



AMBIENT LIGHTING DESIGN

FOR PERSUASIVE ENVIRONMENTS

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EXECUTIVE SUMMARY

As we move towards a world in which the lines between the physical and the digital are increasingly blurred, we see a maturing vision for architecture that actively participates in our lives. Our architectural surrounding has become so closely tied to technological trends that the two ultimately define each other. The push for ubiquitous networking and device inter-connectivity in buildings is fueling the development of a new wave of smart devices with embedded electronics, sensors and wireless connectivity that can collect, process and exchange vast amounts of data. This data can be used to inform and ultimately enhance the experience of the occupants and users of built environments. It is thus understandable that, the more recent trends in lighting design, has been to use it as a form of ambient light communication to create more lively and dynamic environments based on live data. The research shows that the interaction which is created between the users and their actions and how it affects the visualizations, creates an aesthetically appealing and exciting atmosphere for the occupants. This thesis project focuses on exploring the use of this technology in architectural environments in order to enrich the experience of users of public architectural environments with the aid of ambient light communication to inform them of relevant information and entice them to perform desired actions.

Ambient light communication is a hybrid form of spatial interaction that is simultaneously digital and physical, made possible with technology and concepts rooted in human biology. Humans have the substantial ability to process ambient and peripheral information that directly affects their feelings and subconscious contextual understanding without the need of activate cognitive thought processes. Public built environments create the opportunity to inform and enhance the experience of countless people through the use of this technology and yet this potential is underutilized. One of the primary reasons for this is the fact that the capacity of ambient communication to convey complex information is not very well understood. To be able to convey meaningful information derived from live data, without the need for prior training or a visual legend, more research is required. Furthermore, although there has been plenty of research on lighting and its effects on human behavior, this research has not been applied in large public spaces. We must prove that light characteristics remain as effective in such environments in order to be able to utilize it with confidence in a slow to evolve field such as architecture, building and construction.

Thus, to achieve the stated project goal, two research questions are defined to fill their respective gaps: Whether it is possible to convey the meaning of

social media data categories, using light visualizations without the need for a priori knowledge or training? Whether it is possible to attract and guide the attention of people through light visualizations?

To answer these questions, two experiments were designed and carries out. The results of the first experiment showed that most participants did indeed have a common perception of the selected data categories. This means that the participants shared a common understanding of these visualizations which suggests that in more general terms, light visualization can be used to form a very basic language to transfer information. Similarly, after conducting the second experiment, it was concluded that ambient light communications can be used effectively to trigger certain desired behaviors and actions in humans (specifically, direct the attention and gaze of humans using directional cues).

As a demonstration of how the prior information can be used to improve the lives and experiences of the occupants of built environments, business environments or more specifically office environments was studied. The primary reason for selecting office environments, stems from the fact that this type of architectural environments has become a hot topic in the recent years with a lot of focus on using live data and integrated sensors to increase sustainability

and improve productivity. Furthermore, most of the techniques applied for office environments are also applicable to other similar architectural buildings such as educational and institutional buildings. Combined, these three types of buildings receive the highest number of visitors and thus have a larger impact on our lives.

4 different novel applications of ambient light communication concepts within office environments were presented which combined its aesthetical value, its ability to convey meaningful information and trigger desired behaviors. Specifically, we explored how the results of the experiments could be used in order to find more concrete solutions in a specific scenario. It was shown that the conclusions drawn from the first experiment could be used effectively to determine the best visualization to communicate a particular information and that the proposed concepts can often take advantage of various light characteristics and their effects on human physiology as well as psychology to create persuasive environments which are intended to improve the experience of the occupants and users. In summary, the concepts provided in this project are merely a demonstration of the capabilities and benefits of ambient light communication and its ability to provide useful information and create persuasive environments which enhances the experience of the

users of built environments. The approach taken in this project can also be applied to other architectural environments by future researchers.

co

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INTRODU

In this section, we provide a short introduction to the projects, and introduce the sponsoring company. The layout of this thesis is outlined in order to provide an overview of the following contents.

UCTION

CHAPTER 1

1.1 INTRODUCTION

The architecture, building, and construction industry, often acknowledged as a low-technology and an inefficient industry [1], is one of the largest in the world accounting for one-tenth of the world's gross domestic product [2]. Currently, the industry is facing enormous technological and institutional transformations with their resultant difficulties and challenges. Several researchers have identified the following major trends in their studies: sustainability, embracing technology, focus on environment and infrastructure, cross disciplinary technologies such as intelligent building systems [3]. Above all else, the most important instrument to such change is the use of information technology and ubiquity of computing.

This thesis project focuses on exploring the use of one such technology, namely ambient light communication. Through the use of the double diamond design process, the thesis will cover 4 different stages of Discovery, Definition, Development, and Delivery of the concepts. In all creative processes a number of possible ideas are created (divergent thinking) before refining and narrowing down to the best idea (convergent thinking). When visually represented this is manifested by a diamond shape. This process occurs twice in the Double Diamond design process: once to confirm the problem definition and once to create the solution [4].

In chapter 2, we provide a comprehensive list of background information about the current trends and developments in the field of architecture and building technology, and specifically lighting design in such environments. This represents the Discovery phase of the project. Based on the research, a number of key areas are identified which hold potential for further development. Subsequently, in the Definition stage we try to make sense of all the possibilities for research which were identified and come up with a vision for an improved lighting design. Stemming from this vision, a project goal is defined and subsequently the research questions required to achieve it. This entire process is covered in chapter 3.

To achieve the vision resulting from the VIP process, two gaps in the current body of knowledge must be first filled. Firstly, most of the research on the topic of ambient light communication and its uses have primarily focused on conveying very simple data streams often as symbolic reference to the data. In order to extend the usage of ambient light communication for conveying complex information (which can convey useful information) based on live data, we must first determine its suitability for this purpose.

An important step in the design of a visual language for ambient light communication is the categorization

constructing feasible visual messages. In chapter 4, the entire process of determining the range of potential visual variables and using them to create visualizations which are used to convey information is explained. An experiment is setup and conducted with the ultimate goal of concluding whether it is possible to convey complex information using light visualizations without prior training or a visual legend.

Secondly, the research gathered in the background study phase of the project suggests that ambient light can trigger certain behaviors in humans. There are quite a number of products that claim to use this property to achieve their own specific objectives. However, little quantifiable data can be found for its effectiveness in large public spaces. Hence, a more concrete experiment is required in order to conclude that ambient light communication can be an effective means of influencing behavior.

In chapter 5, an experiment is conducted using a publicly placed display panel in order to determine if specially designed visual content is effective in attracting the attention of passersby and directing it towards performing a desirable action (scanning a QR code). The ultimate goal of this experiment is to see if it is possible to attract and guide the attention of people through light visualizations. The broad

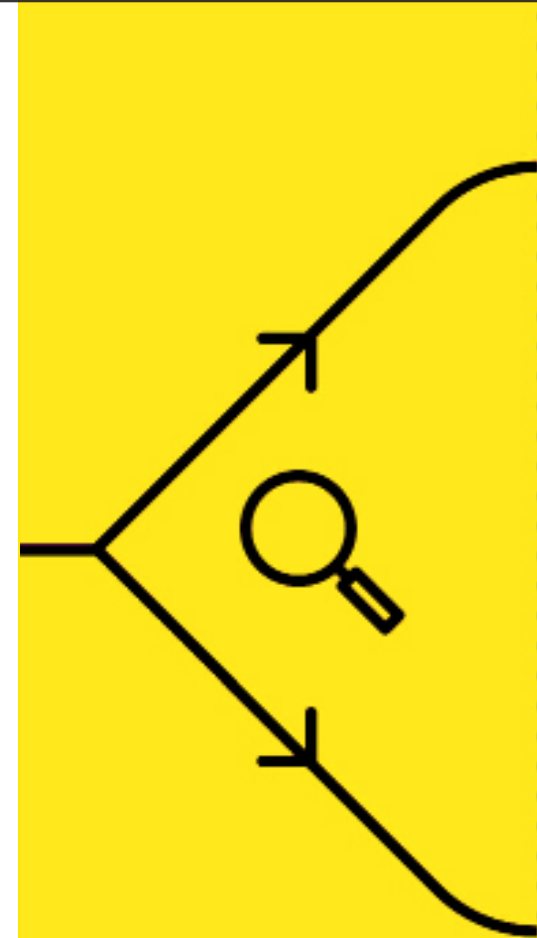
DOUBLE DIAMOND

design process

objective of the experiment is to indicate whether ambient light visualizations are capable of triggering behavior in public spaces.

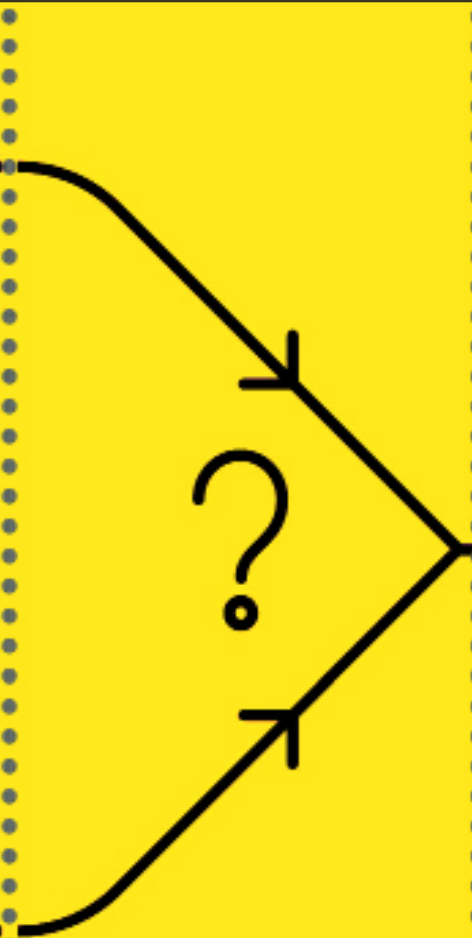
Finally, after the results of both experiments are evaluated and discussed, conclusions are drawn with respect to the formulated hypotheses for each experiment. Based on these conclusions, in chapter 6 we explored a number of architectural environments and selected office environments to demonstrate the potentially beneficial uses of ambient light communication. 4 different novel applications of ambient light communication within office environments were presented which combined its aesthetical value, its ability to convey meaningful information and trigger desired behaviors. Ultimately, this thesis aims to pave the way for future research by presenting a systematic approach to creating effective ambient light communication systems for architectural environments.

DISCOVER



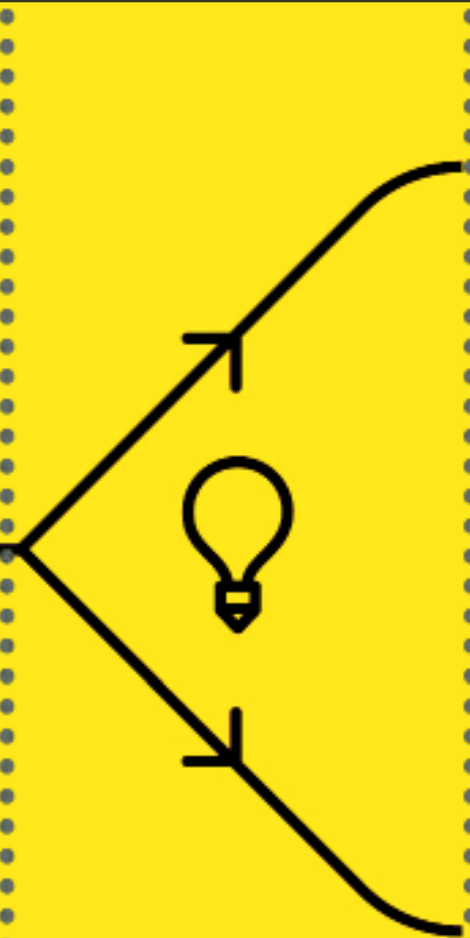
In chapter 2, we provide a comprehensive list of background information about the current trends and developments in the field of architecture and building technology, and specifically lighting design in such environments.

DEFINE



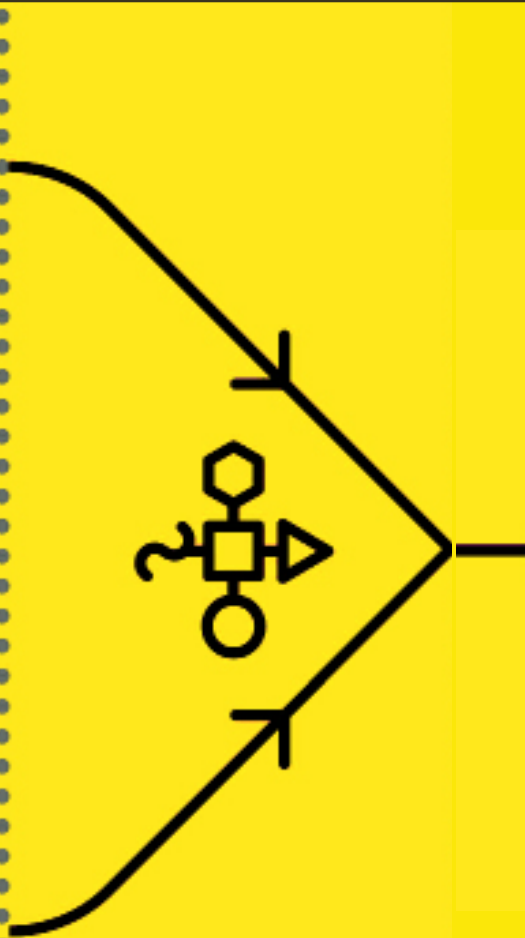
In chapter 3, the vision for an improved lighting design is outlined which is used to define the project goal and subsequently the research questions.

DEVELOP



In chapters 4 and 5, two experiments have been conducted due to the research questions, to see whether is possible to convey information and/or trigger behavior using ambient light visualizations.

DELIVER

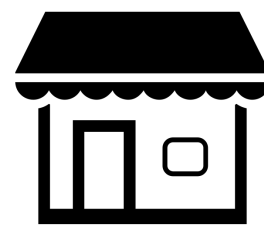


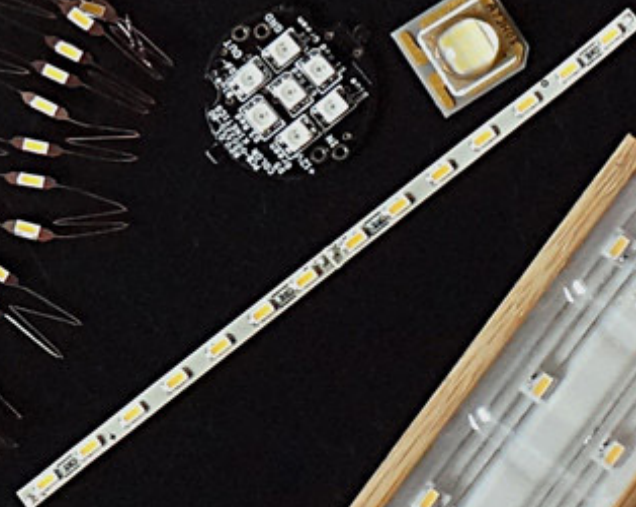
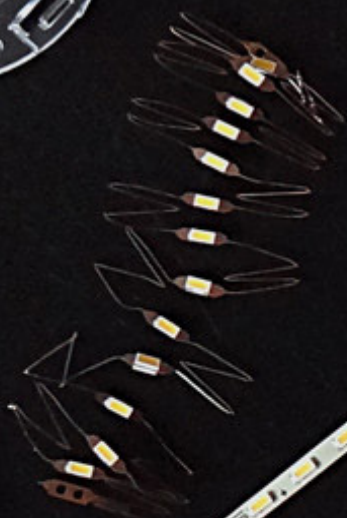
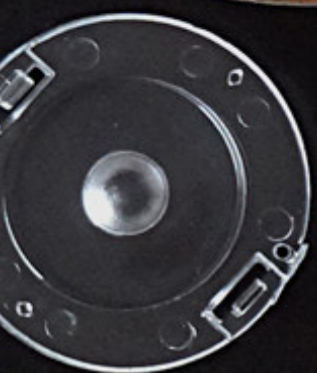
Finally, in chapter 6, we explored a number of architectural environments and selected the office environments for further exploration. And lastly, 4 different applications of ambient light communication were presented.

1.2 PARTNERS

The above assignments and research goals have been defined together with Brad Koerner, the company mentor and the founder of KOERNER DESIGN. The company mentor has been introduced by the chair, Dr. Sylvia Pont, and the project has been firstly discussed in a short meeting with Brad after his lecture for the Lighting Design course.

KOERNER DESIGN is a lighting design studio founded in 2018. Its specialization is in the intersection of architectural lighting and digital media systems and providing a range of services. KOERNER design helps clients design new location-based digital experiences and environments mainly for hospitality, retail and commercial projects.





DIS

In this section, a comprehensive list of background information has been provided about the current trends and developments in the field of architecture and building technology, and specifically lighting design in such environments.

COVER

CHAPTER 2

2.1 INTRODUCTION

In this chapter, a survey of all recent trends and developments in the field of architecture and specifically lighting design in built environments is performed in order to indicate any emerging themes and to give the architectural context within which these themes were developed. It is shown that tools, technologies and design approaches have changed as lighting technology has developed and lighting researchers have found new interesting ways to apply the results of scientific research to lighting design and application.

Currently, the architecture, engineering, and construction industry is facing enormous technological and institutional changes and challenges including the proliferation of information technology and appropriate application of sustainable practices. The 21st century engineer and architect must be able to deal with a rapid pace of technological change, a highly interconnected world, and complex problems that require multidisciplinary solutions.

As we move towards a world in which the lines between the physical and the digital are increasingly blurred, we see a maturing vision for architecture that actively participates in our lives. Our architectural surrounding has become so closely tied to technological trends that the two ultimately define each other. The promise of ubiquitous computing has secured a permanent foothold in our lives and has begun to infiltrate our

devices and objects as well as our buildings and environments [5].

The push for ubiquitous networking and device interconnectivity in buildings is fueling the development of a new wave of smart devices with embedded electronics, sensors and wireless connectivity that can collect, process and exchange vast amounts of data [6]. This data can be used to inform and ultimately enhance the experience of the occupants and users of built environments.

Accurate occupancy information such as user location and activity are already used to develop smarter algorithms that enhance energy efficiency, user satisfaction, comfort, light quality, and functionality of smart buildings [7]. For instance, by using the current time of day and the position of the sun in the sky, Taghaboni designed rooms that have the ability to rotate in order to manipulate the light intensity based on this live data (Figure 2.1) which ultimately resulted in creating an engaging, exciting and sustainable environment for living [8]. Furthermore, at TU Delft faculty of architecture, students from “Why Factory” students are trying to enlarge the boundaries of designing with data; students investigate the using live data about the usage and position statistics of the occupants to dynamically reshape the interior of a building in order to create a flexible living and working space which adapts to the current needs of the use [9].

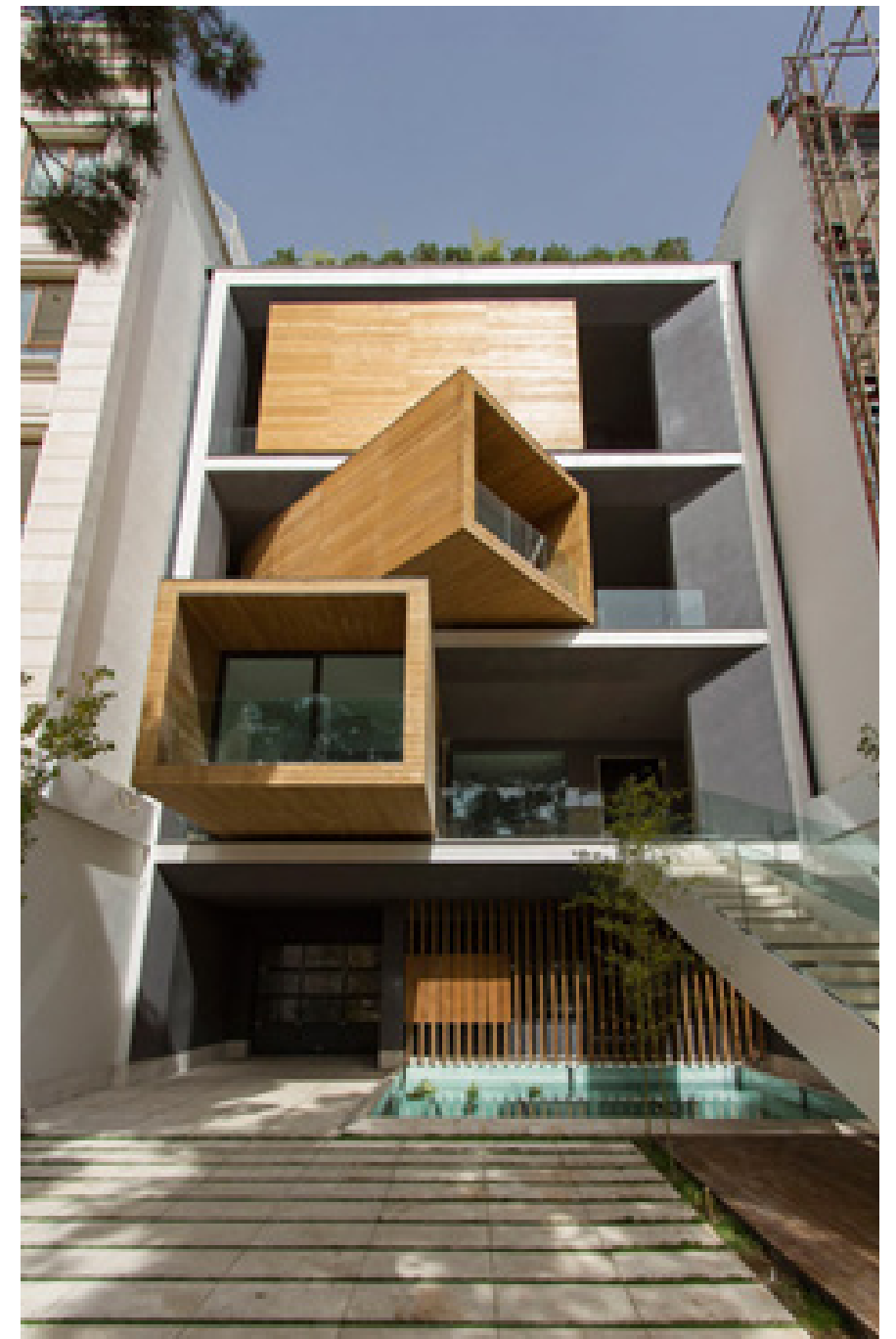


Figure 2.1: Sharifiha house

The more recent trends in lighting design, has been to use it as a form of ambient light communication to create more lively and dynamic environments based on live data. The research shows that the interaction which is created between the users and their actions and how it affects the visualizations, created an aesthetically appealing and exciting atmosphere for the occupants. The ability of the architect or designer to manipulate light based on this live data has a profound effect in creating pleasant environments and has been the focus of a lot of attention in the recent years. The intersection of lighting design, live data and human perception (Figure 2.2) is represented by ambient light communication and behavior proves to hold vast potentials for future architects and designers.

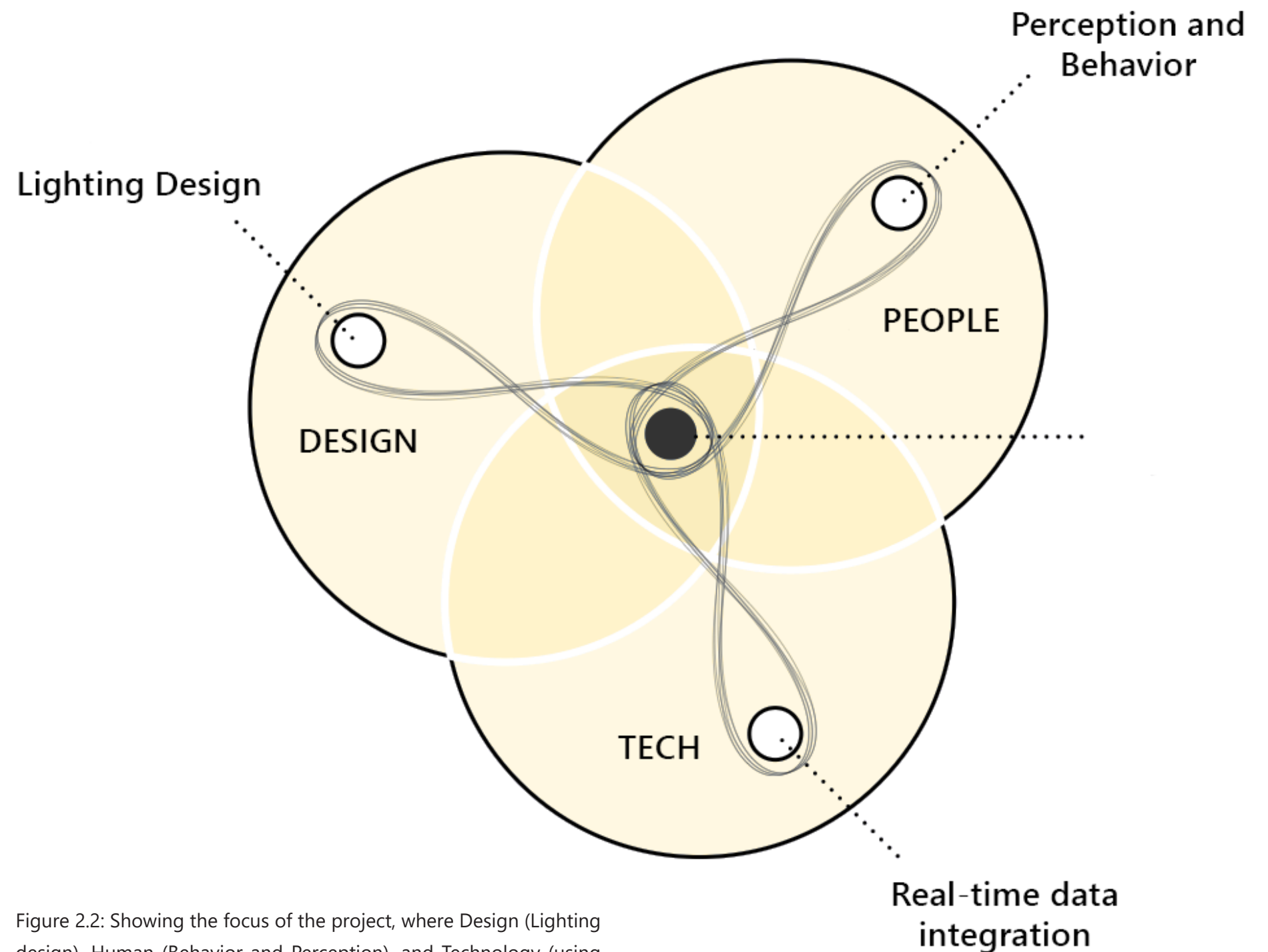


Figure 2.2: Showing the focus of the project, where Design (Lighting design), Human (Behavior and Perception), and Technology (using Real-Time data) intersect and work together



Preattentive Processing:

- Fast
- Uses long-term memory
- Hue, intensity, flicker, direction of light & motion

Attentive Processing:

- Slow
- Uses short-term memory

2.2 AMBIENT LIGHT COMMUNICATION



Figure 2.3: Some examples of ambient communication

Ambient light communication is a hybrid form of spatial interaction that is simultaneously digital and physical, made possible with technology and concepts rooted in human biology [10]. Humans have the substantial ability to process ambient and peripheral information that directly affects their feelings and subconscious contextual understanding without the need of activate cognitive thought processes. Some basic examples have been pointed out in Figure 2.3 using light and sound. Ambient communication offers a way of conveying information, supporting human behavior and providing services without demanding attention and cluttering the architecture [11].

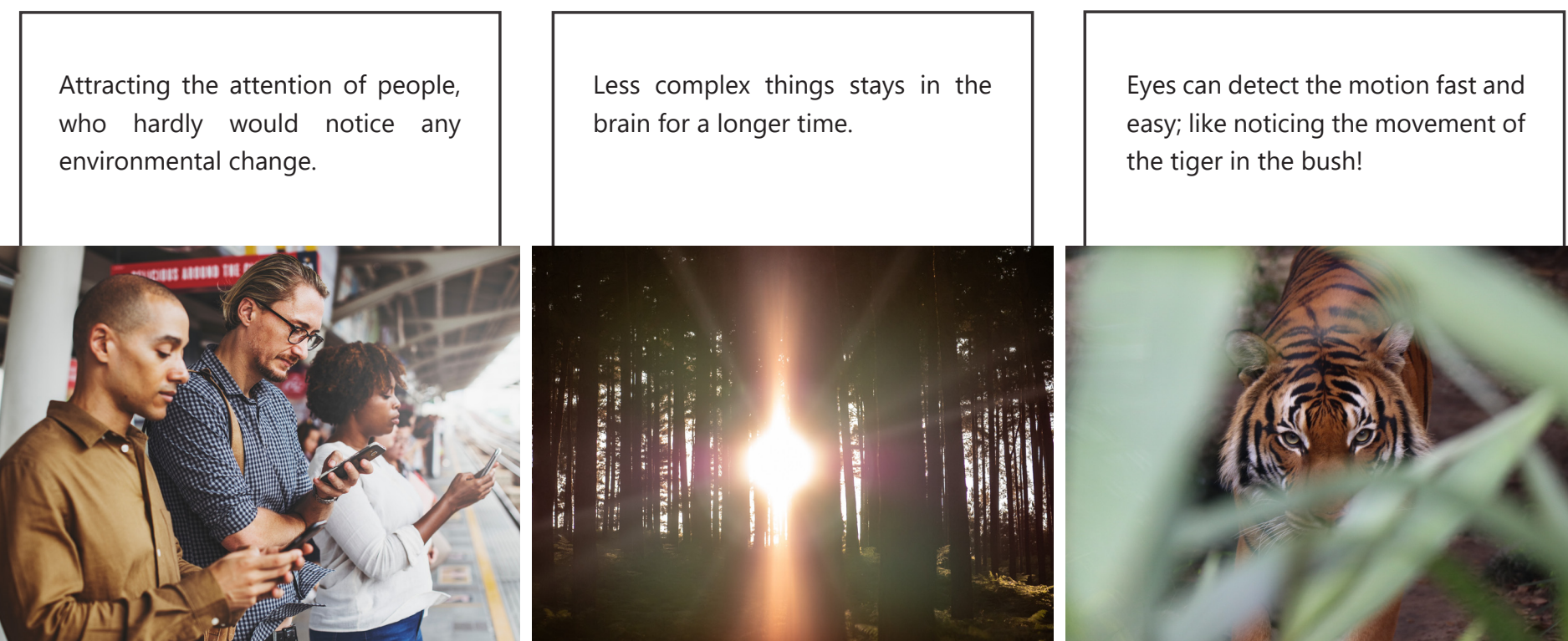


Figure 2.4: Advantages of using ambient light

One of the key advantages of ambient light communication is the fact that it prevents information overload when compared to factual and graphical visualizations on displays. Ambient displays can remarkably reduce the amount of information mentally processed. By providing an overview of the content by having information subtly portrayed in the periphery of one's attention [12], people can perform their primary tasks in the foreground while simultaneously receiving context information in the background of their attention. This can be beneficial specially in the era that people often experience "information overload". This advantage is key in allowing ambient light communication to take a more prominent role in design and future architectural environments.

There are a number of projects that have attempted to use this technology within built environments. For instance, Figure 2.5 shows the Particle Falls project which aims to incorporate ambient light visualization of live data. This project reveals the presence and impact of particle pollution through a real time artistic visualization on the side of the building, in the form of a waterfall [13]. The vision for this project was to raise awareness amongst the public about air pollution. Since it measured in real time, it was able to show directly in what way human activity can make the air quality worse.

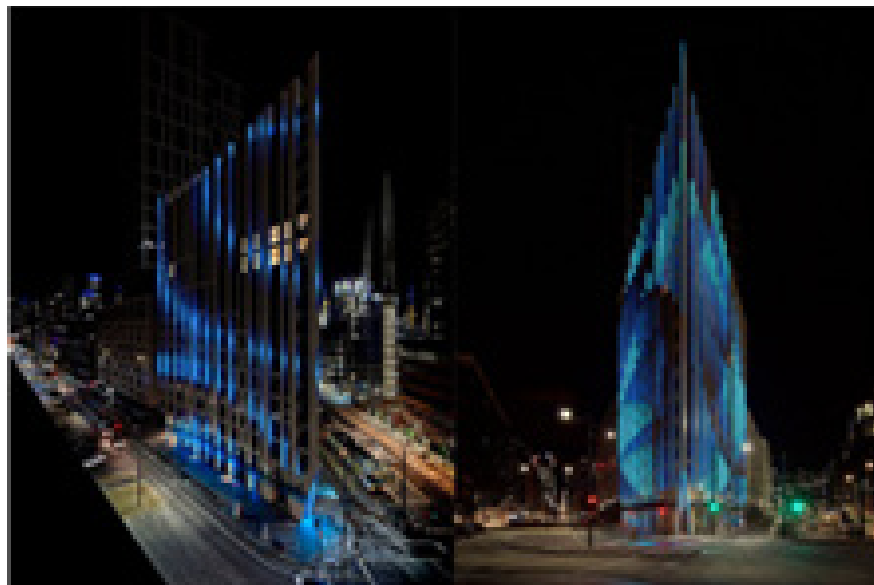


Figure 2.5: Particle Falls project

Similarly, TIETO has created an intelligent building by using countless sensors to collect and analyze data, which in return was visualized by thousands of individually controlled LEDs (Figure 2.6). In this installation the beam width and the color of the lights changes in response to the live digital content which symbolizes the data flow [14]. The vision for the energy Tower Facade Lighting in Roskilde (Figure 2.7) was to make "a structure with the ability to communicate and

messages of sustainable energy to the public" by displaying variations of dynamic light scenes in its facades. At night the backlight perforated facade transforms the incinerator into a gently glowing beacon, a symbol of the plant's energy production [15].

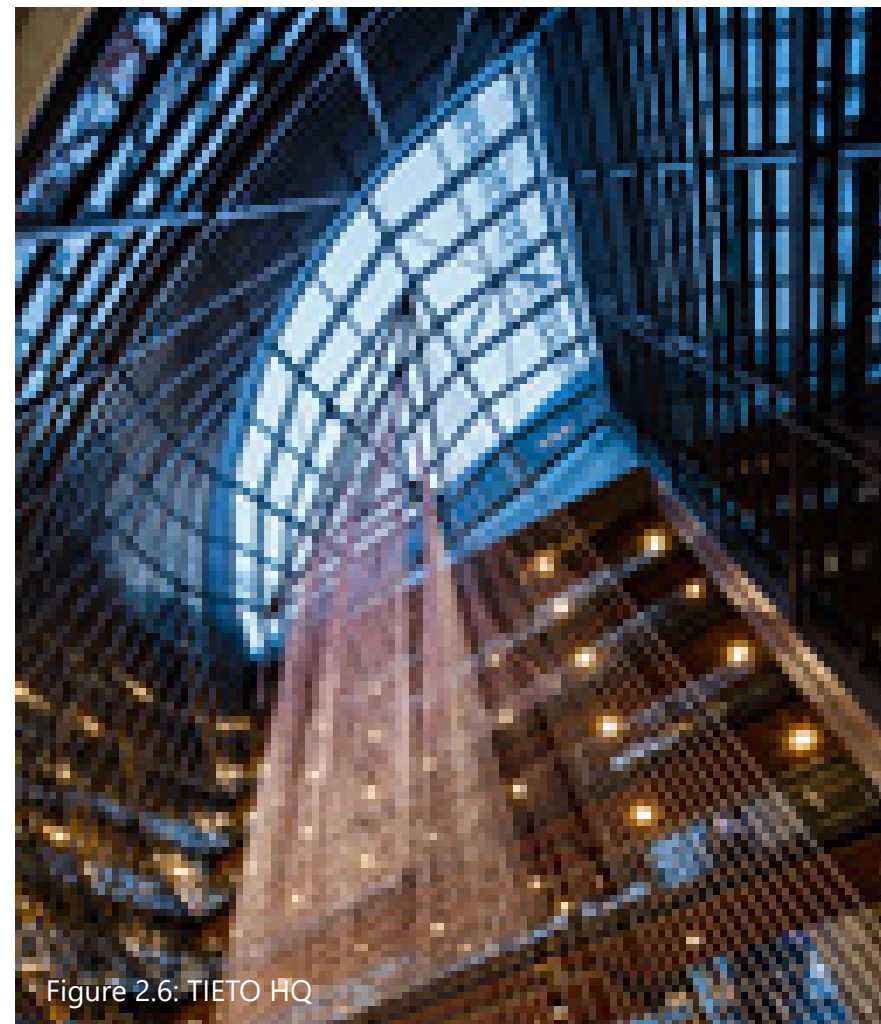


Figure 2.6: TIETO HQ

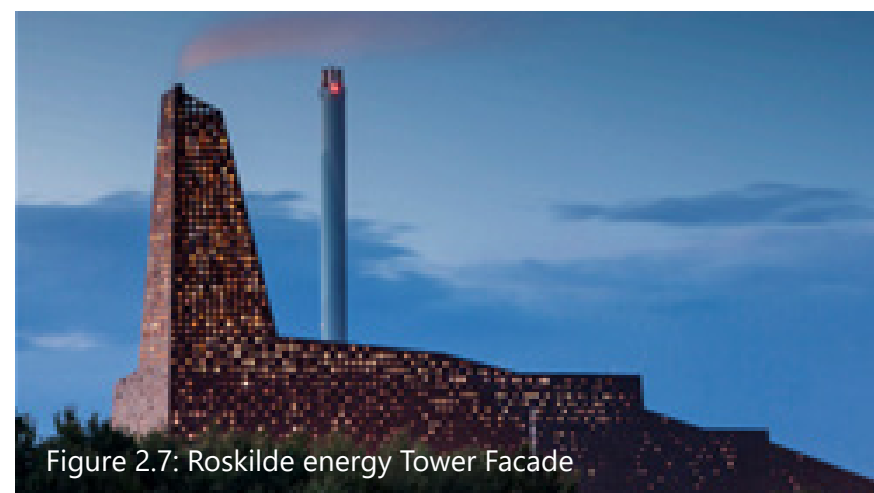


Figure 2.7: Roskilde energy Tower Facade

There are countless other examples of architects using ambient light communication fed by live data to create dynamic and visually appealing environments for the users. In principle, the author believes that this a good trend, but this simple use of ambient light communication is missing the full potential of this amazing technology. Specifically, the meaning of such live data can play a much more prominent role in enhancing the experience of the users. Thus far, architects and designer have used this technology in symbolic ways rather than for providing valuable information to the users of such environments.

