# A context aware dynamic lighting system for the SmartXp

Creative Technology Bachelor thesis by

Jeroen Jansen van Rosendaal

Supervised by

Ir. Ing. R.G.A. Bults

Dr.ir. E.J. Faber

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# Abstract

The goal of this project was to research how to develop a context aware dynamic lighting system that suits the different use cases of the Smart experience laboratory, SmartXp in short. The SmartXp is a large room or hall, at the University of Twente (Zilverling building), that acts as an education and research facility for EEMCS students and researchers. It hosts different use cases, like lectures, selfstudy, projects, etc.
The project was split into two parts, one of which focussed on the technical aspects of developing such a system, the other on all aspects related to human factors, e.g. the influence lighting conditions have on users and which conditions are preferable in each use case.
This thesis was written focussing on the technical part of development. The SmartXp currently features a system that sets lighting conditions according to eight different use cases, based on information from the schedule of the SmartXp or from a user input interface that acts as a manual override.

# Acknowledgements

Thanks to Heleen Kok for being a reliable project partner, who took on the part of this project which was related to human factors and whose work integrated seamlessly with mine throughout the course of our graduation semester.

Thanks to A.P. de Vries, SmartXp technician, who was very helpful in sourcing hardware components and teaching me how to operate the lighting trusses and wire DMX cables.

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# 1. Introduction

At the University of Twente in Enschede, the Netherlands, the study Creative Technology (under EEMCS faculty) makes use of the Smart experience laboratory, the SmartXp in short. This education and research facility is used for several different use cases[1]. According to the client, the EEMCS faculty of the University of Twente, the SmartXp is meant to be a place where Creative Technology students can come together, be educated, develop interesting ideas and host events. The SmartXp needs to be an attractive, pleasant, productive and creative environment. Example use cases of the SmartXp are workshops, lectures, project supervised, project unsupervised, study, meeting, activities.

In order to host these different activities, the SmartXp is divided into four sections. Three trusses, which are metal structures used to mount lighting and audio equipment, divide the room into three rectangular sections. The fourth section is a balcony that spans alongside all three trusses, over the length of the SmartXp. Several use cases may be happening at the same time, but despite of the room division there is often unclarity about what use case is desirable, or even allowed, in each section. This unclarity often leads to unwanted or disturbing behaviour; for example, noise from one use case, like having a conversation while studying, may cause noise complaints from other students that are trying to follow a lecture. Another frequently observed example is when students sit down at tables in the ‘lecture’ truss before and without realizing a lecture will start later on. This causes nuisance to them or to those involved with the lecture, because they will either be sitting in a lecture area when they shouldn’t, or they need to pack up and move.

An advanced theater lighting system is present in the SmartXp but unfortunately not used to its full potential. The operation of the lighting system takes effort and requires an understanding of DMX[2] theater lighting protocols and controls and there is no proper lighting plan for specific use cases. The goal of this project is to research how to utilize the present lighting system to turn the SmartXp into an environment that suits different use cases and does so by being context aware; essentially sensing what is the current use case and using the lighting to help steer the behaviour of occupants of the SmartXp to prevent the aforementioned conflicts and optimize lighting conditions for the ongoing use case(s). Therefore the research question, followed by three sub-questions for this paper are:

- How to develop a context-aware lighting system that supports the different use cases of the SmartXp?

- What are the SmartXp’s use cases?
- Which generic light plan can be used for all SmartXp use cases?
- What light conditions are best suitable for each use case?”.

The structure of this thesis is so that its chapters relate to the phases in which the project was executed. It starts with a literature review to deepen the understanding of the topic in chapter 2. After background research the used methods and techniques are described in chapter 3, followed by four chapters that describe the execution of the project; 4. Ideation, 5. Specification,

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[1] A use case describes a discrete, standalone, activity that an actor can perform to achieve some outcome of value.

[2] Digital multiplex protocol makes use of a string containing 512 channels (max.). All light fixtures are daisy chained so the signal reaches each fixture. A fixture may use several channels to receive data, see chapter 5.1.1.

6. Realisation, 7. Evaluation. The project and thus thesis is then settled by a concluding chapter 8.

# 2. State of the Art on lighting systems

In order to create a lighting system that caters the needs related to different use cases, it is imperative to gather knowledge about existing light systems and the effects that light can have on human behaviour, moods and wellbeing. This is achieved by taking human factors and ergonomics regarding lighting into account, not disregarding possible (ethical) issues that such a lighting system may induce. Furthermore, for the system to be able to adjust lighting to the required use case, it needs to be able to determine what this use case is by using contextual information. In this chapter, existing work regarding these aspects is discussed, and the gained insights are used to study what lighting conditions and light plans may fit the SmartXp's use cases.

## 2.1 Effects of lighting on creative performance

The quantity of light, also referred to as brightness, and the quality of light, which can be defined as the level to which light is evenly distributed,  have an impact on creativity[3], but research shows different views of the effect's emergence. Steidle et al. [1] found that dim illumination and priming darkness have a positive effect on creative performance, due to the subject experiencing a feeling of freedom from constraints. In contrast, Ceylan et al. [3] showed that creative performance is optimal under bright lighting conditions . McCoy et al. [2] conducted studies on the impact of environmental factors on creative performance and came to the conclusion that neither quantity nor quality of light have a significant effect on creativity .
It may seem that these three studies have opposite claims, whereas upon closer inspection it turns out they do not necessarily disagree. Steidle et al. [1] found that the positive effect on creativity was limited by light setting and the stage of the innovation process in which they measured creativity. The darkness-related increase in creativity disappeared when using a more informal indirect light instead of direct light, or when evaluating ideas instead of generating creative ideas. What Ceylan et al. [3] found was that when focussing on generating ideas, where a manager had to solve a difficult task, brightly lit offices elicited a feeling of being free from constraints. These offices were in fact, indirectly or evenly lit, a condition which, according to Steidle et al. [1] caused darkness-related increase in creativity to disappear. This means that when using direct lighting, creativity can be influenced positively if the surrounding area is relatively dark and the light isn't too bright and that when using indirect or evenly distributed lighting, a higher brightness is desirable to stimulate creativity.
When comparing that conclusion to the study by McCoy et al. [2], in which they found no significant positive correlation between the quality nor the quantity of light and creativity, their results do show similar results to those of  Ceylan et al. [3]. Both show that there is a  negative correlation between the brightness of lighting and the level of visual detail [2] or complexity [3], which are similar concepts. This means that if a room is brightly lit, the complexity or amount of visual detail should be low and vice versa, for the highest creativity rating.

[3] Creativity is generally defined as the production of novel and useful ideas as well as problem solutions and refers both to the process of idea generation and the idea itself.

These two studies also had different results regarding colour, as McCoy et al. [2] suggest warmer colours and Ceylan et al. [3] suggest cooler colours to have a positive effect on creativity. Differences in colour temperature may have to do with managers feeling that warm colours have too much of a stimulating effect [3]. This may be related to managers generally being in a different age group and having different priorities in their creative process compared to students. This is in agreement with what Ceylan et al. [3] hypothesize with regards to the difference between their findings and those of McCoy et al. [2], they differ due to a number of reasons:

> "*McCoy and Evans also studied the creativity potential of physical environments by analyzing a large set of physical characteristics. However, they studied educational environments (classrooms, hallways, libraries, etc.) for undergraduate students. Although both studies showed that windows are associated with high creativity potential, the other physical elements that were measured in both studies (complexity, light, color, plants, natural materials and furniture) showed considerable differences. Probably, the two studies are not comparable in terms of study population (managers versus students), environment (offices versus educational environments), cultural differences (Turkey versus United States), and methodological differences. If and how these differences between the studies can explain the differences in the environment–creativity potential relationship is still unclear and open for further exploration after replication studies have become available. One (theoretical) reason for the difference between the results of both studies may be that it is difficult to compare studies on the effect of physical characteristics if the range of levels of physical characteristics is different.*"

Ceylan et al. [3] are not sure what causes the differences, but they do point out that there are many factors which can have an influence on test results, having to do with testing environments, users, research methods and cultural differences. They also point out that both they and McCoy et al. [2] found that windows have a distinct positive correlation with creativity. Despite of having many differences between study results, it is clear that the desired brightness of light shows correlation with both the type of lighting, which can be direct or indirect, and many surrounding factors, of which an important one is environment complexity. The studies performed by Steidle et al. [1] and McCoy et al. [2] show the most promising results for application in the SmartXp, especially because McCoy et al. tested with educational environments. However, it is important not to disregard the findings of Ceylan et al. [3], because it shows that differences in tasks performed, culture and other aspects may lead to different results. This is relevant because the SmartXp hosts users from different nationalities, who perform various tasks, that may show different preferences regarding brightness, distribution of light, natural light, etc. Furthermore the SmartXp has a varying amount of visual complexity per area, within the room itself and depending on what is required, which can cause differences in desired brightness of lighting.

### 2.2 Lighting ergonomics and ethics

When it comes to including users in the design of the context-aware dynamic lighting system, a further look into ergonomics of light shows that light can influence the human mind and body in several ways. Afshari et al. [4] highlight the following human-related aspects in lighting;

> "*The human eye and body responds to light in a complex fashion. Light not only affects vision, but also the circadian rhythm, mood and perception*."

In line with Küller et al. [9] and according to Figueiro and Rea [10], a lack of short wavelength light (blue) in the morning negatively influences the sleeping patterns of students, thus increasing the amount of short wavelength light in the morning may improve students' sleeping habits.

Two other studies by Sleegers et al. [11] and Hathaway [12] conclude that bright fluorescent lighting has positive effects on students' concentration, attendance and achievements, Hathaway [12] even claims the fluorescent light test group had less dental cavities forming than under regular classroom lighting. Combining this with the creativity-related aspects mentioned, there are plenty of human-factors that can and need to be taken into consideration when designing a context aware dynamic lighting system for the SmartXp.

Students are not the only users of the SmartXp and of this system, but are the main target users, because influencing their behaviour is important to other stakeholders.For example, lecturers, researchers and others working in the SmartXp can benefit from behaviour-steering lighting on students. Example ideas on this are; "Lecturers can use the system to monitor or even increase student attention levels with light colours or patterns.","Researchers that reserve a section of the SmartXp to work in may be able to increase their focus by using appropriate lighting colours and/or direct lighting and may also be able to highlight their area as 'theirs' so that they can work unbothered by students that are unaware of the reservation." "SmartXp manager/technician A. de Vries may benefit from the system by letting it use and steer student behaviour, so he can focus on his most important tasks."

The lighting system in the SmartXp will make use of different context sources in order to determine use cases and then use this information to change lighting conditions to an optimum. This comes with several potential issues, regarding privacy especially. If the system uses data such as user location, internet activity (with regards to 'if' and 'when', not 'what'), camera feeds, schedules, or any other kind of context information, users may feel uncomfortable or upset knowing that they are being monitored by the system. It is imperative to not only use as little as possible personal or identifiable user data, but also to create transparency when it comes to informing users, so that they know what the system knows about them and how it is used. Further specifics of informing users still need to be looked into.

