main() {
    float dis = (.5+perlin_noise(vec3(gl_FragCoord.xy/RENDERSIZE.xy, TIME*size1)*size2))
        * (1.0+(worley(gl_FragCoord.xy, 232.0)+
        .9*worley(.0*gl_FragCoord.xy,1232.0) +
        0.25*worley(4.0*gl_FragCoord.xy,cellsize) ));
                gl_FragColor = vec4(vec3(dis/red,dis/green,dis/blue),1.0);
}
```

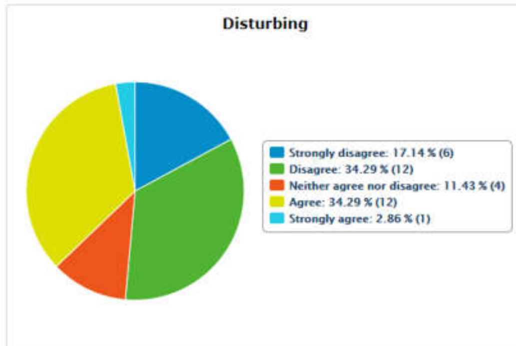
Appendix B – Pretest results

Pattern no. 1

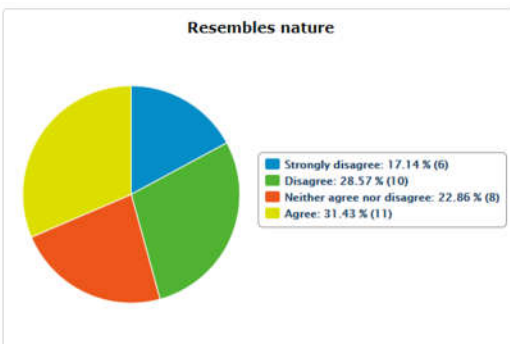


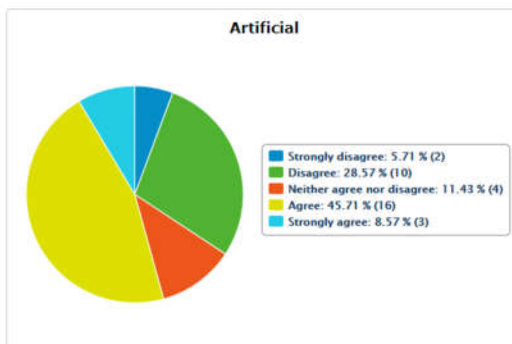


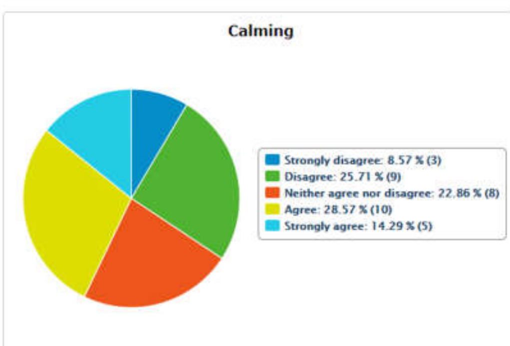


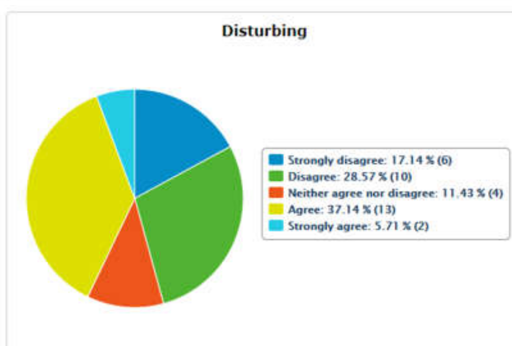


Pattern no. 2

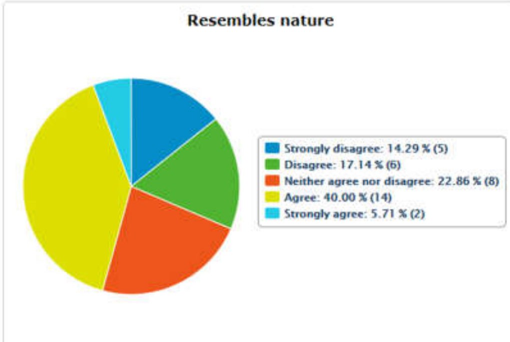


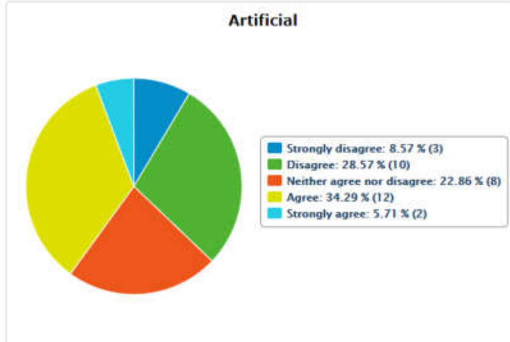


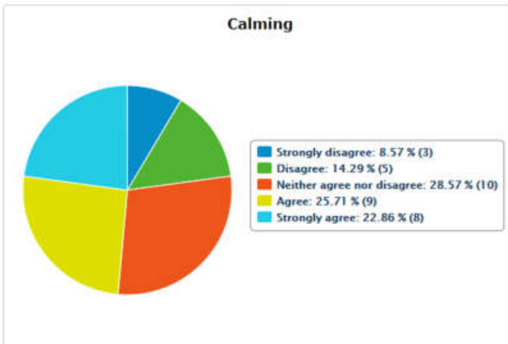


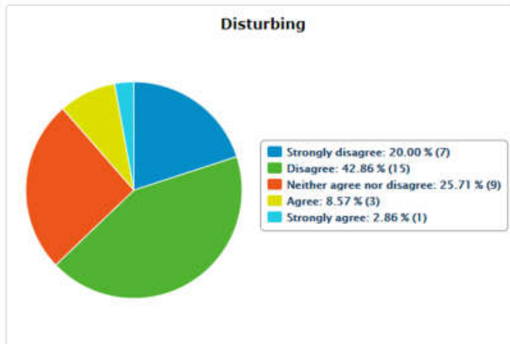


Pattern no. 3

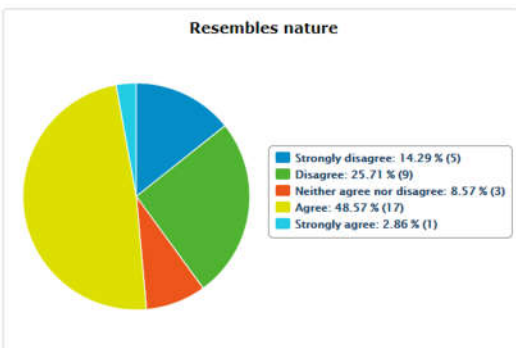


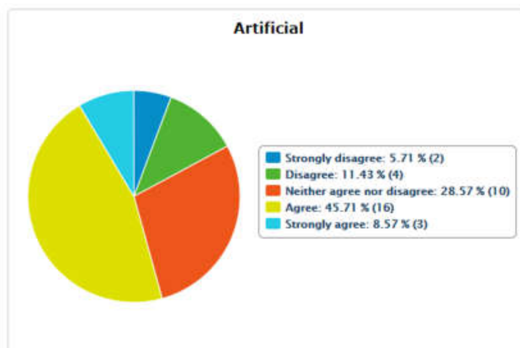


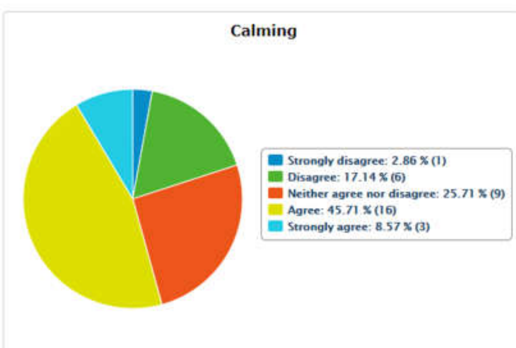


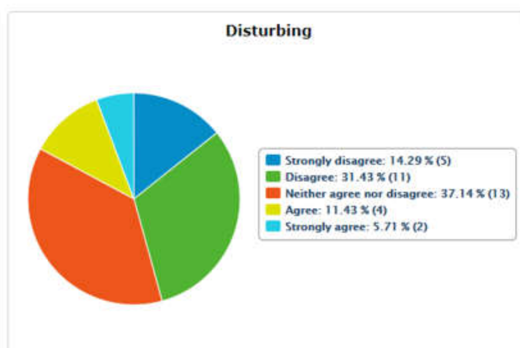


Pattern no. 4









Pattern no. 5


Resembles nature
Agree: 14.29 % (5)
Strongly disagree: 34.29 % (12)
Disagree: 40.00 % (14)
Neither agree nor disagree: 8.57 % (3)
Agree: 14.29 % (5)
Strongly agree: 2.86 % (1)
Artificial
Strongly disagree: 8.57 % (3)
Neither agree nor disagree: 8.57 % (3)
Agree: 57.14 % (20)
Strongly agree: 25.71 % (9)
Calming
Strongly disagree: 14.29 % (5)
Disagree: 42.86 % (15)
Neither agree nor disagree: 17.14 % (6)
Agree: 20.00 % (7)
Strongly agree: 5.71 % (2)
Disturbing
Strongly disagree: 5.71 % (2)
Disagree: 25.71 % (9)