This is a trend which is embraced by product designers. For instance, an ambient device called Energy Orb (Figure 2.8) was used to provide energy consumption information that changed color dependent on the time-of-use tariffs and energy consumption (e.g., by glowing red when energy usage reaches a certain level and green otherwise) [16]. Another example of an ambient product is the Power Aware Cord (Figure 2.9), which can visualize the current uptake of electricity of a connected appliance through glowing pulses, flow, and intensity of light [17]. These devices attempt to provide useful information which can indirectly affect the behavior of the users to take certain desired actions (i.e. reduce power consumption). The effects even be more direct by using the light visualizations and characteristics that trigger certain behaviors in humans.



Figure 2.8: Energy Orb

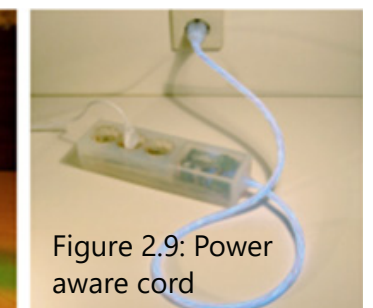


Figure 2.9: Power aware cord



Public built environments create the opportunity to inform and enhance the experience of countless people through the use of this technology and yet this potential is underutilized. So, the question is now why? The capacity of ambient communication to convey complex information is not very well understood. To be able to convey meaningful information derived from live data, without the need for prior training or a visual legend, more research is required. This problem is often resolved in products by providing such a visual legend in the manual. Furthermore, although there has been plenty of research on lighting and its effects on human behavior, this research has not been applied in large public spaces. We must prove that light characteristics remain as effective in such environments in order to be able to utilize it with confidence in a slow to evolve field such as architecture, building and construction.

In this chapter, the definition stage is presented. In this stage we try to make sense of all the possibilities for research in order to find the one which matters the most or has the greatest impact, while still feasible within the limitations of this thesis project.

DEFININE

CHAPTER 3

3.1 INTRODUCTION

In this chapter, the definition stage is presented. In this stage we try to make sense of all the possibilities for research which were identified in the Discovery phase, in order to find the one which matters the most or has the greatest impact, while still feasible within the limitations of this thesis project.

As covered in detail in the previous chapter, lighting design in the past was limited to the design and installation of simple lighting on architectural surfaces, often as a means to provide additional lighting to create a comfortable living and working condition. In the past, the interaction of the occupants of built environments and lighting installations was limited to using manual switches and dimmers. In more public spaces, lighting of individual spaces was often controlled using automatic control systems which relied on time and light intensity data. With the increased ubiquity of energy efficient and cheap LED lighting which can create colorful visualizations as well as distributed computing and sensor networks (IoT), the lighting design of present architectural spaces has evolved into a far more attractive and interactive experience. Smart lighting systems in today's architectural environments have evolved from traditional manual lighting control to autonomous control of light through feedback from integrated sensors, user data, cloud services and user input and interactions. This data is currently used as a means

of creating a cozy and comfortable surrounding for occupants depending on sensor data.

The present context for these light installations is plentiful and all around us. There has not been much development in this regard and most designers follow the established methodologies to incorporate these lighting systems. In more recent years, the advancements in technology and multidisciplinary approach of designers has seen the incorporation and addition of more dynamic and interactive light installation into public spaces. In the future, it expected and that buildings incorporate more and more of these installations in grander scales and new forms.

In these future contexts, ambient light communication is used not only to provide a visually appealing environment, but also to provide useful information to the occupants of the environment. This interaction can extend to triggering desired behaviors which ultimately enhances the experience of all users and creates potential ways of improving sustainability. Thus, in the future, it is our vision that incorporation of ambient light communication into the architectural design process in a meaningful way can inform people and help create a more dynamic, sustainable and exciting living and working environment. It will be interesting to see how the application of this technology when mapped against the future architectural contexts, will develop over time.

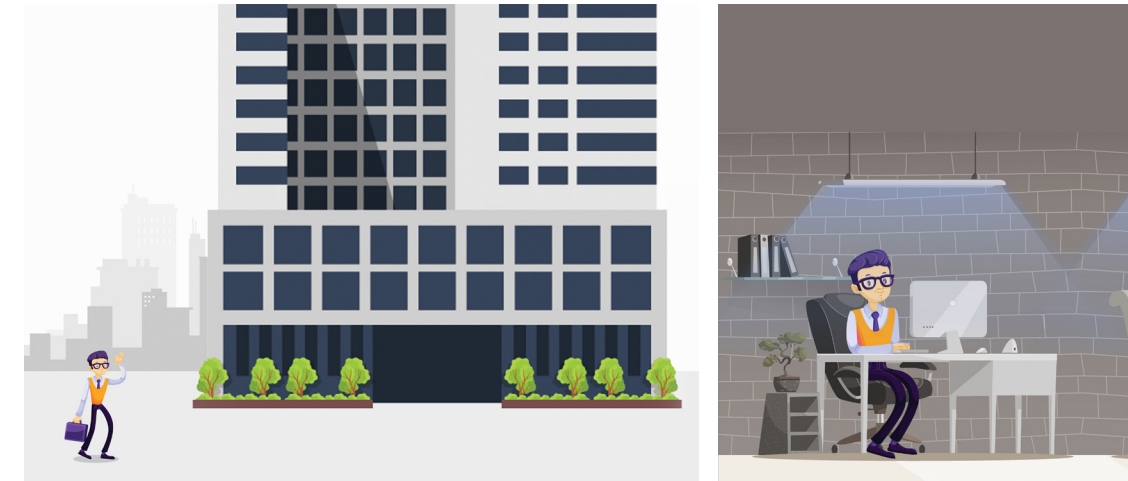


Figure 3.1: Office environments

Office overhead lights can be fed with live data about the time spent



Figure 3.1: Educational institutions

The lights in front of each studio can glow with a different color depending on the activity in the periphery of vision.



Figure 3.1: Restaurants

Sensors can detect the arrival of clients and change the lights to a different color in order to prioritize service based on the waited time.



ent behind the desk. Changes in color temperature of light can indicate that it is time for break. Completion of milestones or other events can be signaled used these lights.



pending on whether the studio is reserved, a lecture is in progress and if workspaces are available. The intensity of these lights conveys a meaning of crowdedness which can be observed

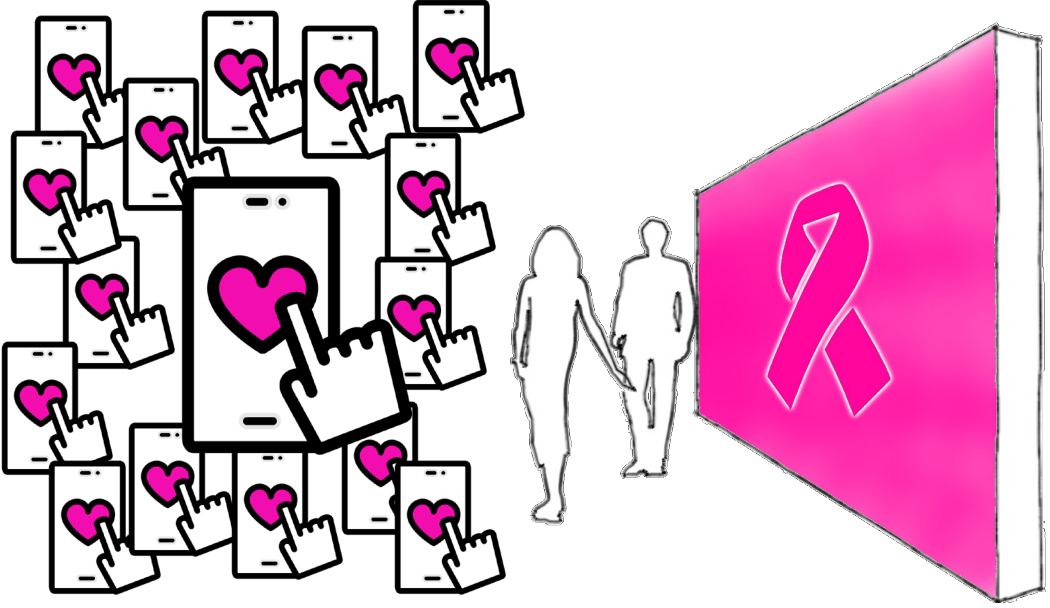


warmer color to create a cozier atmosphere for them. The color saturation can increase at a constant rate until the clients receive service. This information can be used by the waiters in

3.1.1 Potential Benefits

Here we present 6 concepts in order to clarify our vision. The first 3 concepts show how ambient light communication can be used in various architectural contexts (Figure 3.1). The second 3 concepts, illustrate some of the potential problems that can be solved by this technology (Figure 3.2). These concepts are merely used as a method to explore the opportunities that ambient light communication can bring. They provide us with a hint of the potential benefits of this technology in various contexts and the challenges we may face in order to implement them. This should help us in defining a project goal which has the highest impact and creates the largest value.

Breast cancer awareness
Social causes can drive participation goals via ambient communications by depicting accumulation data (social media likes or mentions) with the gradual presence of a signature color filling a space.



Service satisfaction rate
Hospitality locations can intuit their service ratings by depicting social proof (reviews and star ratings) as evolving patterns of sparkling light embedded into feature walls.



Product selling rate
Retailers can depict live Online retail activity in bricks and mortar locations via ambient communications by expressing an action rate (customer purchases) by varying the rate of a motion pattern.

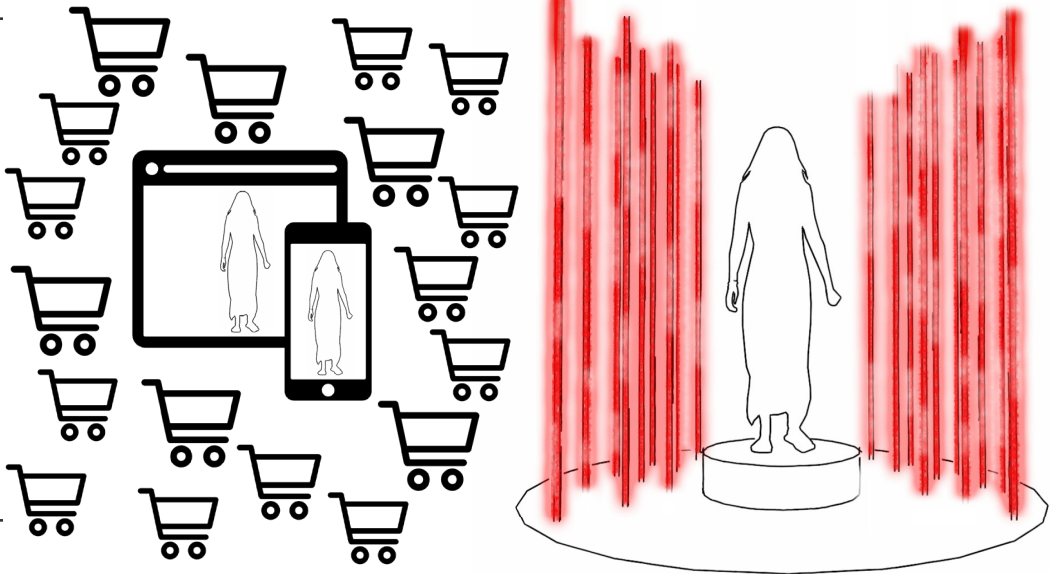
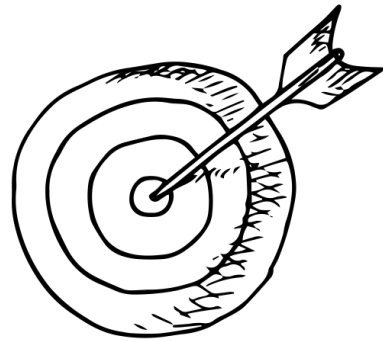


Figure 3.2: Potential problems that ambient light communication can target | lucpt.com/2018/12/15/wrap-your-spaces-in-social-media

3.2 PROJECT GOAL

The primary goal for this project is derived from the vision which was defined in the previous section. After consultation with the company mentor, to ensure that the project goal is also aligned with the objectives of the company as well as the author's personal interests, the following goal was derived:



“To richen the experience of users of public architectural environments with the aid of ambient light communication to inform them of relevant information and entice them to perform desired actions.”

3.3 RESEARCH QUESTIONS

Chapter 2 illustrated that there are two gaps present in our current body of knowledge in the field of ambient light communication and its effects on human behavior. Thus, to achieve the stated project goal, two research questions are defined to fill their respective gaps:



- 1. Whether it is possible to convey information using light visualizations without the need for a priori knowledge or training?***
- 2. Whether it is possible to trigger a desired behavior in humans using light visualizations?***

These questions are further refined and reformulated after conducting a thorough literature study on the topic. The collected background information and the experiments attempting to answer these questions as well as the analysis and the conclusions are

DE

In this section, two experiments have been conducted due to the research questions, to see whether it is possible to convey information and/or trigger behavior using ambient light visualizations.

VELOP

CHAPTER 4

4.1 INTRODUCTION

Graphic representations seem to play an increasingly important role in our lives. As it has been asserted countless times before, our modern life does indeed appear to be characterized by an ever-growing access to information. While the common sources of information (e.g. books, newspapers) used to be mainly textual, we are now seeing more and more information presented through diagrams, pictograms, maps and charts. We see such graphic representations on papers but more commonly on digital signage and on screens. In more recent years, ambient light installations have become more prevalent. The diagrams, maps and digital signages, as well as all the other traditional forms of text based visual means of conveying meaning, rely on written languages. Written languages rely on the composition of symbols to form words that convey information to the reader. Similarly, ambient light communication will also need to establish its own visual language through the composition of various light characteristics (such as color, brightness, saturation) to convey information to the observer.

An important step in the design of a visual language for ambient light is the categorization of graphical objects and the composition rules for constructing feasible visual messages. The presence of different typologies of visual languages, each with specific

typologies of visual languages, each with specific graphical and structural characteristics, yields the need to have tools that unify the design steps for different types of visual languages [18]. In this chapter, the entire process of determining the range of potential visual variables and using them to create visualizations which are used to convey information is explained. As the source of information, social media platforms have been selected. The choice of using social media data streams for this test was largely due to its alignment with the broader objectives of the project (influencing behavior for the purposes of advertisement). Moreover, it has been assumed that the participants (who are entirely from a student population) would be able to easily relate to social media as a familiar platform where they spend a significant amount of time. Future researchers can however expand the proposed visual language by focusing on other data streams such as weather, traffic, etc.

The hope is that the result of the test can be used directly to construct a visual language for expressing social media data categories, or indirectly as an example of how such a visual language can be constructed for a specific case. However, for the scope of this thesis project, the ultimate goal of the test, is to conclude whether it is possible to convey the meaning of concepts of social media, using light visualizations.



Clark's

4.2 BACKGROUND INFORMATION

4.2.1 Visual Variables

In order to prove that ambient light is able to convey information, we need to understand how we can encode information in the form of light visualization. This section contains a review of literature which examines the visual variables that can be varied to encode information. Generally speaking, these variables can be divided into two groups: static variables that describe the graphic dimensions that are invariant to time [19], as well as dynamic variables that also encode information in the temporal dimension. The following two sub-sections, dive deeper into these two groups of variables in order to provide a detailed overview of the current state of the research. The final goal is to compile a list of suitable visual variables that can be played with to create the visualizations for this test. The process of realizing these visualizations, is outlined in section 4.2.1.

4.2.1.1 Static Visual Variables

"The nature of the pigments provides the basis for sensations of light and colour; that is, brightness, hue and saturation. The geometrical demarcation of these qualities provides the physical basis for perception of areas and their shapes. Altogether, these factors constitute the vocabulary of the language of vision and are acting as the optical forces of attraction." [20] In this quote, Gyorgy Kepes, lists several visual attributes in his research paper dating back to 1944. These visual factors have been picked up by many designers and authors ever since. Jacques Bertin subsequently extended and proposed a new list that contains: position, direction and differences in size,

shape, brightness, colour and texture (Figure 4.1). [20] There have been a large body of work centered on research into visual variables and their uses across a wide range field such as cartography and information visualization (infovis). Over the years, the body of knowledge concerning this topic has increased drastically. Figure 4.2, outlines the visual variables that have been added to the language of vision in the field of cartography. It can be seen that for instance Morrison was the first to propose the addition of new variables: arrangement and saturation (third dimension of color) in 1974. Another important turning point was when MacEachren realized that the basic visual variables distinguished by Bertin were insufficient to visualize the phenomenon of uncertainty, and for this reason he proposed expanding the list by additional variables: crispness, resolution and transparency. Similarly, the field of information visualization has emerged from research in human-computer interaction, computer science, graphics, visual design, etc. It is increasingly applied as a critical component in scientific research, digital libraries, data mining, financial data analysis, market studies, manufacturing production control, and drug discovery [21]. Information visualization presumes that "visual representations and interaction techniques take advantage of the human eye's broad bandwidth pathway into the mind to allow users to see, explore, and understand large amounts of information at once". To this end, the research into information visualization focuses on determining visual variables that are highly effective in conveying abstract information in intuitive ways (size, shape, orientation) [22].

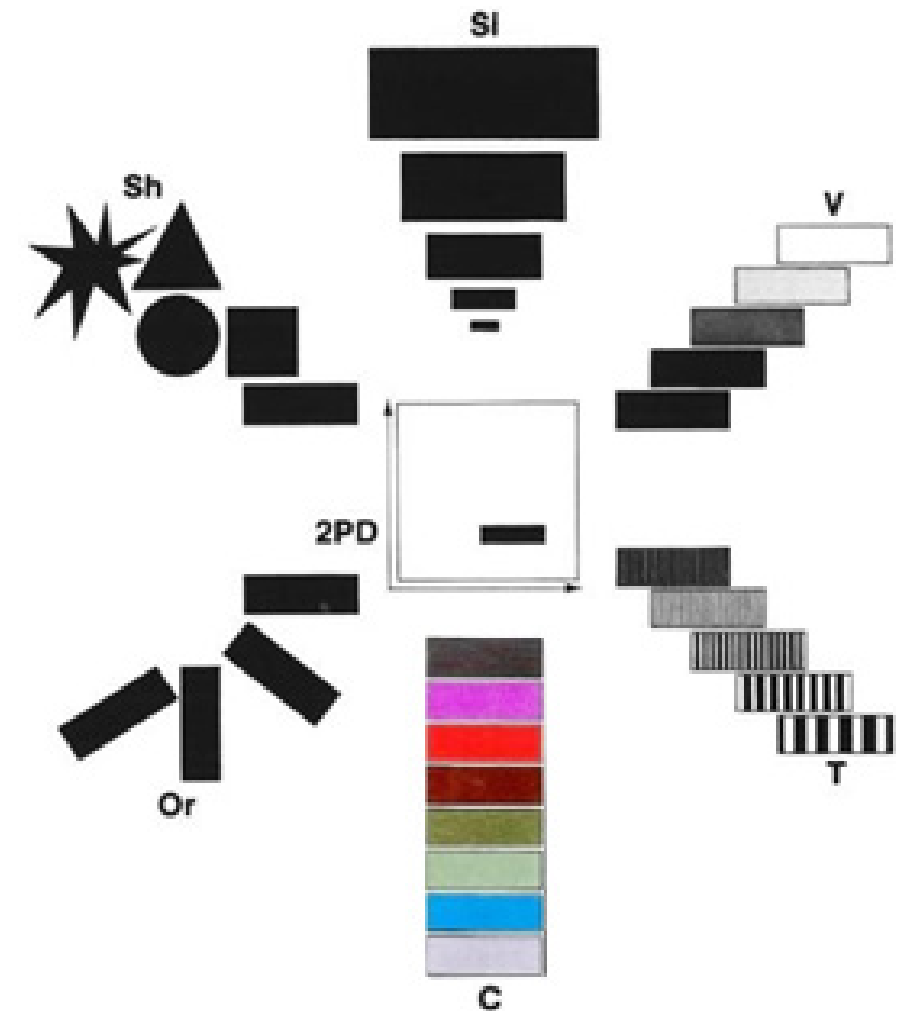


Figure 4.1: Bertin's visual variables.

COMMENT: The figure shows Bertin's set of "visual variables" that can be used in graphic representation: size (SI), value (V), grain (T), color (C), orientation (Or), Shape (Sh), and the spatial dimensions of the plane (2PD).

Visual Variable	Author	Example
Size	Bertin (1967/83), Morrison (1974), MacEachren (1995), Kraak & Ormeling (2003), Krygier & Wood (2005), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Shape	Bertin (1967/83), Morrison (1974), MacEachren (1995), Kraak & Ormeling (2003), Krygier & Wood (2005), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Lightness/ value	Bertin (1967/83), Morrison (1974), MacEachren (1995), Kraak & Ormeling (2003), Krygier & Wood (2005), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Color (hue+saturation)	Bertin (1967/83).	
Orientation	Bertin (1967/83), Morrison (1974), MacEachren (1995), Kraak & Ormeling (2003), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Texture	Bertin (1967/83), Morrison (1974), MacEachren (1995), Kraak & Ormeling (2003), Krygier & Wood (2005), Dent et al. (2009), Tyner (2010).	
Location	Bertin (1967/83), MacEachren (1995), Kraak & Ormeling (2003), Krygier & Wood (2005), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Hue	Morrison (1974), MacEachren (1995), Kraak & Ormeling (2003), Krygier & Wood (2005), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Saturation/ intensity	Morrison (1974), MacEachren (1995), Krygier & Wood (2005), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Arrangement	Morrison (1974), MacEachren (1995), Dent et al. (2009), Slocum et al. (2010), Tyner (2010).	
Focus/ crispness	MacEachren (1995).	
Resolution	MacEachren (1995).	
Transparency	MacEachren (1995).	

Figure 4.2: Breakdown of static visual variables

Thus, given the mentioned literature, a list of static visual variables was compiled. Table 4.1 provides an overview of these variables. This table does not aim to be a comprehensive list of all static visual variables, but it covers the primary variables that are mentioned and used by the researchers.

Variable	Description
Size	Size describes the amount of space occupied by the graphic object.
Shape	Shape describes the external form (i.e., the outline) of the graphic object. The shape can vary from highly abstract, such as circles, squares, or triangles, to highly complex geometries.
Lightness	Lightness describes the relative amount of energy emitted or reflected by the symbol. Variation in color value results in the perception of shading, or areas of relative light (high emission) and dark (low emission). Accordingly, color value is sometimes referred to as "lightness" in color theory.
Color hue	the degree to which a stimulus can be described as similar to or different from stimuli that are described as red, green, blue, and yellow. This is one of three visual variables associated with the perception of "color."
Color saturation	Saturation is the "colorfulness of an area judged in proportion to its brightness", which in effect is the perceived freedom from whitishness of the light coming from the area [23]. This is the third of three visual variables associated with the perception of color. Bold or saturated colors emit or reflect energy in a concentrated band of the visible spectrum, whereas pastel or desaturated colors emit or reflect energy evenly across the visible spectrum.
Orientation	Orientation describes the rotation of the graphic object from "normal." The normal orientation typically is relative to the neat line (either explicitly included or inferred by negative space), but in some cases it can be relative to the projected spatial coordinate system
Texture	Texture is a higher-order visual dimension with three constituent components: the directionality of the texture units (related to the visual variable orientation), the size of the texture units (related to the visual variable size), and the density of the texture units (approaching the perceptual effect of shading associated with the visual variable color value).
Location	Location describes the position of the graphic symbol relative to a frame.
Arrangement	Arrangement describes the layout of graphic objects constituting the whole. The visual variable arrangement varies from regular to irregular.
Crispness	Crispness describes the sharpness of the boundary of the graphic object. Crispness also is referred to as the inverse of "depth-of-field" and "fuzziness" in information visualization.
Resolution	Resolution describes the spatial precision at which the graphic object is displayed.
Transparency	Transparency describes the amount of graphic blending between a graphic object and the background or underlying graphic objects.

Table 4.1.: Definition of visual variables [24]

4.2.1.2 Dynamic Visual Variables

Even though Bertin did not have a lot of confidence in the usefulness of dynamic maps. He stated, even as early as 1967, that motion would dominate the graphic variables he distinguished (size, value, grain, color hue, orientation and shape), thus revolutionizing the effectiveness of the field of cartography. Recent research confirms Bertin’s opinion by showing that visual variables can indeed be used on the individual frames of an animation in such a way that these images effectively communicate a message to the user, while the movement of the animation gives the message an extra dimension and “new energy” [25] . Furthermore, the findings of Koussoulakou showed that using animated graphics helped users grasp the contents of a message in a more effective manner compared to using traditional static visualizations [26].

It has become clear that the traditional visual variables, which we called the static visual variables, do not suffice in describing the added depth of information that we have available today. To this end six “new” dynamic visual variables were introduced by MacEachren in 1994 [27]. These are: moment, duration, frequency, order, rate of change, synchronization. Table 4.2 provides an overview and description of these variables.

Variable	Description
Moment	The moment that a graphic object changes during an animation can be used for temporal as well as non-temporal animations.
Duration	Duration indicates the duration in real-time a graphic object is visible during an animation. For instance, if province A has twice the amount of annual sunshine of province B, province A would be highlighted twice as long during the animation.
Frequency	The dynamic visual variable frequency uses the rate of occurrence of graphical elements.
Order	Animation actually is the presentation of individual frames in a given order. Chronologically showing temporal data is probably the most used form of animation.
Rate of change	The rate of change can be described as M/D, where M is the change magnitude and D is the duration for that change.
Synchronization	With synchronization two (or more) phenomena are related to each other by showing their development synchronously in one animation.

Table 4.2: Description of dynamic variables

4.2.2 Data Categories

As mentioned in the introduction, social media has been used to represent the data. The changes and trends in this data is what we want to convey using ambient light visualizations. However, social media platforms have a wide range of data streams. To select which data streams are of a higher importance, a literature study was performed to identify the key streams that have been used successfully in the field of advertisement. Again, here the specific purpose of advertisement is selected as a result of the broader project goals of the company. The first paper that was studied, assessed the effectiveness of advertising in the social media platforms [28]. The two social media platforms they studied were Facebook and Instagram, as they are the top 1 and 3, respectively, in terms of worldwide active users. In order to measure the effectiveness of advertisement, they believed it is important to measure the click through rate (the ratio of individuals that have seen an Online ad, email or a general website and clicked on the call-to-action), and the conversion rate (the number of individuals that after having access to company’s website complete an action. Those actions are, more commonly, a sale or subscription) but also: clicks, impressions (number of times an ad is displayed), frequency (Impressions by the number of unique users the campaign has reached), audience reach, and the amount spent in each campaign [28]. The second literature’s aim was to assess Facebook as a recruitment tool in a study for Spanish- and English-speaking smokers [29]. An extensive inventory of metrics was created to assess the success and connectivity of advertisement/recruitment strategies

The metrics (Figure 4.3) were divided in two section: those based on Facebook algorithms and those based on participant behaviors. The following metrics resulted from the study:

Metrics based on participant behaviors	
Clicks	Number of clicks on an ad. Counts multiple types of clicks.
Consents	Number of individuals consented to participate in the research study.
Conversion rate	Metric calculated based on the Unique Outbound Clicks.
Cost per consent	Cost per consenting individual obtained.
Cost per link click (CPC)	Average cost per each link click, benchmark for ad efficiency and performance. Calculated by dividing the total amount spent per click.
Link clicks	Number of clicks on ad links to specific destinations or experiences, both on and off FB-owned properties (e.g., websites, click-to-call).
Post comments	Number of comments per ad, which counts all comments made by individuals while the ad was running.
Post reactions	Number of times individual users reacted to a post with a click, which includes reactions such as "like" and "love."
Post shares	Number of shares per ad while running, but does not count engagement with the post after the share.
Metrics based on Facebook	
Click-Through Rate (CTR)	Percentage of times individuals see an ad and click on a link.
Engagement	The total number of actions that people take involving the ads.
Impressions	Number of times an ad is shown on screen for the targeted audience.
Reach	Number of individuals that see an ad at least once.
Relevance	Calculated based on an ad's positive feedback (app installs, clicks) and negative feedback (User clicks "I don't want to see this" on the ad) and ranges from 1 to 10.
Social reach	Number of individuals that see an ad when displayed with social information, acting as word-of-mouth for advertisers
Unique Outbound Clicks (UOC)	Number of clicks on links that redirect users off FB and to the targeted site.

Figure 4.3: Metrics made by definitions based by facebook Business' (2018) Glossary of Terms

Lee in his paper studies the association of various kinds of social media marketing content with user engagement defined as Likes, comments, shares, and click-troughs with the messages [30]. What's interesting about his research is the fact that he identified a reversed pyramid relationship between the Reach, Impressions and Engagement, amongst

other relationships between the various metrics used in social media. These relationships can be used to categories the data streams more effectively.

Another study performed by Smith focuses on the aspect of engagement within the context of social media [31]. Smith argues that engagement is conceptually distinct and involves cognitive and emotional immersion that may not characterize all social media usage. He states that engagement is what publics feel about social media content and then what they do about it, including searching for, commenting on and sharing content Online. In his paper he shows that engagement represents a transition from the one-way reception of messages to active user involvement in responding to, creating, and distributing information, as well as using such information to express oneself Online.

Similarly, the final study investigates the motives for YouTube user engagement that has been conceptualized as active participation and passive content consumption [32]. It states that individuals deal with content in three main ways: consumption, participation, and production.

Content consumption is when users watch a video, read comments and view likes/dislikes but do not respond. The study views participation to include user-to-user and user-to-content interaction (commenting, sharing, liking, disliking). Lastly, the same study views production involving a greater degree of engagement that comprises actual publishing of content such as uploading a video on YouTube which has been categorized as a participatory act. Thus, the concept of YouTube engagement is conceptualized under

two main categories, participation and consumption. Figure 4.4 depicts these engagement classifications.

Variable	Description
Participation	
Like	Likes on social media represent a form of user vote or an expression of appreciation of content. The number of likes indicates the popularity of content.
Dislike	A dislike is form of user vote used to express disapproval of some content.
Comment	Comments may vary in length and are an expression of text-based communication to express opinions about a topic.
Share	By sharing a YouTube video, a user may take a conscious decision to make the video available (sometimes on other social media platforms) within one's network of friends.
Upload	Uploading a video on YouTube may be considered as a higher level of participation in which a video is shared through uploading with the wider audiences on the site.
Consumption	
View	YouTube offers a video count on the site based on the number of times a video is viewed. The number of video views indicates popularity.
Read Comments	YouTube users can read comments that appear at the bottom of each video. This is a passive content consumption act.

Figure 4.4: Classification and Meanings of engagement variables in participation and consumption level

Using these literatures, it was possible to compile a large list of data streams that we commonly use to achieve a broad spectrum of objectives by providing value information and insights into the world of social media. This list is by no means complete and only aims to identify what are the key concepts and aspects of social media that are important to convey by means of ambient light communication. These data streams form a basis of the data categories that were selected for this test. The process of selecting grouping and defining these categories is outline is section 3.2.

RESEARCH QUESTION:

Whether it is possible to convey the meaning of social media data categories, using light visualizations without the need for a priori knowledge or training?

4.3 METHODOLOGY

This chapter provides an overview of the methods and procedures used in this test. This should allow future researchers to reproduce and extend the experiment in order to improve upon the results achieved within the limited time and scope of the project. A detailed description of the visual stimuli, participants and test procedure is outlined below.

4.3.1 Stimuli

A number of static and dynamic visual variables were identified in section 4.3.1 which can be used to encode information. According to the literature study, these variables are: Size, Shape, Color value, Color hue, Color saturation, Orientation, Texture, Location, Arrangement, Crispness, Resolution, Transparency, Moment, Duration, Frequency, Order, Rate of Change, and Synchronization.

Given the fact that the visualizations are intended to be displayed using a screen, some of the aforementioned variables are either impossible to demonstrate or reduce to the same variable. In this test, it was decided to use a vertical line as the main graphic object. Studies reveals that using vertical aligned lines to visualize data can be perceived more accurately by human (Figure 4.5) [33]. This fixes the variables Shape and vertical Size, thus removing them from the design space for developing the visualizations. This was done to reduce the scope and thus the complexity of the test by a considerable margin. A line is the simplest geometrical shape (it's considered one dimensional in this context) which is the reason why it was selected. Any shape that defines both a vertical as well as horizontal boundary would also require 2 parameters to define its Size and Location. While a line requires one (width and position along the horizontal axis) making it easier to map to most quantitative information. This leaves room for improvements in future research.

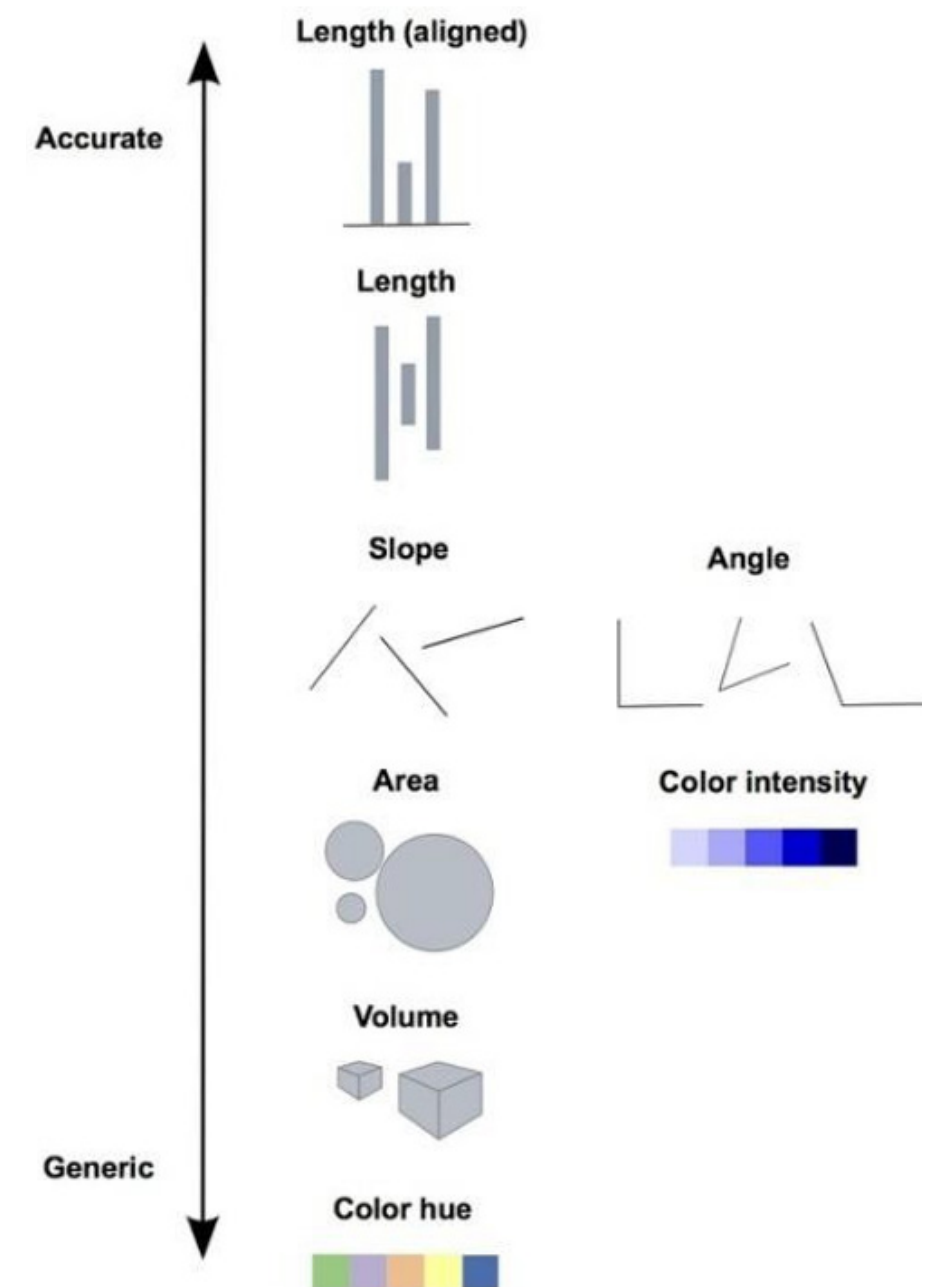


Figure 4.5: Accuracy level of perceiving graphical objects

Furthermore, Texture is also eliminated as variable as the aim of the project was to communicate information using ambient light. Light reflecting off a surface cannot represent Textures. The visible Texture is a property of the surface reflecting the light and its control is out of the scope of this test. Focus and Resolution carry the same effect when it comes to visualizing with light; therefore, in this study Focus has been chosen since it has a better similarity to blurriness which is a light property. Similarly, Transparency and Lightness (of the foreground graphic object), as defined in the previous section, become equivalent when using light visualizations.

Lastly, regarding the dynamic visual variables, due to the complexity and the number of visualizations required to cover all these variables, it was decided to focus on a few of the more distinct variables. Synchronization was not used as only a single graphic object (the line as described above) is displayed. Furthermore, Moment and Duration represent two sides of the same coin and thus are captured on every visualization as such there are not isolated in their own specific visualization.

Due to the above reasoning, the final selection of the visual variables for creating the light visualizations for this test are as below: Size, Lightness, Colour, Location, Saturation, Focus, Moment, Frequency, Order, Rate of change. From these variables, 9 visualizations were created. These visualizations are designed to incorporate and display one or more of these variables.

Since these variables are varied frame by frame, it is vital to also consider the inverse order for each visualization. Hence, each visualization is created as a pair of converse animations.