Another aspect of the system that may cause concerns in users, is the effect that the lighting conditions have on their behaviour or wellbeing. To determine to what extent it is morally acceptable to influence behaviour, further research in the form of surveys, interviews or user tests need to be performed, not disregarding any minority user groups that may have severe issues with regards to the system.

### 2.3 Features of a context-aware dynamic lighting system

An context-aware dynamic lighting system should be able to autonomously make decisions based on information from context sources. The adaptive, e.g. context-aware, lighting testbed system developed by Afshari et al. [4] had a number of functionalities; colour control, energy efficiency and localization, self-commissioning and human-factors. These are the main aspects of their lighting system, but they also make a good candidate to form the base of any such system, including that of the SmartXp.

Colour control serves the purpose of adjusting lights so that the colour is optimal for the required use case. Light colour can have an influence on user creativity [2],[3] and affect the moods of those in a workspace, according to Küller et al.[9]. Küller et al. conducted tests in offices worldwide to determine how office workers feel under certain lighting conditions, where different preferences were observed among different cultural groups and countries.

A context-aware light system can be applied to reduce energy use from lighting, even though it has more functionalities than a regular fluorescent lighting system. Energy efficiency was not necessarily a goal or part of this assignment to create a context-aware light system for the SmartXp, but according to Afshari et al. [4] "*Energy efficiency is a key focus of smart lighting systems.*" and can be achieved by measuring daylight levels in different areas and having the system increase or decrease light intensity according to the amount of daylight.

A similar method is used by Uhm et al. [5], but they further increase energy saving (as it was their main goal) by using user-location detection with motion sensors and use a network and user-pattern mapping to determine or even predict when and where lights can be turned off within an office building. More research to develop a smart lighting system for domestic and industrial use was done by Ciabattoni et al. [6] in order to minimize energy use, the researchers emphasize that energy efficiency is a global concern and that using lighting systems that automatically adjust to make their users comfortable and save as much energy as possible is a stepping stone towards a sustainable future.

Self-commissioning functionalities are what make any adaptive or context-aware system truly autonomous. Self-commissioning, according to Afshari et al. [4], is the system's capability to react to changes in the environment. In their case lighting values are coupled to a model that ensures the correct light intensity and colour produced even if a light is moved or installed elsewhere. Such a plug-and-play method is very convenient, but in the case of the SmartXp, too limited in functionality to achieve the desired results. However, the general idea of self-commissioning, which is responding and adjusting to changes in the environment, is an important feature, if not the foundation, of any context aware dynamic light system.

A human centered design approach is key to the success of this system, because without user inclusion the SmartXp lighting system serves no purpose (, other than perhaps reducing energy use). Human-factors, or ergonomics, is a scientific discipline and design methodology aimed at designing products taking aspects of human behaviour and preference into account.

### 2.4 Context in a lighting system

In order to determine user living patterns and use cases, it is imperative to determine what context is in relation to a lighting system and measure it so that it can be used by the system to adjust lighting conditions accordingly. Context is, according to Dey [7]

"*... any information that can be used to characterise the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.*"

and Shafer et al. [8]

"*CAIEs (context aware intelligent environments) obtain context via sensors that can measure a variety of information. This information can be categorized as information about location, activity, time, and identity; or, in other words, information about "where," "what," "when," and "who.*"

Combining these definitions we are able to determine context to be the physical characteristics of people in the area, and the activities and purpose that the area hosts in relation to its users, which is information that can be measured using a variety of sensors. For example, cameras, heat sensors, colour sensors, motion sensors, device signals are sensors that can be used to determine relevant context in a lighting system [4].

Knowing what context is and being able to measure it using sensors is not all that is needed for a context-aware lighting system to determine what the lighting conditions should be. Using sensors for occupancy detection, and given a 'clever' computer system, scenario/use case detection can be applied by monitoring user location and activity [4],[5], user 'activity' can be any sensor input that determines what the user is doing. This 'clever' computer system should be programmed using sensor input to calculate light output values. Using this information the light system will adjust its own brightness, color, position, etc., depending on what the system determines to be the use case, e.g. the combination of all context values and on what the optimal lighting conditions are for the specific use case.

Sensor values for context-input and lighting output values can only be obtained by testing the system, or parts thereof, in practice. It is not possible to obtain these exact values from existing research, as there is no plug-and-play light plan or all-in-one context determining device, let alone one that is optimal for use in the SmartXp. Theory as described in this chapter, in combination with test setups will be used to base input and output values upon.

### 2.5 Lighting architecture

Plenty of literature can be found on lighting conditions like brightness and colour, and on technical aspects of sensing context and activating light, however there is a general lack of explanation when it comes to the reasoning of choosing specific locations for light sources and the effects thereof in the literature discussed thus far. It seems that most of the sources [1]-[12] chose light placement according to what areas they wanted to light for their research.

In order to create a light plan for the SmartXp an analysis must be done per use case to determine who are involved, what tasks are involved and what lighting conditions would be most suitable.

According to research discussed, and supported by research by Hawkes et al. [13], in which lighting placement is divided into ‘visual lightness’ and ‘visual interest’, these terms are used to describe perceived general brightness and variations in illumination pattern, respectively. Their research shows subjective preferences for lighting was found in rooms which had relatively high visual lightness and visual interest, but when only either lightness or interest was high, the preference disappeared. This means it is not preferable to be in rooms that are relatively dimly lit with variations in lighting, and in rooms that are evenly and brightly lit. Interesting to note is that the SmartXp is currently both unevenly and dimly lit in all cases (*Fig*. 1), as many windows are blinded and light sources are randomly scattered throughout the trusses. Combined with the high amount of visual complexity (as discussed in the first part of this chapter) that the SmartXp features with all its truss posts, tables, and all kinds of other randomly placed objects, it is evident that the SmartXp needs more light, higher brightness/visual lightness to at least compensate for its visual complexity.
In order to increase visual lightness and create a comfortable lighting plan, the architectural characteristics of the building and the transitions between areas also need to be taken into account according to Jay et al. [14].

1. Figure: SmartXp, dim and uneven lighting, image by H. Kok

### 2.6 Conclusion

Light can influence creativity in several ways, using brightness, direct or indirect light sources, and colour. When using direct lighting, creativity can be influenced positively if the surrounding area is relatively dark and the light isn't too bright. When using indirect or evenly distributed lighting, a higher brightness is desirable to stimulate creativity. Furthermore, there is evidence of a negative correlation between the brightness of lighting and the level of visual detail in the area. This means that if a room is brightly lit, the complexity or amount of visual detail should be low and vice versa, for the highest creativity rating. Another environmental aspect which proved to have a positive effect on creativity is the presence of windows or a natural view. However, when it comes to using light colour to influence creativity, the results are not conclusive. Two studies show that colours influence creativity, but their findings don't agree on whether to use warm or cool colours. A possible explanation for this is that the influence of light colours differs per task and target user group, which should be further researched with users from the target group of the SmartXp lighting system.

Colour control, energy efficiency and localization, self-commissioning and human-factors are good foundational aspects of a context-aware dynamic lighting system. Colour control serves the purpose of adjusting lights so that the colour is optimal for the required use case Energy efficiency can be optimized by making use of daylight and user living patterns, self-commissioning is an important feature, if not the foundation, of any autonomous light system and human-factors based design is key to the success of this system, because without user inclusion the system serves no purpose, other than perhaps reducing electricity usage.

In order to determine user living patterns and use cases, it is imperative to determine what context is in relation to a lighting system and measure it so that it can be used by the system to adjust lighting conditions accordingly. Context can be described as the physical characteristics of people in the area, and the activities and purpose that the area hosts in relation to its users, which is information that can be measured using a variety of sensors and by interpreting schedules. This sensor output needs to go through a computer system that is programmed to determine from the context parameters what the current use case is and how the lighting should be adjusted accordingly.

Furthermore, architecture is found to have a significant influence in the way that lighting is perceived by users. Research showed It is generally not the preference of test subjects to be in rooms that are relatively dimly lit and have variations in lighting, and in rooms that are evenly and brightly lit. The lighting in the SmartXp is currently rather dim and has plenty variation. The SmartXp also has a high amount of visual complexity. These aspects would suggest that the SmartXp is not a desirable environment with regards to lighting conditions combined with architectural features.

The purpose of this literature review was to gather knowledge about existing light systems and the effects that light can have on human behaviour, moods and well being in an attempt to answer the research question and its sub-questions:

- How to develop a context-aware lighting system that supports the different use cases of the SmartXp?

- What are the SmartXp's use cases?
- Which generic light plan can be used for all SmartXp use cases?
- What light conditions are best suitable for each use case?".

The research question of how to develop such a system, was not answered by this literature review. Even though many of the aspects and features that are involved with such a system were reviewed, the question and proposed project remain novel. There is no clear answer to the main question and none of the sub-questions were answered. Some of the use cases of the SmartXp are evident and were identified by the client, however more could be found through practical research. There is no plug-and-play light plan, nor a set of lighting conditions found in existing research that can be applied directly to the SmartXp's use cases.

# 3. Methods and Techniques

In this chapter the methods and techniques that are used during the development of this project are described, including the model used to structure the project as a whole followed by techniques that were used to realise different aspects of the project..

## 3.1 Creative Technology design process

This project is executed conforming guidelines for development as generally prescribed for graduation projects of Creative Technology students. These guidelines are designed by Mader & Eggink [15] and consist of a four-phase flow model, as depicted in *Figure 2*. These phases are ideation, specification, realisation and evaluation. The phases are designed to structurize the design process into a per-phase exploration of possible approaches and solutions. Its aim is converging many broad ideas into a single executable product, streamlining the design process, with the possibility to re-iterate in each phase.

### 3.1.1. Ideation phase

The ideation phase is an explorative process in which research questions are shaped into potential approaches and ideas for project development. As this is the first phase of development it is key to take into account existing knowledge in the field and base development choices on existing findings combined with newly gathered information. The ideation phase consists of brainstorm sessions (see 3.2), analysis of stakeholders (see 3.3), determining use cases, applying theories from literature, determining suitable and available hardware and setting preliminary requirements (see 3.5). This phase ends with clear ideas for possible solutions, that will be further specified and made ready for execution in the next phase.