Neither agree nor disagree: 22.86 % (8)
Agree: 34.29 % (12)
Strongly agree: 11.43 % (4)

Appendix C - The path test results

Scenario 01 (control)

Age group	No. Of participants
18-24	3
25-34	7
35-44	1
45+	0
ALL	11

Decided direction	
RIGHT	LEFT
7	4
63,60%	36,40%

Measured times in seconds:
5,56
5,80
8,93
13,56
29,85
30,25
30,59
30,70
44,68
47,36
52,82
AVERAGE: 27,28 sec

Open question 1: What visual clues did you use to decide where to go?

- Signs, screen
- The screens, and the signs
- Was not sure if the gate is in that direction, the screen information. I knew where to go. Visually the screen
- The departure board, and then two roads with signage, I would still go left because of the screen
- The screen, and the signages with a clear straight A path on the right
- I looked at the departure screen, then I turn around to find signs, I did not notice that there are two directions, its confusing.
- Information boards and signs afterwards.
- The screen, and the I followed the signs, I chose the one which had only A.
- Flight information and look around for the arrow with A.
- I could see that Paris was in A and the gate AB was confusing so I took the way A.
- I could se the gate A15, and then I could see you can go to the left or to the right

Open question 2: Do you have any comments?

- Fun test, I was familiar with the airport
- First concern was to find information about the flight such as information screen.
- Was not sure I had to find the information, had to think logically.
- I like the skylights, it also helps for wayfinding its like a path.