Some visualizations have been made using POET software which is a real-time generative content editor that facilitates creating visualizations using live data streams [34]. Other visualizations were created using a Python script and a simple game engine library (PyGame). Figure 4.6 provides an overview of the 9 pairs of visualization categories:



Figure 4.6: Visualization categories

You can find the
light visualizations
on the next page

Created Light Visualizations:

You can scan the QR codes to see the visualizations in motion

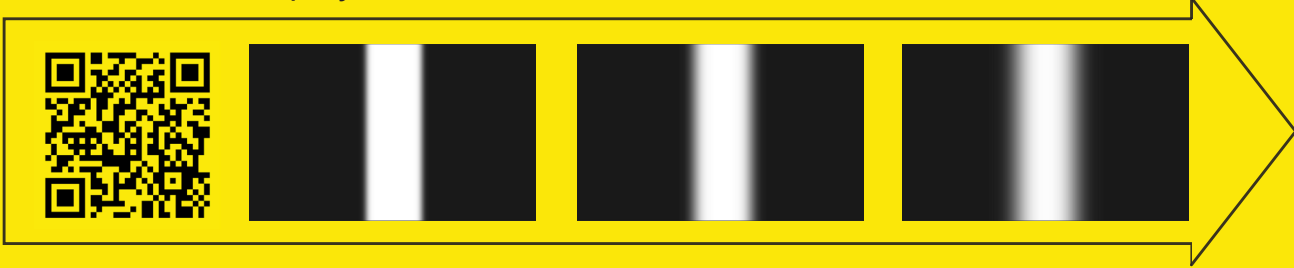
Aggregation

This visualization is the most complex one. It plays with the Location, Moment and Order variables. Together, they become equivalent to texture for light.



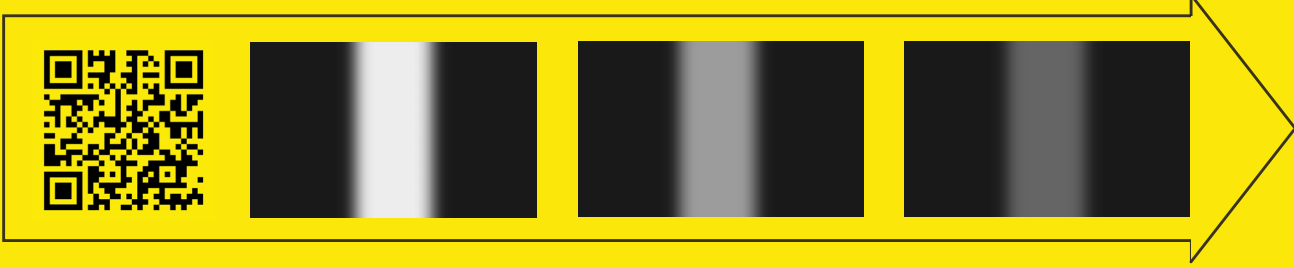
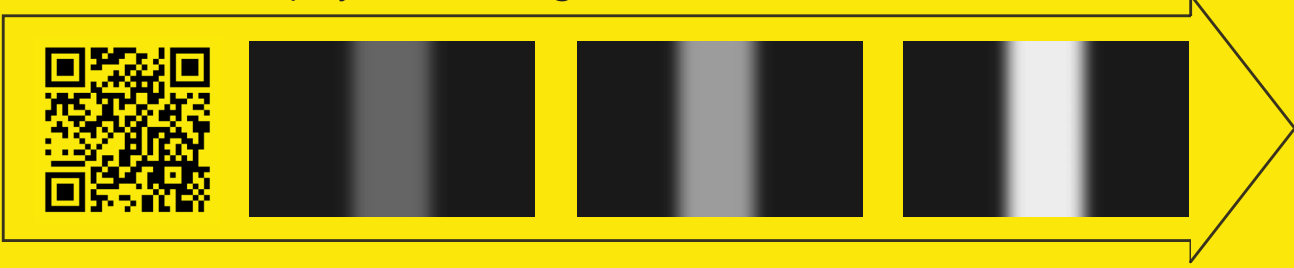
Blur

This visualization plays with the Focus variable.



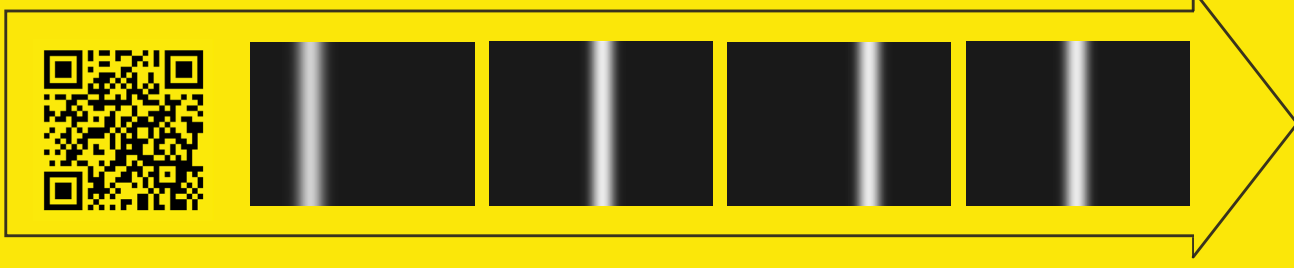
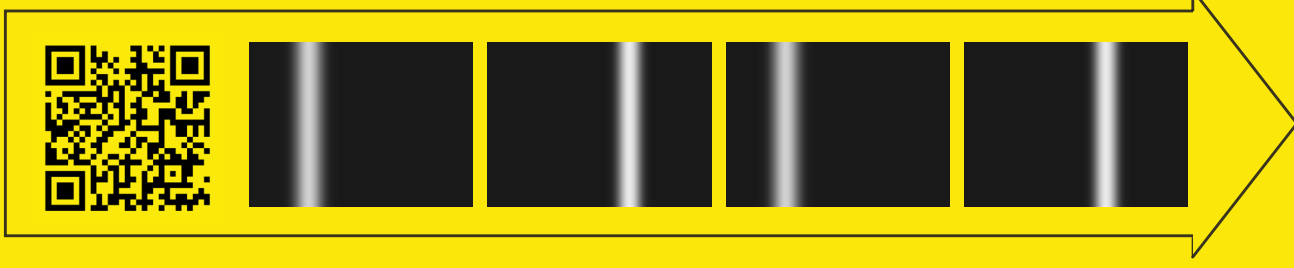
Intensity

This visualization plays with the Lightness variable.



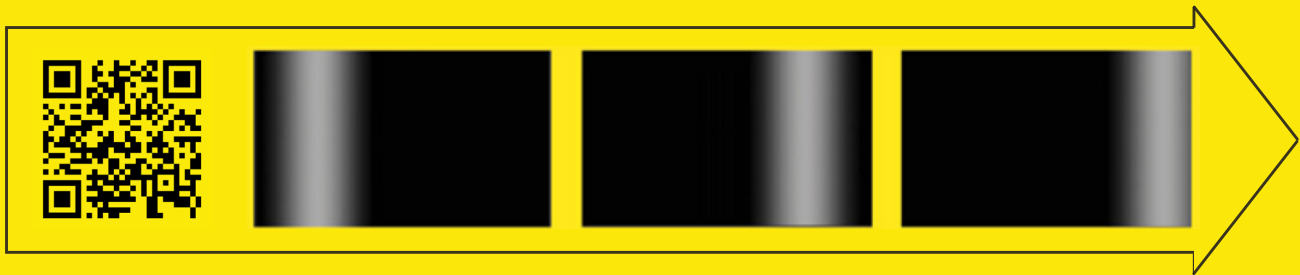
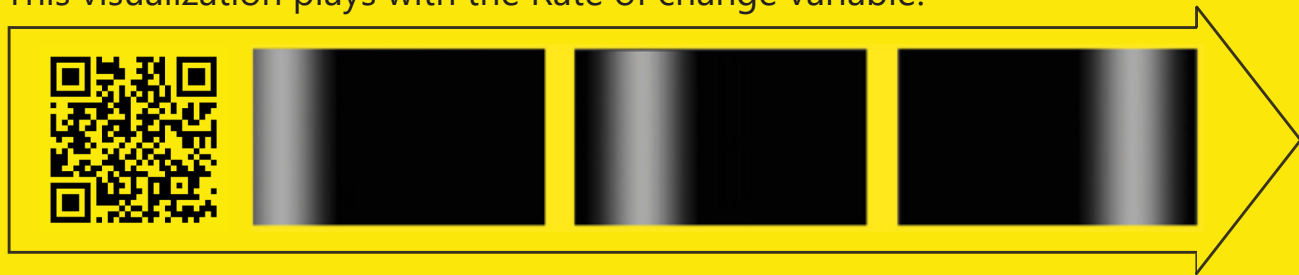
Rhythm

This visualization plays with the Frequency variable.



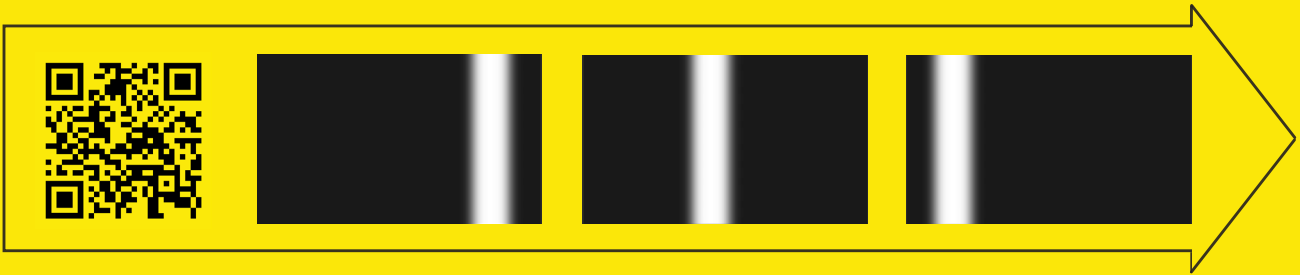
Acceleration

This visualization plays with the Rate of change variable.



Direction

This visualization plays with the Location variables.



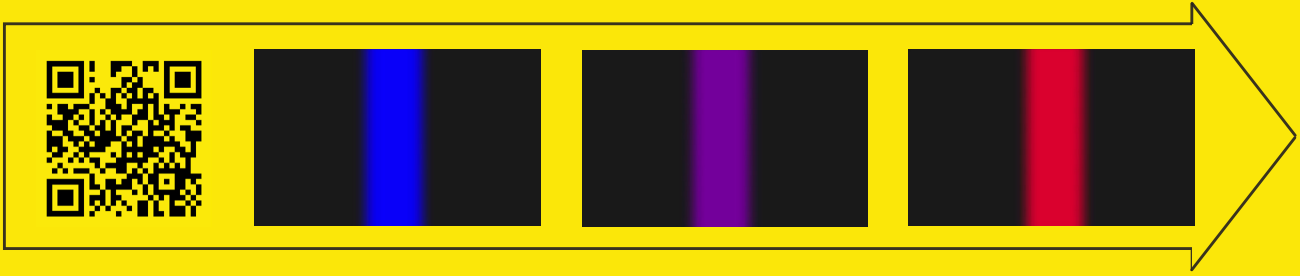
Size

This visualization plays with the Size variable.



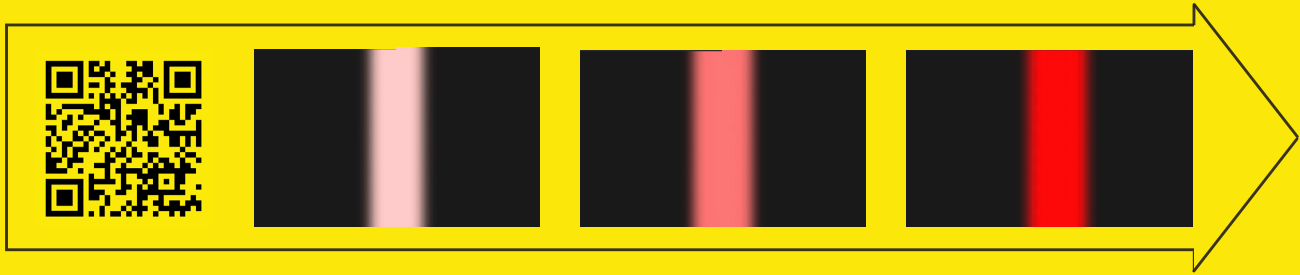
Color

This visualization plays with the Color variable.



Saturation

This visualization plays with the Saturation variable.



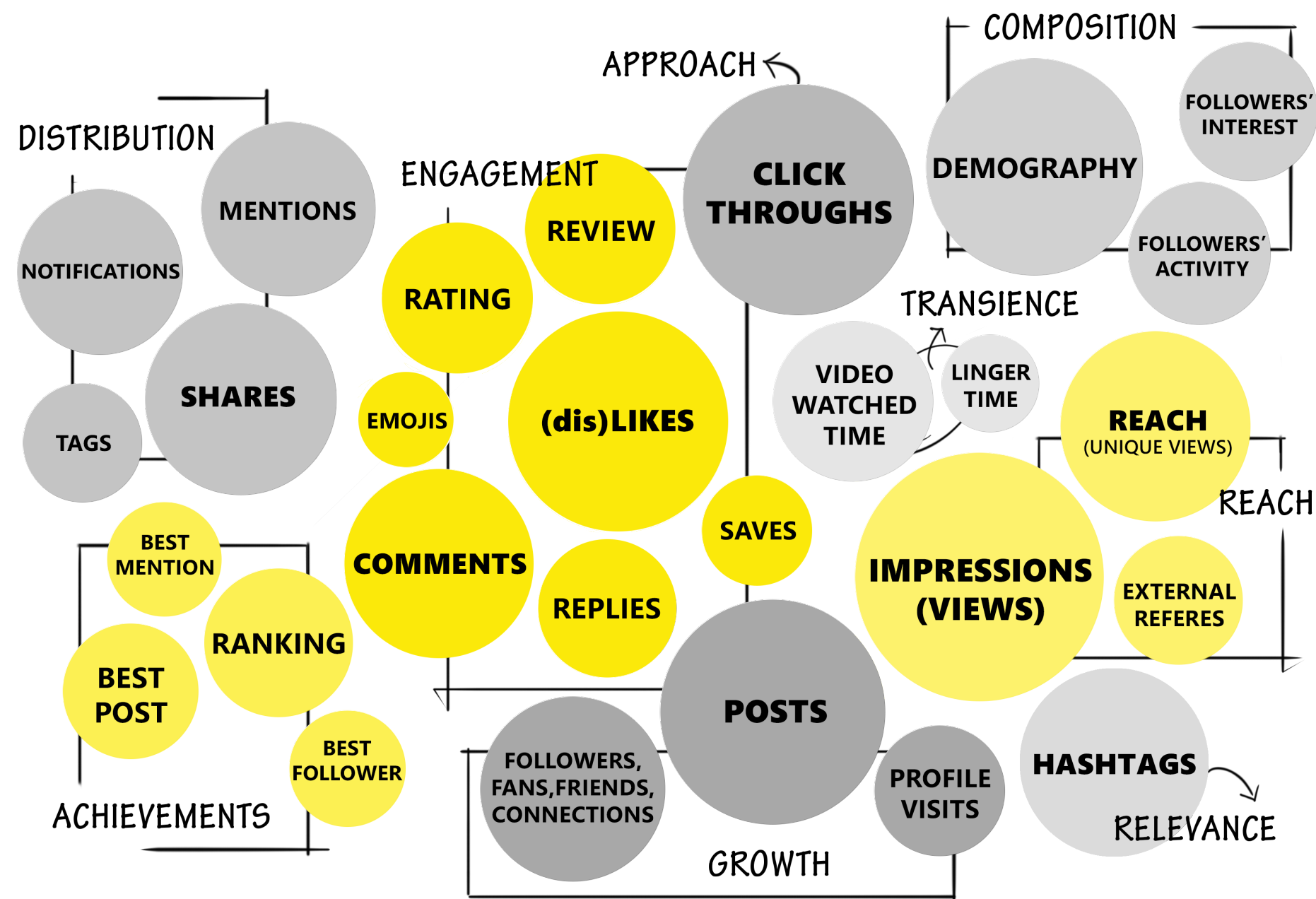


Figure 4.9: Assigning names to data category clusters

Data Category	Description
Reach	Number of times a post has been exposed to the users.
Approach	Number of clicks in order to view a post.
Transience	Ratio of average minutes watched per view over the total time length of the post.
Engagement	Ratio of the number of likes and comments over the 'total number of views' (approach).
Distribution	Ratio of the number of shares and mentions over the 'total number of views' (approach).
Growth	Change in the number of followers, friends, or subscribes.
Achievement	Special event, like when a post receives the highest number of likes.
Historic Legacy	The number of times a Hashtag has been used or searched for.
Composition	Arrangement of the users' specifications, like gender.

Table 4.3: Data categories' definitions

In order to come up with a reasonable number of categories to assign to different data streams, 5 of the most commonly used social media platforms (Facebook, YouTube, Instagram, Twitter, LinkedIn) [35] was selected (Figure 4.7). Subsequently, a list of all of the data streams for each social media platform was compiled and clustered based on similarities (Figure 4.8). Finally, according to the literature study regarding the different social media categories, the most appropriate names have been assigned to the clusters (Figure 4.9) which resulted in the 9 data outlined in table 4.3.

4.3.3 Procedure

Now with a set of light visualizations and data categories at hand (Figure 4.10), we can establish a test procedure to explore which data category the participants would perceive after watching each visualization.

The test consists of two phases: Answering an Online questionnaire as well as the complimentary interview. At first, a short introduction is provided to each of the participants. The aim of the introduction is to explain the meaning of the social media categories (Figure 4.11), as well as the test procedure and survey layout. Next, the participants will be asked to fill in an Online survey after reading and signing the informed consent form (to use the results of the survey for the purpose of this project). The participants were also given an estimation of the time required to complete the questionnaire and an email contact in case they had any questions.

SogoSurvey was used as the Online platform to host the questionnaire. There are 18 questions in total each

corresponding to a particular visualization. At the top of each question, a short (5 second) visualization is displayed. The video is looped in case the participants want to have another look. It is important to note that before the start of the visualization, a brief message is displayed that counts down to the start of the visualization. This is done in order to ensure that a constantly repeating visualization does not produce unintended effects (such as conveying frequency etc.). Furthermore, the order of the questions is randomized to improve the accuracy of the results. This also helps combat the effect of participants losing focus at the end of the survey, thus providing less elaborate answers for the latter questions.

Below each visualization, the participants have the ability to select one or more data categories that they perceive as being related to the displayed visualization (see Figure 4.12). Each selection can be elaborated using a textual answer.

The next phase of the test is an interview with the participants. This will take place after the results of the participant was briefly analyzed. This is done in order to focus on the more interesting answer due to time restrictions. The aim of the interview is to clarify any ambiguities in the provided answers as well as gaining other insights that may be triggered after a one to one conversation. It is important to only perform the interview after the survey has been fully completed, as to not influence the results.

4.3.4 Participants

In total there were 18 participants that took the survey. All participants were TU Delft Students, out of which, 8 were female and 10 were male. The age of the participants was between 21 to 31 with an average of 25. The participants originated from 8 countries, 3 of which is located in the European continent, 2 in America, with the final 3 being located in East Asia.

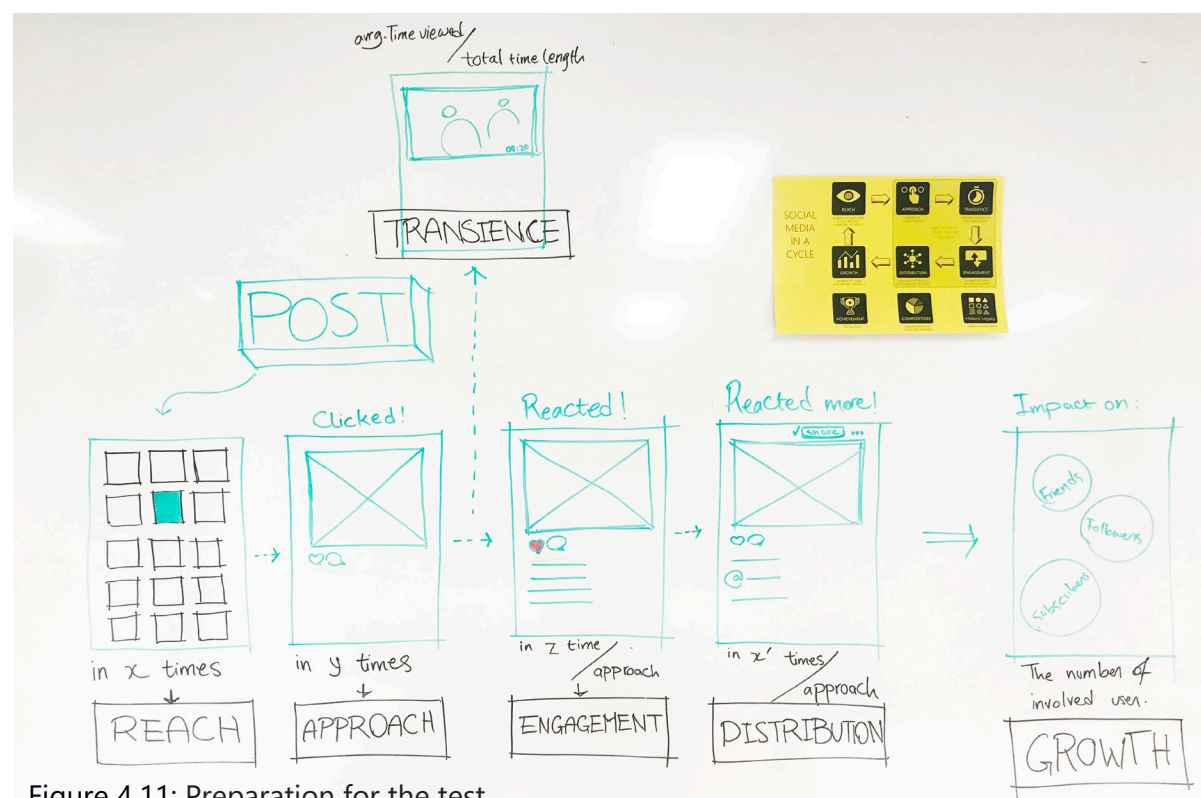


Figure 4.11: Preparation for the test

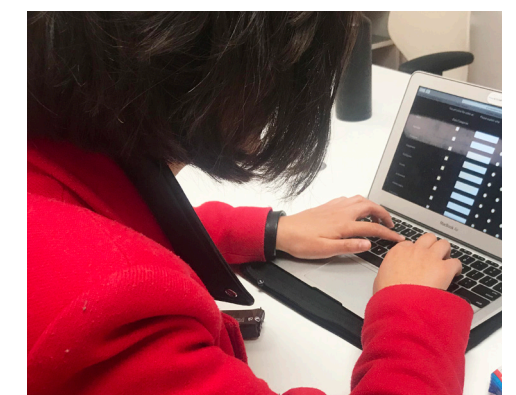
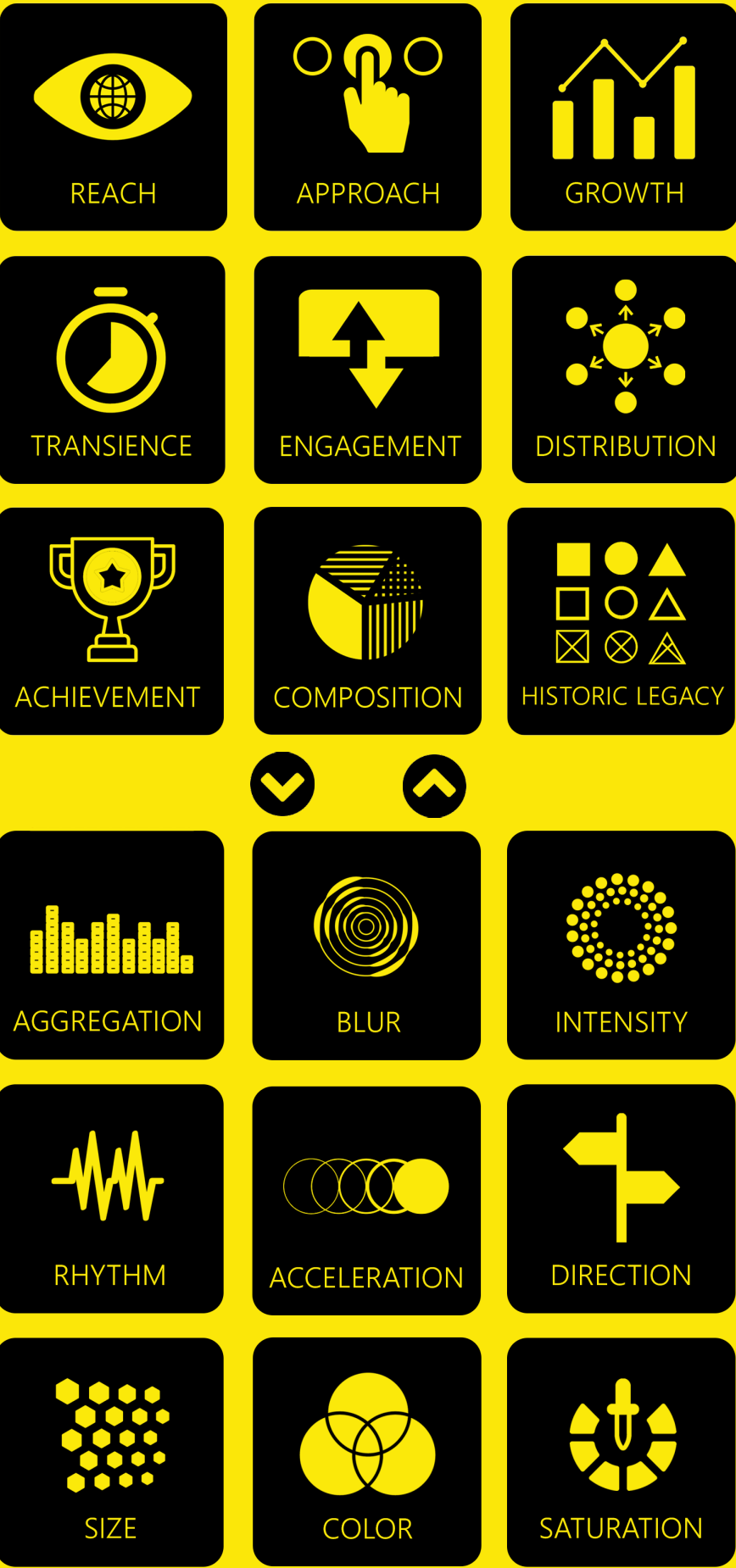



Figure 4.10: two sets of categories for light visualizations and data



How do you perceive the following video?



You perceive the video as:	Please explain why:	You perceive the transformation as:			
	Data Categories		decrease	constant	increase
Reach	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Approach	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Transience	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Engagement	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Distribution	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Growth	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Achievement	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Historic Legacy	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Composition	<input type="checkbox"/>	<input type="text"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 4.12: Multiple choices structure of the survey

4.4 RESULTS

To be able to draw valid conclusions from the data collected through the experiment, it is important to summarize, process and visualize the data in a form that can best be analyzed. In this study, this is done by visualizing the relationship between the independent and dependent variables through bar charts. The aim of the bar chart is to facilitate the analysis by highlighting any trends in the dependent variable as well as enabling us to compare it to the mean, median and the standard deviation as well as other dependent variables. Whenever necessary, statistical calculations and analysis are also provided to assess the significance of the results.

The analysis is broken down into two parts. The first part examines if each of the 18 visualization can be used as an effective method for conveying the meaning of one of the selected data categories. The distribution of the votes between the data category trends is the subject of the second part of the analysis. There, the possibility of using the 18 selected visualizations, as a means of conveying a sense of increase, decrease or constancy (hereafter referred to as data category trend) is examined. In each section, a quantitative analysis is performed based on the gathered numerical results (the number of votes for data categories and data category trends), as well as a qualitative analysis based on the interviews performed with the participants.

4.4.1 Visual Variables

This part examines if each of the 18 visualization can be used as an effective method for conveying the meaning of one of the selected data categories. This is done by observing any outliers that fall outside of the normal distribution of the dependent variable.

To achieve this, the dependent variable, representing the total number of times that the participants have selected a data category for a particular visualization (here after referred to as votes), is placed on the y-axis of the bar charts.

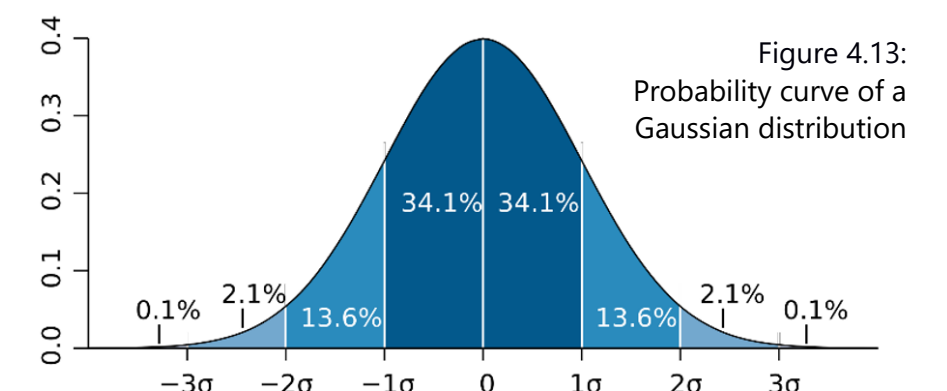
Similarly, the independent variable is represented by the 9 selected data categories and are labeled on the x-axis. It is important to note that the total number of votes for each data category is spread amongst the three data category trends (increase, decrease and constant). However, for this part of the analysis, the votes are all summed up to obtain the total number of times a particular data category has been selected by the participants for each visualization.

In the following 9 sub-sections, a pair of bar charts corresponding to a pair of converse visualizations is illustrated. Pairing matching visualizations may allow us to observe other interesting results which may have otherwise been missed. The mean and median values of the number of votes across all data categories is illustrated as a blue and red line, respectively. The mean is used to quickly see if the number of votes for any of the data categories is above the average number of votes for that particular visualization. The median is also used as a more robust statistical average (against data sets that may contain extreme outliers). If we assume that the visualizations do indeed convey one or more data categories more successfully than the rest, outliers are expected, and the median will serve as a more accurate average. Other important elements on these bar charts are the highlighted segments that represent the 1 and 2 sigma (denoted as σ) boundaries.

In statistics, the standard deviation (SD, also represented by σ) is a measure that is used to quantify

the amount of variation or dispersion of a set of data values [36]. A low standard deviation indicates that the data points tend to be close to the mean of the set, while a high standard deviation indicates that the data points are spread out over a wider range of values. In this study instead of expressing the variability of a population, the standard deviation is mostly used to measure confidence in statistical conclusions.

If it is assumed that the participants observe no correlation between the visualizations and the data categories (the null hypothesis), then distribution of the number of votes amongst the data categories will represent a normal Gaussian distribution according to the central limit theorem [37]. If one or multiple data categories receive significantly more votes than the average number of votes, standard deviation can be used as a tool to assess the likelihood that the result is insignificant or that the participants found a compelling reason to select (vote for) those particular data categories. As it can be seen in Figure 4.13, if the number of votes for a particular data category is more than the mean value plus the standard deviation, there is a 15.9% probability that result is not caused by a correlation between the visualization and that data category. This is also referred to as passing the 1σ interval. If the number of votes passes the 2σ interval (is more than the mean value plus 2 times the standard deviation), that probability reduces to 2.3%.

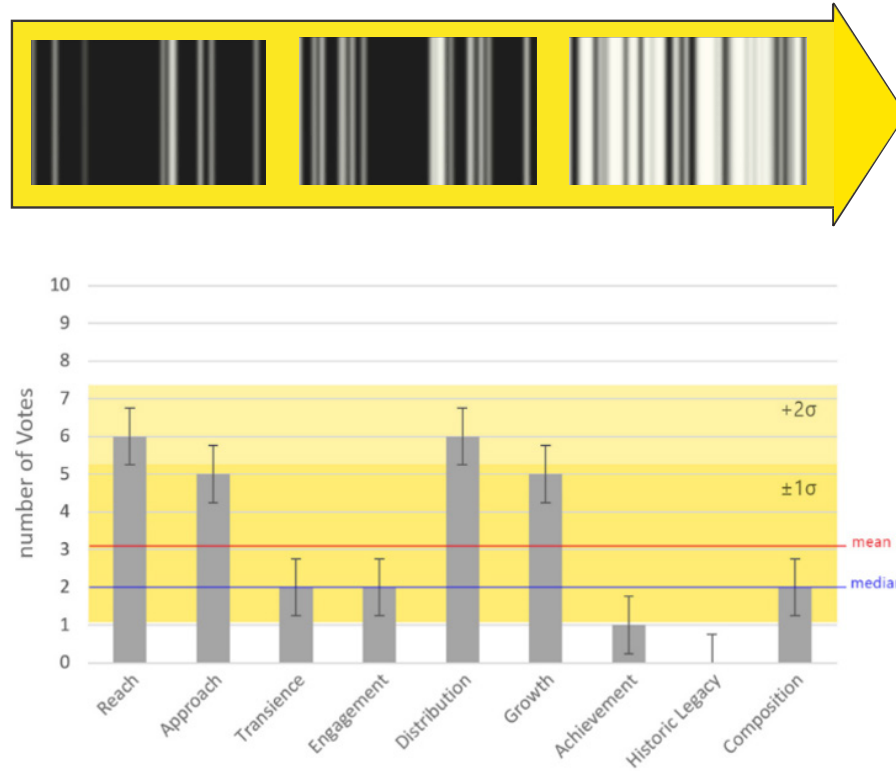




Finally, the error bars that can be observed on top of the bar charts (representing the number of votes for each category), show the standard error (SE). The SE is determined by calculating the expected standard deviation in the results if the same test were to be conducted multiple times. This number is identical for all bars within a chart and is used as a tool to compare the number of votes between data categories for each visualization in order to determine if one is (statically) significantly better than the other. If the difference in the number of votes for two data categories (which are being compared), is within margin of error (the error bars overlap), then it cannot be assumed that the data category with a higher number of votes is necessarily better.

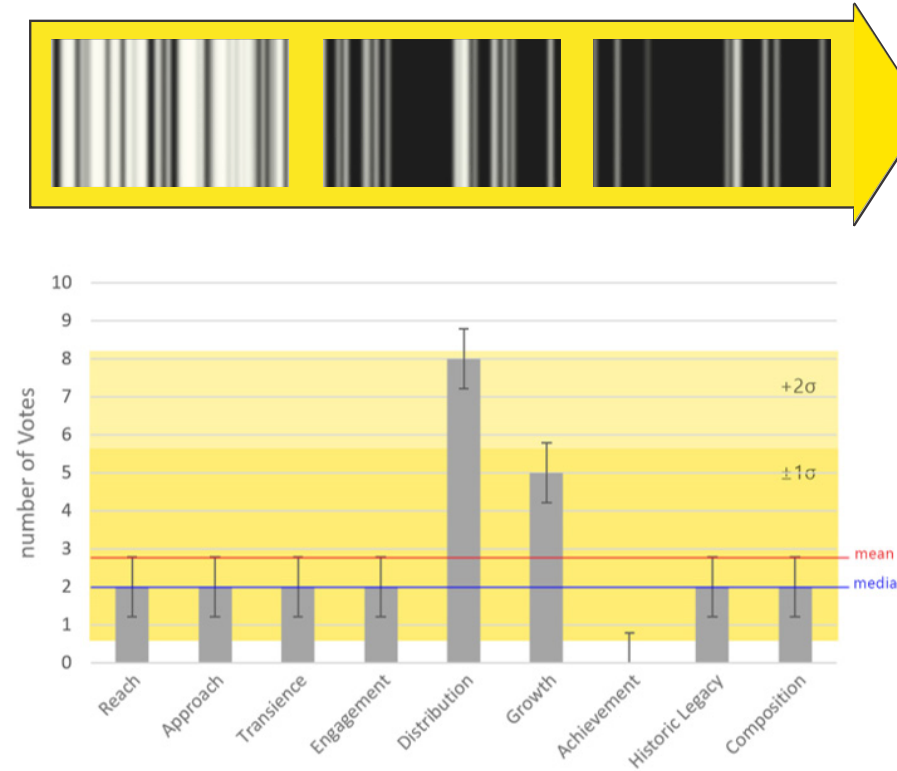
4.4.1.1 Aggregation

Normal



From the results, it can be observed that the data categories Reach, Approach, Distribution and Growth have received more votes than the mean and median values for this visualization. However, the number of votes for Reach and Distribution pass the 1σ making them slightly more suitable candidates to be used with this visualization. The error bars of all 4 aforementioned categories are overlapping however, meaning that no statistically significant difference exists between them. In summary, it can be concluded that this visualization is best suited to be used in first place to convey a meaning of Reach and Distribution, or secondly Approach and Growth.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Distribution and Growth. However, a quick glance at the chart shows that the clear winner and ideal candidate for this visualization is Distribution. The number of votes for this data category approaches the 2σ boundary and even when considering the measurement error, it is still far above the other data category Growth. Thus, according to the quantitative analysis, it can be concluded this visualization (Aggregation_Inverse) has a statically significant result and that it is best used to display Distribution.

Conclusion

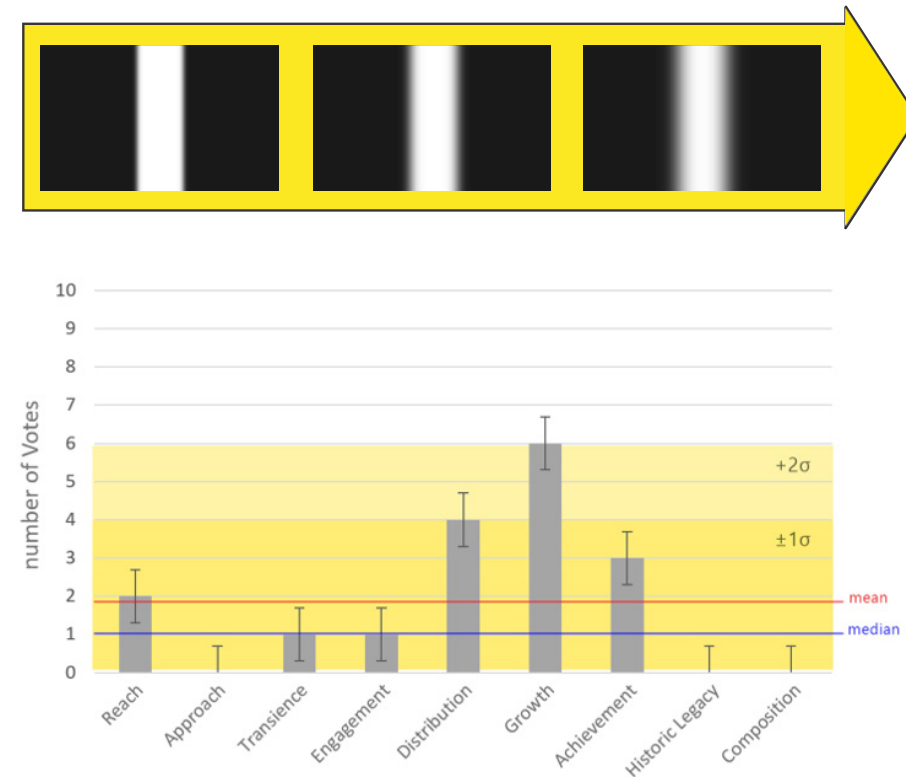
To summarize, this pair of visualizations is a good candidate to be used for representing Distribution in later designs, since both the normal and inverse visualizations conveyed a meaning of increase/decrease in Distribution. Furthermore, when considering the qualitative analysis, Growth and possibly Reach may present other alternatives. Due to the explanation of the meaning of Reach (the number of times a post has been exposed to the users), this data category can only increase therefore can be represented through the first visualization (Aggregation_Normal).