### 3.1.2. Specification phase

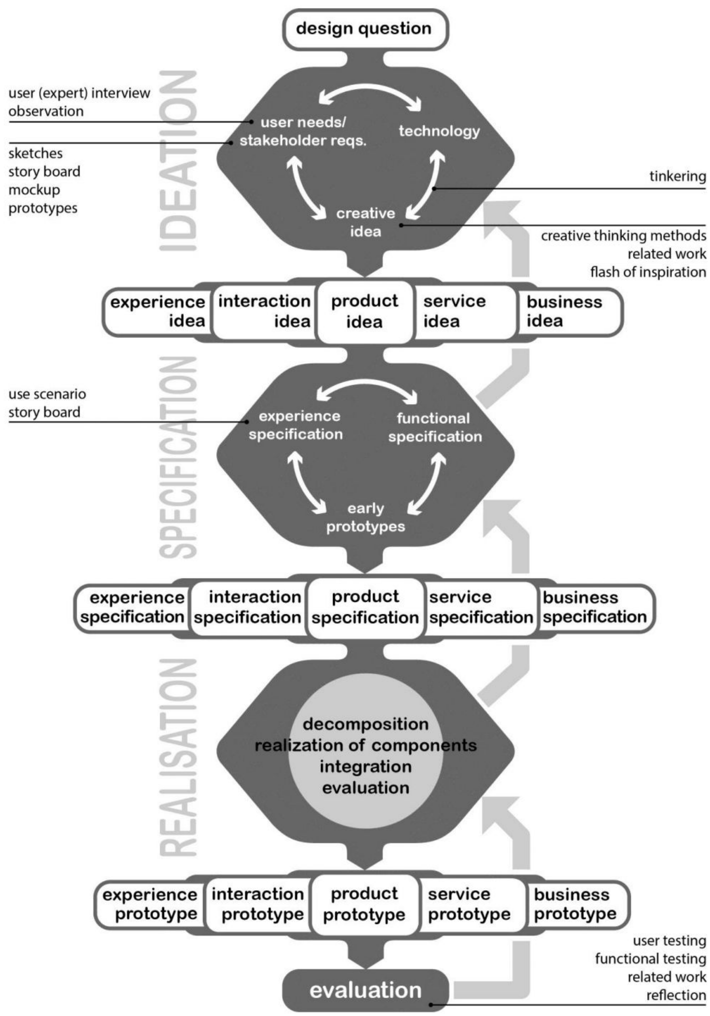
In the specification phase the ideas from the previous phase are specified to the extent where they are ready to be implemented as system features.  System requirements are determined and those that must be included for the system to be usable are used to design system functions and create executable plans for realisation.

### 3.1.3. Realisation phase

In this phase a prototype of the system as specified in the previous phase is built. As system design now shifts from high-level to low-level design, final choices are made regarding hardware implementation and software design. In the realisation chapter of this report any deviations from the original specification are discussed, design choices explained and functional diagrams included.

3.1.4 Evaluation phase

The evaluation phase serves the purpose of checking whether the built prototype meets the set requirements. There are two types of evaluation; functional evaluation and user evaluation. Functional evaluation is used to assess whether all system components work as designed and any deviations are discussed. User evaluation is used to assess whether users can operate the system as designed and whether the system affects them according to predictions and requirements. Both types of evaluation are performed on this project. The user evaluation is performed by Heleen Kok as her part of the project requires focus on user inclusion. The functional evaluation is performed by the author and is discussed in this paper.




2. Figure: Mader Eggink model

### 3.2 Brainstorm techniques

Two techniques are used for brainstorming; free-form brainstorming and mind map brainstorming. Free-form brainstorming is used throughout the entire project, mostly between project partner Heleen Kok and me, and occasionally our supervisor R. Bults. The purpose of free-form brainstorming is to quickly generate ideas to solve certain problems that are encountered and to synchronise any differences between the ideas on approach between us. The other brainstorm technique used, mind mapping, serves the purpose of structuring existing knowledge into an insightful graphic display and to generate ideas within the same structure. First, a main concept is written down, then sub-concepts are written down around it, connecting concepts with lines to indicate their relations. The process is repeated per sub-concept until participants agree that the mind map exists of an extensive enough expansion of sub-concepts. This leaves a semi-structured 'map' of concepts and categories to which new ideas and concepts can be added.

### 3.3 Stakeholder identification and analysis

An important aspect of product design is identifying and gaining insight in the roles of any person or group involved in the project.The identification of stakeholders is done through means of previously described the mind map brainstorm, where a category 'people' consists of types of stakeholder who have any sort of connection to the project.
In the actual stakeholder analysis, these (groups of) people are individually analysed and their role in the project is categorized as 'System users', 'Supervision and support', 'Project developers', or 'Otherwise affected'. This is the author's take on Sharp's stakeholder categories [20], 'Users', 'Developers', 'Legislators' and 'Decision-makers'. The differences are that 'Legislators' are omitted as they are not dealt with in this project, an extra category is added for those who are affected by the system without a meaningful role to its development, and 'Decision-makers' is re-named 'Supervision and support' to also include supportive stakeholders that don't make ultimate decisions in project development.
Each stakeholder is displayed in an interest-influence matrix [21], which is a stakeholder mapping method. This type of matrix consists of two axes along which the stakeholder's level of interest is rated from low to high on the horizontal axis, the stakeholder's level of influence is rated from low to high on the vertical axis. Each stakeholder is represented in the matrix and falls in either one of four quadrants of the matrix. The four quadrants of the matrix are 'monitor', 'keep informed', 'manage closely' and 'keep satisfied'.

### 3.4 Survey

A cross-sectional group survey is performed among users of the SmartXp in order to determine what activities they perform in the SmartXp. The aim of the survey is qualitative, as the main interest is determining the different types of activities users perform in the SmartXp. However, internet based social medium *Facebook* [22] is used to perform the survey *Appendix 2* as it provides easy access to the target group without requiring physical presence, and quantitative data is automatically gathered by Facebook’s polling system. This data is also useful as it provides insight to priority use cases. Another advantage of Facebook’s polling system is that it allows for users to add (use case) entries that other respondents can also select.

### 3.5 Requirements analysis

In the ideation phase, some preliminary requirements are theorized by applying knowledge found in literature to key aspects of use cases. These aspects are related to the purpose of the use case, e.g. who does what, spatial layout, user tasks, focal points and natural light available. The preliminary requirements consist of a description of system design choices that would optimize conditions per use case. The requirements are categorized according to the MoSCoW [23] method as ‘must have’, ‘should have’ and ‘could have’ so that priorities are clear throughout the project. Often included in MoSCoW analyses are ‘won’t have’ requirements, however these are not specified for this project. In the specification phase these requirements are converted to functional requirements by determining what hardware and software implementations are required to be able to meet them. The final requirements set in the specification phase are either met or not met during development in the realisation phase, which is checked in the evaluation phase.

# 4. Ideation

This chapter describes several steps that were taken to identify all parties involved in the project, what kind of use cases the SmartXp hosts that should be taken into account in the system, what opportunities exist to create a context-aware system, and what requirements should be met during the development of this system.

### 4.1 stakeholder identification and analysis

In a preliminary brainstorm session Heleen Kok and I drew a mind map, which can be found in appendix 1, which featured a category ‘people’. A number of stakeholders were identified, whose roles can be categorized under ‘System users’, ‘Supervision and support’, ‘Project developers’, or ‘Otherwise affected’. This chapter discussed each of the identified stakeholders, describing their role, interests and influence (*Figure 3*) on project development, ending with a table-form summary in *Table 1*.

#### 4.1.1 Students

Students play a big role in the development of this project, as the focus of the project is developing a lighting system that supports use cases of the SmartXp, most of which they are likely the main participators, making them *system users*. To a certain extent, they will also be consulted in the design process when it comes to use case determination, requirements analysis and user evaluation (performed by Heleen Kok). It is important to note that even though they have a relatively high level of influence, see *Figure 3*, their influence is indirect. Even though the success of the project largely depends on the wellbeing students and fulfillment of the requirements of students’ use cases, they can not autonomously make decisions in project development.

#### 4.1.2 Lecturers

Workshops, lectures, lunch lectures and hybrid forms of teaching or assistive teaching are part of the SmartXp’s daily business and are part of the *system users*. Aside from students being taught, the system affects those teaching, assisting and presenting both directly and indirectly. They are affected by lighting conditions themselves through all kinds of conscious and subconscious (human) factors, but also by the effects that lighting have on the behaviour of students present in the room, whether they are students that are part of the teaching event or not. They will have influence on the project as they need to work with it and benefit from it, meaning they should indicate desired student behaviour (to Heleen) and lighting positions may also be set accordingly.

#### 4.1.3 Researchers

Even though it doesn’t happen on a daily basis, the SmartXp offers facilities and room for all kinds of experiments, regarding robotics (including drones), virtual reality, motion controls and more. They fall in the category ‘*otherwise affected*’ as their use cases aren’t regularly

encountered and differ in specification per researcher, which is too unpredictable to take into account when designing lighting conditions and a light plan.
However, having identified such a stakeholder indicates there are at least some situations in which the system will likely have to be manually set to neutral lighting conditions as to not disturb their activities, which is also an indication of their potential interest in- and influence on the way the system operates.

### 4.1.4 Technician

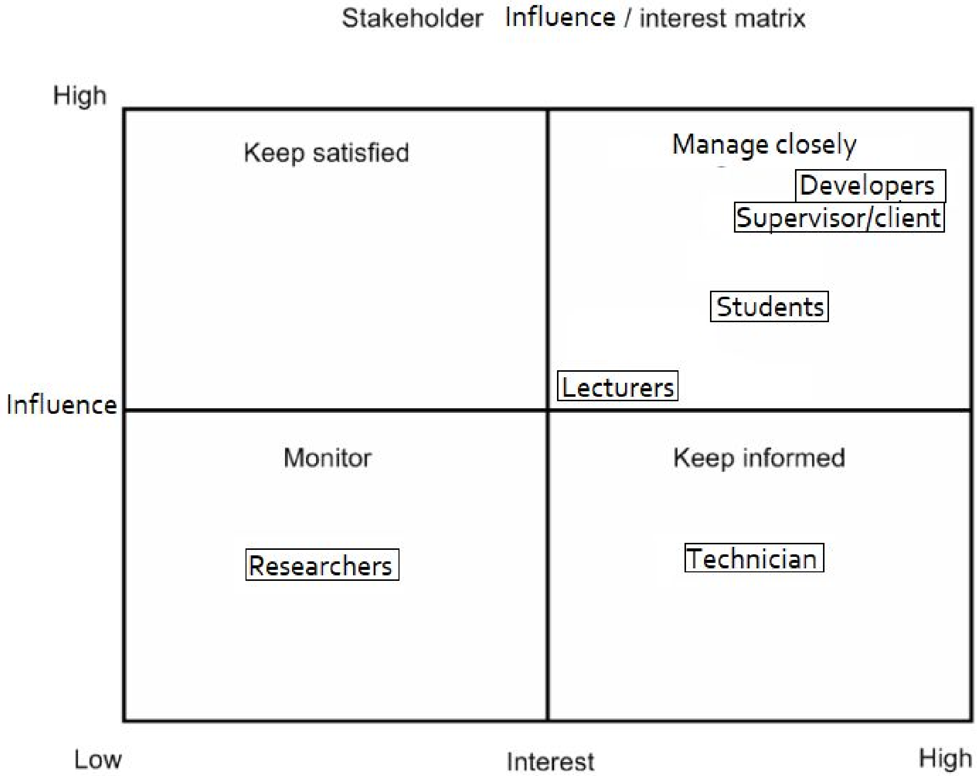
Alfred is a faculty employee who supervises the SmartXp and assists students with technical issues and is thus part of *supervision and support*. Before the development of this system, he used to manually set each light's colour and brightness to values he deemed suitable for the SmartXp. He will play a significant role in both the development and use of the system, as he is knowledgeable on the cable routing and signal distribution for the system used prior to this project. Furthermore he will be responsible for placing orders of any hardware equipment required for the development of the project.