- Its confusing, two signs were leading to the same depiction that's why I chose to go there. I got confused which path would be the fastest for me.

Scenario 02 (design)

Age group	No. Of participants
18-24	1
25-34	18
35-44	1
45+	1
ALL	21

Decided direction	
RIGHT	LEFT
12	9
57,10%	42,90%

Measured times in seconds:
8,21
9,60
10,00
10,93
11,16
12,50
12,73
13,02
13,40
15,01
17,53
21,41
23,00
24,00
42,40
49,00
52,77
58,00
67,00
67,00
74,00

AVERAGE: 29,17 sec

Open question 1: What visual clues did you use to decide where to go?

- Screen and signs
- Seems closer to go to the left, there is a lot of concentrated colors over the screen
- First sign with A (path to the right) is saying only A. Seems closer
- Signs, and then other signs that branched out and I got confused
- Signs.
- Dots in the ceiling, blue screen which was more apparent, but it was visible it is connected with color with the dots
- screen, signage,
- Screen, sign,
- Wider road, more lights, seemed like a better choice
- Screen, 'A' sign because it is just A and not AB,
- Light visualisation + the entire path was lit with the installation, which was leading through the alley,
- Signs, the screen
- Screen and sign arrows
- The screen and signs, the gate information
- Then lighting installation, it seemed brighter, I knew where to go
- Screen for gate and then signs for a
- Screen, and AB direction with an arrow
- The signs, the screen the lights
- The screen and the signs

Open question 2: Do you have any comments?