Interview

During the interviews, it was mentioned multiple times that the white lines were perceived as people/followers/viewers. Consequently, the change in the number of lines was also perceived as a change in number of viewers (Distribution and Reach) and followers (Growth). Moreover, 2 people mentioned that Aggregation was the easiest visualization to translate, giving an example of coordinating location to the line placement. Another interesting observation was that 3 of the participants mentioned that it was hard to distinguish white lines from black lines and whether the white is increase or conversely the black is decreasing.

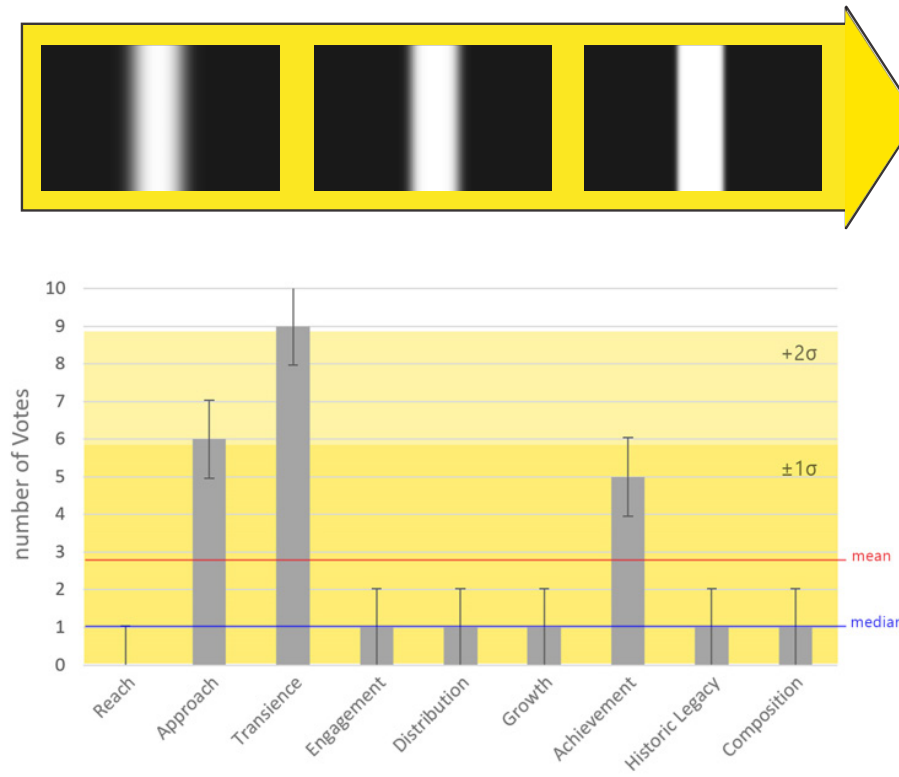
4.4.1.2 Blur

Normal



From the results, it can be observed that the data categories Reach, Distribution, Growth and achievement have received more votes than the mean and median values for this visualization. However, the number of votes for Distribution and Growth pass the 1σ and 2σ boundaries making them more suitable candidates to be used with this visualization. When considering the margin of error (as shown by the error bars), one can conclude that Growth is ultimately the best data category to be used with this visualization.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Approach, Transience and Achievement. Out of these data categories however, the number of votes for Approach and Transience reach a statically significant amount. A quick glance at the chart shows that the clear winner and ideal candidate for this visualization is Transience. The number of votes for this data category approaches the 2σ boundary and the even when considering the measurement error, it's still far above the other data category Approach. Thus, according to the quantitative analysis, it can be concluded this visualization has a statically significant result and that it is best used to display Transience.

Conclusion

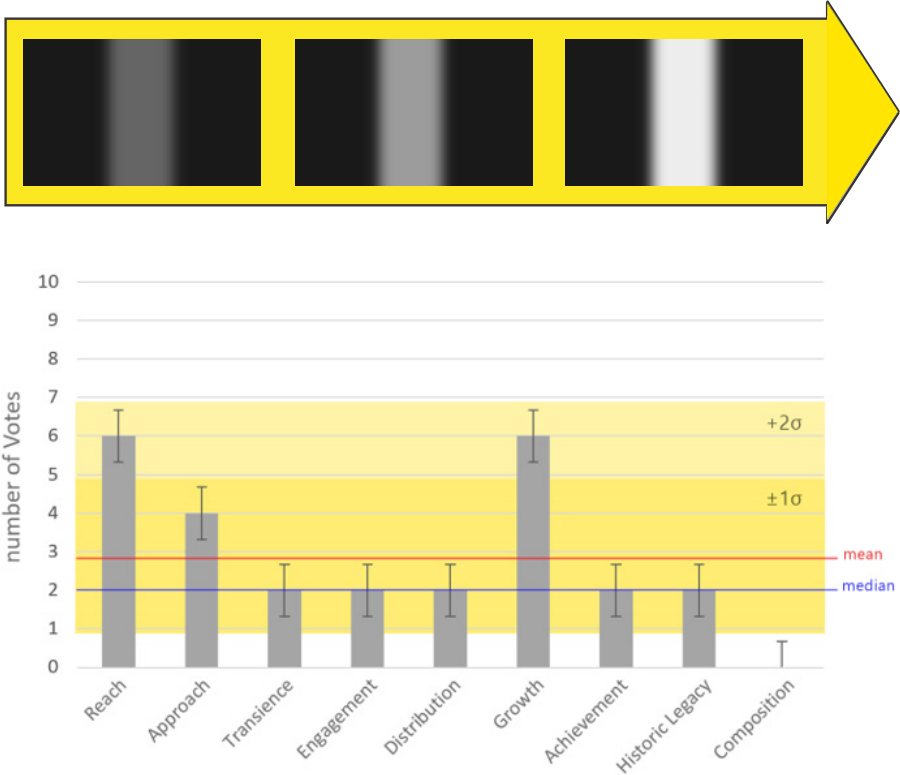
Unfortunately, this pair of visualizations do not share any common data categories. This means that even though each visualization by itself may be used to convey Growth or Transience, it is not very wise to use this pair to convey and increase or decrease in any of the data categories. The qualitative analysis also confirms the quantitative analysis (i.e. participants cannot associate these visualizations with an increase or decrease). Blue_Inverse can however be employed by itself for conveying Transience (for instance approaching the end of something).

Interview

During the interviews, most of the participants stated that they perceived a decrease in blur as approaching an object. As one gets closer, the object becomes more apparent and clearer. Other participants related the decrease in blurriness as the passage of time or the content (image or video) loading. As time passes one gets closer to seeing what they wanted. Lastly, no particular data category trend was observed by the participants.

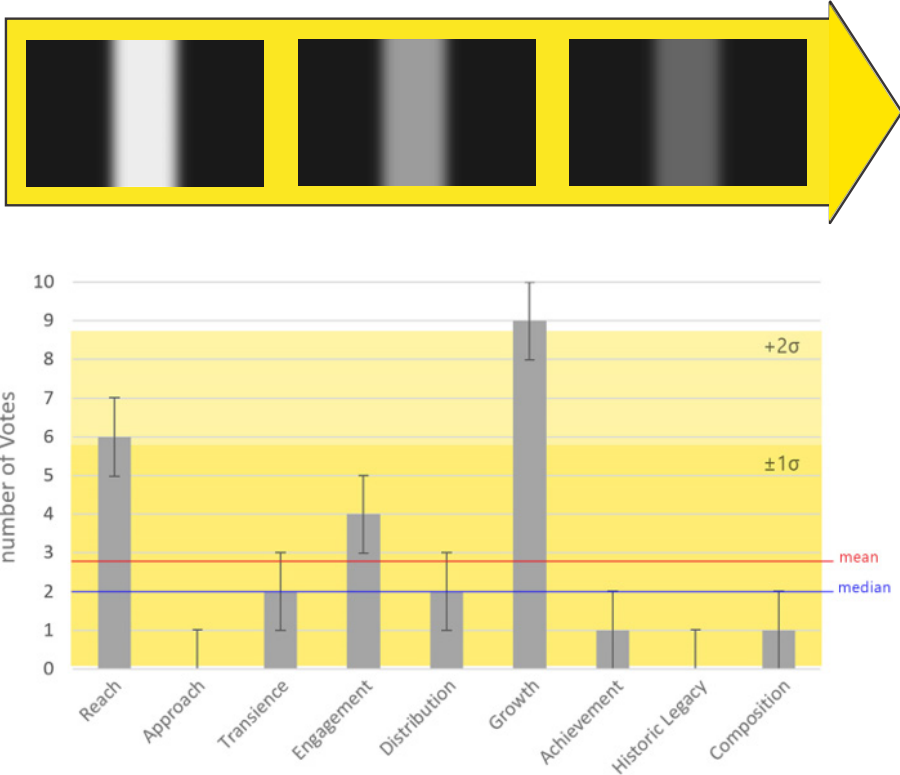
4.4.1.3 Intensity

Normal



From the results, it can be observed that the data categories Reach, Approach and Growth have received more votes than the mean and median values for this visualization. However, the number of votes for Reach and Growth pass the 1σ boundary making them more suitable candidates to be used with this visualization. Moreover, the 2 aforementioned categories have received the exact same number of votes, meaning that no other conclusions can be drawn to distinguish the leading candidate amongst them. In summary, it can be concluded that this visualization is best suited to be used to convey a meaning of Reach and Growth.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Reach, Engagement and Growth. Out of these data categories however, the number of votes for Reach and Growth reach a statically significant amount. The number of votes for these two data categories passes the 1σ and 2σ boundaries making them more suitable candidates to be used with this visualization. With more than 3 votes as compared to Reach, the chart shows that the clear winner and ideal candidate for this visualization is Growth. This remains true even when considering the measurement error. Thus, according to the quantitative analysis, it can be concluded this visualization has a statically significant result and that it is best used to display Growth.

Conclusion

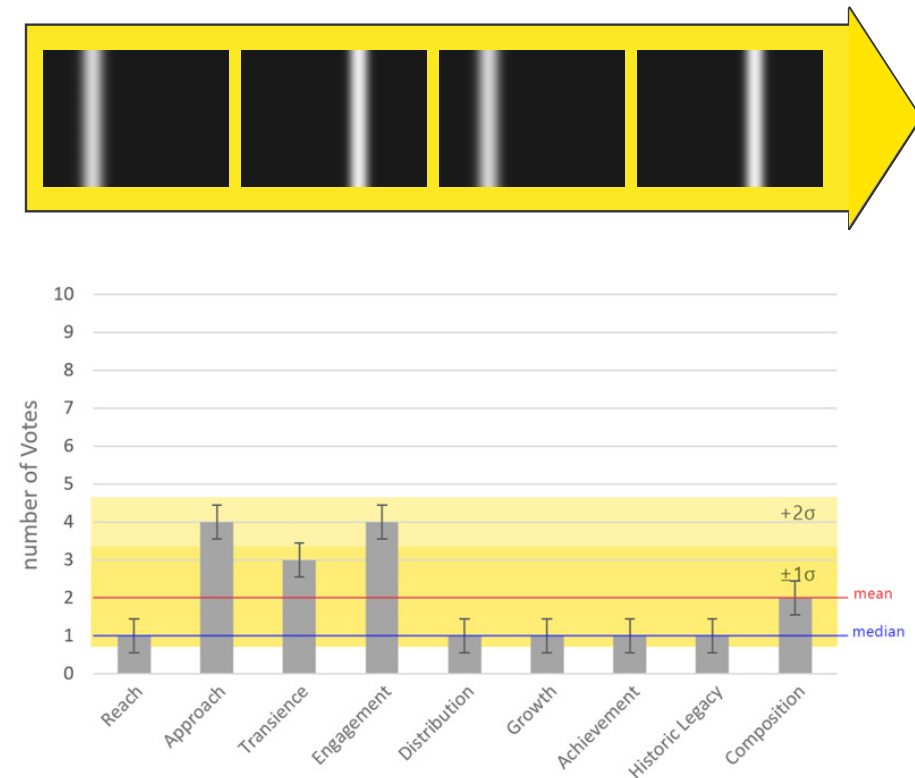
The results show that this pair of visualizations is an ideal candidate to convey Growth. The converse pair also performs very well when conveying a sense of increase or decrease leaving little ambiguity when it comes to these two visualizations.

Interview

Similar to the "Aggregation", perceived the increase or decrease in intensity as the number of viewers or followers changing. Thus, they associated this visualization with Reach and Growth. Others attributed a decrease in intensity, as a post disappearing as it loses interest over time. This a decrease in brightness tends to convey a feeling of passage of time and being forgotten.

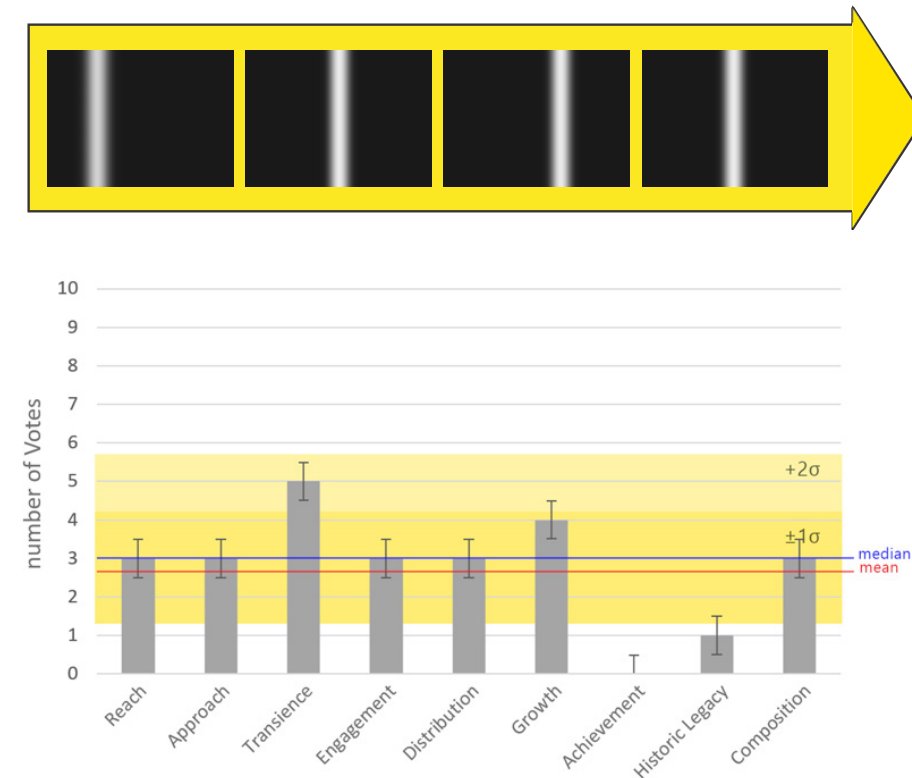
4.4.1.4 Rhythm

Normal



From the results, it can be observed that the data categories Approach, Transience and Engagement have received more votes than the mean and median values for this visualization. However, the number of votes for Approach and Engagement pass the 1σ boundary making them more suitable candidates to be used with this visualization. Moreover, the 2 aforementioned categories have received the exact same number of votes, meaning that no other conclusions can be drawn to distinguish the leading candidate amongst them. In summary, it can be concluded that this visualization is best suited to be used to convey a meaning of Approach and Engagement.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Transience and Growth. Out of these data categories however, the number of votes for Transience reaches a statically significant amount. The number of votes for this data category passes the 1σ boundary making it a more suitable candidates to be used with this visualization. This remains true even when considering the measurement error. Thus, according to the quantitative analysis, it can be concluded this visualization (Rhythm_Regular) is best used to display Transience.

Conclusion

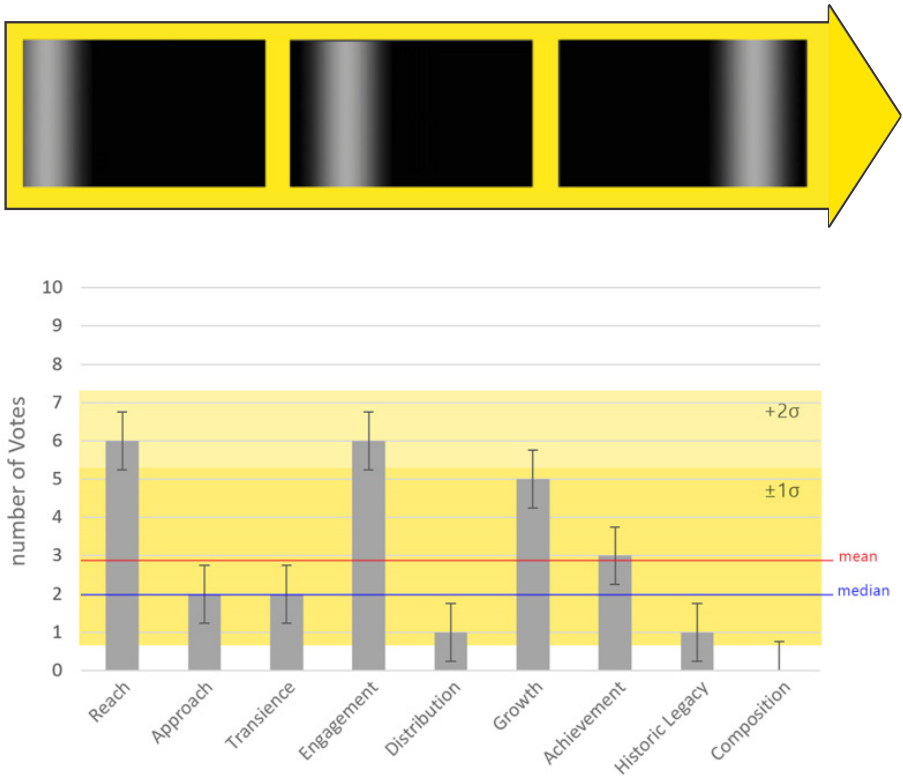
Unfortunately, this pair of visualizations do not share any common data categories. This means that even though each visualization by itself may be used to convey Engagement or Transience, it is not very wise to use this pair to convey and increase or decrease in any of the data categories. The qualitative analysis also confirms the quantitative analysis (i.e. participants cannot associate these visualizations with an increase or decrease) or even a common data category.

Interview

A number of interesting observations resulted from the interviews. Some participants perceived the back and forth motion of the line as scrolling or flipping through pages of a book. Others related the irregular motion of the line to a conversation between two persons and described it as engagement. Last but not the least, cultural differences seem to be boldened for this particular visualization. Several Indian participants perceived the regular left/right motion as "no" as it resembles a person shaking their head to show disapproval. Other European participants perceived this motion as something akin to dancing and thus viewed it in a positive light. With regards to observing a trend in the data category (increase/decrease), most participants could not sense such a trend and were motivated to select "constant".

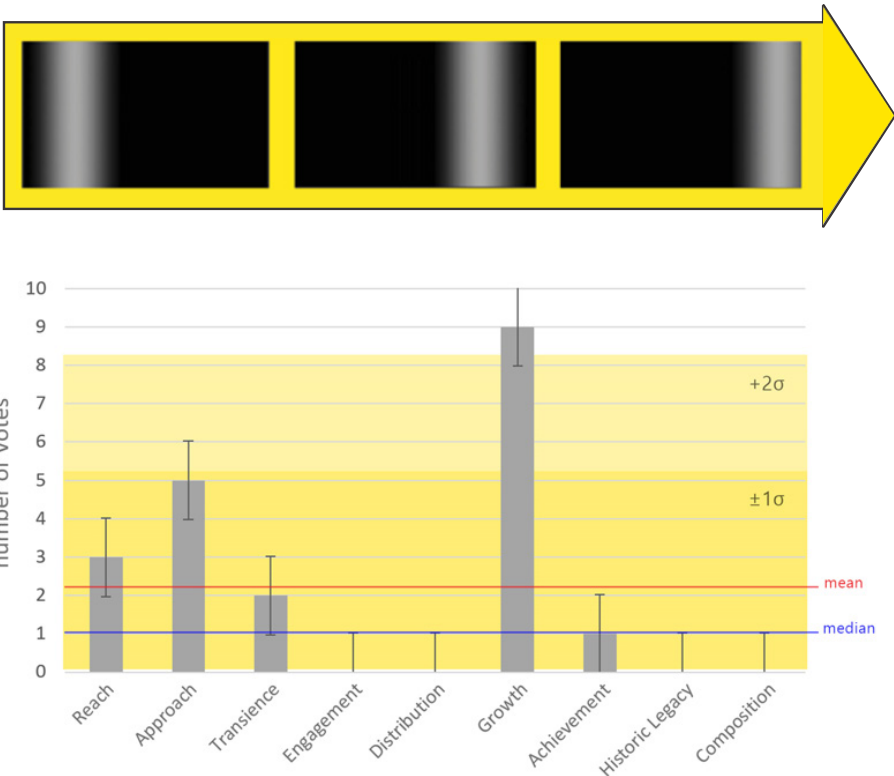
4.4.1.5 Acceleration

Normal



From the results, it can be observed that the data categories Reach, Engagement, Growth and Achievement have received more votes than the mean and median values for this visualization. However, the number of votes for Reach and Engagement pass the 1σ boundary making them more suitable candidates to be used with this visualization. Due to the margin of error, no other conclusions can be drawn to distinguish the leading candidate amongst these two categories. In summary, it can be concluded that this visualization is best suited to be used to convey a meaning of Reach and Engagement.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Reach, Approach and Growth. Out of these data categories however, the number of votes for Growth stands far above the other 2 categories and even surpasses the 2σ boundary. Thus, it can be confidently concluded that according to the quantitative results, this visualization is best used to display Growth.

Conclusion

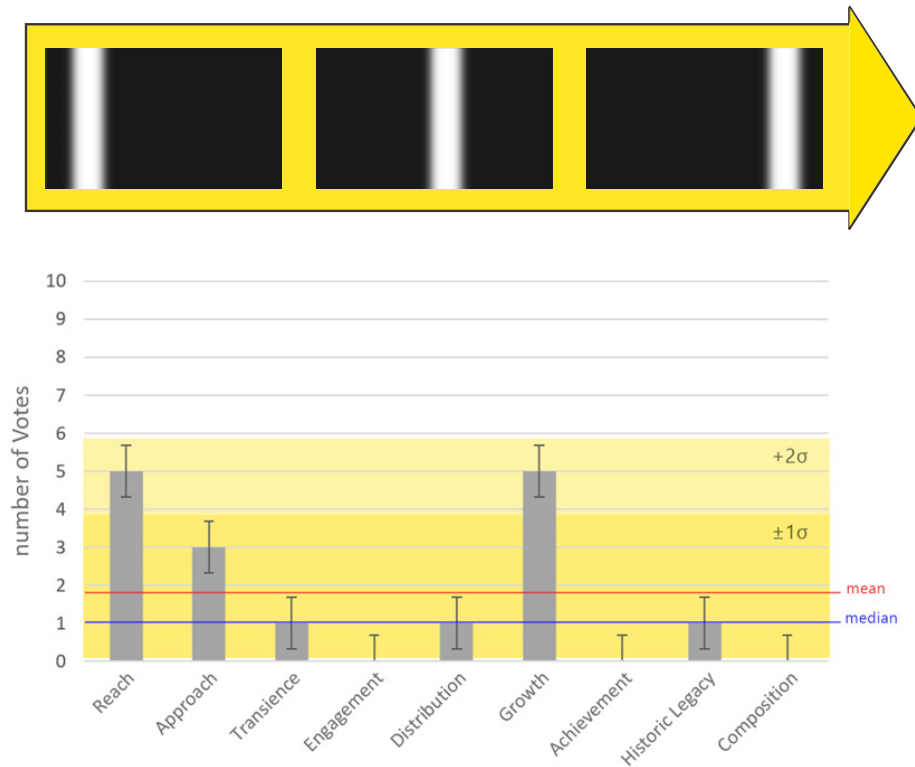
Unfortunately, this pair of visualizations do not share any common data categories. This means that even though the two visualizations by themselves may be used to convey Reach/Engagement or Growth, it is not very wise to use this pair to convey and increase or decrease in any of the data categories. The qualitative analysis (combined with the quantitative results) suggest that Growth can be conveyed somewhat successfully with this visualization, but further research is required.

Interview

During this interview an interesting theme became apparent. Participants show a great tendency to perceive Growth from any visualization that conveys a strong data trend (increase/decrease). The increase and decrease in speed were almost universally seen as increase and decrease in Growth. There were a couple of participants who still felt that the left to right movement is dominant, so they preferred to choose "increase" for a decelerating motion. It is also important to mention that many participants perceived such movements as the passage of time.

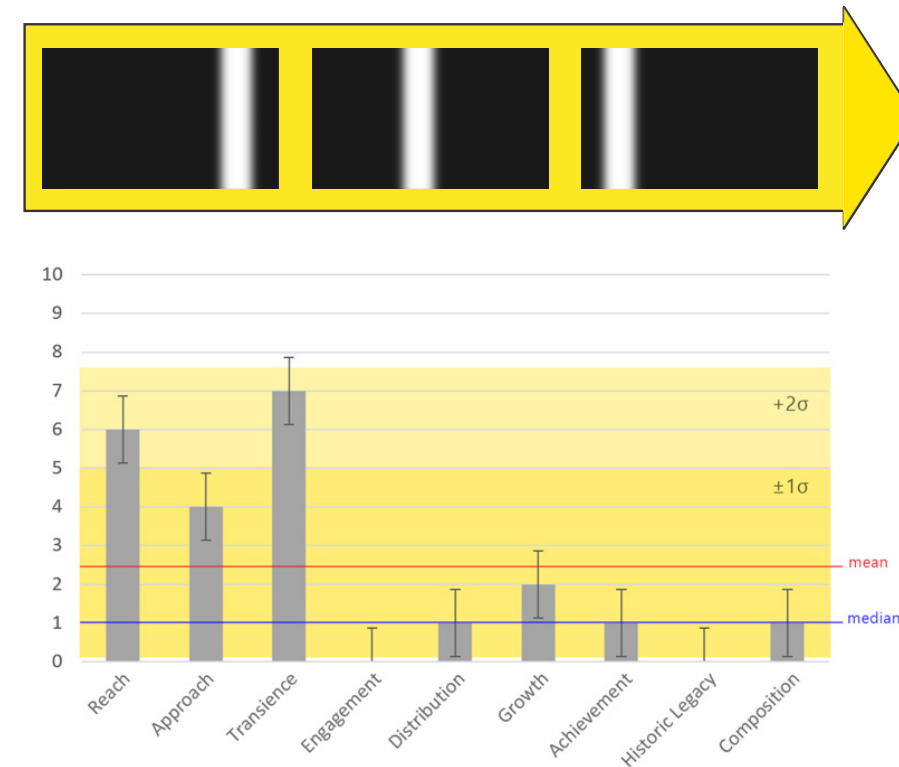
4.4.1.6 Direction

Normal



From the results, it can be observed that the data categories Reach, Approach and Growth have received more votes than the mean and median values for this visualization. However, the number of votes for Reach and Growth pass the 1σ boundary making them more suitable candidates to be used with this visualization. Moreover, the 2 aforementioned categories have received the exact same number of votes, meaning that no other conclusions can be drawn to distinguish the leading candidate amongst them. In summary, it can be concluded that this visualization is best suited to be used to convey a meaning of Reach and Growth.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Reach, Approach and Transience. Out of these data categories however, the number of votes for Reach and Transience reaches and surpasses the 1σ boundary. However, given the margin of error, no further conclusions can be drawn and both data categories remain equally suitable to be used with this visualization.

Conclusion

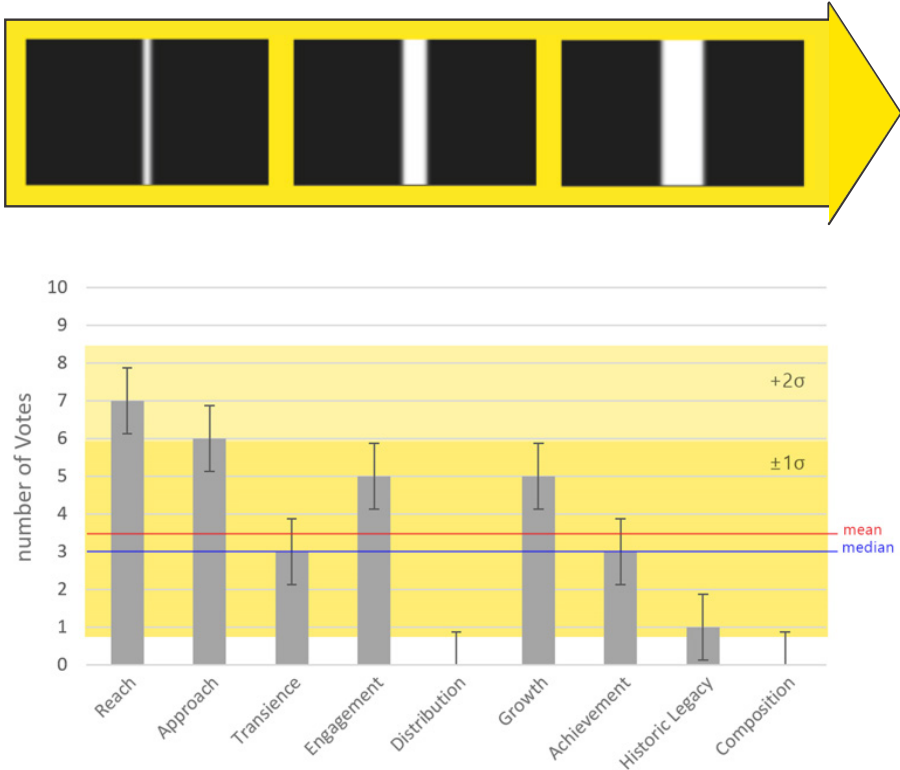
To summarize, Reach is the only common data category that can be conveyed using this pair of visualizations. The qualitative analysis also shows that given a similar target group (with regards to the native language they use) a sense of trend (increase/decrease) can also be reliably conveyed.

Interview

Some interesting insights were obtained from the interviews with regards to this pair of visualizations. A large number of participants perceived the left to right motion as forward progress (for instance a video playing and the progress bar moving to the right). Therefore Transience was the most popular option for this particular visualization. With regards to the perception of a trend in the data category, the results were mixed. Participants that natively used left to right languages (such as Europeans), perceived a right to left motion as inverted and associated it to a decrease (going backwards). Other participants observed did not make this association.

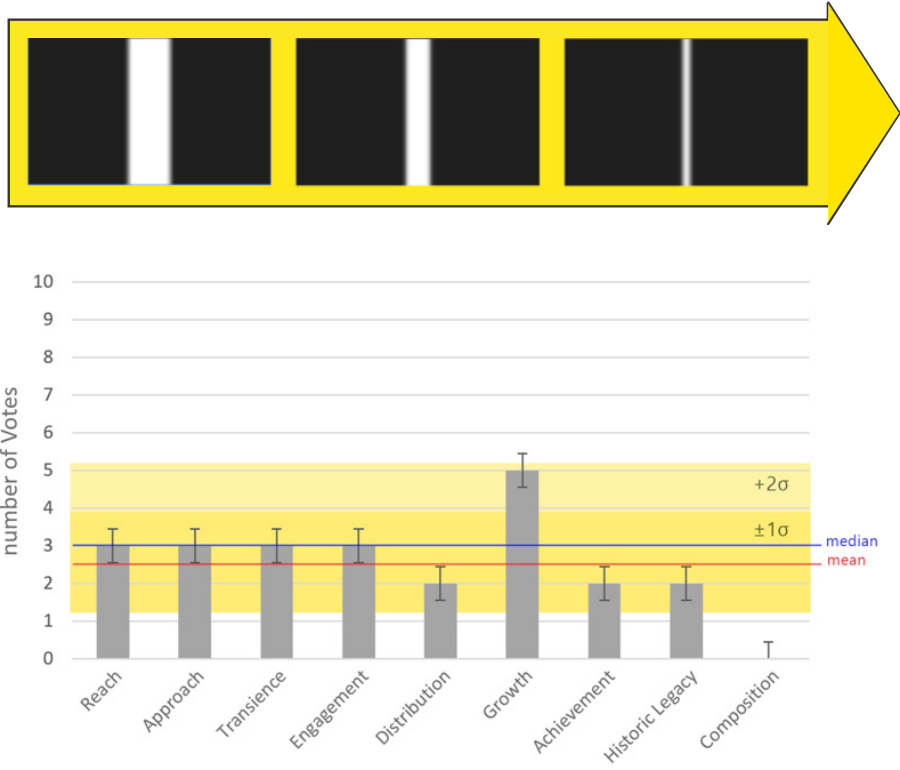
4.4.1.7 Size

Normal



From the results, it can be observed that the data categories Reach, Approach, Engagement and Growth have received more votes than the mean and median values for this visualization. However, the number of votes for Reach and Approach pass the 1σ boundary making them more suitable candidates to be used with this visualization. Due to the margin of error, no other conclusions can be drawn to distinguish the leading candidate amongst these two categories. In summary, it can be concluded that this visualization is best suited to be used to convey a meaning of Reach and Approach.

Inverse



It can be observed that the only data category with a total number of votes higher than the mean and median is Growth. Furthermore, the number of votes for Growth stands far above the other categories and approaches the 2σ boundary. Thus, it can be concluded that according to the quantitative results, this visualization is best used to display Growth.

Conclusion

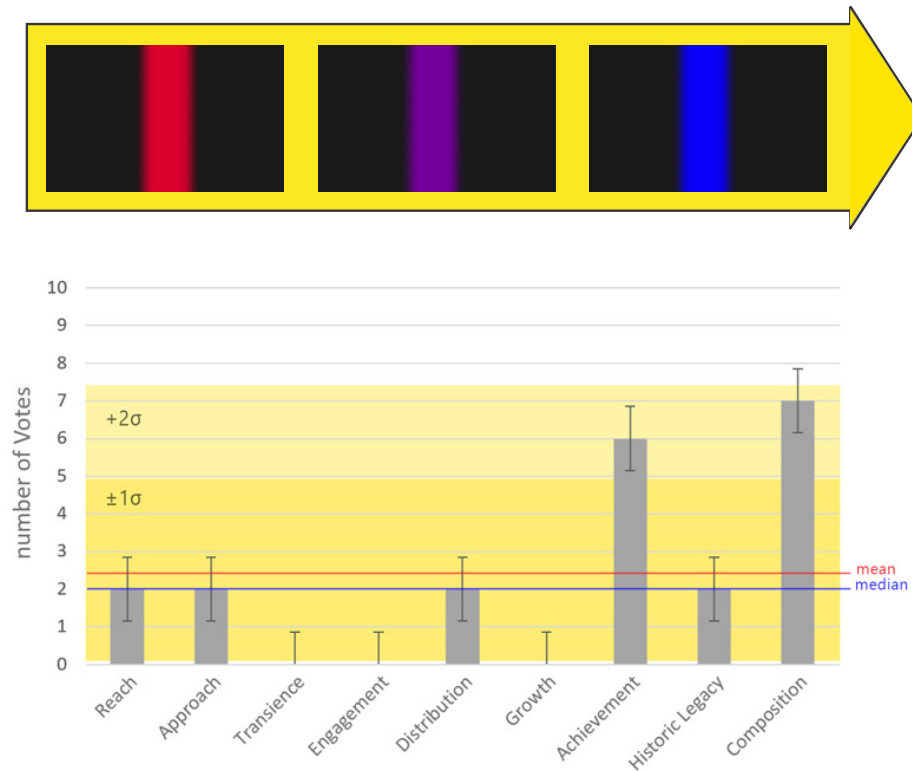
Unfortunately, this pair of visualizations do not share any common data categories. This means that even though the two visualizations by themselves may be used to convey Reach/Approach or Growth, it is not very wise to use this pair to present any of the data categories. The qualitative analysis (combined with the quantitative results) suggest that these visualizations are excellent for conveying a trend (increase/decrease) however.

Interview

A noticeable observation was that the participants had an associated a change in size to a very wide range of meanings (for instance change in the number of views/followers or likes/comments, etc.). Interestingly, some participants commented that a growing light that starts from the middle is similar to opening a door, thus they perceived it as Reach and Approach. And with the opposite description, they mentioned that this door closure can represent something which is getting forgotten, losing interest, or coming to an end.