### 4.1.5 Supervisor and client

As the supervisor of this project Richard Bults represent the EWI faculty (client) when it comes to the development of the project. The faculty is in supervision of the system as this project was commissioned with the purpose to improve the SmartXp as a pleasant and stimulating educational facility to its students. The client/supervisor is the main stakeholder of the project, with a very high level of both interest and influence, and is part of *supervision and support*, with a strong say in the *developers*' area.

### 4.1.6 Developers

Heleen Kok and I are the leading figures in this project, we brainstorm and discuss most design choices, with her focus on human factors and mine on system functionality.




3. Figure: Stakeholder Influence - interest matrix

1. Table: Stakeholder analysis summarized

| Stakeholder | Role | Interest | Level of influence |
|---|---|---|---|
| Students | System user | Positive effect on performance and wellbeing | Medium/high |
| Lecturers | System user | Positive effect on student behaviour | Medium |
| Researchers | Otherwise influenced | Non-disturbing lighting conditions | Low |
| A. de Vries | Supervision/support | Safety, suitable hardware, ease of use | Low/Medium |
| EWI and R. Bults | Supervision/support | Meeting project goals and guiding project developers | High |
| H. Kok and author | Project developers | Meet project goals | High |

### 4.2 Use cases of the SmartXp

The SmartXp hosts many different activities, which can be categorized under a number of use cases. In this chapter the use cases are identified, after which the results of a brainstorm session on the implementation of each of these use cases is summarized.

#### 4.2.1 Determining use cases

As recommended in chapter 2, a survey was performed with SmartXp users to confirm the evident use cases mentioned before and to discover use cases that were unthought of thus far. The survey was performed through a poll on Facebook[22], on the pages of the study Creative Technology, on the page of the study association of Creative Technology, and on the page of the Creative Technology class of 2017 page. In this poll the respondents could indicate several use cases, and also add more use cases for others to vote on. The results in *Table 2* show that a number of socially involved use cases were added by SmartXp users. Highlighted in bold are the use cases that were deemed most important by the client/supervisor, of which unsupervised studying and project are to be combined.

2. Table: Poll results regarding use case occurrence

| **Use case** | **Respondents** |
|---|---|
| **Lectures** | 29 |
| **Project unsupervised** | 28 |
| Activities (like study association workshops) | 21 |
| Eating lunch (added by respondents) | 20 |
| **Studying (unscheduled)** | 20 |
| **Meeting friends (added by respondents)** | 16 |
| **Project supervised** | 14 |
| Meetings | 13 |
| Workshops | 6 |
| Consulting A.P. de Vries (technician) (added by respondents) | 3 |

### 4.2.2 Brainstorm on use case implementation

To maximize the effect and efficiency of the system, the theories discussed in the third chapter should be applied to each use case individually, in order to determine specific essential needs for each use case, that can be taken into account in the development of the general light plan that will be applied in practice in the SmartXp. It is important to note that *Table 3* shows only relatively superficial, tentative takes on the definition of these use cases. The results in this Table are a summary of a free-form brainstorm between Heleen Kok and me, the author.

3. Table part A: use cases and preliminary thoughts

| **Use case** | **Thoughts for implementation** |
|---|---|
| Lectures | During "traditional" lectures where there is a teacher in front of a class of students the lighting should enable the teacher to be the main focal point. Thus having spotlights on the location of the teacher and dimming the light in students' peripheral vision will make them feel drawn towards the teacher and feel less comfortable looking around the room. The illumination of the speaker should be neutral in colour to avoid any conflicts with the beamer screen or the theme of the lecture. |
| Project unsupervised | The general idea is the same as in the row above, but without the teacher or student assistant walking around to answer questions. In this case the context aware features of the system could be applied to help students find a designated place to work and somehow use colour or brightness to highlight which tables are occupied and which are available. |
| Activities (like study association workshops) | Custom lighting should be an option for activities that can not be categorized under any of the existing use cases, allowing users to set their own parameters, preferably with a user-friendly, easily accessible user interface. |
| Eating lunch (added by respondents) | No theories found thus far, but as lighting has influence on human physiology and psyche, it may influence eating habits. It is however not desirable that the SmartXp is used as a lunch room, so using lighting to stimulate eating may not be adequate. |
| Studying (unscheduled) | Unsupervised and independent studying is an activity many students undertake in the SmartXp, but without any form of organization involved. It is not always clear where students are allowed to sit down and study, so often it happens that a lecture starts and students who have no affinity with the lecture are still sitting in the lecture area. Therefore it may be useful to use a similar system as described in the cell above. |

3. Table part B: use cases and preliminary thoughts

| Use case | Thoughts for implementation |
|---|---|
| Project supervised | In a supervised project situation, often following a lecture, it is usually the case that students work on some form of assignment and have the possibility to ask questions to one or several teachers and student assistants. In order to maximize students' focus on their individual work spot lights could be used to directly light each table, thereby also creating a balance between visual interest and lightness in the entire room. It may be possible to apply the context aware features of the system to highlight tables from students who have a question to ask, for the teacher to find those tables without hands needing to be raised. |
| Meetings | In a business or study meeting, the purpose of coming together is to discuss certain topics and listen to each others thoughts on what it is that the project entails. In such a scenario it is important to be able to see what others are indicating through motions, facial expressions, or writing (on paper or whiteboards). Because meetings may have different purposes like; problem solving, creative solutions, presentation of knowledge, discussions, etc. it may be best to use comfortable, but neutral, forms of lighting like relatively bright white lighting and natural lighting where possible. |
| Workshops | Creative Technology workshops are mostly practical, often paired with messy tables full of electronics and students trying to fidget together all kinds of electronical components to create some sort of invention, device, or even toy. Often, the "mess" paired with workshops further increases visual complexity in the SmartXp, and students all over the SmartXp are trying to focus on their work, there is no need for a main focal point. This provides an interesting issue, it would seem that because of the increased amount of visual detail, it would make sense to compensate this by decreasing visual interest in terms of light placement, this however would not combine well with bright lighting, in terms of visual comfort and creativity, that is needed for students to properly see small electronic parts. Further investigation is required to determine what conditions work best in such a situation, by monitoring or interviewing students who participate in workshops. Furthermore, variety in lighting (visual interest) could be used to highlight certain areas with given functions, for example tables where students can get parts could be lit extra brightly (or with peripherals where brightness is decreased) using spot lights, possibly even with different colours according to the function of the area being lit to emphasize their presence to the students. |

### 4.3 Identifying context sources

In order for the system to be as autonomous as possible and for it not to require active user input to determine the current use case(s), a number of context sources have been identified during the mind map brainstorm, as seen in *appendix 1*. In *Table 4* the purpose of each context source is described as well as some thoughts on the potential implementation and achievability thereof.

4. Table part A: Context sources, their purposes and possible implementations

| **Context source** | **Function** | **Possible implementation** |
|---|---|---|
| Schedule | Events that are planned in the existing schedule for the SmartXp already contain a type indication, which can be used to determine the current and future use case in a fairly straight-forward manner. | The device that will be used to output the DMX string which controls the lighting should be equipped with an internet connection. This internet connection will be used to download the schedule and parse it for keywords regarding event types and thereby use cases. |
| Noise sensing | Sensing noise is most likely unsuitable as a way of direct use case determination, because it is difficult to determine whether or not users should be talking loudly or softly without further context. Therefore it will be used in combination with the schedule, for example if there is a lot of noise during a presentation or lecture, this is likely to be unwanted behaviour, so the lighting should be adjusted to decrease the urge to conversate loudly. | A microphone should be placed over each truss, and possibly another above section 4. These microphones will be hooked up to the lighting controller and their signal strength will be processed to approximately determine sound level, without being able to record any audio data. |
| infrared | Infrared imaging could be used to determine where and how many users are present in the SmartXp, without being able to identify individuals. | Even though the time and effort it would take to implement this context source is outside the scope of this project, it would provide very useful data and could possibly be implemented in the future. It would take at least an infrared camera, possibly a kinect, and existing image processing software to recognize individual users (without identifying them). |

4. Table part B: Context sources, their purposes and possible implementations

| **Context source** | **Function** | **Possible implementation** |
|---|---|---|
| Device signals | Most users of the SmartXp make use of one or several mobile devices, that are connected to each other or to the internet through bluetooth, 3G, 4G, GSM, Wi-fi, etc. These signals can be measured in both quantitative and qualitative ways, providing useful data regarding occupation of the room, attention levels, and possibly more. | Using a signal receiver it is possible to determine signal strength and location to a certain extent (distance to receiver(s)). Using more advanced software (Wireshark e.g.) it is possibly to qualify data to the extent where it is possible to determine what kind of servers users are accessing and what their device names are. Using qualitative data is ill-advised as it poses all kinds of ethical issues. |
| User input | Implementing a manual override is useful in situations that don't fit in an existing use case definition. | A user interface can be designed so that users can select lights and their colours and brightness in an intuitive way, with a backend that communicates the user's parameters to a processing unit. |
| In- & out flow | Sensors could be placed on all three entrances of the SmartXp to determine flow rate and give indication of how busy the SmartXp is. | If two sensors (for example laser-receivers) with some distance between them are used on each entrance, it is possible to determine whether they were in- or outgoing. If only one sensor per door is used, it is still possible to measure flow, but without reliable data on how busy it is inside the SmartXp. |
| Beamer on/off | Sensing whether or not the beamer is being used can help determine what the current use case is, as it is likely that the beamer is used for a presentation or lecture of some sort. It is also useful input to change the lighting to compensate for the light the beamer emits, and to turn off any lights that are illuminating the beamer screen. | There are several ways which can be used to determine whether the beamer is on, a few examples are a light sensor, a relay triggered by the power feed of the beamer, a power consumption meter, etc. |
| Motion detection | Useful way of determining whether there are people in the SmartXp, for example outside of regular opening times. This may be useful to increase energy efficiency by turning off lights when there is no activity in the area. | The signal of a motion sensor can be processed to determine whether the lights should be on or off in a straightforward manner by connecting it to the lighting controller (which should be equipped with signal processing capabilities). |

### 4.4 Requirements Elicitation

A number of requirements must be set and prioritized before developing the system. This chapter first describes requirements for the implementation of use cases in the system and ends with a description of the requirements set for the development of the project in general. All requirements are categorized as ‘must have’, ‘should have’, or ‘could have’, so that priorities for development are clear throughout the project.