- I don't know, I saw the blue lighting but maybe its an art installation, but I dont know if it tells me anything
- I feel dizzy in in this environment
- The blue piece was too high o notice at first.
- The lighting installation was nice but the movement was too slow to notice at first
- I saw the light installation but didn't realise it was moving
- installation was not fast enough to notice - after the decision was made I actually noticed that the lighting had dynamics
- I feel like im too tall in the space, I noticed dynamic lighting only after a while, after making the decision
- The light at the beginning and end helped to decide it was the right path. The dynamic was visible only after a while.
- This could be misleading, with both ways. Maybe the lighting installation was a mistake.
- Did not notice anything else

- I can see the blue installation, I noticed it when I was looking for directions, I could maybe understand that it is for wayfinding.
- Only noticed the blue lights later

Appendix D - The gate test results

Age group	No. Of participants
18-24	2
25-34	33
35-44	2
45+	2
ALL	41

Test questions with YES-NO-IDK (I DO NOT KNOW) format:

1. I could understand that the dynamic lighting has a function
2. The dynamic lighting made me decide to approach the gate immediately
3. The dynamic lighting suggested that I still have some time to go to the shop
4. The dynamic lighting suggested that I have a lot of time to go to the shop
5. The dynamic lighting suggested that no plane is leaving from this gate anytime soon
6. I find the added lighting as an useful add-in in the terminal space
7. I find the added lighting as an unnecessary component
8. The dynamic lighting confused me
9. The dynamic lighting was pleasing

Summary of answers to the 9 questions:

PATTERN/QUESTION	P01 BLUE			P02 ORANGE			P03 GREEN			P04 RED			P05 YELLOW		
	YES	NO	IDK	YES	NO	IDK	YES	NO	IDK	YES	NO	IDK	YES	NO	IDK
Question 1	26	8	7	32	5	4	30	6	5	29	5	7	33	6	2
Question 2	3	37	1	21	18	2	2	36	3	25	13	3	6	33	2
Question 3	28	7	6	11	23	7	27	8	6	5	31	5	24	10	7
Question 4	21	9	11	0	36	5	25	8	8	0	33	8	4	32	5
Question 5	9	18	14	4	28	9	17	16	8	8	28	5	5	28	8
Question 6	26	9	6	27	8	6	26	7	8	28	5	8	29	8	4
Question 7	7	29	5	5	30	6	6	28	7	5	29	7	9	28	4
Question 8	5	32	4	11	30	0	9	27	5	9	28	4	11	29	1
Question 9	31	2	8	25	4	9	31	4	6	26	5	10	30	5	6

Summary of the time estimation per pattern per participant (HH:MM:SS):

P01BLUE	P02ORANGE	P03GREEN	P04RED	P05YELLOW	
00.10.00	00.00.00	00.00.00	00.00.00	00.00.00	
00.15.00	00.00.00	00.00.00	00.00.00	00.00.00	
00.20.00	00.05.00	00.00.00	00.00.00	00.00.00	
00.20.00	00.05.00	00.00.00	00.00.05	00.10.00	
00.30.00	00.05.00	00.15.00	00.02.00	00.10.00	
00.30.00	00.05.00	00.20.00	00.02.00	00.10.00	
00.30.00	00.05.00	00.30.00	00.03.00	00.10.00	
00.30.00	00.05.00	00.30.00	00.04.00	00.15.00	
00.30.00	00.05.00	00.30.00	00.05.00	00.15.00	
00.30.00	00.05.00	00.30.00	00.05.00	00.15.00	
00.30.00	00.05.00	00.30.00	00.05.00	00.15.00	
00.30.00	00.05.00	00.30.00	00.05.00	00.15.00	
00.30.00	00.05.00	00.40.00	00.05.00	00.20.00	
00.40.00	00.05.00	00.45.00	00.05.00	00.20.00	
00.40.00	00.10.00	00.45.00	00.05.00	00.20.00	
00.40.00	00.10.00	00.45.00	00.05.00	00.20.00	
00.40.00	00.10.00	01.00.00	00.05.00	00.20.00	
00.45.00	00.10.00	01.00.00	00.05.00	00.20.00	
00.45.00	00.10.00	01.00.00	00.05.00	00.20.00	
00.45.00	00.10.00	01.00.00	00.05.00	00.20.00	
00.45.00	00.10.00	01.00.00	00.05.00	00.20.00	MEDIAN
01.00.00	00.15.00	01.00.00	00.10.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.10.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.10.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.10.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.10.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.15.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.15.00	00.30.00	
01.00.00	00.15.00	01.00.00	00.15.00	00.30.00	
01.00.00	00.20.00	01.00.00	00.20.00	00.30.00	
01.00.00	00.20.00	01.30.00	00.25.00	00.30.00	