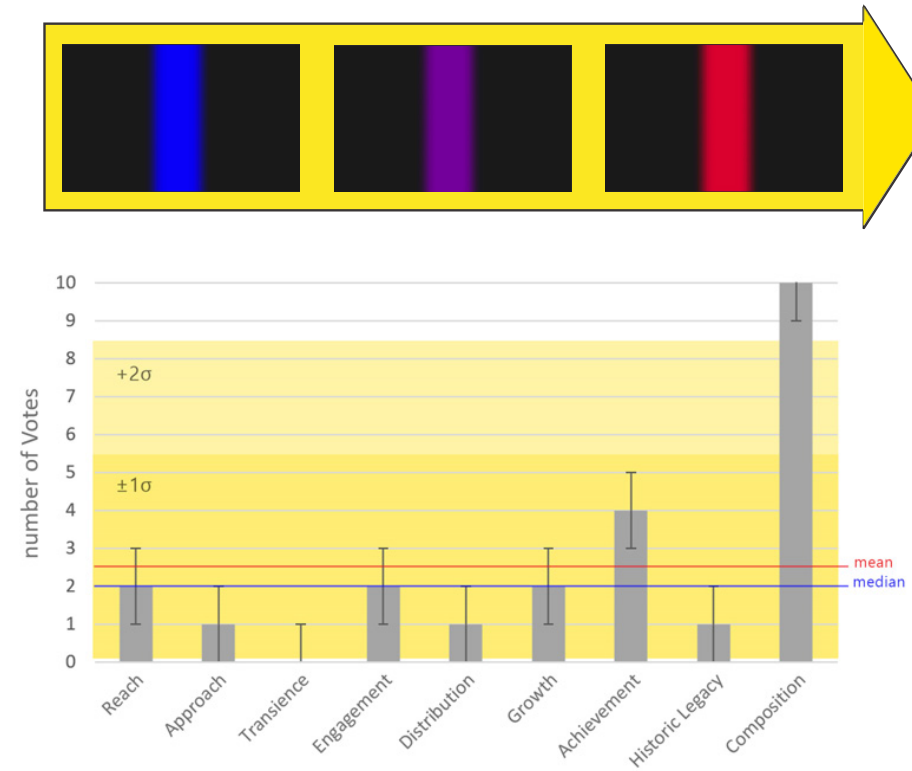
4.4.1.8 Color

Normal



From the results, it can be observed that the data categories Achievement and Composition have received more votes than the mean and median values for this visualization. The number of votes for both categories pass the 1σ boundary making the results statistically significant. Due to the margin of error as shown by the error bars, it is impossible to narrow than this selection to a single category. As such, it can be concluded that this visualization is best suited to be used to convey both Achievement and Composition.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Achievement and Composition. Out of these data categories however, the number of votes for Composition reaches and surpasses a statically significant amount (the 2σ boundary). Thus, it can be confidently concluded that according to the quantitative results, this visualization is best used to display Composition.

Conclusion

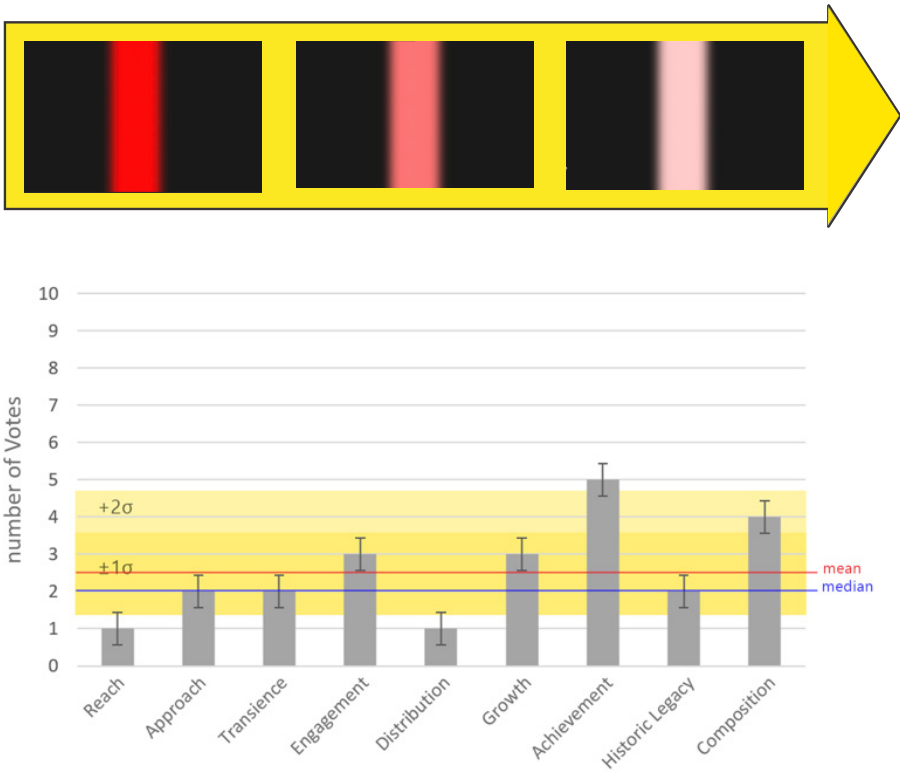
To summarize, this pair of visualizations is a good candidate to be used for representing Composition in later designs. However, nothing can be concluded regarding the trend of the data category. Most people perceive cannot associate a change in color to an increase or decrease. This fact is quite intuitive when considering the fact that composition is defined as a ratio of constituents where the total is always constant.

Interview

The most noticeable comments received from the participants were with regards to allocating meanings to different colors. For instance, a number of participants translated color to gender (they identified blue as male and red as female). One participant mentioned that colors can be assigned to different social medias; for instance, blue for Facebook or Pink/Purple for Instagram. Overall, it can be concluded that most people do not have any a priory understanding of colors and that these associations are made over the time through visual clues. Moreover, it is important to consider the feeling that some colors may convey. For instance, some participants associate red with a negative feeling. But more commonly, participants translated the transformation from a cool color to warm as something positive. Finally, the majority of participants did not perceive a trend (increase/decrease) for this pair of visualizations.

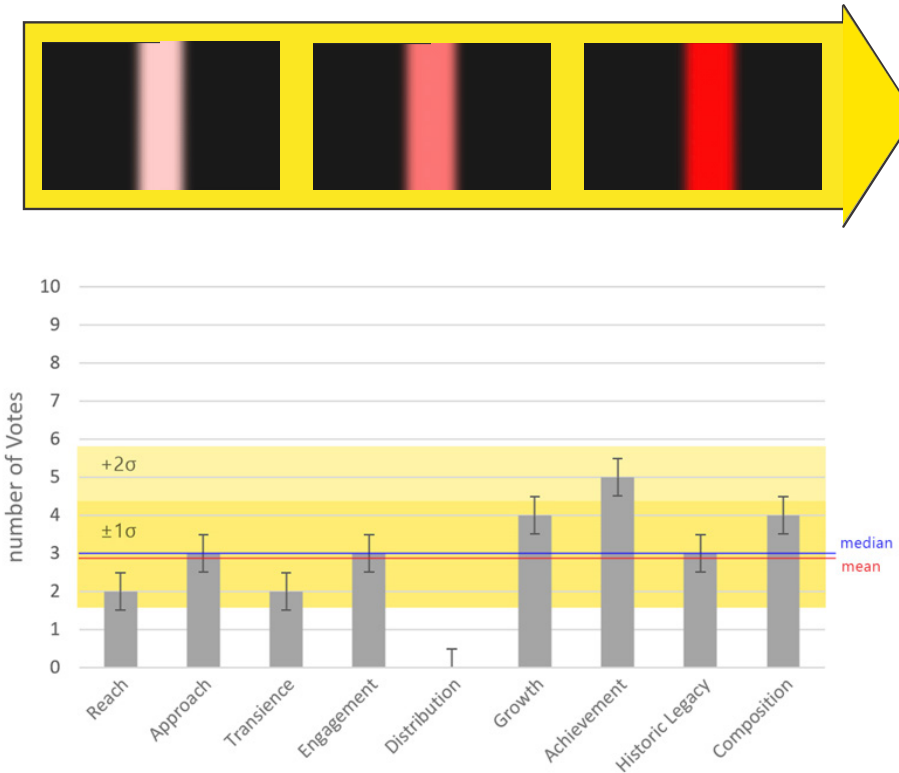
4.4.1.9 Saturation

Normal



From the results, it can be observed that the data categories Engagement, Growth, Achievement and Composition have received more votes than the mean and median values for this visualization. However, the number of votes for Achievement and Composition pass the 1σ boundary making them more suitable candidates to be used with this visualization. Due to the margin of error, no other conclusions can be drawn to distinguish the leading candidate amongst these two categories. In summary, it can be concluded that this visualization is best suited to be used to convey a meaning of Achievement and Composition.

Inverse



It can be observed that the only data categories with a total number of votes higher than the mean and median are Growth, Achievement and Composition. Out of these data categories however, the number of votes for Achievement reaches and surpasses the 1σ boundary proving to be a slightly better candidate. However, given the margin of error, no further concrete conclusions can be drawn and both data categories could be suitable to be used with this visualization.

Conclusion

To summarize, adding the insights gained from the qualitative analysis as well as the results from the quantitative one, Achievement is the leading candidate to be conveyed using this pair of visualizations. Composition is another alternative data category that may be used successfully.

Interview

Participants had two opposing views with regards to this pair of visualizations. Some of them commented that a transition from colorless to a saturated color is positive and therefore they could relate to an achievement. On the other hand, some of the participants found this transition to be negative, since the red color is becoming more prominent and in their point of view red is associated with something bad or wrong. Similarly, the second group perceived the converse visualization (from a saturated red to colorless) as an achievement because the red is becoming less dominant until it loses all of its color therefore showing a positive progress. This highlights the importance of choosing the color while using saturation as a tool.

4.4.2 Visualizations vs data category trends

The distribution of the votes between the data category trends is the subject of the second part of the analysis. In this section, the possibility of using the 18 selected visualizations, as a means of conveying a sense of increase, decrease or constancy (here after referred to as data category trend) is examined. As such the total number of votes for each data category trend (this means across all data categories) is summed up for each of the 18 visualizations and plotted on the y-axis of the 3 bar charts that represent increase, decrease and constancy. Similarly, the independent variable is represented by the aforementioned 18 visualizations and are labeled on the x-axis.

In the following sub-sections, a pair of bar charts corresponding to the increase/decrease data category trends are illustrated. Pairing these charts will allow us to observe if converse visualizations do indeed convey a converse trend to the participants. The mean and median values of the number of votes across all data categories is illustrated as a blue and red line, respectively. The mean is used to quickly see if the number of votes for any of the data category trends is above the average number of votes for all visualizations. The median is also used as a more robust statistical average (against data sets that may contain extreme outliers). If we assume that the some of the selected visualizations are indeed able to convey one of the data categories trends more successfully than the rest, outliers are expected, and the median will serve as a more accurate average. Other important elements on these bar charts are the highlighted segments that represent the 1 sigma (denoted as σ) boundary.

4.4.2.1 Increase/Decrease

The key in finding a good visualization for conveying a sense of increase or decrease is to find a pair of converse visualizations that show an inversely proportional relationship when we observe its number of votes in Figure 4.14 and 4.15. To clarify, this means that whenever a visualization receives a high number of votes for increase, it's converse visualization should receive a low number of votes. Similarly, when looking at the number of votes for decrease, this pair of visualization should present the opposite results. Any pairs of visualizations that this illustrate behavior is an ideal candidate to convey increase and decrease in a reliable manner.

When looking at the first bar chart (illustrating the number of votes for the increase), it can be observed that the following visualizations received more votes

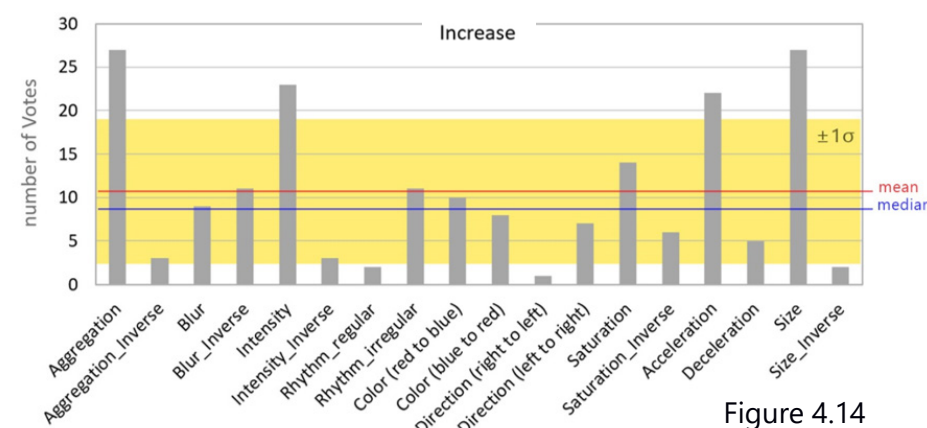


Figure 4.14

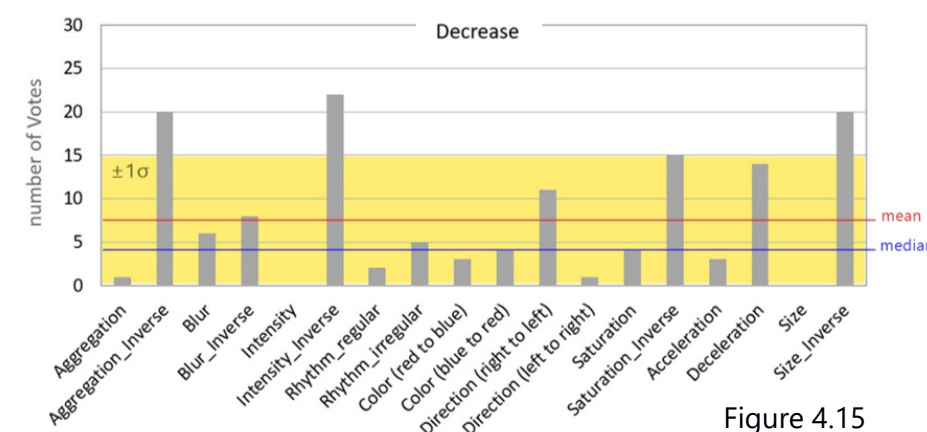


Figure 4.15

than the mean and median value: Aggregation, Blur (inverse), Intensity, Rhythm (irregular), Saturation, Acceleration and Size. Out of these visualizations, the number of votes for Aggregation, Intensity, Acceleration and Size pass the 1σ boundary and thus show a statically significant result. Furthermore, their converse visualization has a number of votes that are far below the mean and median. These four visualizations are excellent candidates to convey a sense of increase. On the other hand, Figure 4.15 illustrates that, Aggregation (inverse), Blur (inverse), Intensity (inverse), Direction (left to right), Saturation (inverse), Deceleration and Size (inverse) have received more votes than the mean and median values. Out of these visualizations, Aggregation (inverse), Intensity (inverse), Saturation (inverse) and Size (inverse) show statistically significant results by obtaining enough votes to pass the 1σ threshold. Moreover, their converse visualizations have received less votes than the mean and median value of votes.

Comparing the above 2 sets of visualizations side by side, it can be observed that Aggregation, Intensity and Size are form pairs of visualizations that indeed display the all of the requirements to be used as a method to convey a sense of increase and decrease reliably. Though not as statically significant, the results hint that Saturation and Acceleration can also be used successful for this purpose. As mentioned before, interviews show that the color used to display Saturation and the direction of motion for Acceleration play an important role in how they are perceived. Further research is advisable to draw more concrete conclusions with regards to the suitability of these two visualizations.

4.4.2.2 Constant

If one needs to convey the meaning of one the selected data categories without an associated sense of increase or decrease, which visualization is suitable? This section aims to answer this question. From Figure 4.16, it can be observed that the following visualizations received more votes than the mean and median value: Blur (inverse), Rhythm (regular), Rhythm (irregular), Color (red to blue), Color (blue to red) and Direction (left to right). With the exception of Blur and Direction, the other 4 visualizations form a pair (Rhythm, Color), meaning that both the normal as well as the converse visualizations don't seem to convey any sense of increase or decrease. These visualizations can be used with other visualization to provide additional information without affecting the overall sense of trend.

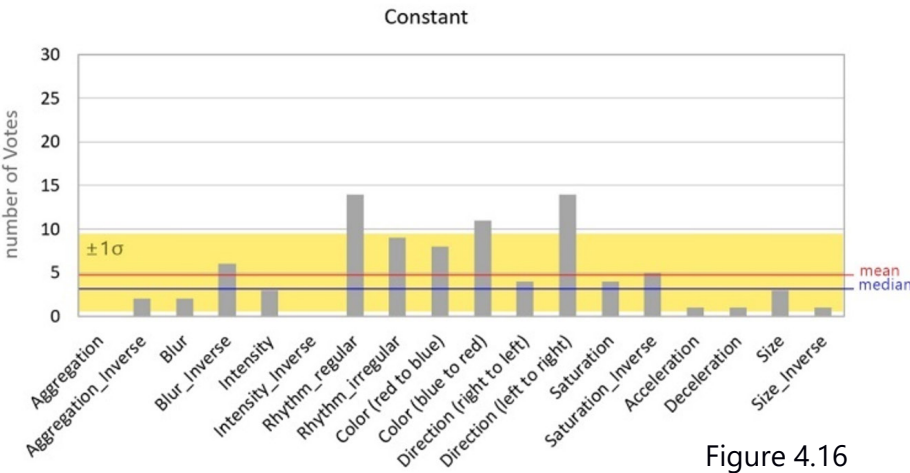


Figure 4.16

4.5 CONCLUSIONS

In this section, all the knowledge gathered from the quantitative as well as qualitative analysis of the results is combined in order to see if the objectives of this test have been accomplished. As a reminder, this experiment was established and performed to conclude if the selected data categories can be conveyed using any of the prepared visualizations. The results showed that most participants did indeed have a common perception of some of the data categories. This means that the participants shared a common understanding of these visualizations which suggests that in more general terms, light visualization can be used to form a very basic language to transfer information. The results for some of the data categories were more concrete than others. For instance,

Distribution, Growth and Composition are best displayed using Aggregation, Intensity and Color, respectively. Achievement can be conveyed by using Saturation provided more that an appropriate color is selected. This of course is a good subject for further study. Furthermore, Transience can be displayed successfully by Rhythm if there is no need to also convey a trend in this data category. The results also showed that a pair of converse visualization may be used for conveying 2 different data categories. For instance, Acceleration and Deceleration can display Engagement and Growth, respectively. This knowledge can be applied in more specific cases by designers. Lastly, it was also shown that data trends (increase/decrease) are best expressed using Aggregation, Intensity and Size, and that people tend to get a sense of constancy from a shifting color or regular/irregular

Data Category	Visualization
Reach	Aggregation (Normal), Intensity (Normal), Direction (Left to Right), Direction (Right to Left), Acceleration (Normal), Size (Normal)
Approach	Rhythm (Regular), Size (Normal)
Transience	Blur (Inverse), Rhythm (Irregular), Direction (Right to Left)
Engagement	Rhythm (Regular), Acceleration (Normal)
Distribution	Aggregation (Normal), Aggregation (Inverse)
Growth	Blur (Normal), Intensity (Normal), Intensity (Inverse), Direction (Left to Right), Acceleration (Inverse), Size (Inverse)
Achievement	Color (Red to Blue), Saturation (Normal), Saturation (Inverse)
Historic Legacy	-
Composition	Color (Red to Blue), Color (Blue to Red), Saturation (Normal), Saturation (Inverse)

Table 4.4: Selected Visualizations for each Data Category

movements. This experiment does not fill every gap in our current understanding of the subject. In contrary, a lot more research is required in this area to be able to define the building blocks for this new language. However, the results of the experiment should provide a solid foundation for future researchers.

4.6 RECOMMENDATIONS

As it is expected, there were many choices that had to be made through out this experiment. In here, we reflect on some of these choices and discuss their consequences and possible alternative approaches. Even though, the tests show strong evidence that this is indeed possible, some parts of the tests were far from conclusive. It is the author's belief that further research into this matter is highly beneficial both for this project as well as other applications of ambient light communication. For instance, the interviews identified that color plays a vital role in every visualization. The impact and meaning of color is highly dependent on a wide variety of factors such as culture and context. Ambient displays that rely on color must select it with utmost care and after user tests.

Most prior research into ambient light communication, hinted that long duration exposure to these visualizations is required for good learning results. As with any other language, humans require time to learn this new

visual language. To avoid this, the meaning of various social media data streams was thoroughly explained to the participants. In a real-life scenario, such an explanation is impossible or very hard to provide. Thus, the ambient light visualizations must be clear and simple enough that people can understand without a prior knowledge of its meaning.

Lastly, it is vital to perform this experiment using an ambient light source instead of a computer screen as was done here. The ambient nature of the light, could affect the result of the test in unexpected ways and must be analyzed Furthermore, it is important to research of ability of people to learn such visual languages over an extended period of time, especially when using an ambient light source as the medium. During short duration tests, the participants will focus their attention on the object under test thus invalidating the ambient nature of the test. Unfortunately, these additional steps could not be taken due to the limitations of the project.



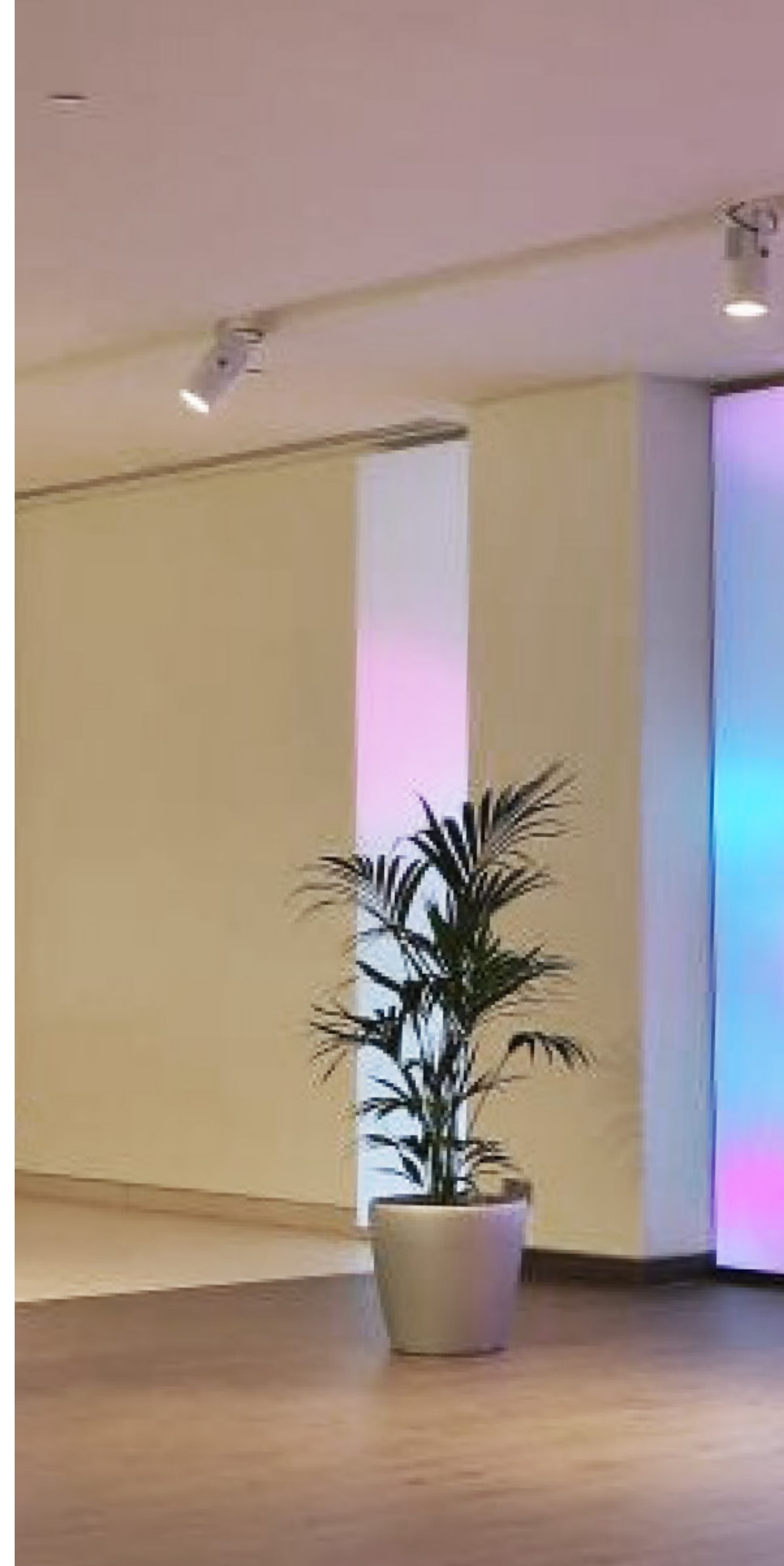
CHAPTER 5

5.1 INTRODUCTION

Large interactive displays presenting useful content are becoming ubiquitous in public places such as shopping malls, museums and campuses. A commonly observed issue with such deployments, however, is that these displays often go unnoticed, and thus are underutilized [38]. Even when considering the low power consumption of these modern displays, sustainability concerns are not without reason. After all, what good are these displays if at best they go unnoticed or at worst annoy the passersby with unwanted information. Ambient light displays or installations are both far more power efficient, but also none intrusive. However, in order for them to be used effectively, we must first determine if these displays capable of attracting the attention of potential users and encourage them to perform a desired action. As mentioned in the previous chapters, the literature is light on quantifiable data in this regard.

In this chapter, we describe an experiment using a publicly placed ambient light display in order to determine if specially designed visual content is effective in attracting the attention of passersby and directing it towards performing a desirable action (scanning a QR code); in general, we want to see if light is capable of triggering behavior in a public environment. First as a starting point, the background information on the topic is examined and the relevant hypotheses are formulated. Next the procedure for the

experiment is outlined in detail. And finally, the results are evaluated and discussed. The broad objective of the study is to see if it is possible to attract and guide the attention of people through light visualizations. This goal is further refined into three hypotheses which are defined in the follow sections.





5.2 BACKGROUND INFORMATION

To set the context of this research, an overview of the relevant research on the use of visual concepts for drawing attention and directing it towards a specific action is provided. Literature in psychology and cognitive science describe attention as an internal state of the perceiver, which can be initiated simultaneously by top-down (high-level stimuli such as goals) and bottom-up (low-level stimuli such as motion) perception processes [39]. These stimuli can be generated externally and can therefore be incorporated into designs for visualizations.

5.2.1 Hypothesis 1

The first hypothesis revolves around the fact that variations in environment lighting levels (intensities) does (or does not) affect human behavior. In this hypothesis we are specifically looking for evidence demonstrating that increased local luminance increases dwell time and human traffic.

There are plenty of research on this topic. For instance, Taylor and Socov illustrate that in the context of a retail store, light influences the route consumers take through the store. This study indicates that people are drawn to light and that they will choose the more illuminated path when passing [40]. This is indeed a well-known mechanism and was also supported by research done by POPAI [41]. They concluded that adding stimuli to displays positively affects shopper behavior by increasing dwell time, response, and creates the opportunity for increased sales.

During this experiment, light is added to the display (see Figure 5.1) in two distinct ways. Firstly, to visually depict the steps "1, 2, 3" and secondly a back-lit panel on the



Figure 5.1: Lighting in product

right of the display showcased product information. When light was added to the display, respondents gave overwhelmingly positive responses. The display with lights increased shopper dwell time by 215% and the display with lights had an Impact Ratio (a measure of the number of shop-pers who look at a display as a ratio of the total number of shoppers who have an opportunity to pass and see it) 4.8% greater than the display alone (Figure 5.2).

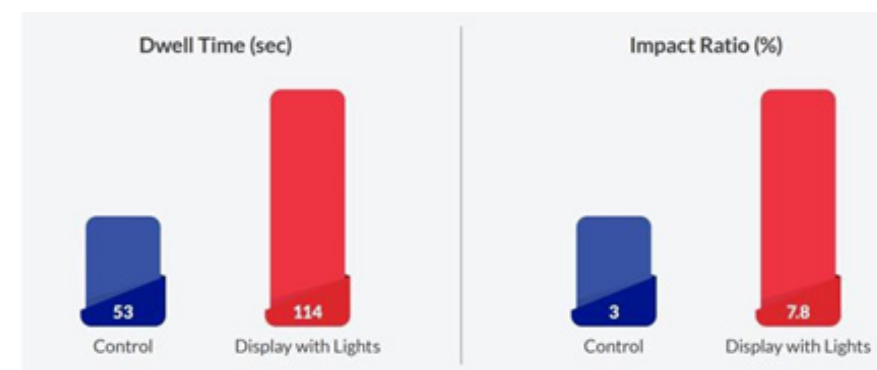


Figure 5.2: Effect of lighting in grabbing attention

The studies above show that increasing light levels will not only attract attention, but also change behavior; people change direction by going towards the light and therefore the time they spend in certain areas changes. People share more time in the areas in which the illumination was increased relative to the surroundings.

The studies above show that increasing light levels will not only attract attention, but also change behavior; people change direction by going towards the light and therefore the time they spend in certain areas changes. People share more time in the areas in which the illumination was increased relative to the surroundings.

Thus, we can formulate the following hypothesis:

Humans are attracted towards and stay longer in areas with increased local luminance. As such, changing light levels is effective in triggering human behavior.

5.2.2 Hypothesis 2

Another way for light influence human behavior is through its effects on the atmosphere, in other words by changing the chromaticity (determined by colorfulness and hue) of the light source. Environmental cues have a large effect on human beings. For instance, interior light can influence people's mood, well-being and behavior (e.g. [42], [43] and [44]). In this section, some of the literature in this area is studied in order to gain a better understanding of the state of the research and formulate an appropriate hypothesis.

Vogels et. al. demonstrated a method to quantify the perceived atmosphere of an environment. Atmosphere is defined as the affective evaluation of the environment. Her experiments demonstrate that atmosphere can be described by four underlying dimensions, called Coziness, Liveliness, Tenseness and Detachment. Kuijsters et. al. used these dimensions to hypothesize that ambiances with a clearly recognizable, positive affective meaning could be used to effectively mitigate negative mood in elderly. He first induced a sad mood using a short movie in two groups of subjects. He then immersed one group in a positive high arousing (i.e., activating) ambience (Figure 5.3), and the other group in a neutral ambience. Similarly, after inducing anxiety with a short movie tried to counteract the effects by immersing the group in a pleasant low arousing (i.e., cozy) ambience (Figure 5.4). After measuring the physiological responses of the subjects (through skin conductance response (SCR) and electrocardiography (ECG)), he found that the activating ambience was indeed more arousing than the neutral ambience. Furthermore, the cozy ambience was more effective in calming anxious elderly than the neutral ambience [45].



Figure 5.3: Cold color creating an activating environment

The above research as well as countless others provide a very strong evidence that atmospheres created by light can affect the behavior of humans.

This leads us to formulate a second hypothesis:

Light atmospheres, as defined by their chromaticity, are effective in triggering behavior, in other words, humans' moods are influenced towards the lighting atmosphere they are in.

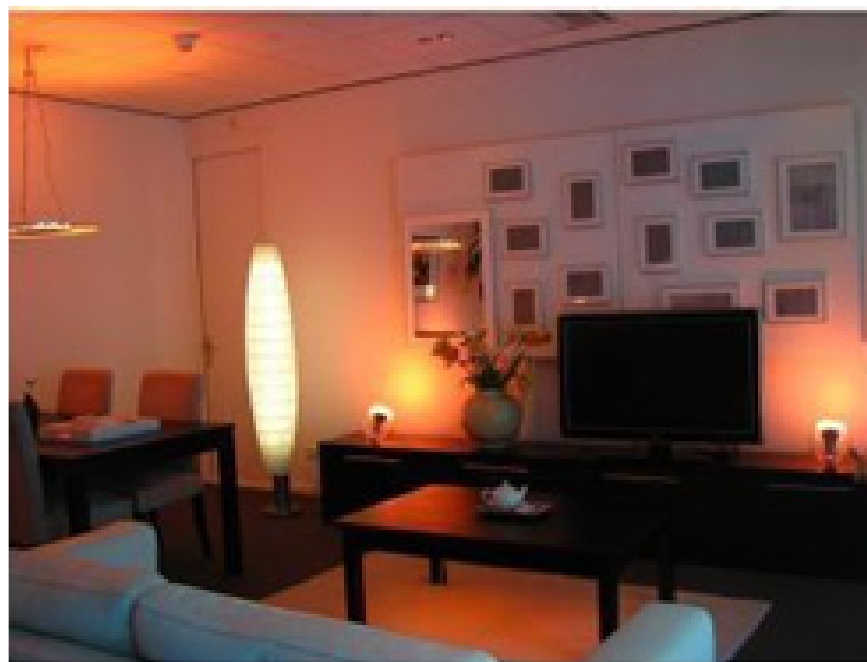


Figure 5.4: Warm color creating a cozy environment

5.2.3 Hypothesis 3

The same study stated in support of hypothesis 1, which presented light as a tool to affect people's behavior, suggests that introducing motion will result in a higher effect in triggering behavior. In the study, motion is introduced to the display in the form of turntable motors that slowly rotated the product; the motors are introduced in addition to lighting on the display. It is explained that shoppers found the motion as the most eye-catching component. Adding motion doubled the number of respondents, demonstrating that motion can be used effectively to attract attention to specific areas of the display (see Figure 5.5) [41].

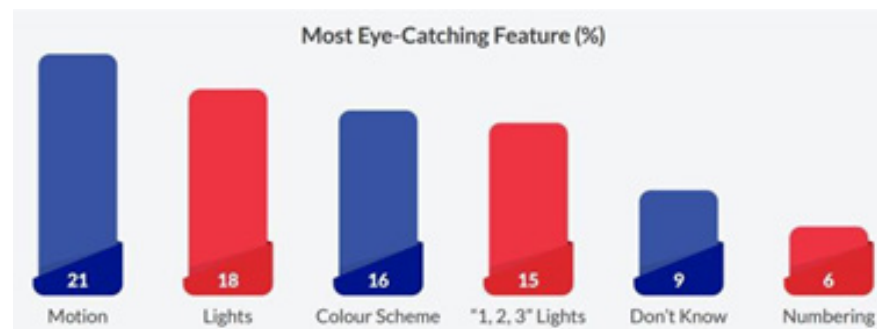


Figure 5.5: Advertisement techniques and corresponding effectiveness

Similarly, there are many studies that show the effectiveness of movement in peripheral vision. It is mentioned that peripheral vision is very sensitive to motion and it reacts twice as fast as central vision to a moving object. People can't help but notice movement in their peripheral vision. For example, if you're reading a text on a website and there's some animation or something blinking off to the side, you can't help but look at it [46]. This mechanism is exploited for instance by online advertisement firms, with great results.

Another literature which supports the positive impact of adding motion to light, used this method to "encourage" people towards a socially desired behavior, taking stairs when moving between

floors. In this study a display of twinkly white lights was envisioned that would be triggered whenever someone approached them (Figure 5.6). The idea was to design an aesthetically pleasing flowing pattern that suggested organic growth toward the entrance of the stairwell. The lights were also meant to distract people from focusing their attention on the elevator, which is more visible than the stairs as they first enter the building [47].



Figure 5.6: Follow the light concept

The results show that embedding playful ambient displays that lure and guide people toward a direction (Follow-the-Lights) can induce positive attitudes and a level of behavioral change. They reveal that even though most people (93%) said they were not aware of changing their behavior, logged data of their actual behavior showed a significant change (a 30% increase in the ratio of the number of people taking the stairs to the number of people taking the elevator).

Alt et. al. [48] presented an approach that could actively guiding users to arbitrary target positions in front of displays using visual cues. By varying properties, such as brightness or resolution of images, depending on the user position, they demonstrated that passersby would anticipate the spot where they can optimally

perceive the content and move there accordingly. Their work showed some of the most tangible results when it comes to influencing human behavior through visual cues.

In their research Cheung et. al. showed that motion used in visualizations is an effective method of grabbing the attention of passersby [49]. In their experiment, the speed of application content (images of their university campus) decreased in a stepwise manner as a passerby approached the display, so as to provide sufficient opportunities for interaction to occur, and the change more likely to be noticed. Speed for each content item was randomly chosen from between 11.3 to 22.5 cm/s as the starting speed, and was used when the passerby was furthest away from the display. When the passerby moved closer, the content would move at 60% of its starting speed; and at the closest distance to the display, it would move at 20% of its starting speed. Overall, the approach was found to attract and entice interaction with the display, compared to the control condition. Furthermore, the visual concept increased users' length of stay (linger time) at the display over the control condition.

These studies lead us to hypothesize that:

Light animations are effective in triggering behavior: humans' attention is attracted by motion and animation more than by other visual cues, and thereby can guide humans to focus in a certain direction.



RESEARCH QUESTION:

Whether it is possible to attract and guide the attention of people through light visualizations?

5.3 METHODOLOGY

With a set of hypotheses to test, we established an experiment to prove or disprove them. This chapter provides an overview of the methods and procedures used in this experiment. This should allow future researchers to reproduce and extend the experiment in order to improve upon the results achieved within the limited time and scope of the project. A detailed description of the visual stimuli, participants and test procedure is outlined below.

5.3.1 Visualizations

The visualizations are displayed using the Luminous Textile Panels designed and produced by Philips. The panels integrate multi-colored LEDs seamlessly within fabric covered panels. The 2.5m by 1.2m panel was mounted on a portable white-board and placed in the main hall of the Industrial Design faculty in TU Delft. Figure 5.7 shows the panel in its final position.

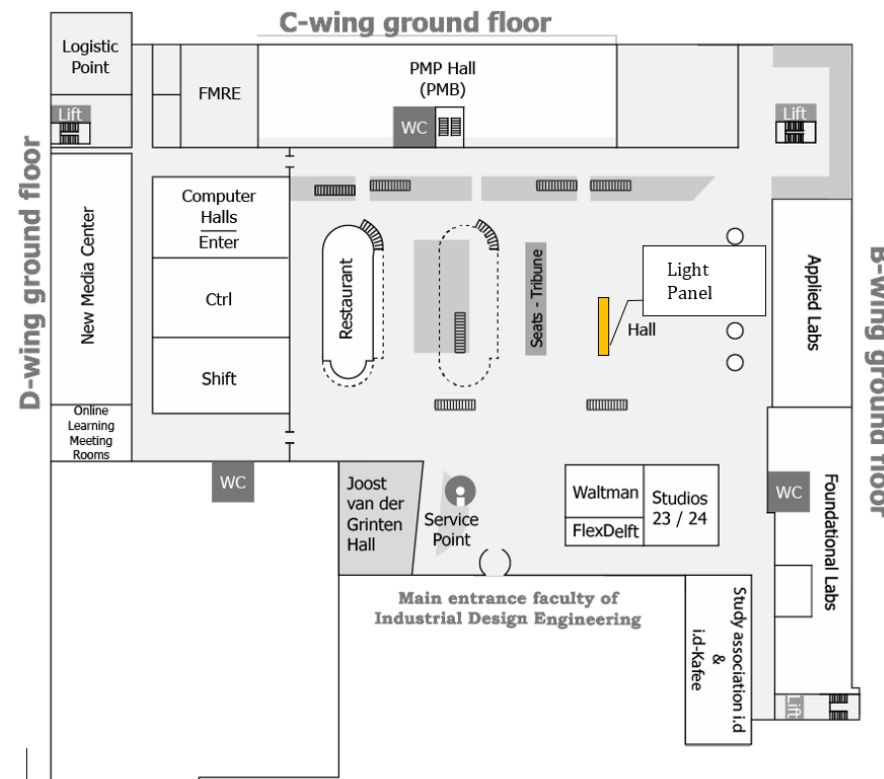


Figure 5.7: Location of the light panel in the IDE faculty

The data connection to the panel is made through a single Ethernet cable. This connection, in conjunction with Philips' own Content Manager software can be used to upload and display proprietary formatted video files. In order to be able to visualize video files in more standard formats, as well as visualizing live dynamic animations, a pixel mapper is required. As the name suggests, a pixel mapper maps a high resolution 2D content onto a custom defined arrangement of LEDs. For this test, Pharos VLC+ was used to map the designed visualizations on to the light panel and to control the uploaded content.