4.4.1 Use case requirements

Described in chapter 4.2.2 are high level ideas on the implementation of use cases in the lighting system. These ideas were used to contrive explicit requirements, which are described per use case in *Table 5*. These requirements were designed in cooperation with Heleen Kok.

5. Table part A: Use case requirements

| **Use case** | **Requirements** |
| --- | --- |
| Lectures | **Must have:**<br>-White spot light(s) on speaker.<br><br>**Should have:**<br>-Sections 1-2 lit<br><br>**Could have:**<br>-Lower lightness in areas that fall in the peripheral vision of students<br>-Lights under section 4 passage dimmed<br>-Moving head illuminating and tracing speaker |
| Project unsupervised / Unscheduled selfstudy<br><br>(combined) | **Must have:**<br>-Spot lights directed to tables<br>-High visual lightness/overall brightness<br><br>**Should have:**<br>-Coloured spot lights directed to tables<br>-Highlighted study areas<br><br>**Could have:**<br>-Led strip traffic lights along walls to indicate where seating is allowed<br>-More light in section 1 for optimal focus and to not mix with students in lectures etc. |

| | |
|---|---|
| | |

6. Table part B: Use case requirements

| Use case | Requirements |
|---|---|
| Workshops<br>/<br>Activities (like study association workshops) | **Must have:**<br>-Lighting directed to table tops<br><br>**Should have:**<br>-Customizable colours<br><br>**Could have:**<br>-Moving heads in section 2 and 3 (where activities usually take place)<br>-Possibility to close blinds to decrease visual interest |
| Meeting friends<br>/<br>Meetings<br><br>Combined | **Must have:**<br>-Coloured spots in at least one section to indicate where seating is allowed<br><br>**Should have:**<br>-Indicate where entry into the SmartXp is allowed<br><br>**Could have:**<br>-use colour spots on table groups<br>-Intimate atmoshpere, warm colours and relatively high visual interest, open all blinds if possible.<br>-Work with schedule, adjust colours with regards to nature of meeting. |
| Project supervised | **Must have:**<br>-Spot lights directed to tables<br>-High visual lightness/overall brightness<br><br>**Should have:**<br>-Coloured spot lights directed to tables<br>-Highlighted non-study areas for other SmartXp users<br><br>**Could have:**<br>-Led strip traffic lights along walls to indicate where seating is allowed (for non-participating students) |
| SmartXp empty | **Must have:**<br>-Hallway ‘traffic light’ green, orange or red to indicate if SmartXp is open<br>**Should have:**<br>-Automated light dimming |

| | |
|---|---|
| | **Could have:**<br>-Lights off, blinds open to save energy without making the SmartXp dark.<br>-Lit wall panels in evening |

4.4.2 System requirements

A number of requirements not specifically related to the use cases, instead to the project in general, are discussed in this paragraph.

-Not only the use cases deemed important by the supervisor, but all use cases analysed under chapter 4.4.1 *must* be included in the system. It *must* be possible to at least activate the lighting conditions set for each use case manually in software for Heleen Kok's testing purposes, however they *should* eventually all be linked to context parameters that determine the use case in question to be active.

-In order to guide users, there *must* be a comprehensible form of signalling, e.g. some sort of traffic light, that indicates which SmartXp access and staircase users may use in order to decrease disturbance from users that are in different use cases. For example, during a lecture the front access should be avoided by other users so that the lecture can continue undisturbed.

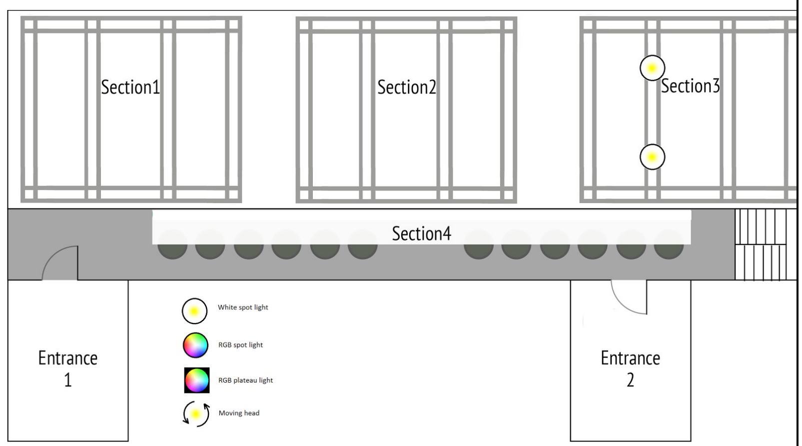
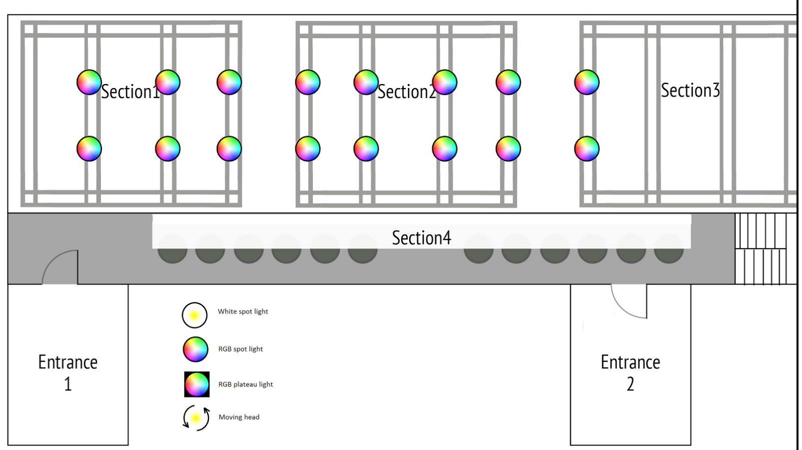
-According to the client, the system *should* make use of existing hardware components, such as light fixtures and attachments, and infrastructure such as signal distributors and cabling.

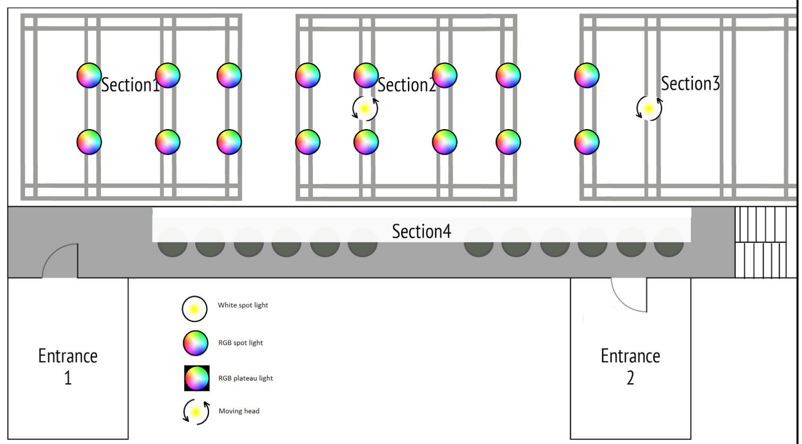
-A minimum of two of the context sources described in chapter 4.3 *must* be implemented, to be selected based on time-frame achievability and highest possible accuracy within the limits thereof, as requested by the supervisor.

### 4.5 Light plan Concepts

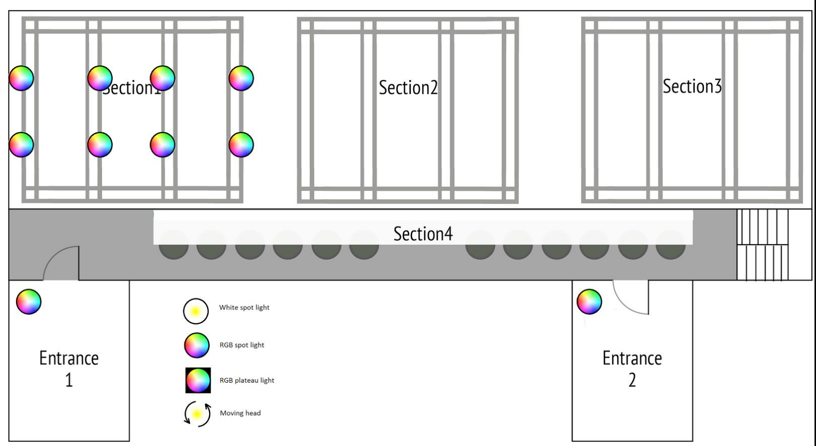
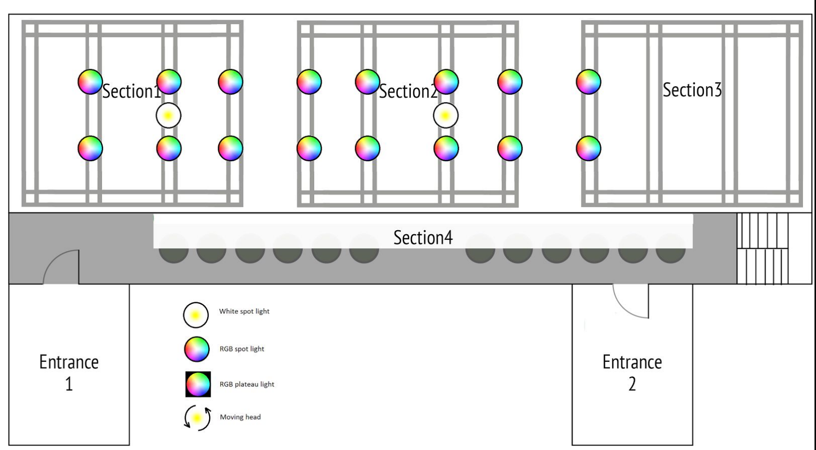
The requirements set in chapter 4.4.1 are subdivided into must-have, should-have and could-haves. The must-have requirements are foundational demands of what the final lighting system should at least be able to achieve from a technical point of view to be able to effectively light the SmartXp for each use case, hence they are all included in the concept light plans described in *Table 6*. Most should-have and some could-have requirements are also taken into account in order to maximize the quality of user experience. The right column of table 6 shows a map, from this point referred to as 'light plan', that displays the approximate location of fixtures that must, should, or could be placed in order to achieve lighting conditions suitable for the use case.