01.00.00	00.20.00	01.30.00	00.30.00	00.30.00	
01.00.00	00.20.00	01.30.00	00.35.00	00.45.00	
01.00.00	00.25.00	01.30.00	00.50.00	00.45.00	
01.00.00	00.30.00	02.00.00	01.00.00	00.45.00	
01.00.00	00.30.00	02.00.00	01.00.00	01.00.00	
01.01.01	00.30.00	02.00.00	01.00.00	01.00.00	
01.30.00	01.00.00	02.00.00	01.00.00	01.30.00	
02.00.00	01.00.00	03.50.20	01.40.30	02.00.00	
02.20.40	02.10.50	05.00.00	04.00.00	03.20.40	
30.00.00	15.00.00	45.00.00	15.00.00	20.00.00	

Comments:

- In my opinion, if we have a lot of time before the flight, the light should be peaceful, pulsing very, very slowly - light green or blue color. If the gate is gonna be closed soon the color should be aggressive red pulsing very fast.
- zgubi_am si_ troch_ w interpretacji znaczenia kolorów (translated from polish – i got lost in the interpretation of colors)
- I think the yellow was misleading. The other combinations seemed logical
- Seeing two blue clouds I was confused and didn't recognize the function of them but by subsequently comparing these with the other patterns I finally understood the concept.
- After seeing those lights all over airport I might understand their function, but I would need a clear explanation somewhere to be sure. Usual trafic lights colors suggest, the closer to the red color spectrum, the more to the danger. Red could mean both delayed plane or very little time to departure. Finally -> considering how important it is to get to the flight on the, I would need some information at the entrance to the airport that would make me 100 % sure about it.
- At the beginning it was difficult to understand but when I saw how the colors were changing I realized that the light was communicating something. In some cases I was a bit confused because the speed was different, maybe if the red light should also increase speed?
- The second question in each round should be optional. Also I felt a bit confused at first round, but starting from second I got to understand what is the questionary and the lighting about
- I understand the overall idea of the lighting effect. If I were a lighting wizard, and would try to influence the airpot, then I would use different patterns (colours are ok) of light and also different frequencies at which the patterns move. For example, if I wanted to suggest to travelers that there is very little time until the gate closes, then I'd use the colour red for lighting, and the frequency should be high, to suggest "agitation" thus create the cognitive incentive to hurry up.
- Super great idea but not intuitive to me unfortunately
- czerwone barwy s_ najbardziej informacyjne (translated from polish: the red was the most informative)
- I could not make it full screen, so I'm not sure if there's anything I missed. But besides that, I liked the one where it was only blue color. I think the other ones did not convey the meaning of it as well. And also I think the last question where you would have to put a time was relly difficult. So I think I kind of put some random numbers.
- I wasn't sure how to answer the function question after the first scenario because after that one you begin to get an idea of what is going on.
- I think this is a good idea , and with some simple information board on the walls it would be great add-on.
- Great idea but the yellow color is not necessary
- Only after the second video I realized that the color represents time remaining before the gate closes. At first it seemed just as more noticeable markers to locate the separate gates
- I had to go through one scenario before I understood what the dynamic pattern was supposed to do. And only after going over the scenario did I understand the purpose of the following scenarios. So I am not sure, I would understand the dynamic pattern in the airport, where I wouldn't have something to compare it to.
- The questions should have been on a format "how much do you agree from 0 to 5 to the following". The yes/no format did not fit what I needed to answer.