Pharos includes additional features which helps in building a dynamic, customizable, pre-programmed lighting displays based on timelines and scenes (Figure 5.8).

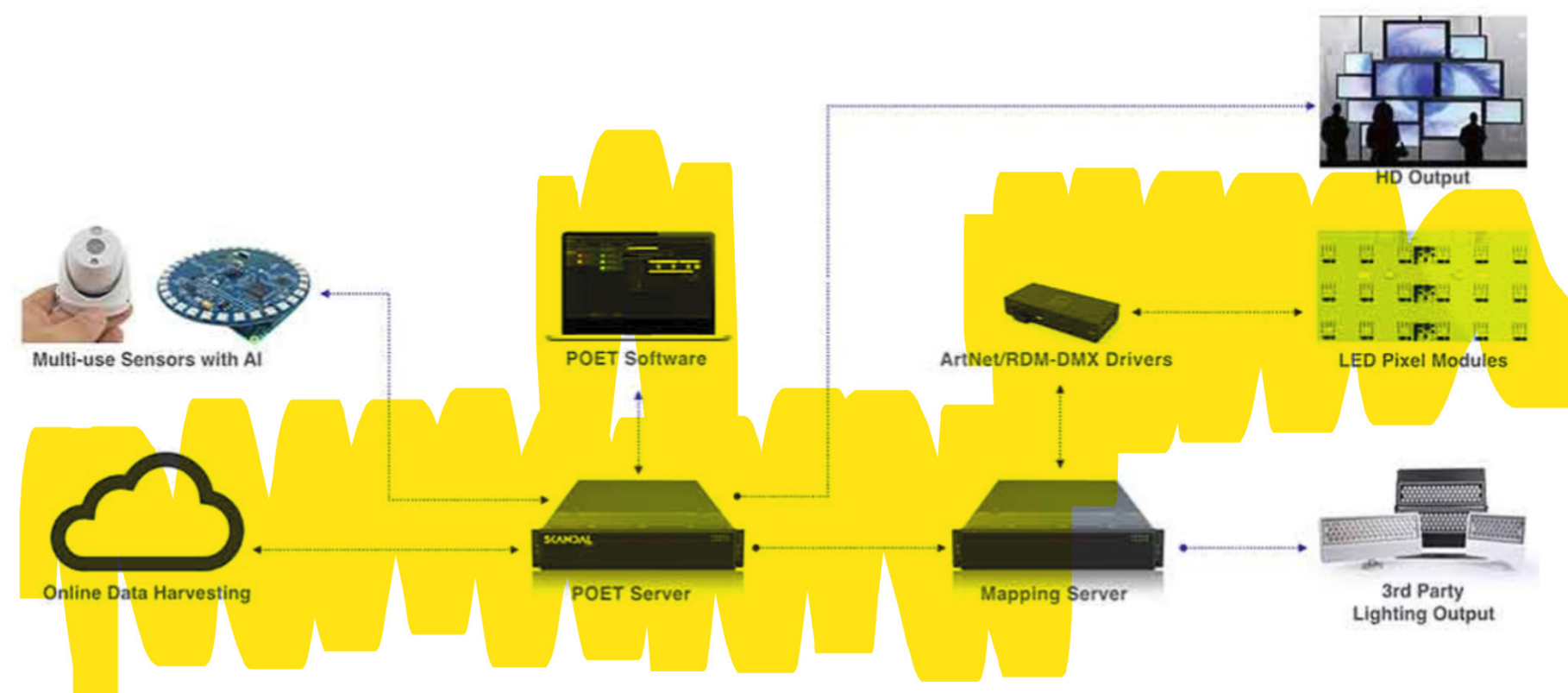


Figure 5.8: Parts of Pharos software interface



5.3.2 Data Collection

In order to quantify the effectiveness of the visualization in changing the behavior of the subjects, we need to gather a number of behavioral statistics during the tests. The analysis of this data is what ultimately allows us to draw conclusions and to prove or disprove the hypothesis. To this end, two independent set of measurements were done: behavioral measurements collected through the Advertima platform, and access statistics to a website reached through scanning a QR code. These measurements are outlined in the following sections in detail.



The process of displaying light visualization using live data /
The connection between various equipment: POET + Mappind server (Pharos) + LED pixel modules (Philips luminous textile panel)





BEHIND THE SCENES

Yasaman Mavvaji, IDE



5.3.2.1 Advertima

Advertima is a self-learning software that uses computer vision, machine learning, and big data in real- time to interpret the visual appearance, walking paths, and body language of people. In combination with the ZED camera positioned above the Luminous panel, Advertima can detect and analyze people within a range of 1m to 6m and a vertical field of view of 100 degrees (Figure 5.9).

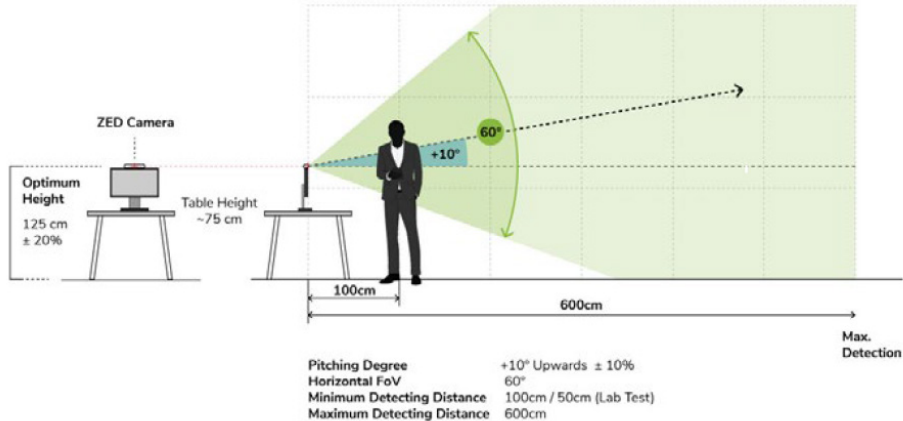


Figure 5.9: Advertima Detection range

Advertima uses head poses to understand the attention of people and can interpret 18 body joints (per person) to understand body language and gestures. Each joint is described in real-time with 2D and 3D coordinates. Furthermore, face and body features are used to uniquely identify the detected subjects. This information is processed (on the edge) by their proprietary software to provide the real-time statistics illustrated in Table 5.1.

Due to the nature of the Advertima, privacy concerns have been an important matter from the start. Advertima uses on the edge processing for real-time analysis. This means that all the data is only stored locally on the equipment itself. Internet access is fully encrypted and is only used for device health monitoring and uploading of the statistics. The sophisticated encryption makes unauthorized access

is fully encrypted and is only used for device health monitoring and uploading of the statistics. The sophisticated encryption makes unauthorized access to the data all but impossible. Furthermore, the Advertima software engine anonymizes people in real-time. Their algorithms use solely pseudonymous data to operate on an individual basis without the need to reveal any real-world identities. Given the restrictions in place, Advertima is in full compliance with the strictest privacy laws in the world and is implemented within the legal framework of EU and GDPR.

Statistic	Description
Number of detections	The number of subjects which are currently detected and identified.
Number of unique detections	The number of unique detections in the past interval. This means that the same person is not counted twice if it's detected twice. The database of identified persons is purged every 24 hours, meaning the same person will be counted as a unique detection after a 24-hour period.
Number of viewers	The number of subjects currently viewing the panel.
Average detection length	The average period that the subjects are detected.
Average view time	The average period that the subjects have viewed the panel.

Table 5.1: Statistics Advertima can provide

5.3.2.2 QR code and Web server

The second method for collecting measurements used for behavioral analysis, is a website that is served when a QR code is scanned. The website is served using a simple webserver implemented using the Python programming language. The URL for this site is encoded into a QR code which is placed at the center of the panel. When a subject scans the QR code, he or she is directed to this website. Upon entering the website, the server assigns a unique ID to this user which persists indefinitely. This allowed us to remove duplicate entries from the logs (incase a subject re-scan the QR code or refreshed the website). Aside from the unique ID, the server also logs the access time and the submitted text.

As it can be seen from Figure 5.10, the web page contains a text field which can be used by the subjects to explain why they scanned the QR code. The answers are used to gain additional insights into the results. The aim of the website is to assess how different visualizations affect the rate at which people scan the QR code. Again, potential privacy concerns have been addressed by adding a small GDPR privacy policy to the bottom of the page. Contact information was also provided for the participants, in case they had additional questions or comments.



Figure 5.10: The web page that people see after scanning the QR code

5.3.3 Procedure

The same study stated in support of hypothesis 1, 8 tests were designed to be carried out over 8 weekdays. Each test started at the same time on 10 AM and ended at 6 PM, thus lasting for 8 hours. Using the same part of the day is very important as it keeps environmental variables (such as daylight and human traffic) as close as possible between the tests. However, even under such conditions, daylight and human traffic can vary widely between the days.

TU Delft's main hall was selected as the context to perform the experiment. This provided an opportunity to conduct the test in a real-life scenario. This is especially important for these tests as psychology plays a great role, resulting in more accurate data when the people are not aware of an ongoing experiment thus acting more naturally. However, just like any public space, it has its own disadvantages which are mainly related to the number of uncontrollable variables.

Firstly, the ambient light intensity could not be controlled; the test was conducted in a space where the light was controlled using wide windows on the roof which guide the day light inside. Therefore, the light intensity surrounding the panel was highly dependent on the daylight conditions. The ambient light intensity plays an important role as the relatively low intensity of light panel draws much more attention to itself when the surrounding area is darker. 3 sets of measurements were taken (during morning, afternoon and evening) using a lux meter to ensure that lighting conditions are known. This allowed us to take into account any affects that lighting conditions had when analyzing the results. The mean, median and standard deviation of the ambient light intensity is provided in the analysis. It is hoped that light intensity measurements

can provide some insights into the effects of ambient light conditions.

Secondly, the amount traffic passing in front of the panel will be different each day. Advertima was used to count the number of detected subjects, which is taken into account when analyzing the results. For instance, using the ratio of the number of viewers or scans over the number of detections shall reduce the impact of this variable.

Furthermore, it might occur that people inside the environment participate in the test (for instance viewing the light panel or scanning the QR code) couple of times. Fortunately, Advertima can also detect and identify subjects and keep their features stored for 1 day. New detections are compared to the database of subjects and the number unique detections is generated. For privacy reasons, the database is automatically purged after each day, which is one of the primary reasons for conducting the tests for the duration of 1 day. Similarly, each viewer of the website (accessed through the QR code) is given a unique ID which is used when they re-enter the website. This allowed us to remove non-unique visitors from the measurements.

Lastly, since the selected context was an educational institute, it goes to reason that at least some of the subjects that participated in the test would have returned the following days. Their participation influences their behavior (they may lose their curiosity, etc.) with regards to how they act during the following tests. This effect has been considered and compensated for by the test arrangement; see below for details.

Day 1:

As the control test, during the first day the light panel was not turned on and did not display any visualizations (see Figure 5.11). The panel simply stood in the hall while Advertima and the Webserver were logging their measurements. This test establishes a baseline for comparing the results with the following days in order to determine if the visualizations play affect the behavior of the subjects thus proving the validity of the first hypothesis.



Figure 5.11: Light display on day 1



Day 2:

On the second day, the panel displayed light, in other words, a locally increased luminance, of a warm color (see Figure 5.12). In this case orange (R:255, G:106, B:0) has been selected since it has been determined from the interviews (of the first test) that some people have a negative feeling towards red light which might affect their behavior and produces bias. The static warm color creates an increased local luminance which should attract more people and make them stay longer in that area as specified in hypothesis 1. This test should provide us with the data required to support this hypothesis.

Day 3:

During this day, the impact of shifting light from a warm color to a cold color was tested. The light panel displayed the previously used orange for a longer period (25 sec) and then changed to display a blue color (R:3, G:44, B:252) for a short time (10 sec) (Figure 5.13). As mentioned in the literature studies, it is hypothesized that this change from a cozy feeling environment to an activating one, triggers people's behavior. Thus, this test is designed to test hypothesis 3.

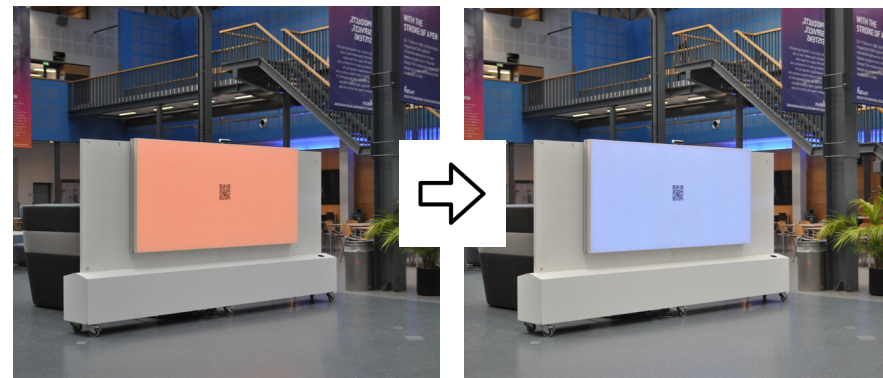


Figure 5.13: Light display on day 3

Day 4:

The fourth test expanded on the previous test by adding visible movement to the visualization. The same warm and cold colors were used as the previous test (orange and blue) in order to eliminate the effect of the color and make the results comparable to the previous test. However, through the use of directional patterns, the visualization tried to guide the area of focus of the viewer to the center of the panel where the QR code is located. The visualization showed a static orange color for a longer period (25 sec) which began to turn into blue (10 sec), starting from the 4 edges of the panel. This is easier to understand by looking at Figure 5.14.

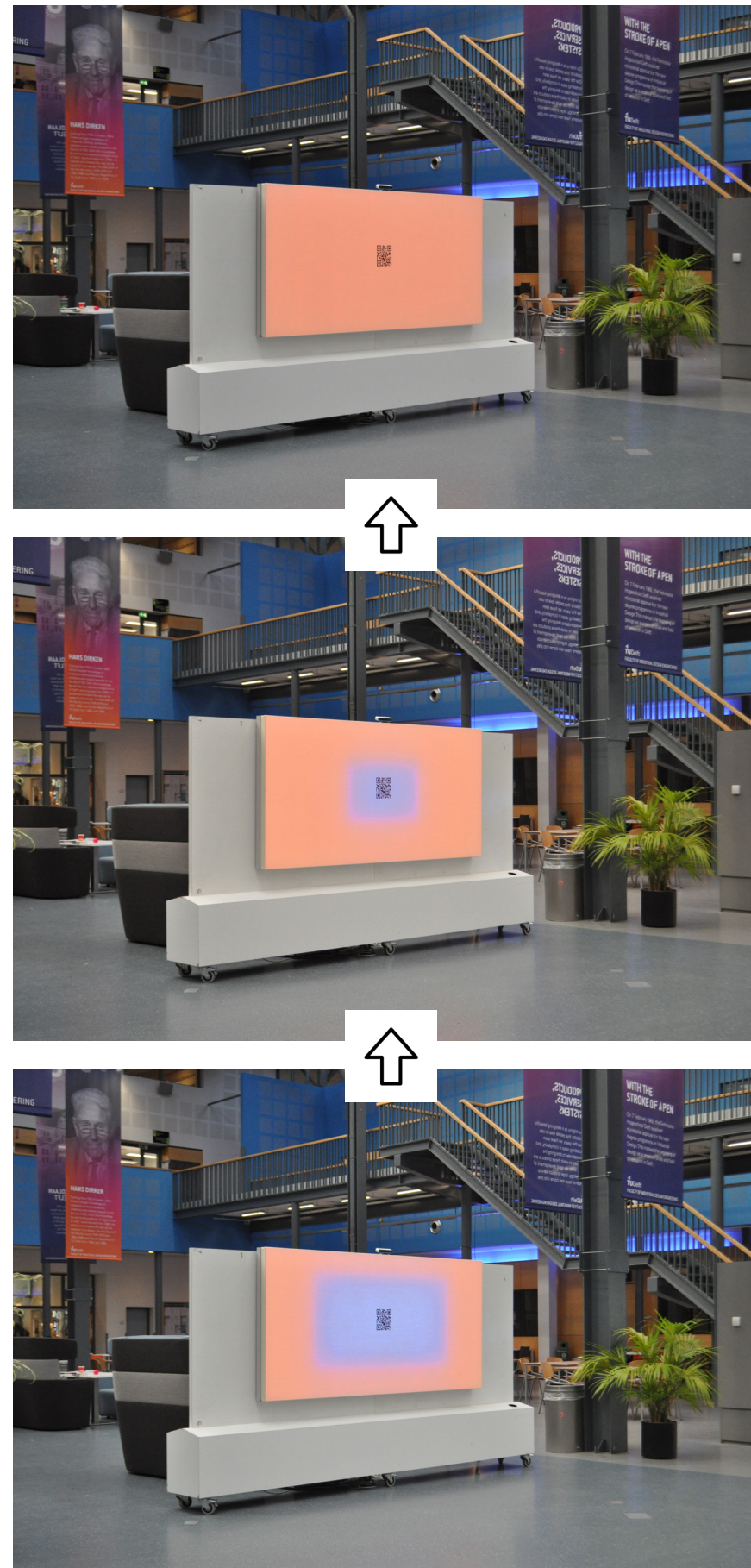


Figure 5.14: Light display on day 4

Day 5, 6, 7 and 8:

As briefly mentioned before, there is a high possibility that the participants of one of the previous tests returned for the follow up tests. However, participating in the test influences the behavior of the participants, which may have affected the outcome of the following tests. For instance, people who have already scanned the QR code during the test on Day 2, may not be inclined to scan it again on Day 3 as they have lost interest. It is hypothesized that the number of viewers, average view time and the number of scans will increase over the course of the 4 tests (control, static color, shifting color, shifting color using motion). It can also be reasoned that the interest of the subjects will start to diminish over the course of the tests and thus counteract the effect of the visualization to some extent.

By repeating the 4 tests for a second time, and observing the same increasing pattern, we can conclude that the change in the behavior of the subjects is indeed associated with the visualization. This also provides another opportunity to observe the influence of the color temperature on triggering behavior. For the second set of tests, the dominant color (the color that is displayed for the longer period of 25 seconds) is blue, while the orange is used for the shorter period (effectively switching the role of 2 colors). This allowed us to test hypothesis 2 to determine which atmosphere (activating or cozy) is best at influencing the behavior of the subjects.

5.3.4 Participants

Due to the nature of the experiment (uncontrolled public environment), participants are anonymous. The statistics gathered from Advertima shows that 60% of the detections were male and 40% female. The average age of the detected subjects was 22 years. Another interesting statistic obtained from the logs stored by the webserver is that more than 80% of the participants used Apple iPhones to scan the QR code. It is believed that this is due to the fact that no additional application is required on iPhones (other than the camera app) to scan a QR code.

5.3.5 Environmental Illuminance

Since, we are trying to observe the effect of light on human behavior, it stands to reason that the local illuminance in the vicinity of the panel plays a crucial role. For this reason, this environmental variable is measured and documented throughout the tests. This should also us with additional data to correlate with the behavioral data. Furthermore, reporting the local illuminance allows other researchers to recreate the experiment, or compare the results against their own experiment with better accuracy.

The illuminance was measured using a lux meter at waist height (1.25m from the floor) during 3 different times through a day: 10AM, 1PM and 5PM. As can be seen from Figure 5.15, 9 measurements were performed in a 3 by 3 grid, at distances of: 20cm, 200cm and 400cm from the panel. During the first set of measurements (at 10AM), the influence of the illuminance of the panel on the environment was also measured by performing the measurements while the panel is off. Thus, all in all, 4 sets of 9 measurements were recorded during each day.

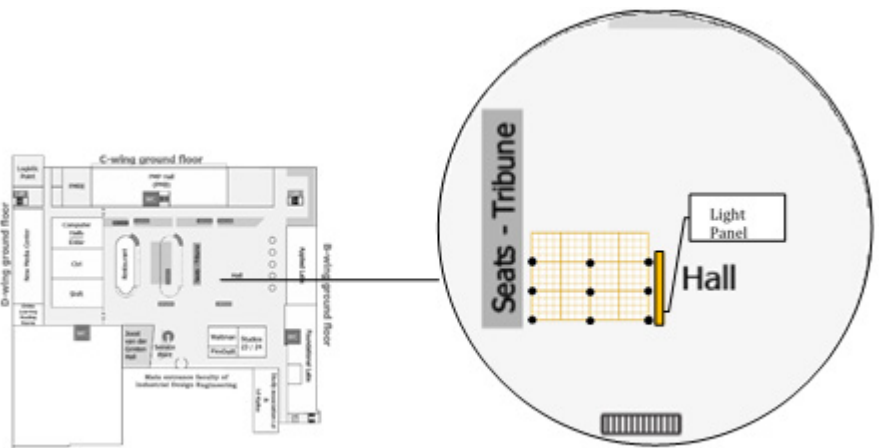


Figure 5.15: Positions of the light measurements

Figure 5.16 illustrates the change in illuminance when the panel is turned on (averaged over the 8 testing days). It can be seen, that the increase in illuminance is only measurable in the closest set of measurements (20 cm). Measurements at a distance of 200cm and 400cm do not show any significant change in illuminance as a result of the panel. This result is expected as the overhead windows pass a lot of the sun light inside the TU Delft’s IO faculty main hall. The illuminance of 5200 lx illustrates that the sun light is accounting for most of the measured light intensity and starts to dominate the light coming from the panel at a distance greater than approximately 50cm.

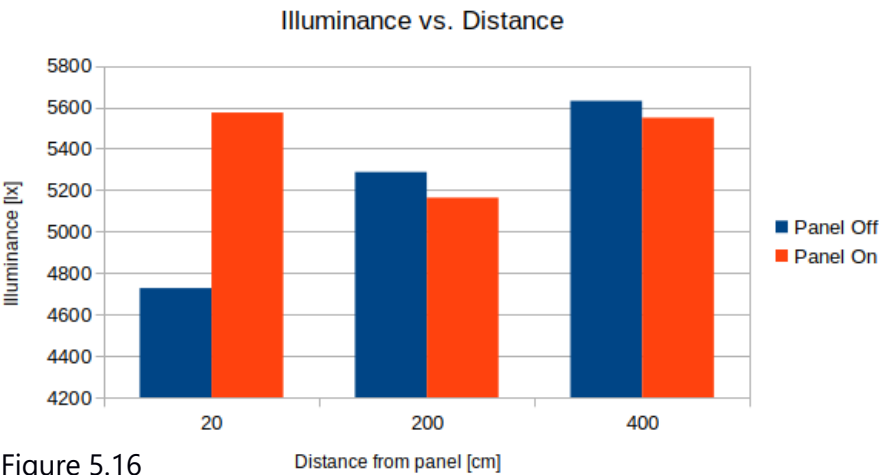


Figure 5.16

Figure 5.17 illustrates the change of local illuminance throughout the day. These results are averaged measurements across all 8 testing days and 3 distances. It can be seen that during May, the light levels remain fairly consistent and high throughout the day. For reference, the average illuminance inside a well-lit office space is around 500 lx while under direct sunlight it’s 100,000 lx [50].

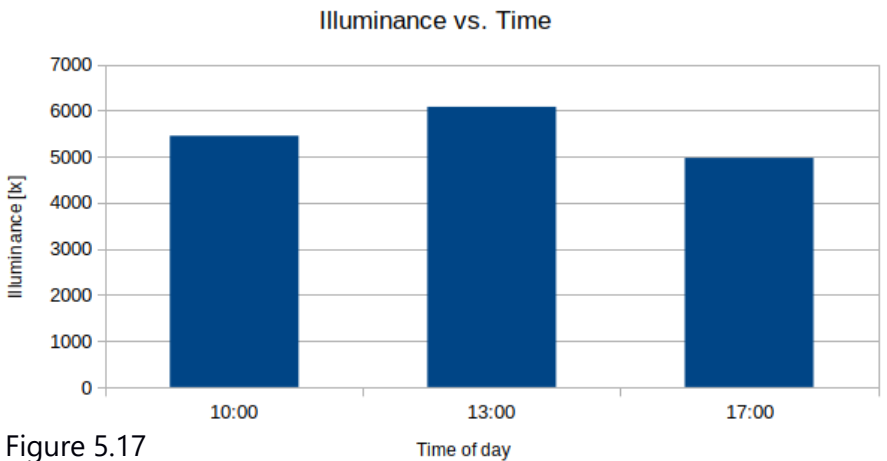


Figure 5.17

Finally, Figure 5.18 illustrates the average illuminance throughout the campaign. The only interesting result was the last test during which the heavy and constant cloud formation obstructed the sunlight and the illuminance was decreased considerably. During that particular test, the panel seemed perceivably brighter than the other tests.

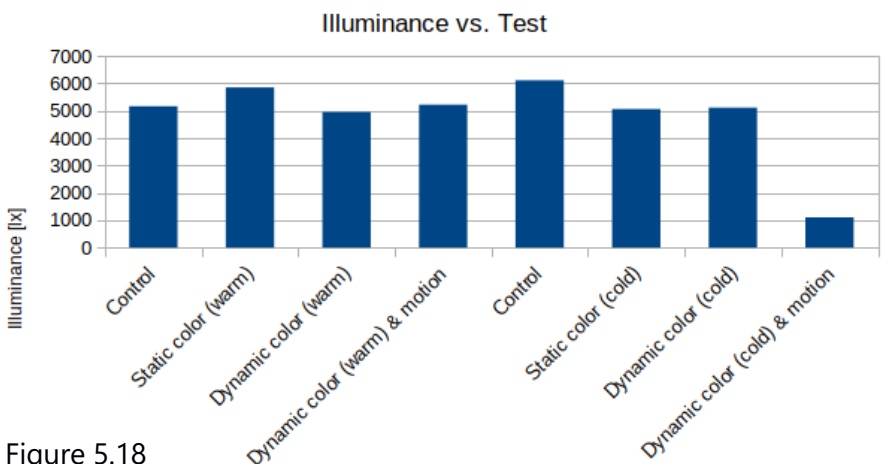


Figure 5.18

5.4 RESULTS

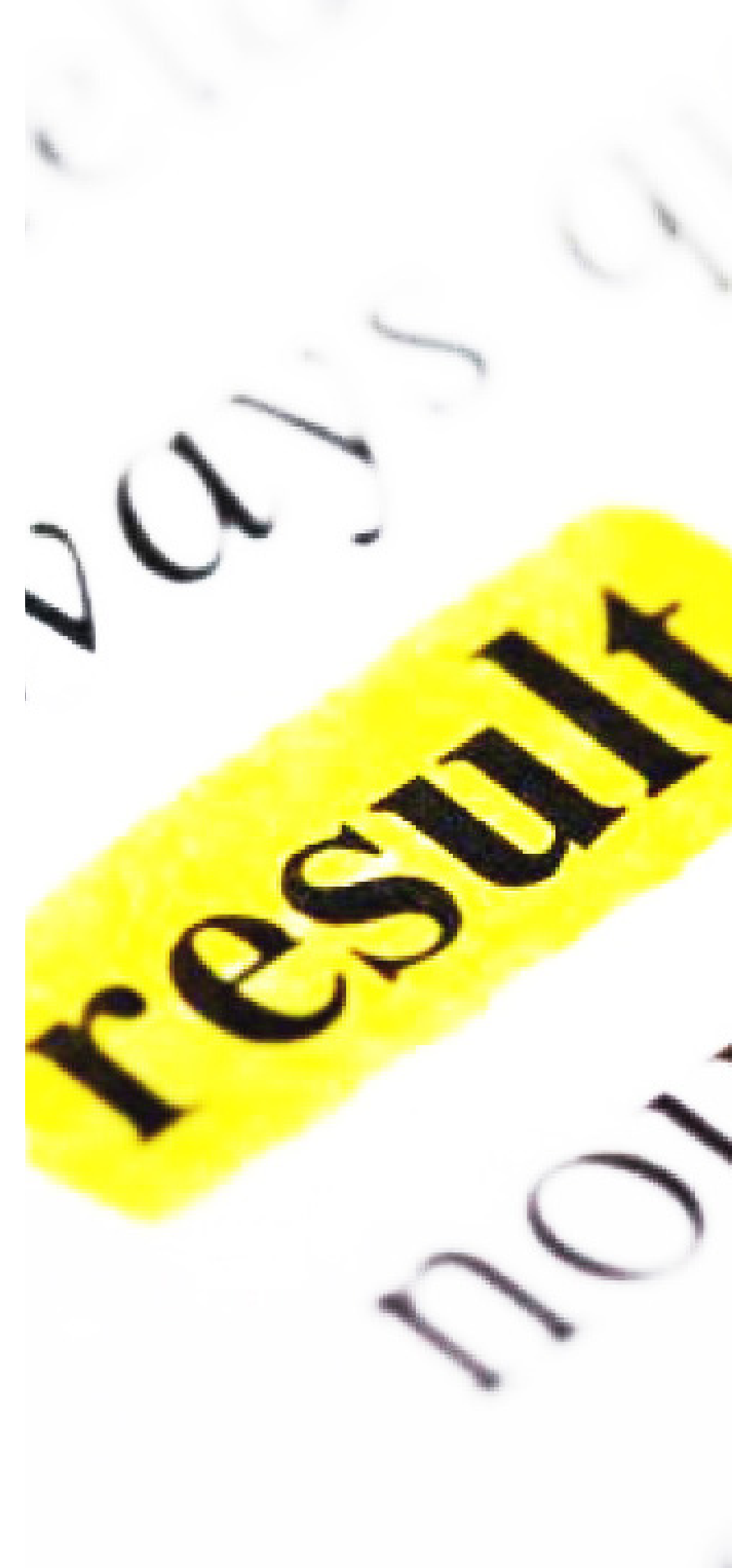
In order to prove the stated hypothesis, we need to find a correlation between the measured variables (ratio of the number of viewers to unique detections, average view time and the ratio of scans to the number of viewers) and the visualizations. Thus, a correlation coefficient can be calculated (one for each of the above variables and the visualization) based on the obtained results; a correlation coefficient measures the extent to which two variables tend to change together. The coefficient describes both the strength and the direction of the relationship.

The most commonly used correlation coefficient is the Pearson correlation. The Pearson correlation evaluates the linear relationship between two continuous variables [51]. A relationship is linear when a change in one variable is associated with a proportional change in the other variable. However, for this test, the strength of the relationship between the variables is unknown (i.e. it is not known how much the behavior is affected for a given visualization). All that is hypothesized is that for each consecutive visualization (control, static color, dynamic color and dynamic color using motion), the effect on the behavior increases.

The Spearman rank-order correlation is thus a more appropriate choice. The Spearman correlation evaluates the monotonic relationship between two continuous or ordinal variables. In a monotonic relationship, the variables tend to change together, but not necessarily at a constant rate. The Spearman correlation coefficient is based on the ranked values for each variable rather than the raw data [52]. In this test the four visualizations control, static color, dynamic color and dynamic color using motion are ranked 4, 3, 2 and 1 respectively.

It is important to note that the strength of the Spearman's correlation is not an indication of the statistical significance of the relationship. For this we need to calculate the t-value of the dataset. The t-value can in turn be used to perform a t-test to determine the probability (p) that these results could have been obtained if the null hypothesis was true. On the other hand, the statistical significance testing of the Spearman's correlation does not provide you with any information about the strength of the relationship. Thus, achieving a value of $p = 0.001$, for example, does not mean that the relationship is stronger than if you achieved a value of $p = 0.04$. This is because the significance test is investigating whether you can reject or fail to reject the null hypothesis. If we set our rejection threshold $\alpha = 0.25$, achieving a statistically significant Spearman rank-order correlation means that we can be sure that there is less than a 25% chance that the strength of the relationship we found (our Spearman's coefficient) happened by chance if the null hypothesis were true. Normally, the threshold value is set to a much smaller value (often 0.05) in order to prove that the results are statistically significant. However, since the sample size in this experiment is very small, none of the results can ever be considered statistically significant under these conditions. Instead $\alpha = 0.25$ is selected to show that the results are practically significant meaning that the difference between the results and the null hypothesis is large enough to be meaningful in real life.

Next, the behavioral measurements obtained from Advertima and the Webserver is analyzed using the Spearman's correlation coefficient in order to determine whether the stated hypotheses were correct.



5.4.1 Warm color

The ratio of the number of views to the number of detections for the first set of tests (using a warm color) is illustrated in Figure 5.19. By looking at the chart we can identify a general increasing trend. The Spearman's correlation coefficient was calculated to be 0.8 for this dataset, which shows a strong correlation between the ratio of Viewers to Detections and the visualizations. The t-value is calculated to be 0.93 which means that $p = 0.23$ (Figure 5.20). Since $p < \alpha$, we can conclude that this relationship is practically significant. This shows that the more dynamic visualization managed to draw more attention, i.e. a larger portion of the people passing in front of the panel viewed the panel for longer than 3 seconds (the threshold required to be counted as a viewer by Advertima). The results provide a strong support for hypothesis 1 and 3.

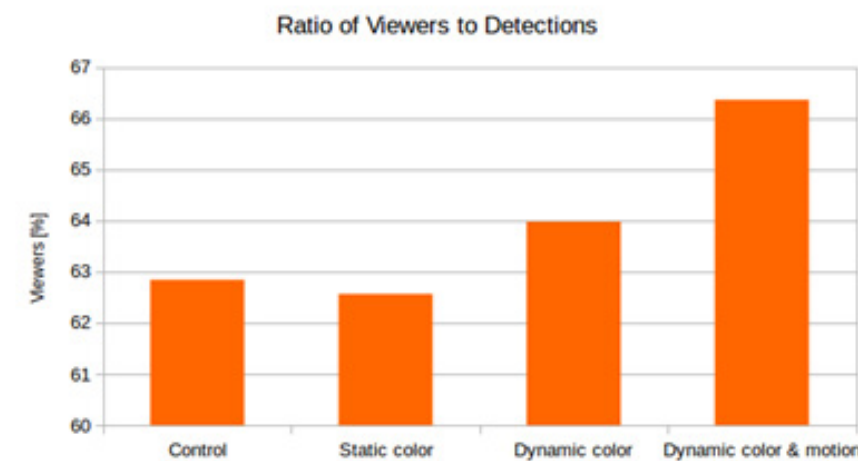


Figure 5.19

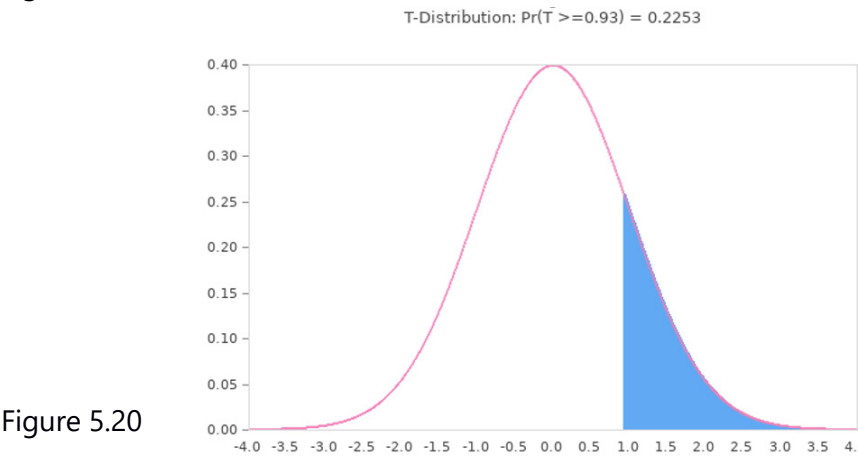


Figure 5.20

From Figure 5.21, it can be seen that the average view time also tends to increase over the course of the tests. In fact, the average view time more than doubled from the control test's 6 seconds (no visualization) to over 12 seconds for the 4th day (displaying a dynamically shifting color using motion). The Spearman's coefficient is calculated to be 1.0 showing a very strong correlation between the two variables. The t-value is calculated to be 1.0 which means that $p = 0.21$. Since $p < \alpha$, we can conclude that this relationship is practically significant. This result is also in accordance to hypothesis 1 and 3. The average view time between the static color visualization and the dynamic one is nearly identical.

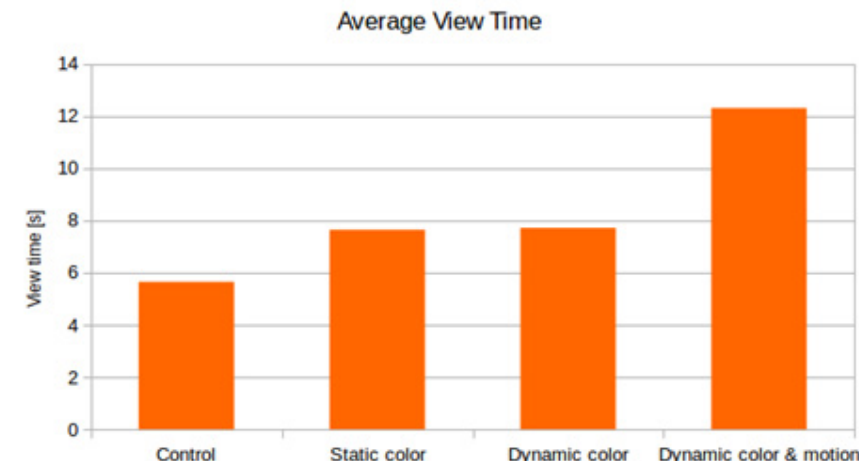


Figure 5.21

Perhaps, the most interesting result is the number of scans for all the tests. Figure 47 illustrates a bar chart that shows the ratio of the number of scans to the number of views (i.e. how many of the viewers actually scanned the QR code). Again, an increasing trend can be observed which is also confirms by the Spearman's coefficient of 1.0 showing a perfect correlation. The

Perhaps, the most interesting result is the number of scans for all the tests. Figure 5.22 illustrates a bar chart that shows the ratio of the number of scans to the number of views (i.e. how many of the viewers actually scanned the QR code). Again, an increasing trend can be observed which is also confirms by the Spearman's coefficient of 1.0 showing a perfect correlation. The t-value is again calculated to be 1.0 which means that $p = 0.21$. Since $p < \alpha$, we can conclude that this relationship is practically significant. It is interesting to point that even during the control test, when the panel was completely off, some people still decided to scan the QR code out of curiosity.