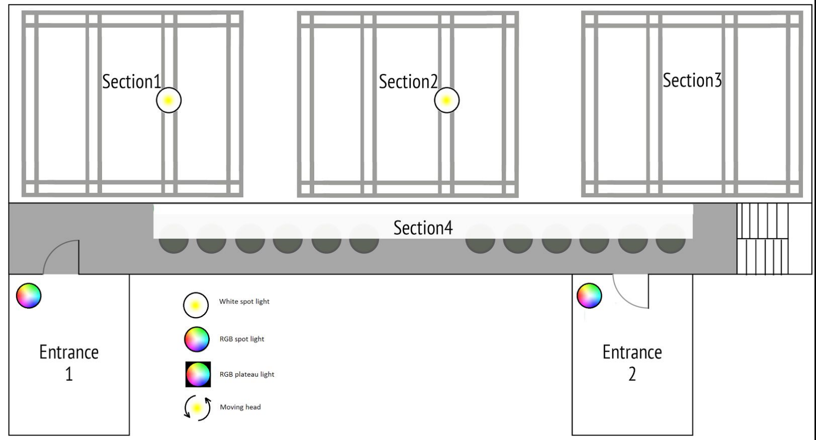
6. Table part A: Use cases, their included requirements and corresponding light plans

| Use case | Included requirements | Priority | Partial light plan |
|---|---|---|---|
| Lectures | -White spot light(s) on speaker. | must |  |
| Project unsupervised / Unscheduled selfstudy<br><br>(combined) | -Spot lights directed to tables | must |  |
| | -High visual lightness/overall brightness | must | |
| | -Coloured spot lights directed to tables. | should | |

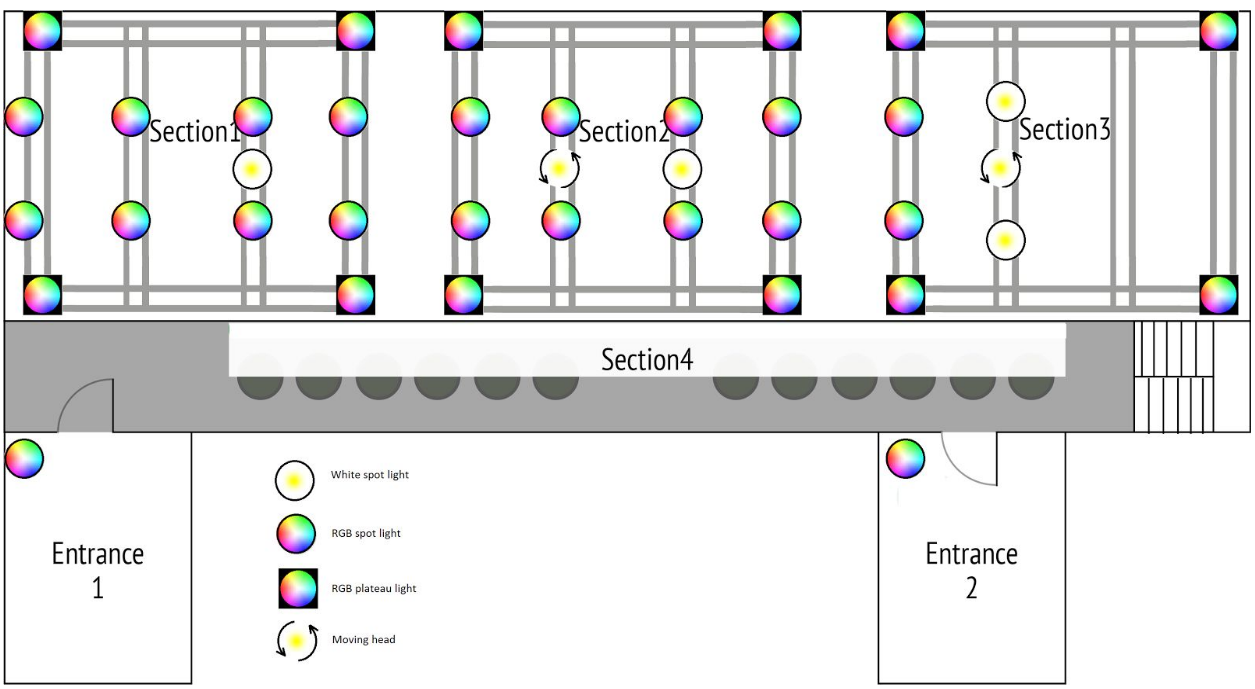
<table>
<tr><td rowspan="3">Workshops<br>/<br>Activities (like study association workshops)</td><td>-Lighting directed to table tops</td><td>must</td><td rowspan="3">
</td></tr>
<tr><td>-Customizable colours</td><td>should</td></tr>
<tr><td>-Moving heads in section 2 and 3 (where activities usually take place)</td><td>could</td></tr>
</table>

6. Table part B: Use cases, their included requirements and corresponding light plans

<table>
<tr><th>Use case</th><th>Included requirements</th><th>Priority</th><th>Partial light plan</th></tr>
<tr><td rowspan="3">Meeting friends<br>/<br>Meetings<br><br>Combined</td><td>-Coloured spots in at least one section to indicate where seating is allowed</td><td>must</td><td rowspan="3">
</td></tr>
<tr><td>-Indicate where entry into the SmartXp is allowed</td><td>should</td></tr>
<tr><td>-use colour spots on table groups</td><td>could</td></tr>
<tr><td rowspan="3">Project supervised</td><td>-Spot lights directed to tables</td><td>must</td><td rowspan="3">
</td></tr>
<tr><td>-High visual lightness/overall brightness</td><td>must</td></tr>
<tr><td>-Coloured spot lights directed to tables</td><td>should</td></tr>
</table>

| | | | |
|---|---|---|---|
| SmartXp empty | -Hallway ‘traffic light’ | must |  |
| | -Lit wall panels in evening | could | |

Overlaying all partial light plans creates a conceptual general light plan as seen in *Figure 4*. In addition, the floor-mounted spot lights are included in all truss corners, as Heleen Kok and the author determined they were difficult to remove from their original location, only suitable for placement on a horizontal surface and potentially useful in highlighting truss areas using their colours and brightness.




4. Figure: light plan consisting of overlaid use case ligt plans

### 4.6 Conclusion

The main stakeholders in this project are the client, the author and project partner Heleen Kok, who are responsible for both high level and low level development choices and realisation thereof. The secondary stakeholders are the students and lecturers that use the SmartXp for educational purposes.

Because there are many possible use cases for the SmartXp, some practical research and brainstorming were performed to determine what use cases occur and to what extent. Even though the author was in agreement with supervision to prioritise the implementation of use cases ‘lectures’, ‘project unsupervised’, ‘studying’, ‘meeting friends’ and ‘project supervised’, the decision was made to include all use cases for the sake of future-proofing and testing purposes.

Context sources are required for the system to operate autonomously and select use cases based on input data. A number of context sources were identified, including potential implementation methods. At least two of these context sources must be implemented in the system.

For the implementation of use cases into the system, a number of requirements are set that are either necessary or desirable to create the desired lighting conditions of each use case, from a technical point of view. Including additional requirements there is enough foundation to form conceptual plans for the placement of light fixtures. By analysing what light fixtures placements are required per use case, a general light plan was conceptualised and ready for further specification.

# 5. Specification

The idea and requirements generated in chapter 4 are further specified, and low(er) level decisions are made to create a clear definition of the project to be realised. This chapter includes a specification of the system and its functionalities, followed by a further specified light plan and addressing of light fixtures.

## 5.1 System specification

The hardware used by the existing lighting system in the SmartXp and the operation thereof is explained and supplemented with descriptions of the requirements that will need to be met in the realisation phase in order to overcome its challenges. Next, the functions the system will have are described and explained through schematic drawings.

5.1.1 DMX light system
The (spot) lights that were already installed in the SmartXp use the DMX512 [16] (digital multiplexing) protocol to set lighting parameters. This protocol makes use of a single signal string for all lights, which are daisy chained to each other so that the single signal reaches each fixture. The signal is composed of channel signals, each light fixture is set to an adress, which is its starting channel. For example, a 4-channel light (usually red, green, blue, bright) set to address 100 will use the values of channels 100-103 and sets its own parameters to the values of those respective channels. In order to make use of the existing lights and implement additional fixtures it is required for the system to be developed so that it controls lights through DMX512.

5.1.2 System control
In order to control the lighting hardware, a programmable device that is able to receive context input and process it to output signals to hardware is required. After the control device has been connected to the lighting system, use cases can be programmed according to lighting conditions that are precisely determined by Heleen Kok, converted into values that match the channel and address settings of the fixtures. Each use case will consist of a set of DMX controls that are wrapped into functions so that each use case can be called individually. Even though this system will not be fully developed within the scope of this project, it is necessary for Heleen Kok's testing purposes, and desirable for the usability of the system, that all determined use cases are programmed and executable by the program.
The accuracy with which the system is able to determine use cases is dependent on the right use of context sources. In order to make use of the system as soon as possible and during development there are two context determinants that must be implemented first. The two context sources chosen are the SmartXp's schedule and user input, because of their respective accuracy and flexibility. The schedule enables the system to interpret what general use case is going on with high accuracy, since it is solely dependent on the events that are put in the schedule. If a use case occurs that is not scheduled, or if a new type of use case that was previously unthought of occurs, lighting conditions can be set manually, hence the choice of

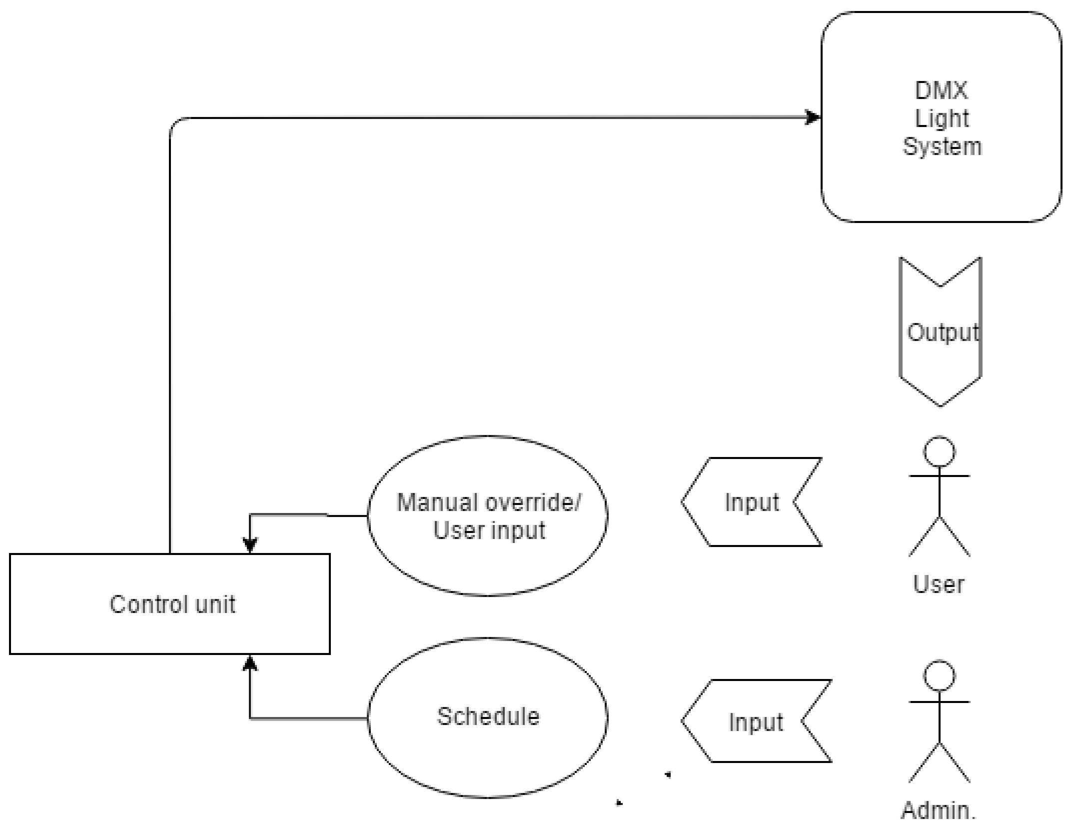
user input, or manual override, as a second context source.