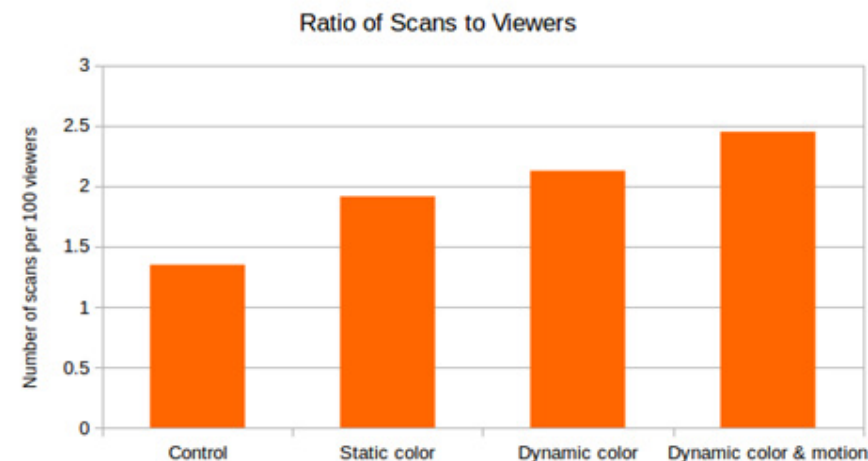


Figure 5.22

5.4.2 Cold color

During the second set of tests, a cold color was used as the primary color and the warm color was using for shorter periods as the activating color. Unfortunately, during this set of tests, the environmental situation surrounding the panel had changed. A number of desks were placed in direct vicinity of the panel (in detection range of Advertima). This makes the absolute values of the number of detections and viewers incomparable to the previous tests as the human traffic was increased considerably. Despite these problems, the tests were carried out and results are analyzed in this section.

Figure 5.23 shows the ratio of the number of viewers to the number of detections for the second set of tests (using a cold color). As it can be seen, apart from the last test (dynamic color using motion) no clear increasing trend is visible. The Spearman's correlation coefficient was calculated to be 0.4 for this dataset which doesn't not indicate a strong correlation. The t-value is calculated to be 0.54 which means that $p = 0.34$. Since $p > \alpha$, we cannot reject the null hypothesis and the results hold no significance. As previously mentioned, during these tests, the layout of the hall was changed. As a result, the nature of the interaction

people had the opportunity to sit in front of the panel for extended periods of time.

It was observed that the people who were enjoying a meal or working with their laptops were regarded as viewers by Advertima. This created a situation where the accuracy of Advertima was severely impacted. This is also supported by some of the other statistic provided by Advertima. For instance, the average detection time for the first set of tests was 35 seconds. During the second set of tests, the average detection time was over 2 minutes. As such no conclusions can be made from this result.

From figure 5.24, it can be seen that again no clear trend is observable between the average view time and the conducted test. The Spearman's coefficient is calculated to be 0.4 thus confirming that there is no strong correlation. The t-value is calculated to be 0.54 which means that $p = 0.34$. Since $p > \alpha$, we cannot reject the null hypothesis and the results hold no significance. These results can again be contributed to a reduced accuracy in the data obtained from Advertima. No conclusions can be drawn from these results either.

What do the results of the Webserver show us? These results were obtained independent of Advertima and thus should not be affected by the change in the environmental setup. Figure 5.25 indicates a clear increasing trend in the number of scans over the course of the tests. The Spearman's correlation coefficient is calculated to be 1.0 as expected. This shows a very strong correlation between the number of scans and the rank of the visualization. The t-value is calculated to be 1.0 which means that $p = 0.21$. Since $p < \alpha$, the results are practically significant which provides a strong support for hypotheses 1. The number of scans during the last test witnessed a sharp increase. This is most likely the result of lower environmental luminosity which was described in detail in section 3.5.

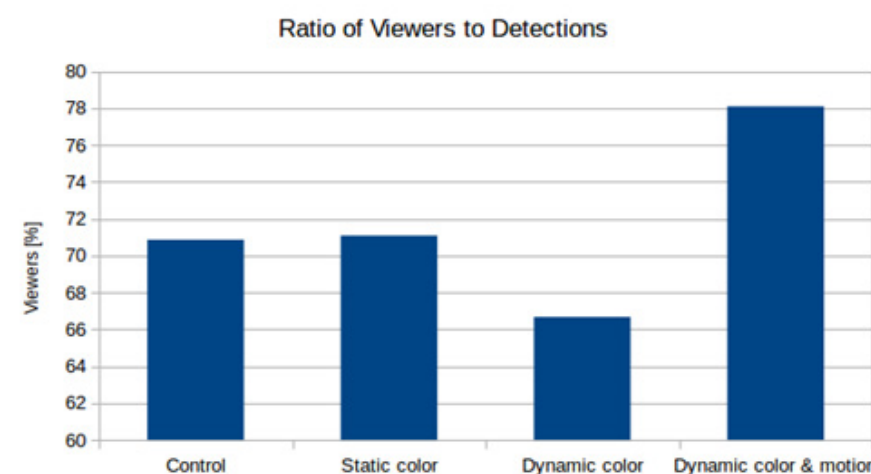


Figure 5.23

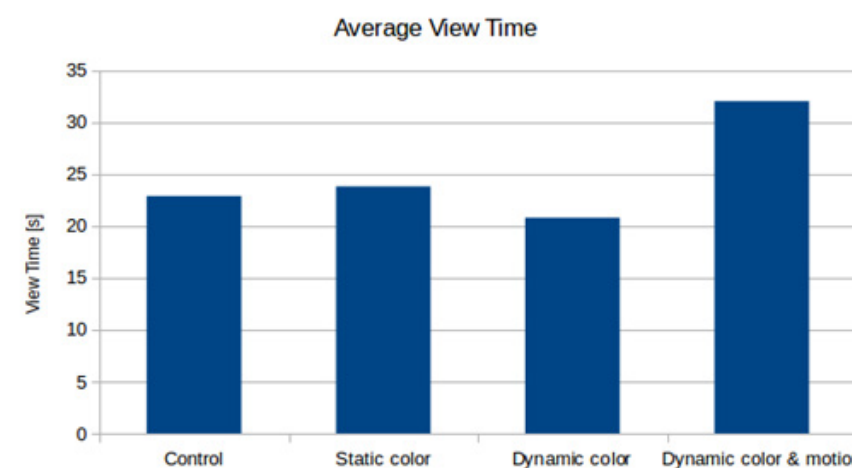


Figure 5.24

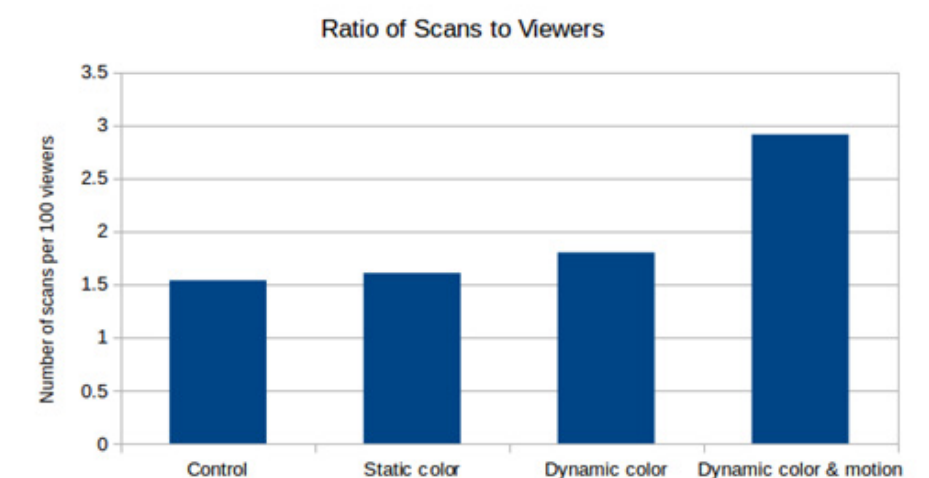


Figure 5.25



5.5 DISCUSSION

5.5.1 Test results

As observed during the first set of tests, the number of viewers (relative to the total number of detections), the linger time of the participants (as shown by the average view time) and the number of viewers who ended up scanning the QR code increased steadily over the course of the test. The Spearman's coefficient calculated for the data set showed a statically significant correlation between these variables and the tests. The results provide a strong support in favor of both hypothesis 1 and 3.

Even though the measured local illuminance did not increase significantly by turning the panel, it was observed that it had a positive effect with regards to attracting people and keeping them in front of the panel for longer. This is most likely causing by the more noticeable contrast (in terms of color and brightness) with the environment.

We also saw that visualizations involving motion are very effective in triggering the behavior of the participants by guiding their attention towards the QR code. During the first and second sets of experiments, the number of scans was increased by 75% and 50% respectively. Furthermore, both the first set of tests as well as the second set showed an increasing trend in the effectiveness of the visualizations. This illustrates that the visualizations remain effective even after extended exposure. Due to the selected context for the experiment, it is estimated that a large number of the participants had observed the panel multiple times. Yet the visualizations ranked to have the

most effect did indeed manage to influence the participants during the second set of tests. This proves that even after the element of novelty and curiosity is diminished, the visualization with a shifting color and motion tend to perform better at triggering the desired human behavior.

Unfortunately, not all of the objectives of this experiment could be accomplished. Due to the change in the environment between the first and second set of tests, no valid comparison could be made between the effectiveness of different chromaticities in triggering human behavior. As mentioned before, due to the nature of the room setup, there was a spike in the observed traffic around the panel during the second test. This corrupted the data to a extend (both as Advertima became less accurate and due to increased traffic) that no valid conclusion can be drawn with regards to hypothesis 2.

5.5.2 Recommendations

There are many points to improve upon with regards to these experiments. Firstly, even though the trade-off between running the experiment under the real-life conditions or in a control environment was known and discussed in section 5.3.3. In hindsight, a more controlled environment (controlled traffic, lighting conditions, room layout etc.) could have provided more accurate results. Alternatively, extending the duration of the test over a longer period would have also averaged out these effects resulting in a more accurate data. However, in terms of the assessing

the reaction and response of the participants to the visualizations for the purposes of advertisement, it can be argued that testing under a real-life condition was the more appropriate choice.

Furthermore, Advertima although advertised as a highly capable and accurate method for gathering statistics on the human responses, failed to deliver on its promises. The results showed that under certain conditions (when it was in range of a large number of people for an extended period of time) its accuracy was negatively impacted. Furthermore, various activities such as eating or working with laptops, were misinterpreted as viewing the panel by Advertima (depending on the head pose of the subject). A controlled environment would have also improved the quality of the data gathered by Advertima.

Furthermore, to be able to reach statically significant levels of confidence in the results, the sample size must be increased. This means that the test must be repeated for a longer period. This also helps to average out other uncontrollable effects.

Lastly, the selected context was a brightly lit hall with wide open windows on the ceiling. This meant that the luminosity of the area around the panel was quite high when compared to most office spaces. As a result, the relatively low intensity light coming from the panel did not provide a very strong contrast with the environment. On the last day of the experiment when there was overcast conditions, the effect was greatly magnified. This was observable in the obtained results. Repeating this experiment in an environment where the effect of the panel is more prominent would

increase the accuracy of the result by emboldening the role of the visualizations.

5.5.3 Form submissions

As mentioned previously in the section 5.3.2.2, people passing the panel were able to send messages through a website after scanning the QR code. By exploring the comments passersby sent, some interesting points can be noticed. Besides comments about the light visualizations (color, and movement), there were people mentioning some other factors affecting their decision to scan the QR code. One of the interesting points is regarding the effect of the presence of the camera located on top of the panel; many people mentioned that after seeing the camera, they expected something happen (change in the visualizations) by scanning the QR code or getting closer to the panel, and they wished to be able to interact with the panel. Furthermore, in plenty of the submitted forms people referred to their curiosity as the first reason for scanning the QR code. And lastly, some participants described the panel and its properties (large size, interesting texture, etc.) as a factor for attracting their attention.



DI

In this section, we explored a number of architectural environments and selected the office environments for further exploration. And lastly, 4 different novel applications of ambient light communication within office environments were presented.

ELLIVER

CHAPTER 6

6.1 INTRODUCTION

In the previous chapters we explored how ambient light communication, combined with live data can prove to be an invaluable addition to modern built environments. It was shown that according to the results of the experiments, light visualizations can be used to convey complex information to the viewers without the need of prior training or a visual legend or dictionary. Furthermore, we discovered that ambient light communications can be used effectively to trigger certain desired behaviors and actions in humans. With this knowledge, we can now start to envision how such a powerful tool can be used to improve the lives of the occupants of built environments.

There are of course a nearly infinite number of permutations of architectural spaces and contexts that can benefit from this technology. The architectural buildings have been divided into several types based on their occupancy. According to the International Building Code [53], there are 10 types of occupancy classification and use designation:

Assembly: including any building or portion thereof in which groups of people congregate or assemble for recreation, amusement, social, religious, political, cultural, travel and similar purposes.

Business: including any building or portion thereof which is used for any business transaction other than mercantile.

Educational: including any building or portion thereof in which education, training and care are provided to children or adults.

Factory and Industrial: the use of a building or structure, or a portion thereof, for assembling, disassembling, fabricating, finishing, manufacturing, packaging, repair, cleaning, laundering or processing operations that are not classified as a hazardous occupancy.

Hazardous: the use of a building or structure, or a portion thereof, that involves the manufacturing,

processing, generation or storage of materials that constitute a physical or health hazard.


Institutional: the use of a building or structure, or a portion thereof, in which people are cared for or live in a supervised environment, having physical limitations because of health or age are harbored for medical treatment or other care or treatment, or in which people are detained for penal or correctional purposes or in which the liberty of the occupants is restricted.

Mercantile: buildings and structures or a portion thereof, for the display and sale of merchandise, and involves stocks of goods, wares or merchandise incidental to such purposes and accessible to the public.

Residential: including any building or portion thereof providing sleeping and living accommodations to related or unrelated groups of people.

Storage: the use of a building or structure, or a portion thereof, for storage, such as for warehouses, storage rooms, freight depots and distribution centers, when not classified as a hazardous occupancy.

Utility and Miscellaneous: buildings under this Occupancy group shall include special buildings not covered in other Occupancy groups.

A photograph of a modern office interior, viewed through a glass wall. In the foreground, a large, light-colored wooden conference table is partially visible, surrounded by several black leather office chairs with casters. The background shows a bright, open office space with large windows and structural columns. The text is overlaid on the left side of the image.

As a demonstration of how the prior information can be used to improve the lives and experiences of the occupants of built environments, business environments or more specifically office environments have been studied in this chapter. The primary reason for selecting office environments, stems from the fact that this type of architectural environments has become a hot topic in the recent years with a lot of focus on using live data and integrated sensors to increase sustainability and improve productivity. Furthermore, most of the techniques applied for office environments are also applicable to other similar architectural buildings such as educational and institutional buildings. Combined, these three types of buildings receive the highest number of visitors and thus have a larger impact on our lives.

6.2 BACKGROUND INFORMATION

This section aims to study the literature on current issues, challenges and trends in office environments and to compile a background information which can serve as a starting point for designing lighting systems which rely on ambient light communication in order to enrich the experience of the occupants.

6.2.1 Problems

A thorough review of the literature seems to indicate that there are 5 major problems in office environments which are being tackled at the moment: health, poor communication, lack of knowledge, time management and challenges of flexible workplaces. These issues are briefly discussed below.

With the advent of electric lighting humans are no longer dependent on daylight for their lighting needs which has allowed us to work at any time of day regardless of the availability of natural light. This can lead to many benefits such as extended work hours but this also has a negative effect on people's health. Lighting design for workplaces has focused mostly on providing sufficient light for visual performance, minimal glare, good comfort and sustainability. However, the effects of lighting on non-visual systems, including circadian rhythm that affects sleep and mood, has received very little attention.

Poor lighting can affect the health of people at work causing symptoms like eyestrain, migraine and headaches [54]. Furthermore, circadian rhythms are primarily set by people's connection to natural light. The human body expects little to no light at night, increasing light from dawn till midday, and decreasing

light towards sunset [55]. Artificial lighting is able to provide constant levels of light at any time. This can shift or reset the circadian rhythm which is proving to have negative effects on the lives of everyday people. An example of this is reduced sleep quality [56]. To confirm this, Figueiro et al. measured objective and subjective sleep and self-reports of mood from participants and concluded that strategies to increase circadian light exposures in buildings should be a consideration in architectural design [57].

Lighting characteristics also plays an important role on the comfort of employees in the workplace. An important factor that affects workers' ability to see well in the workplace is the quality of light. Quality lighting, created by attention to brightness, contrast, quantity, and color of light, results in visibility and visual comfort. Contrast between a task object and its immediate background must be sufficient to enable the worker to clearly view the task [58]. Too much or too little light can affect the ability to effectively see the task. This light level is dependent on man factors such as age, gender and personal preference. For instance, a 60-year-old worker needs 2 to 3 times as much light as a 20-year old worker to achieve the same visual performance [59]. The appropriate light levels also vary for each specific task. The more rapid, repetitive, and lengthy the task, the more important it is to have enough light. With these types of tasks, the eye is more susceptible to fatigue which reduces productivity.

Stress is another common problem that occurs in most jobs. Stress responses are considered natural and healthy when they occur during situations which are perceived to be challenging or threatening (for

instance walking on the edge of cliff). Unfortunately, many chronic stressors, such as work pressure have negative health ramifications. For example, employees and managers within the organizations or students in universities have their own specific duties and responsibilities which creates pressure to perform. Therefore, stress is an aspect that individuals normally experience within work environments [60].

Communication is regarded to be one of the most important elements to the success of any kind of organization or an institution. Without effective communication between the employees or individuals, misunderstandings and mistakes can occur. There are many forms of communications. For instance, speaking is considered to be a verbal communication medium. Writing emails, letters, faxes, notices, articles, documents and so forth are considered to be written forms of communication. When the communication process is not adequately developed or there are a number of barriers to effective communication, then it becomes difficult for the individuals to accomplish their tasks in an effective manner. This has been identified as one of the most important problems in the work environment [60].

Similarly, for all the individuals who are employed, it is important for them to possess the required knowledge and information to be able to perform their work duties. For instance, if an individual is engaged in an educational institution or a company then it is vital that he/she should possess the required skills and know how that is necessary to perform the task at hand. On the other hand, lack of knowledge, information and practice would affect the performance of the employees in a negative manner [60]. This up-to-date knowledge

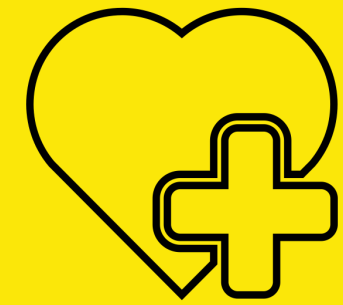
is even more important in new development methods such as agile development. Agile development is a development method based on iterative and incremental development, where requirements and solutions evolve through collaboration between self-organizing, cross-functional teams [61]. It promotes adaptive planning, by using a time-boxed iterative approach which encourages rapid and flexible response to change. Unlike plan-based process methods, agile methods deal with unpredictability and changes by trusting on the team members instead of formalized processes and guidelines. This puts a huge emphasis on knowing the status of the project at all times.

Moreover, time management has become an increasingly important skill for today's workforce. As more and more jobs are becoming agile and time dependent, poor time management is starting to become the bottleneck for increasing productivity. One common activity which is affected by poor time management is team meetings which can often exceed their allocated time slot. Furthermore, adults who are engaged in full time jobs, have several other responsibilities too, which they have to take care of. There are family responsibilities which require individuals to manage his/her family and household. In such cases, an individual is required to implement the time management strategies in an adequate manner so that he does not feel work pressure which as was discussed can lead to stress and negatively impact their health. Therefore, appropriate time management skills are essential for an individual to possess [62].

Aside from the traditional individual or cubicle workspaces, more and more office environments and organizations are turning towards new concepts and

approaches to sharing workspaces. Hot-desking is the process in which office workers do not have any assigned seating. Instead, they may use any of the available desks to work for that particular day [63]. The concept is based on research that suggests as much as 40% of an office's dedicated desk space remains unused on any given day. This can be due to employees being on vacation, or work a flexible schedule, or are stuck in back-to-back meetings. These flexible work programs offer employees a greater scope for work-life balance and employers a number of cost saving opportunities [64].

As with any new approach, hot-desking has also a number of pitfalls. For one, employees feel uncomfortable looking for space. Studies are beginning to show hot-desking can take a toll on employees. From the anxiety of wondering if they'll have a desk for the day, especially if they're late due to traffic or a doctor's appointment, to the politics of sharing space with others, some employees would rather not participate [64]. Furthermore, it can take longer for employees to get settled. Hot-desking can result in lengthy morning routines of finding a workplace and getting setup and connected [65]. Lastly, hot-desking prevents any opportunity for personalization of the work environment which has a negative effect on the mood of workers [66].



HEALTH



COMMUNICATION
and KNOWLEDGE



TIME MANAGEMENT



FLEXIBLE WORKPLACES

6.2.2 Prior Work

Above, some of the most critical and important issues of the modern 21st century office environments was outlined. In this section, we'll explore how designer's have tried to solve these problems using dynamic lighting techniques. These solutions can form a basis for designing ambient lighting products that also incorporate elements of ambient light communication and persuasive technology.

As mentioned before, the use of artificial lighting in office environments has led to a decrease in sleep quality. Because people use artificial lighting later in the day, when the body is expecting decreased light levels, adjustments in a circadian rhythm results in the body delaying production of melatonin. This results in lower overall melatonin levels which in turn decrease sleep quality. Because of these negative affects researchers have begun experiments to determine ways of correcting circadian rhythms without having to completely remove artificial light from people's environments. Mapel et al. created an algorithmically controlled dynamic, daylight-quality artificial lighting which provides an opportunity to restore occupants' connection to their external environment [67]. In their design, LED luminaires would indicate sky conditions in windowless building interiors while providing high quality ambient illumination. They presented methods to achieve real-time and idealized emulations of sun and sky- light specific to local geographic coordinates, orientation, and time.

The ability of light to be used as an environmental stimulant to create atmosphere, evoke moods, and provide immersive experiences can be taken advantage of in order to combat stress in work places. Yu et al. designed the DeLight system, through which

they aimed to establish a biofeedback-driven lighting environment that informs users about their stress level for intervention and assists them in biofeedback relaxation training [68]. In their study, DeLight is interfaced with a heart rate variability sensor system with two modes for different purposes: stress intervention and relaxation assistance. They evaluated the prototype of DeLight in user studies. The results of the study showed that by providing feedback of the heart rate variability through the changes of ambient light, the users became self-aware of their stress levels. Secondly, it was shown that ambient lighting can be used to trigger behavioral conditioning, such as deep breathing. They claimed that DeLight offers enhanced relaxation effects regarding both subjective experience and measured physiological arousal. These findings suggest that ambient light can perform as persuasive technology in the domain of health self-management. The combination of decorative and informative aspects enables the lighting interface to offer the users a comfortable and relaxing condition for biofeedback-assisted relaxation training.

Downs et al. in their paper described the evaluation of a project awareness system that assists agile development teams to understand current software build status and who is responsible for any build breakage [69]. The system uses ambient awareness technologies (Nabaztag wifi connected lamp, see Figure 6.1), providing a separate, easily perceived communication channel distinct from standard team workflow. Multiple communication methods such as email and software notifications were also evaluated for comparison. The evaluation showed that, while there was no change in the quality of work, the overall

number of build breakages decreased substantially. Team members also reported an increased sense of awareness of, and responsibility for, software builds.



Figure 6.1: Nabaztag wifi connected lamp

As a solution to time management challenges of office environments, Occhialini et al. presented an explorative research to investigate the opportunities of using light as a communication medium to provide peripheral information [62]. They developed an innovative ambient display, using dynamic light patterns on the walls of the meeting room to support time management during meetings (see Figure 6.2). Designed according to the principles of calm technology and information decoration, the system seeks for a balance between aesthetical and informational quality. Two prototypes were created, and qualitative research methods were used to evaluate the concept and the ability of light in conveying information. The results confirm the value of the concept by showing an appreciation of the usefulness and a decrease in the chance of a meeting overrunning its allocated time slot. The project led to

insightful considerations on design guidelines and recommendations for further development of ambient displays to use light to convey abstract information in a subtle, unobtrusive way.

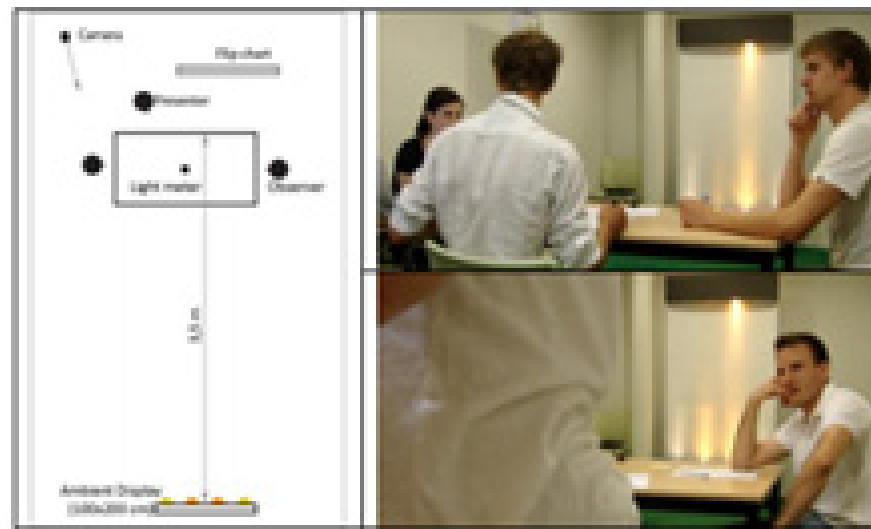


Figure 6.2: Meeting's time management using dynamic ambient light

The Edge is the first building that uses the Philips Ethernet-powered LED connected lighting system resulting in the greenest building in the world, according to British rating agency BREEAM, which gave it the highest sustainability score ever awarded: 98.4 percent. The panels are also packed with sensors: motion, light, temperature, humidity, infrared, creating a "digital ceiling" that connects the entire building in a network. This results in one of the smartest office spaces ever constructed. This has been fully taken advantage of by the building's main tenant, consulting firm Deloitte. They created an application that checks the employee's schedules. When an employee enters the building in the morning, the building recognizes his/her car and assigns them a suitable parking spot near their scheduled activities. Then the app finds a workplace based on their schedule and preferences. The app also

their schedule and preferences. The app also knows the preference for light and temperature of all the employees and staff, and tweaks the environment accordingly to improve productivity and comfort [70]



Figure 6.3: Philips' Interact Office

Another technology which can greatly reduce energy consumption and increase sustainability is adaptive lighting systems. Adaptive lighting systems can adjust artificial light levels depending on the measured levels of natural light in every room of the building. Furthermore, automatic occupancy detection can turn off lights in environments which go unused. When compared to the conventional static lighting system, the adaptive system delivers an average energy savings of 69%. Studies identify significant opportunity for energy consumption and demand savings in open office spaces [71].

Similarly, Philips' Interact Office (see Figure 6.3). uses the lighting infrastructure, real-time occupancy data and accurate indoor position system to guide the employees to wherever they need to the nearest free workspace or meeting room [72]. This work

dynamically changes the lighting temperature and intensity to deliver visual comfort that is suited to the task being carried out.

Zumtobel created flexible desk work environments which allows the employees to personalize their surroundings using lighting [71]. The function of lighting is to also assist individual activities such as concentrated and communicative work, for instance. Rather than uniform general lighting, modern working environments favor a lighting concept that divides space up into zones and, by doing so, caters for various types of use and the needs of individual employees. Each employee is enabled to individually adjust the brightness and color temperature assigned to him/her. They discovered that both employees and their company benefit from a lighting management system that not only makes it possible to configure individual lighting situations but encourages people to do so [71].

Problems in the office environments
identified in section 6.21



Flexible Workplaces

Time Management

Health

Communication and
Knowledge

6.3 IMPLEMENTATION

Previous sections illustrated the common issues and challenges within a modern office environment. Some of the novel approaches taken by product designers and architects to solve these issues were presented. Armed with this knowledge and the results of our previous two experiments, we can now start to image how we could effectively incorporate ambient light communication technology into office environments in order to solve some of the remaining challenges or enhance existing ones. This is presented by this section.

To summarize, the results of the first experiment showed that most participants did indeed have a common perception of some of the selected data categories. This means that the participants shared a common understanding of these visualizations which suggests that in more general terms, light visualization can be used to form a very basic language to transfer information without any a priori knowledge or training. It can be assumed that additional training or long duration exposure can significantly increase the ability to understand complex information through ambient light communication.

Furthermore, the second experiment illustrated that using directional cues created with the aid of dynamic light visualizations, it was indeed possible to direct the attention and gaze of observers towards a specific location or direction. In here it is assumed that such conclusion can also be extended to influencing the direction of travel of people using similar directional cues.

In this chapter, we present a number of solutions to the identified problems in office environments. The

solutions are provided as an example of how ambient light communication can be implemented on top of the existing solutions (mentioned before) to further enhance the experience of the occupants. The goal of this chapter is not to design an ultimate ambient light system, but to investigate the opportunities of light to communicate information in an unobtrusive way. This work fits in ongoing research projects on developing new, innovative, interactive designs for and with lighting in the context of the intelligent office of the future.



WARM
WHITE

COOL
WHITE

D



Before stepping into the next section, it is vital to briefly explain the meaning of High/Low color temperature, and the most preferred light temperature for offices and workstations:

Low color temperature (Warm White)

Warm light sources, have a low color temperature (2200-3000K) and feature more light in the red, orange and yellow range.

High color temperature (Cool White)

Cool light sources, have a high color temperature (>4000K) and feature more light in the blue range [73].

More specifically, shades of red range from about 1000 to 3000K, yellow shades range from 3000 to 5000K, white shades from 5000K to 7000K, and blue ranges from 7000 to over 10000K [74] (Figure 6.4). Colors below white are referred to as “warm”, while colors above white are designated as cool. ***Note that the terms “warm” and “cool” are not temperature related, but are merely visually descriptive.***

The best light temperature for offices is between 3500K and 5500K (Figure 6.5). Anything above 5500K is just too blue and anything below 3500K will make your employees less productive [76]. Therefore, in the following design concepts we will mostly stay in the same range, unless for reaching a special goal or the necessity of exaggerating the ambient light color to make it easier for the eye to notice the change.

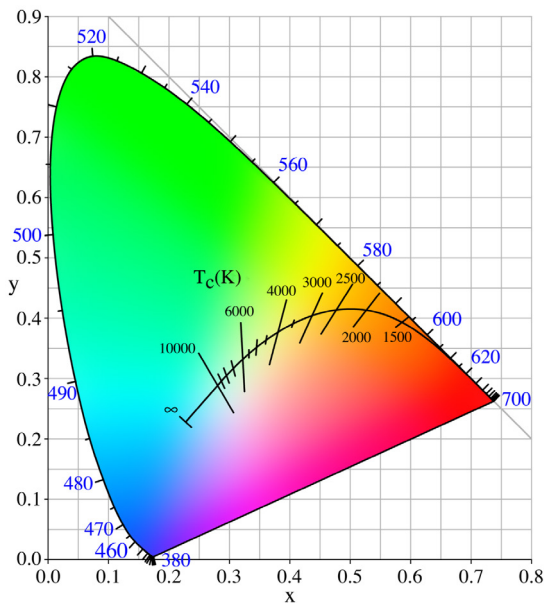


Figure 6.4: showing the chromaticities of black-body light sources of various temperatures [75]

Color Temperature (KELVIN)	2000K - 3000K	3100K - 4500K	4600K - 6500K
Light Appearance	Warm White	Cool White	Daylight
Ambience	Cozy, calm, inviting, intimate	Bright, vibrant	Crisp, invigorating
Best for	Pendants, wall/coach lanterns, restaurant/commercial ambient lighting, residential recessed lighting, table & floor lamps	Basements, garages, work environments, task lighting	Display areas, security lighting, garages, task lighting

Figure 6.5: [77]

6.3.1 Flexible Workplaces

As previously mentioned, the Edge is one of the smartest buildings in the world. From the moment you wake up, your entire work schedule for the day is known by the central system and is processed to streamline your experience as much as possible. Aside from creating a good experience for employees, this also increases sustainability and productivity. For instance, when you enter the parking space, the system assigns you the best possible parking spot to reduce wasted time. This is currently done by displaying the number of the assigned location to the driver. Finding the specified parking location by following the signs can still be a challenging and time-consuming task.

This is one of the areas where ambient light communication can be of further benefit. For instance, by using the overhead luminaires which display directional patterns of increased local intensity which flow towards the desired parking spot, the driver can easily find his/her destination. The moving light has the highest intensity just ahead of the driver to guide that particular car. This allows multiple cars to be guided to different locations simultaneously.

Overhead (installed on the ceiling) luminaires should be used since walls are not usually an option for indoor parking lots and lights embedded in the floor increase the engineering complexity as well as cost and are in direct sight of drivers thus do not have an ambient presence. In this scenario broad spectrum light sources such as LED luminaires should be used which have a higher efficiency and provide a high color temperature (5000K - 6500K). These sources are often characterized as “white” light sources because they emit energy across the visible spectrum and are proven to be ideal light sources for parking

facilities [78]. The surrounding area of the parking lot is illuminated with a wide-angle diffuse light which provides nearly all of the required illumination for safe navigation of the parking environment. The overhead lights are designed to be more focused in order to create a small but noticeable local increase in illuminance with as little energy as possible.

It is commonly known that humans tend to be more comfortable when they have an estimation of how long it takes to reach a destination. Lacking this knowledge can be confusing and stressful in some situations. To solve this issue, the results of the first experiment can be used in order to convey a sense of progress (how far to go before the destination is reached). We can use the resulting visualization for Approach to illustrate this information. As it was concluded in chapter 4, Approach is best visualized using size variation. In our concept for the smart parking lot, multiple lanes of luminaires can be used to guide the drivers to their destination. Initially, only the center row is illuminated (Figure 6.7). As the journey progresses and the car nears its destination, additional lanes turn on (thus increasing the size of the illuminated area) (Figure 6.8), until all lanes are illuminated with a flowing pattern right before the intended parking space is reached. This has other benefits such as increased safety as pedestrians can easily predict the motion of passing traffic. The second experiment has already established that directional cues can be effectively communicated using motion of light patterns. The light trail project presented by Rogers in [47] also provides strong indication that the described solution can be used as an effective means of persuasive technology.

Similar to Philips Interact Office building, once the

employees enter the closest entrance, accurate indoor position information can be used to guide them to the ideal available workspace or meeting room that suits their personal preference. To facilitate pinpointing the assigned workspace, as the employees nears the vicinity, overhead projection lighting can highlight the appropriate area without disturbing the other employees.

Once the employee sits behind his/her workstation, the desk lamp illuminates the close surroundings using the predefined lighting color temperature and intensity. Allowing the users to set the lighting conditions that they are comfortable with (on an individual level) can further improve the health condition, productivity and satisfaction levels of the work environment. The user can also be given the ability to personalize their workspace using creative light visualizations. These features are intended to solve some of the most pressing problems of flexible work environments such the inability to personalize your own desk or having difficulty or needing to spend too much energy to find a suitable workspace. Lastly, to improve sustainability, the system can preferentially assign people desk which are located near large windows or other areas which receiver a large amount of natural sunlight (atrium). This reduces the need for additional artificial lighting which reduces energy consumption and has positive health effects.

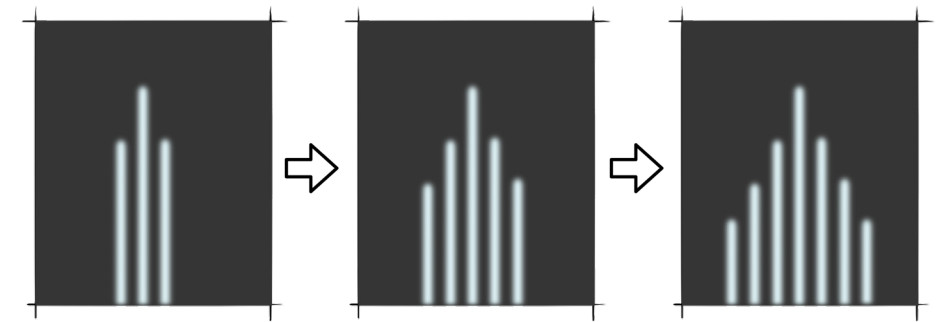


Figure 6.7

Figure 6.8

Increasing the light strips during the time



Figure 6.9 Ambient Light Communication concept for solving flexible workplace issues

6.3.2 Time Management

As identified before, time management is another common issue within office environments. Meetings are essential activities within a working environment. Studies revealed that the number of meetings people attend and the time they spend on them dramatically increased in the past years [62]. Although the studies found several issues such as procedural and hierarchical issues, time management was indicated as a crucial issue within a meeting situation. One of the main causes of dissatisfaction among meetings' participants is the duration of the meeting, often being too lengthy [79]. Moreover, different studies revealed that personal time estimation decreases in accuracy when individuals are simultaneously engaged in a cognitively demanding task [80]. This is often the case during meetings, when people are involved in presentations and discussions.