5.1.3 System functionalities

The system to be developed must be able to:

- Use a control unit that is able to process data from context sources to control the lights through DMX.
- Alter lighting conditions according to a set of output values per use case.
- Switch between use cases by autonomously checking the SmartXp’s schedule.
- Allow the user to manually set lighting conditions through a user interface, preferably online.

The diagram in *Figure 5* shows the relations between different components of the system and how they relate to the user.



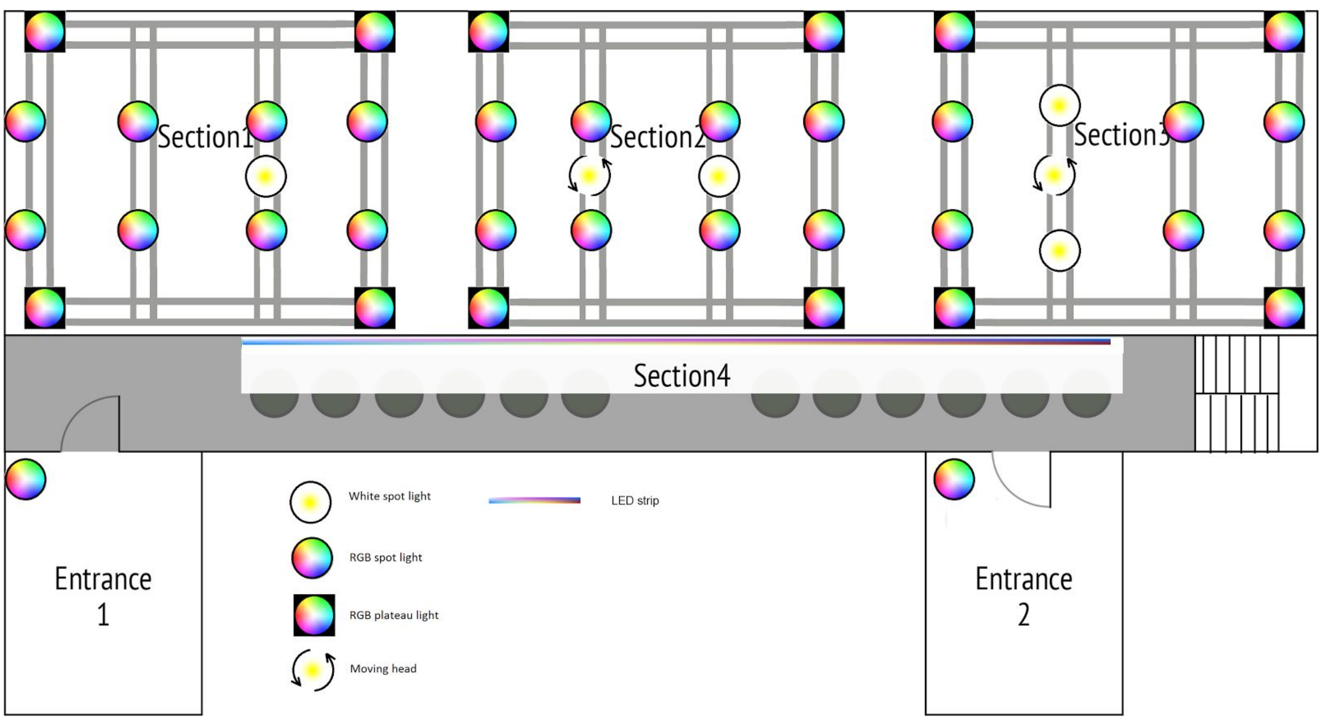

5. Figure: Functional diagram 1

### 5.2 Light plan specification

The light plan as conceptualised in chapter 4.5 is further specified, after which all light fixtures are addressed in the DMX universe.

5.2.1 General light plan second iteration

After discussing the concept light plan with client/supervisor and project partner, a few alterations were made, see *Figure 6*. Further specifications are; the RGB spots in sections 1-3 are directed downwards on the tables, the white spot lights in section 1-2 are directed at the white wall panels (on the upper side of the image), the white spot lights in section 3 are directed downwards to the lecturer, the moving heads are both directed downwards, the RGB spots at both entrances should be directed into the hallways so that their colour may be noticed, without being bothersome. Furthermore, an LED-strip is added on the upper side of section four, mounted on the handrail, meant to use colours which indicate whether the area may be used and what level of audio is allowed to be produced (see Heleen Kok's project report for further details).

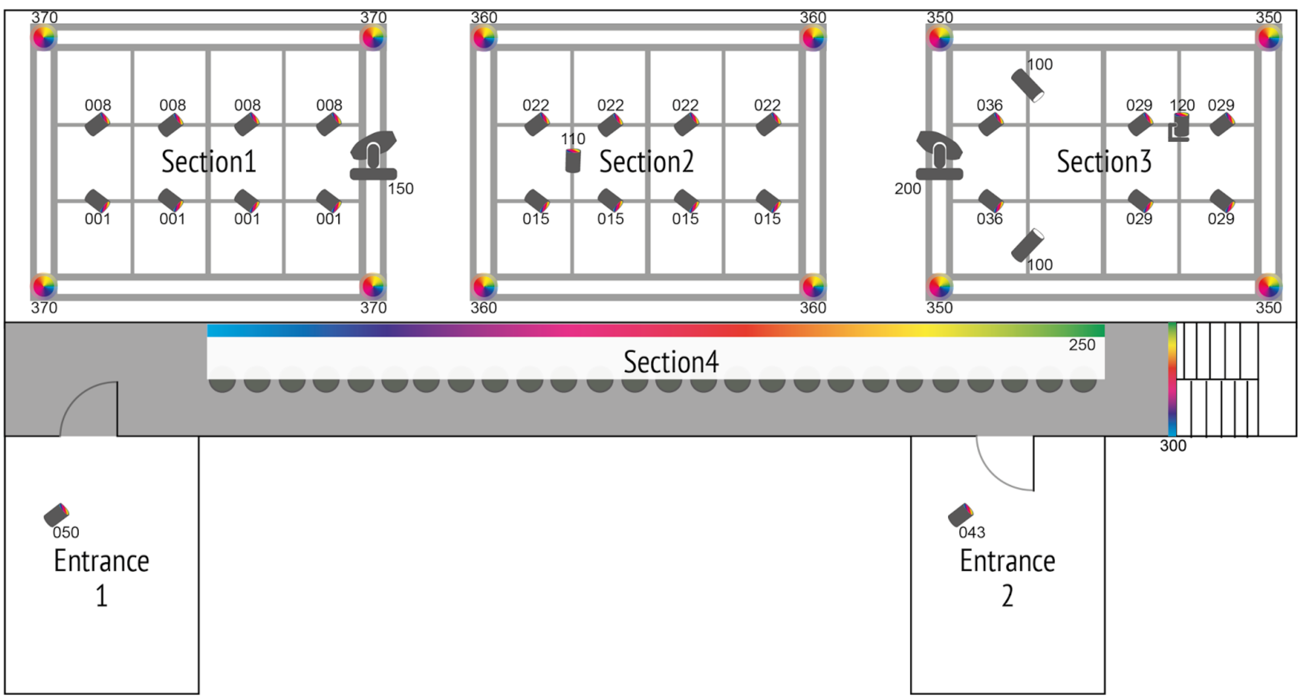



6. Figure: Final light plan before realisation

5.2.2 Addressing light fixtures
DMX lighting systems work with so-called ‘universes’ that can control a maximum of 512 channels. This does not mean that 512 light fixtures can be installed, as each light takes up a couple of channels, for example for its red, green, blue and brightness values (see chapter 5.1).

Counting the amount of light fixtures, including two LED strips, the number is over 40. Assuming at least four channels are used per fixture, 40 fixtures individually addressed would take up more than 160 channels. Even though this does fall within the limits of a single DMX universe, it is too extenstive to manage this in software programming, at least within the scope of this project.

The solution is the design as seen in *Figure 7*[4] below, where a large amount of fixtures are grouped, the addresses 008, 001, 015, 022, 029, 370, 360 and 350 are applied to four fixtures each. For clarification, this does not mean that they are individual DMX universes, they are groups of fixtures set to the same address, all within one universe. This means that several lights take the same channels of the DMX string as their input, as their starting adress is shared. Important to note is that grouping fixtures by address only works if all light fixtures within the group are of the same brand and use the same channel settings. The choice of which lights to group was made in consultation with Heleen Kok.