Occhialini et al. developed an adaptive ambient display which provides timing information inside a meeting room to support time management during meetings where several individual contributions are planned. Their system uses dynamic light patterns to provide a general overview of the meeting and its progress. The system also provides cognitive aid to the people who give an individual contribution to the meeting, for instance by displaying the time available for their presentation, or an indication of their elapsed and remaining time. In their design, eight halogen spots combined with color filters to create the colorful bars. A combination of white and orange beams is chosen to indicate the different activities. They concluded that the visualization was easy to be read at a glance, and simple to interpret, although a certain level of familiarization with the system was required.

Armed with the knowledge gained from the first experiment, we can start to imagine how it would be possible to design a lighting system that can better inform the occupants with less a priori knowledge or training which can also convey additional information such as:

- Meeting progress (percentage of the meeting completed)
- Feedback on individual contribution time (engagement level)
- Notification of transitions between activities (the current activity is almost over and a new phase is starting)

For this scenario, we envision a wall mounted ambient display panel that nearly covers the entire wall of the meeting room. The panel must illuminate the room in order to create an ambient effect while not distracting the occupants. Approach is the perfect candidate since it symbolizes approaching the end of the meeting. The best visualization to convey the Approach and thus the meeting's progress is size. As such, the panel should visualize a bar that is filling the entire panel from left to right as the meeting progresses. The direction with which the panel fills is very important as indicated by the interviews with the participants. Most people tend to attribute a left to right motion with progress (perhaps due to the way most progress bars are visualized).

The color temperature of the light should be high (Figure 6.10). This is proven to create an activating environment which is beneficial during demanding cognitive tasks such as those found in meetings [81]. As the meeting progresses and people get tired or lose focus, the panel is filled with this light

(Figure 6.11) which increases the stimulating effect in proportion to the meeting's elapsed time. A few minutes before the end of the current phase of the meeting, the ambient light solution should notify the occupants of the meeting room that the current phase is nearing completion and the meeting should be wrapped up. This can be seen as an achievement (completing the meeting) which according to the results of the first experiment, is best visualized using a change in saturation. In this case, the light should turn to a lower color temperature (Figure 6.12) and gradually increase in saturation (Figure 13) until the end of the meeting is reached. As low color temperatures create a relaxing environment, the occupants' body becomes prepared for a break or meeting's closure [82]. A similar design can be incorporated into office waiting rooms to indicate the waiting time for visitors or notify them to prepare themselves for an imminent meeting. Studies have shown that satisfaction levels are much higher when people are given a waiting time estimation [83].

Another important information which can be useful in meetings is the contribution time of participants and their engagement level. As each individual in the meeting room speaks, its contribution time increases. This is perhaps best related to Growth which according to the results of the first test can be visualized using intensity. To this end, a number of projection lighting system embedded in the ceiling of the meeting room can be employed. Each light source will be focused on a particular seat in the meeting room. All lights will have an equal light intensity at the start of the meeting. A microphone system can detect when participants speak and reduce the intensity of the corresponding

projection light. This serves two purposes. Firstly, as discussed before, it conveys a sense of how much each participant has contributed in terms of speaking time. Secondly, as some individuals speak more than others, the brightness of their lights is diminished. This shifts the attention to those who have not spoken as much (who are now under brighter spotlights) thus creating a more balanced discussion. The phenomenon whereby an increase in local luminance grabs the attention of people was established in the second experiment as well as prior literature [84].

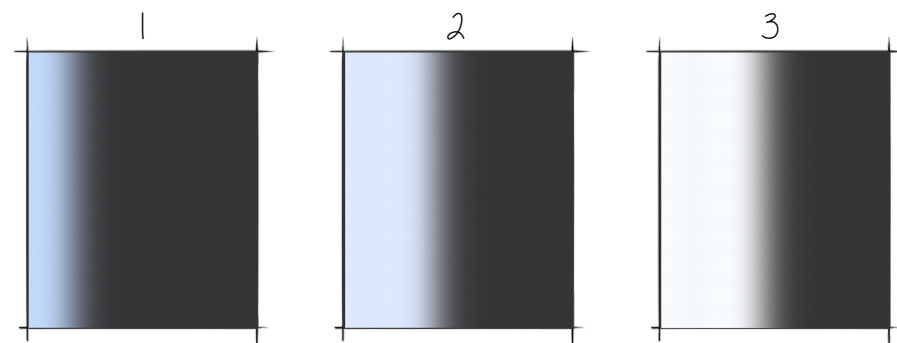


Figure 6.10

Figure 6.11

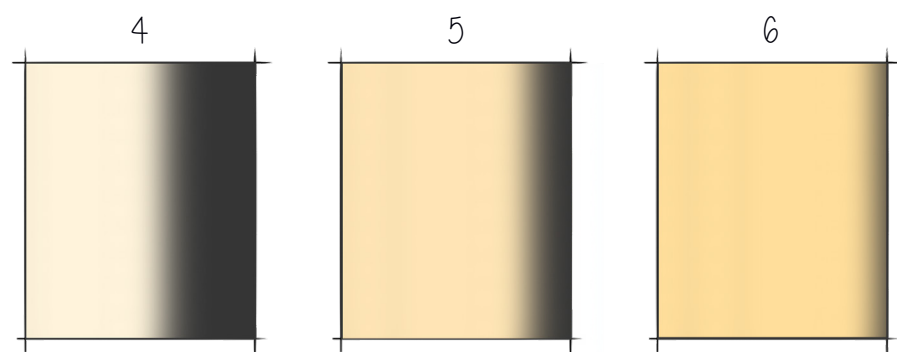


Figure 6.12

Figure 6.13

Light filling the light panel while the color temperate changes

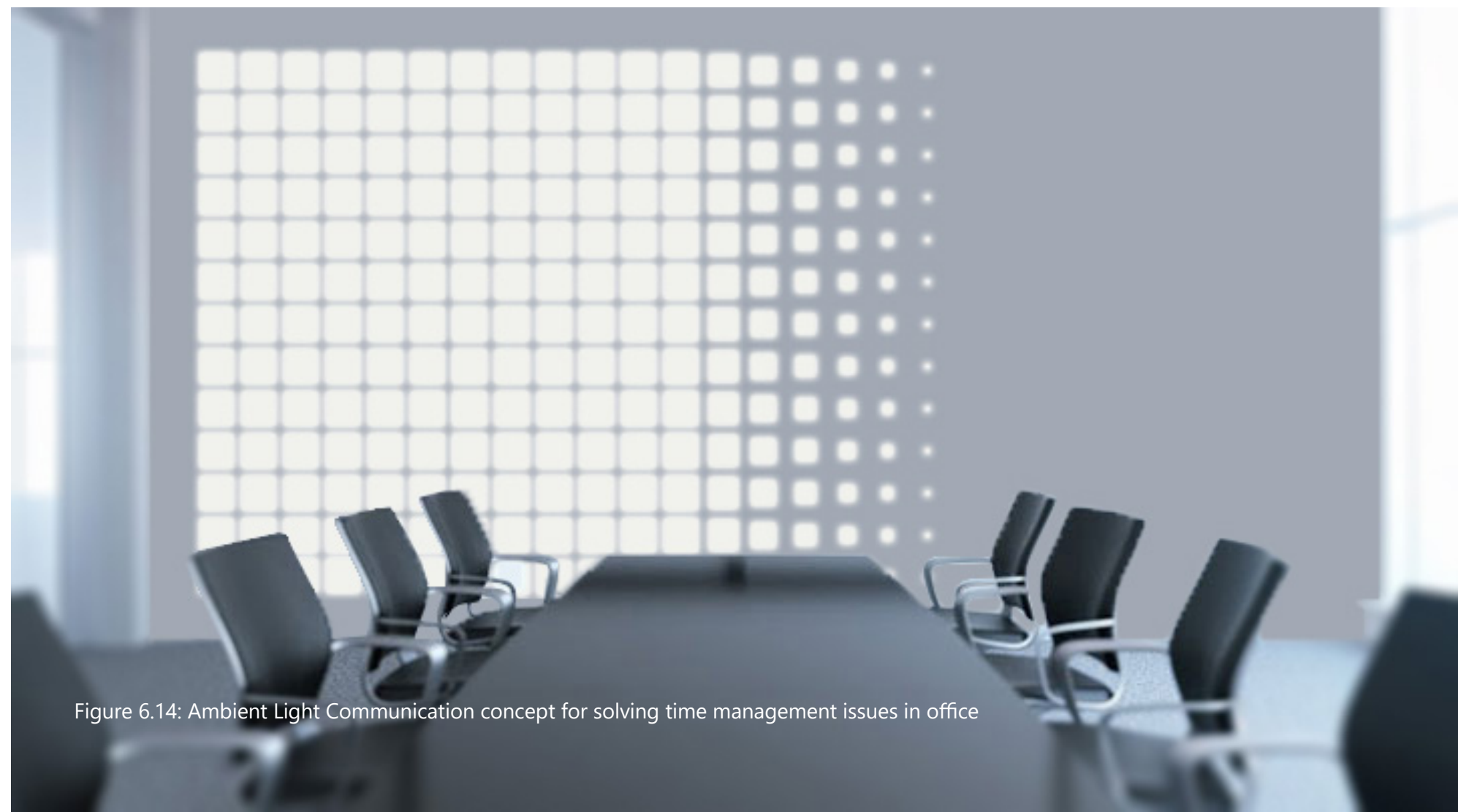


Figure 6.14: Ambient Light Communication concept for solving time management issues in office

6.3.3 Health

Health is first and foremost the most important issue within office environments which is under active research. As previously mentioned, rising levels of stress, reduced sleep quality and eye fatigue and strain as well as headaches and discomfort are some of the most common health related problems that employees experience which can be remedied using proper lighting design. Ideal lighting characteristics for various ages, genders and tasks have been studied extensively by prior researchers [58]. Using the resulting guidelines for controlling the color temperature and intensity of the work environment can already greatly increase comfort and occupant satisfaction. As such further solutions to these problems are not discussed here.

Stress responses naturally occur when a situation is perceived to be challenging or threatening (for instance walking on the edge of cliff). Unfortunately, many chronic stressors, such as work pressure, keep the stress responses always high, causing excess production of the steroid hormone cortisol. Chronically elevated cortisol levels put individuals at an increased risk of numerous health problems, including anxiety, depression, immune dysregulation, heart disease, hypertension, and diabetes [85]. As mentioned in the previous section, Yu et al. presented a biofeedback lighting environment that could not only inform users about their stress level at the periphery of attention through the subtle changes of light color but also assist users in a relaxation training by presenting respiration-related information through the dynamic changes of brightness distribution and color.

In summary, their findings confirm the hypotheses that ambient light could support stress intervention,

improving self-awareness of stress and further triggering a behavioral conditioning, such as deep breathing. In the context of an office environment, this idea can be applied in the form of a personal overhead desk lamp that can convey the employee's stress levels and encourages them to take regular breaks to prevent fatigue, headaches and eyestrain. Initially, the light illuminates the first row of LEDs with a high color temperature (Figure 6.15) which enhances productivity and creates comfortable environment for working. As the employee sits behind his/her desk, a second bar of light with a low color temperature starts to grow (Figure 6.16) and become more prevalent (Figure 6.17). Since the time spent behind the desk increases, it can be seen as growth, which is best visualized through an increase in size according to the first experiments. As the low color temperature of the results in a relaxing environment, the employee should feel need to take a break as the size of the bar gets larger. The color temperature of the ambient light itself should raise self-awareness about the amount of time spent behind the desk.

The same effect can be used to help reduce stress. Biofeedback sensors can detect elevated stress levels and increase the intensity of the LED line with low color temperatures. The brightness should increase and decrease in a cyclic pattern that resembles a deep breathing pattern, which incites the employee to breath at the same rate, thus counteracting the rising stress levels. Once this has been achieved, the light reduces the intensity of the low color temperature LEDs (which is proportional to the detected stress level). This creates a light visualization that changes color from a low temperature to a high temperature. Experiment

1 illustrated that this change of color composition is interpreted as an achievement which conveys the appropriate meaning in the case the employees can manage his/her stress successfully. This concept also provides an indication of stress levels of employees to the surrounding colleagues which facilitates aiding each other and promotes teamwork.

Another important issue which has only recently gained focus, is the effect of artificial lighting on circadian rhythm. Mapel et al. and Zumtobel both presented lighting solutions to simulate daylight. Depending on the season, geographical location, weather situation and the position of the workstations in a room, there is not always sufficient daylight available in indoor areas to synchronize occupant's circadian rhythm. The proposed artificial lighting solution is used to stimulate activity during the day and ensure a sound sleep at night. This technique can also be employed in the outlined concept. In this concept, the same row of low color temperature LEDs can grow as the office hours come to an end, which should promote melatonin production which improves sleep quality [56].



Figure 6.15

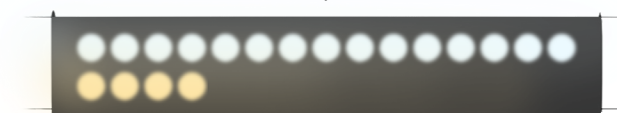


Figure 6.16



Figure 6.17

Showing the increase in the number of low temperature color lights



Figure 6.18: Ambient Light Communication concept for solving health issues in office

6.3.4 Communication and Knowledge

Effective communication and knowledge of accurate and relevant information is vital for teams working in organization or an institution. Without effective communication between the team members, or adequate knowledge and information about the status of all members, productivity and efficiency is severely impacted. Both lack of or poor communication and knowledge were identified as very important challenges facing today's office environments. This is more apparent in agile development and management. Agile project management is a method that adopts a team approach. A project is completed in iterations, each of which emphasizes the involvement of all team members, consistent communication among them and rapid development cycles. A project is thus managed and developed in spurts of activity (often called sprints), focusing on one piece at a time. Agile development has seen widespread adaptation across a wide range of fields due to its many advantages [86]. However, team members must interact regularly and often during non-scheduled times because rapid changes occur throughout project completion, and everyone must adapt. Ambient light communication can be used as a tool to facilitate this communication. As discovered in the literature study, Downs et al. used the principles of ambient communication to design a project awareness system that assists agile software development teams to understand current software build status and who is responsible for any build breakage. Once a build has occurred, team members must be made aware of the outcome of the build and given the opportunity to correct issues that may have been found. However, notification competes with other activities developers are participating in and hence

delays in resolving these issues frequently occur. This was the primary motivation for creating an ambient system to relay this information in an unobtrusive way. This idea can be further extended to relay other critical information of each team member to the whole group. For instance, in teamwork scenarios (as can be found in agile development), tasks are often distributed between all team members. Some individuals may finish their task sooner than others, thus given enough time, the workload tends to become unbalanced. The current solution to this problem is to evaluate the remaining workload of the team and redistribute it at fixed intervals. This can lead to inefficiencies which can be prevented if team members can receive up-to-date knowledge of the status of the workload of other team members through their periphery.

If we think about workload as a quantity which can increase or decrease (Growth), size can be used as a good visualization to convey it. To this end, an ambient wall mounted display panel can be made and placed in the work environment. The panel will have the names of the team members printed on various locations (Figure 6.23). At the start of each sprint, the project's tasks are distributed among the team members (Figure 6.19). This can be manifested as a growing/shrinking circle of light around each name tag which provides an up-to-date status of the workload for that particular member. As tasks for individual members are completed and logged in the system, their corresponding circle will reduce in size to indicate that their workload has lightened (Figure 6.20). This creates an environment where members can easily see the status of the workload of their colleagues and can pro-actively redistribute work packages among themselves in an

The color temperature of the light is neutral (natural light: 4500K) at the start of the sprint and should turn to a blue color as the sprint progresses (Figure 6.20). This creates an ambient effect which can quickly provide an overview of the overall status of the current sprint. If the sprint is near the end (the color of the circles is quite blue) (Figure 6.21) and the size of the circles (the workload of individual members) is still large, the room is illuminated with a blue color which indicates an unsuccessful sprint (many work packages are still remaining). If the assigned tasks are mostly complete, then the size of the circles shrink to a small dot and the blue light is barely visible. The light of the circles, when combined with surrounding ambient light, results in a high color temperature which has an activating effect if the remaining workload is high at the end of the sprint. This helps the employees with a final push to complete the sprint successfully.

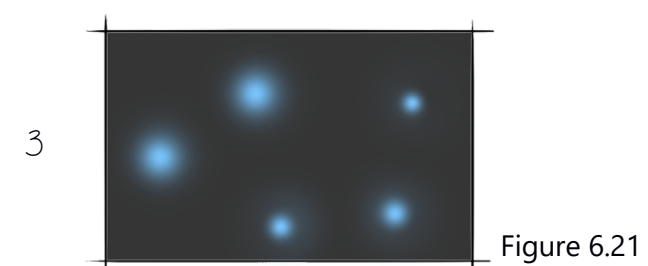
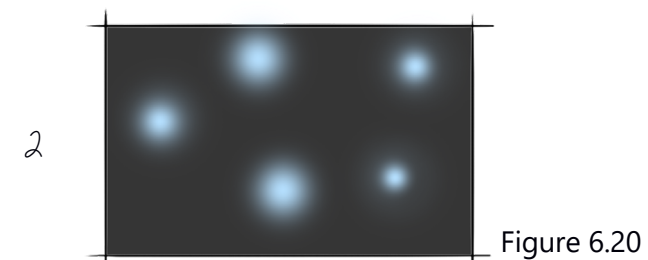
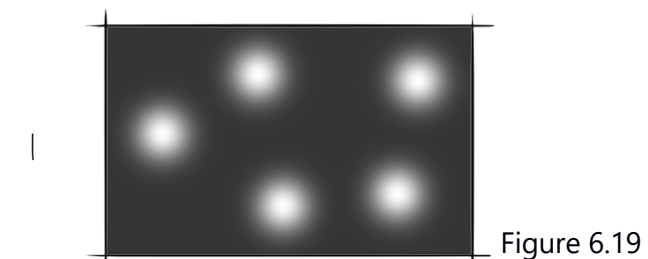




Figure 6.23: Ambient Light Communication concept for solving communication issues in office

6.4 CONCLUSIONS

In this chapter, the literature about the use of lighting in office environments was studied in order to find the most important issues and the current solutions to these challenges. We identified a number of problems and we discovered how new technologies are enabling designers and architects to find ingenious solutions for them.

Current trends in lighting solutions for office environments include dynamic lighting solutions to enhance productivity and well-being (by affecting circadian rhythms), customizable lighting systems to create different atmospheres and moods, and light decorations used to aesthetically enhance working spaces. An ambient display which uses light as a communication medium fits in these current trends, due to its potential aesthetic value. Such system would represent a novelty in comparison to existing lighting solutions, since it combines decorative and informative aspects, resulting both pleasant and helpful for the potential users.

To demonstrate this, 4 different novel applications of ambient light communication within office environments were presented which combined its aesthetical value, its ability to convey meaningful information and trigger desired behaviors. Specifically, we explored how the results of the experiments could be used in order to find more concrete solutions in a specific case scenario. It was shown that the conclusions drawn from the first experiment could be used effectively to determine the best visualization to communicate a particular information.

It was also shown that the proposed concepts can often take advantage of various light characteristics and their effects on human physiology as well as psychology to create persuasive environments which are intended to improve the experience of the occupants and users. Even though, the scope of the second experiment was to determine if ambient light visualization is capable of directing the attention of humans (which could be used directly for some of the design concepts), it also broadened the view of the author with regards to other potentials of creating persuasive environments using ambient light. Literature on the subject and prior work illustrated that lighting characteristics such as color temperature plays a vital role in the human physiology and psychology. These effects can often (and have been used) to enhance the experience, productivity and health of workers in all types of environments and were taken advantage of in the provided concepts.

In summary, the 4 concepts provided in this chapter are merely a demonstration of the capabilities and benefits of ambient light communication and its ability to provide useful information and create persuasive environments which enhances the experience of the users of built environments. The approach taken in this project can also be applied to other architectural environments. In that case, a thorough literature study (for the selected environment and its unique set of challenges) should be performed again as it provided important knowledge which when combined with the results of the experiments, created a set of guidelines for designing effective ambient lighting systems.

6.5 RECOMMENDATIONS

There are many points to improve upon with regards to the experiments conducted or the project as whole. The challenges of conducting the experiments and some of the potential solutions and recommendations for future researchers were outlined in those respective chapters. In this section, we present a broader set of recommendations for future researchers and some pitfalls to try to avoid when designing an ambient light communication product of built environments.

It is important to note that the original research questions that were formulated in chapter 3, could not be fully answered using the 2 experiments conducted during this project. Specifically, there is further research required in order to determine the extent of complexity of information that can be conveyed using ambient light communication without requiring so much cognitive effort that it loses its most important advantage. Further research is also required in order to determine the effect of long duration exposure to ambient light and how it affects the ability to grasp complex information from it. Can people learn this new form of language simply by being surrounded by it, as children do by being around adults? The effect of using live data instead of static data must also be investigated. Perhaps humans cannot or have difficulty in finding or understanding patterns in ambient light products that are fed with such data. Or perhaps, through long duration conditioning they manage to grasp patterns that were not thought of by the designers.

Similarly, the extend of light's ability to trigger various behaviors in humans must be investigated further. The human's physiological as well as psychological

response to light of varying intensity, color temperature or even spatial location is extremely complex. There are vast potentials in using these effects for triggering behaviors which are desirable. In this project, we saw how people have evolved to follow motion or directional cues and how that could be used to guide them to their destination. The literature also demonstrated how human body responses to the color temperature of the light and how that could be used to regulate their attention of stress.

More importantly, these effects are not constant and vary from person to person. Characteristics such as age and gender can determine how light affects a person. These effects when combined with automated real-time vision processing (such as the one used in Advertima), which can categorize the subjects based on these characteristics, would allow future implementations of persuasive environments to dynamically adjust the light patterns to maximize their effect or even selectively trigger behaviors within a certain category.

We could not fully answer these questions due to the limitations of the project. However even the results of our 2 experiments, when combined with the information gathered from the literature, was sufficient to design various concepts that can deliver positive results in a real-world implementation. Our final recommendation is to perform additional experiments with real-life implementation of these concepts in order to validate the conclusions and design procedures outlined in this project.

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APPEN

INDICES

APPENDIX A

Python based web-server implementation

```
#!/usr/bin/python3
# -*- coding: utf-8 -*-
```

```
import http.server
import socketserver
```

```
port = 8000
log = 'log.txt'
form = 'form.txt'
html = 'index.html'
img = 'img.jpg'
```

```
class myHandler(http.server.BaseHTTPRequestHandler):
    def __init__(self, *args, **kwargs):
        self.log = open(log, 'a+')
        self.form = open(form, 'a+')

        with open(html, 'r') as f:
            self.content = f.read()

        with open(img, 'rb') as f:
            self.image = f.read()

        super(myHandler, self).__init__(*args, **kwargs)
```

```
def do_GET(self):
    if self.path == '/':
        # Serve the header.
        self.send_response(200)
        self.send_header('Content-type', 'text/html')
        self.end_headers()

        # Serve the content.
        self.wfile.write(self.content.encode())
    elif self.path == '/img.jpg':
        # Serve the header.
        self.send_response(200)
        self.send_header('Content-type', 'image/jpeg')
        self.end_headers()

        # Serve the content.
        self.wfile.write(self.image)
```

```
def do_POST(self):
    length = int(self.headers['Content-Length'])
    data = self.rfile.read(length)

    if self.path == '/id':
        # Log the request.
        self.log.write("{}","{}",{},{},{},{}\n'.format(
            self.log_date_time_string(),
            self.headers['User-Agent'],
            data.decode("utf-8"),
            *self.client_address))
    elif self.path == '/form':
        # Log form submissions.
        self.form.write("{}","{}",{},{},{}\n'.format(
            self.log_date_time_string(),
            data.decode("utf-8")))
```

```
if name == '__main__':
    """Entry point of the program."""

    httpd = socketserver.TCPServer(("", port), myHandler)

    try:
        print("server started on port {}".format(port))
        httpd.serve_forever()
    except KeyboardInterrupt:
        print("server stopped")
        httpd.socket.close()
```

THANKS!
YOU JUST
HELPED
ME WITH MY
GRADUATION
PROJECT!

WOULD YOU PLEASE LET ME KNOW WHAT
TRIGGERED YOU TO SCAN THE QR CODE?



Submit

This page is part of the graduation project of Yasaman Mavvaj.

Any data we gather will be completely anonymous and kept strictly confidential to TU Delft and the parties who help us run this website.
We promise never to share your data with any other third parties, nor to use your data for any reason other than this graduation project.
For more information you can reach me at y.mavvaj@student.tudelft.nl



APPENDIX B

Submission form - HTML Website

```
<!DOCTYPE html>
<html>
  <body style="background-color:#ffde00" onload="loadDoc()">
    <script>
      function loadDoc() {
        if (localStorage.getItem("id") === null) {
          localStorage.setItem('id', Math.floor(Math.random() * Number.MAX_SAFE_INTEGER));
        }

        var xhttp = new XMLHttpRequest();
        xhttp.open("POST", "/id", true);
        xhttp.setRequestHeader("Content-type", "text/plain");
        xhttp.send("'" + localStorage.getItem('id') + "'");
      }

      function submitForm() {
        var xhttp = new XMLHttpRequest();
        xhttp.open("POST", "/form", true);
        xhttp.setRequestHeader("Content-type", "text/plain");
        xhttp.send(localStorage.getItem('id') + "," + document.getElementById("result").value);
        alert("Your response has been received! Thank you for your participation.");
        document.getElementById("result").value = "";
      }
    </script>
    <p style="text-align:center"></p>
    <p style="text-align:center"><textarea id="result" rows="16" cols="62"></textarea></p>
    <p style="text-align:center"><button onclick="submitForm()">Submit</button></p>
    <p style="text-align:center;font-size:50%;">
      <br><br>
      This page is part of the graduation project of Yasaman Mavvaj.<br>
      <br>
      Any data we gather will be completely anonymous and kept strictly confidential to TU Delft and the parties who help us run this website.<br>
      We promise never to share your data with any other third parties, nor to use your data for any reason other than this graduation project.<br>
      For more information you can reach me at <a href="mailto:y.mavvaj@student.tudelft.nl">y.mavvaj@student.tudelft.nl</a>
    </p>
  </body>
</html>
```


APPENDIX C

Submitted forms via website

23/May/2019

11:14:38",5145106393530643,Ummmmmmmm... I had a feeling it was for something... Curiosity

13:54:08",6672450542046912,Impulsive tendencies

16:07:17",2059259490425249,It was a mystery I wanted to solve

16:08:15",5542876464120655,A QR code is like a mystery which you can 'solve', so i scanned it to find out what was behind it.
Also, it is big and had contrast with the environment so it stands out.

17:24:00",7299915256004875,Curious

17:49:19",719136411266770,I stopped to look at the toilet right next to it. Then I saw the big canvas, and the barcode (If the iPhone didn't do this automatically I would have not bothered to download an app and scan) and sensor, and I thought, ooo there must some digital art going hidden in the ether here ;) whatever it is, I like it. Just for the sake of the interaction. Also, kudos for the local server.

24/May/2019

10:43:28",3573808765009359,Yeaaay

14:34:39",4757347057806888,It stands out for it's simplicity

14:34:58",7785840742796500,My friend

15:46:09",6116308170981378,Het lijkt licht te geven

15:51:37",1513730342844780,Big QR and pink

15:52:57",2852045504852259,I want to know what frame you used

16:30:41",8066699836619489,The canvas

16:59:07",7236928205616434,The bright orange colour- I love it! :) plus plain curiosity!

17:28:19",4684195100155853,Curiosity

17:52:21",1721508959152120,Feels like an art installation

29/May/2019

12:16:42",3523054311556279,Curiosity I guess. The fact that there's a big blank space . But also I was boated and had free time to be distracted. I was also hopping to get some info on the women toilet thingy.

12:22:58",5159345065842112,Study mate as advocaten said, did you scan the code?

13:47:40",2284760880870866,The lighting of the screen and the whitboard not being a whiteboard

14:59:52",5172503302800025,The camera

15:32:05",83872787911097, I wonder where is the projector that changes colours

15:45:02",8660539471871245,Someone asked me" do you know what that qr code is for?" So checked
16:30:24",5941043821915880,It's big, and there's light , no ves obstruction

16:30:32",4725742955875910,In the middle of IO. It has lights and it is big

16:44:41",4798494454395938,The size

16:47:47",4080242944338735,I am triggered by QR codes in general so out of curiosity I had to scan it :)

17:50:42",5492912777669749,I liked the pink Color that i saw the first time, but this time was even

03/Jun/2019

more intriguing the changing of the color without a recognizable Pattern

17:53:12",366117082753507,I was not sure if The colour changed yes/no. If it was a screen. I scanned it to find out.

11:08:44",1017513615581352,It's big and colourful
11:15:53",8795392906568824,I'm curious.

It's human to be curious.

I'm also curious about the data you collect - it looks like you're recording a video? How does this comply with GDPR Regulations? What other stuff are you collecting? I haven't given you consent yet.

What are your intentions with the data? Where are you storing the data and is it encrypted? Have you had your human ethics approved by TU delft and can I see if?

13:40:58",577619300782249,The lights changing

13:51:20",6212492941536975,I was intrigued because there was only the qr code, so I was curious to know where it would lead

13:51:46",5904314163368987,The fact that a big empty screen with only one object - a very recognizable image - is setup in a further mostly empty area (in pathway in the hall)

14:51:52",4214056087357539,the blank board

15:16:40",6576738674381205,Curiosity

17:07:44",1113847177743737,The colour, the mystery

and I wanted to know if the thing was a screen or a painting of sorts

17:31:27",8824293898743187,Big screen with a qr code... No context. So was curious

17:42:14",589149843428030,Code couldn't be overseen and I was curious what the code stands for.

05/Jun/2019

11:09:09",8069575212503431,I thought a beamer was casting on the screen, but I couldn't see a beamer and put my hand in front of the screen there was no shadow. I walked to the toilet, wondering what it was and maybe thought it was an interactive installation due to the camera above. When I came back I decided to scan the QR code and thought I maybe could start the session there.

11:17:37",2722328095998497,Nieuwsgierigheid

12:47:54",3788441154527261,I was having lunch

13:43:04",5892032387915929,Someone said to me: don't you want to scan the code? So I did. I tink the camera is sort of disturbing and the emptiness also triggered me.

13:53:08",7550702138321678,I was curious if something would happen on my phone or on the screen, but i'm rather dissapointed nothing happend. And i'm curious if you violated my privacy by filming me?

15:33:31",3071074507018913,Plenty off plain white background, clear floor space around the screen, prominent location

15:48:29",8259369118141545,Why is the screen lit

up? I was hoping that something would happen to the screen when I scanned the QR-code

17:02:24",5911941096439647,I wanted to scan the QR code just for the sake of it. Also the lit backdrop caught my eye.

06/Jun/2019

10:43:34",6636592191395907,Seeing it in the middle of the space for multiple days. I got curious.

12:32:55",7051966933957701,Cool

13:30:47",3826115657320337,I was curious, I though it was a game. The light triggered my attention

13:30:53",3826115657320337, I was looking forward to see something interesting after scanning

17:42:13",125039034087505,Deception

07/Jun/2019

10:45:26",7693313134360430,Colorrrrr

11:33:31",3524784974306569,It's on a big screen with coloured lights. I'd hoped it to be more interactive with the recorder on top

14:13:06",7534382602104613,My friend

14:13:52",6719929825089580,Curiosity. The board has been (electronically) active for quite a while and I started wondering why.

15:11:31",2490023183466565,My teammate got distracted/annoyed by the screen flashing behind me. I hoped to be able to turn it off

15:48:23",5580726735010290,Someone said to do so

16:34:23",7511253276364459,Adam forced me to, cause he doesn't have a QR scanner.

17:07:56",658282424442647,The change of colour

18:27:03",2564245271500183,No one was around and it was there for a week
Listened to a friend talk about it

APPENDIX D

```
#!/usr/bin/python3
# -*- coding: utf-8 -*-
## Project: Visualization
##
## @file visualize.py
## @brief
```

```
import pygame
import skimage
import numpy
from scipy.ndimage.filters import gaussian_filter
import sys
import sched, time
import subprocess
import os
import random
import math
```

```
width = 800
height = 480
bg_color = (20, 20, 20)
fps = 24
duration = 10
```

```
n_frames = duration * fps
```

```
ffmpeg_cmd = ['ffmpeg',
               '-f', 'rawvideo',
               '-codec', 'rawvideo',
               '-s', '%dx%d' % (width, height),
               '-pix_fmt', 'rgb24',
               '-r', '%d' % fps,
               '-i', '-',
               '-an',
               '-vcodec', 'mpeg4']
```

```
def save_frame(ffmpeg, screen):
    frame = pygame.image.tostring(screen, "RGB")
    ffmpeg.stdin.write(frame)
    ffmpeg.stdin.flush()

def gen_edge(start_color, end_color, w, h):
    """Generate gradient edges."""

    s = pygame.Surface((w, 1)).convert_alpha()
    dd = 1.0/w
    sr, sg, sb, sa = start_color
    er, eg, eb, ea = end_color
    rm = (er-sr)*dd
    gm = (eg-sg)*dd
    bm = (eb-sb)*dd
    am = (ea-sa)*dd

    for x in range(w):
        s.set_at((x, 0), (int(sr + rm*x), int(sg +
gm*x),
                                int(sb + bm*x), int(sa
+ am*x)))

        right = pygame.transform.scale(s, (w, h))
        left = pygame.transform.flip(right, True, False)
        return right, left

def draw_line(screen, x, w, color, blur, magic):
    """Draw a line on the screen."""

    center = pygame.Surface((w + magic, height),
pygame.SRCALPHA)
    center.fill(color)
    screen.blit(center, (x - w/2, 0))

    imgdata = pygame.surfarray.array3d(screen) / 255
    blurred = numpy.rint(skimage.filters.
gaussian(imgdata, sigma=blur) * 255)
    pygame.surfarray.blit_array(screen, blurred)

def aggregate(screen, t):
    # Constants:
    w = 10
    x = width/2
    color = (255, 255, 255)
    alpha = 255
    blur = 2

    # Variables:
    if t % 10 == 0:
        x = random.randint(0, width)
        draw_line(screen, x, w, color + (alpha,),
blur, 0)

def size(screen, t):
    # Constants:
    x = width/2
    color = (255, 255, 255)
    alpha = 255
    blur = 7
```

```
# Variables:
w = 2 + (t / n_frames) * 150
draw_line(screen, x, w, color + (alpha,), blur, 1)

def blur(screen, t):
    # Constants:
    w = 150
    x = width/2
    color = (255, 255, 255)
    alpha = 255

    # Variables:
    blur = 30 - (t / n_frames) * 25
    draw_line(screen, x, w, color + (alpha,), blur, 0)

def intensity(screen, t):
    # Constants:
    w = 150
    x = width/2
    color = (255, 244, 229)
    blur = 20

    # Variables:
    alpha = 200 - ((t / n_frames) * (255 - 100))
    draw_line(screen, x, w, color + (alpha,), blur, 0)

def saturation(screen, t):
    # Constants:
    w = 150
    x = width/2
    alpha = 255
    blur = 15

    # Variables:
    red = 255
    other = 205 - ((t / n_frames) * (255 - 50))
    draw_line(screen, x, w, (red, other, other,
alpha), blur, 0)

def color(screen, t):
    # Constants:
    w = 150
    x = width/2
    alpha = 255
    blur = 15

    # Variables:
    red = 255 - ((t / n_frames) * 255)
    blue = ((t / n_frames) * 255)
    draw_line(screen, x, w, (red, 0, blue, alpha),
blur, 0)

def motion(screen, t):
    # Constants:
    w = 100
    color = (255, 255, 255)
    alpha = 255
    blur = 15
```

```

# Variables:
x = width + w - (t / n_frames) * (w*2 + width)
draw_line(screen, x, w, color + (alpha,), blur, 0)

var_x = (width - 200)/2
def variation(screen, t):
    global var_x

# Constants:
w = 50
color = (255, 255, 255)
alpha = 255
blur = 15

# Variables:
s = 10
dir = -1
if int(t / fps) % 2 == 0:
    dir = 1
x = var_x
var_x = var_x + dir*s
draw_line(screen, x, w, color + (alpha,), blur, 0)

var_x2 = (width - 50)/2
var_ir_dir = 1
def variation_ir(screen, t):
    global var_x2
    global var_ir_dir

# Constants:
w = 50
color = (255, 255, 255)
alpha = 255
blur = 20

# Variables:
s = 10
if t % 10 == 0:
    var_ir_dir = random.randint(0, 1)
    if var_ir_dir == 0:
        var_ir_dir = -1
x = var_x2
var_x2 = var_x2 + var_ir_dir*s
draw_line(screen, x, w, color + (alpha,), blur, 0)

rhythm_x = -100
rhythm_speed = 1
def rhythm(screen, t):
    global rhythm_x
    global rhythm_speed

# Constants:
w = 100
color = (255, 255, 255)
alpha = 255
blur = 15
accel = 1

```

```

# Variables:
speed = 400
x = rhythm_x
rhythm_speed += accel
rhythm_x += rhythm_speed
draw_line(screen, x, w, color + (alpha,), blur, 0)

def run_animation(animation, ffmpeg, screen, clear, frame):
    for event in pygame.event.get():
        if event.type == pygame.QUIT:
            sys.exit()

    if clear:
        screen.fill(bg_color)

    animation(screen, frame)
    pygame.display.update()
    save_frame(ffmpeg, screen)

def save_animation(animation, screen, clear):
    file_name = 'animation/%s.mp4' % animation.__name__

    if os.path.isfile(file_name):
        os.remove(file_name)

    ffmpeg = subprocess.Popen(ffmpeg_cmd + [file_name],
                               stdin=subprocess.PIPE, stderr=subprocess.PIPE)

    for frame in range(n_frames):
        run_animation(animation, ffmpeg, screen,
                       clear, frame)

    ffmpeg.stdin.close()
    ffmpeg.wait()

if __name__ == '__main__':
    """Entry point of the program."""

    # Initialize the pygame module
    pygame.init()
    pygame.display.set_caption("Visualize")

    # Create the surface
    screen = pygame.display.set_mode((width, height))

    save_animation(intensity, screen, True)
    save_animation(saturation, screen, True)
    save_animation(aggregate, screen, False)
    save_animation(size, screen, True)
    save_animation(blur, screen, True)
    save_animation(motion, screen, True)
    save_animation(rhythm, screen, True)
    save_animation(color, screen, True)
    save_animation(variation, screen, True)
    save_animation(variation_ir, screen, True)

```