7. Figure: DMX adressing, image by H. Kok.

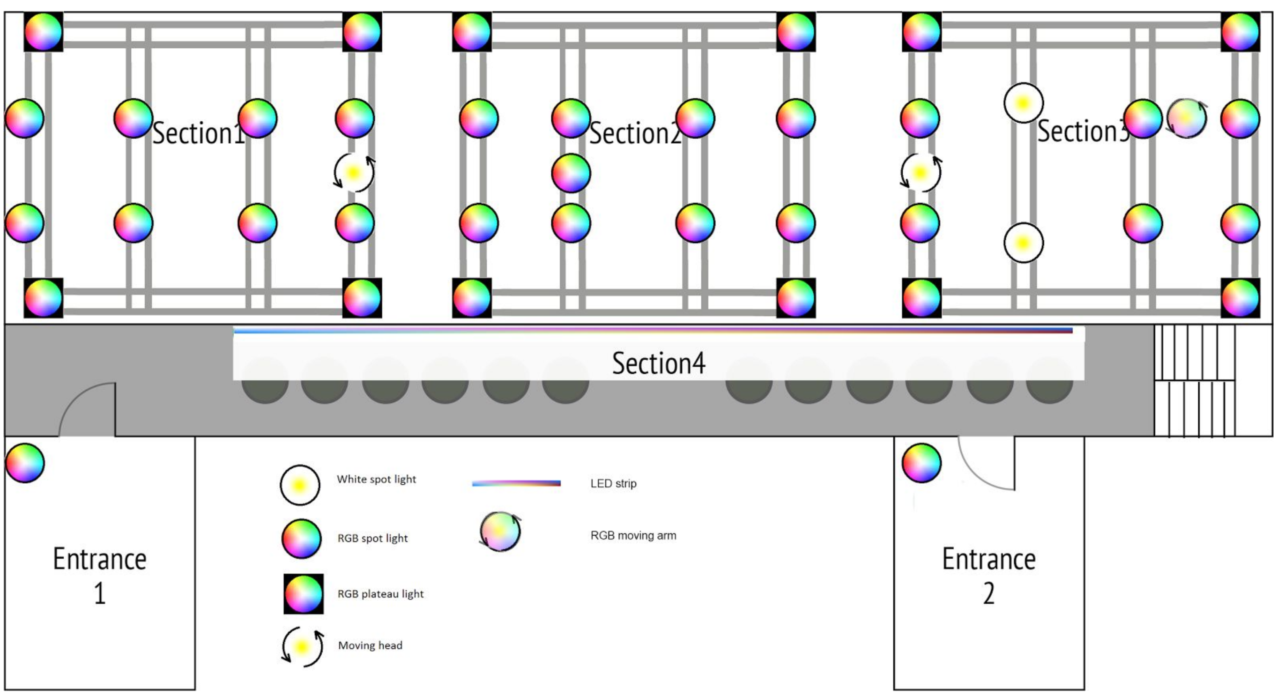
4 Deviations in the positions of light fixtures between *Figure 7* and *Figure 6* are due to practical reasons, see chapter 6.

# 6. Realisation

In this chapter the realisation of project ideas is described. Iincluded in this chapter are an updated version of the general light plan, how the output of the system was programmed, how both input (context) sources were programmed, and finally how the system switches between two inputs.

### 6.1 General light plan third iteration

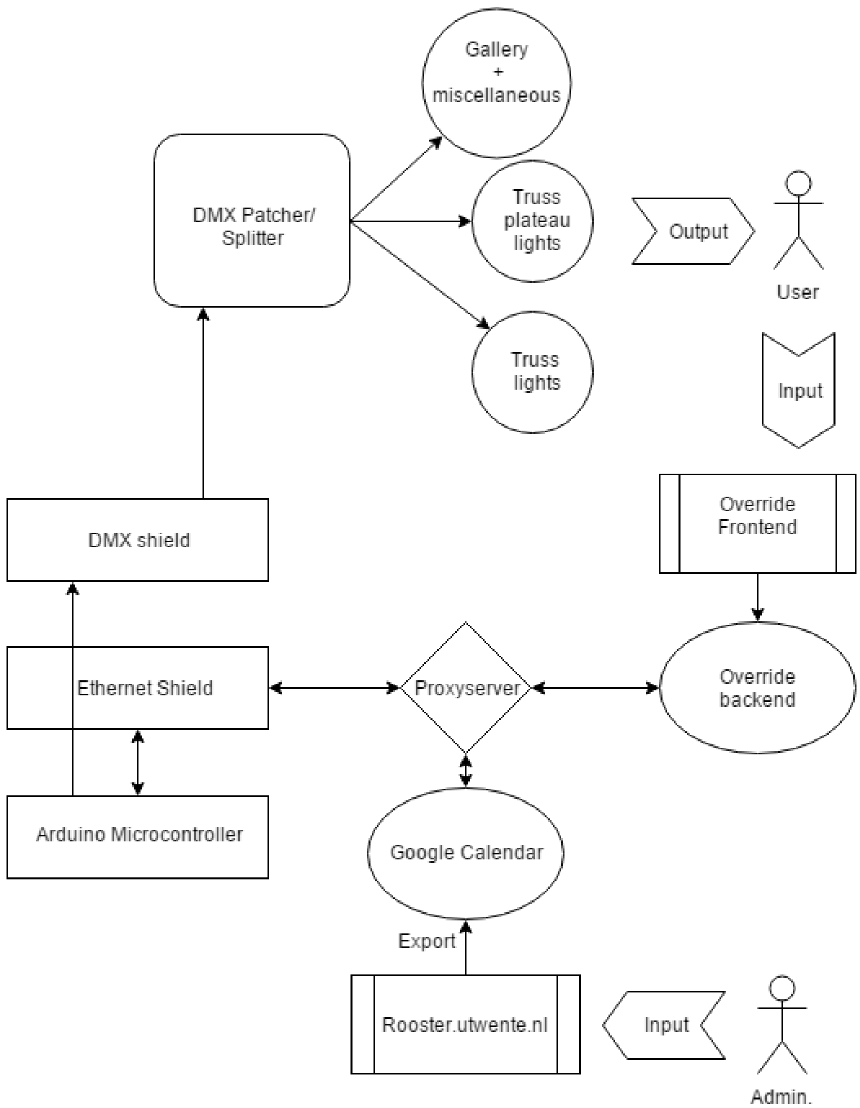
During the implementation of the general light plan, a few more alterations were made. Because the skylights and window blinds were opened up in section 1, this was now the lightest area and section 3 the darkest. Consequently the wall-pointed spot light in section 1 should be moved to section 3 to keep the balance. Another decision was made to replace the aforementioned spot light, and the other white spot light by RGB spot lights, because they could be used more universally and were easy to implement in the DMX control system, the one in section 3 is mounted on a rotating arm to make it possible to change its position if so desired in the future. Another decision was made to move both moving heads to the edges of section 1 and section 3, due to practical reasons regarding the flight cage in section 2 and the position of the beamer in section 3. The moving heads will also be used outside of their specified use cases, because the spot lights on the walls in section 2 and section 3 were too focussed to illuminate entire wall sections. Another use for the section 3 moving head is to illuminate the sitting area created for meeting purposes in the mentioned section. The final version of the general light plan can be seen in *Figure 8*. The DMX addresses in *Figure 7* correspond to the fixture locations of *Figure 8*.



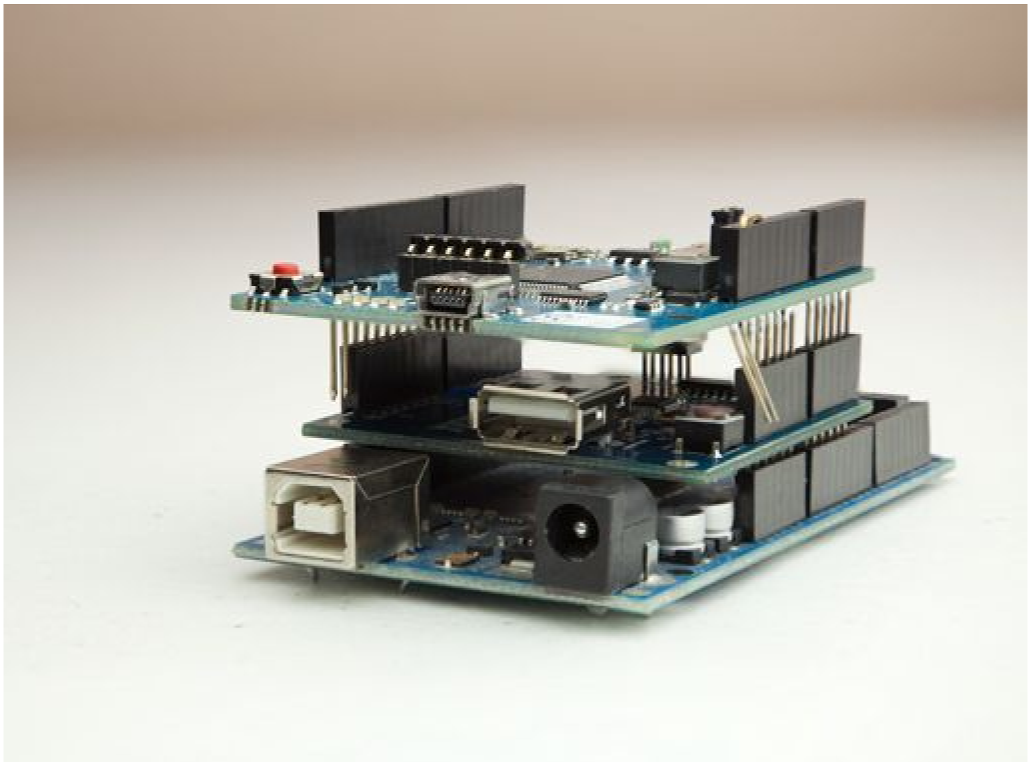

8. Figure: Final version general light plan

### 6.2 System design

Discussed in chapter 5.1.2 and shown in *Figure 5* are high-level preliminary takes on system design. Even though *Figure 5* correctly displays the relations between components, many components were added and relations can thus be described on a lower, more detailed level as seen in *Figure 9.* Parts and their relations will be further clarified in the remainder of this chapter with use of *Figure 9* for reference. Furthermore it is worth mentioning that An *Arduino Mega* microcontroller [15] is the chosen processing unit, it's C/Java - based programming is straight-forward and it is easily expandable on a hardware level.The Arduino, ethernet shield and DMX shield operate as one device with three processing units, as Arduinos and shields are stackable, see *Figure 10*. This means they are three devices that share their pin signals, e.g. if the Arduino outputs a signal on pin 1, both shields are able to read that signal as input.




9. Figure: Functional diagram 2



10. Figure: Arduino mega stacked with two shields, image courtesy Oleg Mazurov

### 6.3 Programming DMX output

As described in chapter 5.1.1, DMX protocol operates with channels and addresses, the address which a light fixture is set to use, is the channel number it will start to read from the DMX string, continuing to read the following channels up to the amount of channels the fixture was set-up for. After outfitting an Arduino with a DMX shield it was possible to use the DMX Master[19] Arduino library to individually address fixtures and program the light output through the Arduino coding interface.
*Figure 11* shows Arduino code which contains the main function 'void loop', in which use case 'lecture' is called for. There are however not one, but four mentions of 'lecture' in the void loop function, each followed by a number. These numbers represent sections 1-3 of the SmartXp and the fourth covers all miscellaneous light fixtures, e.g. the LED strips under the gallery, the LED strip for the stairs, the hallway spot lights, etc.
The reason that for every use case there are different functions for each of the four sections, is a future-proofing measure that allows two things. It keeps the code manageable, finding a certain line of code for a light fixture is simpler when it can be found within the function corresponding to its section. Secondly, it allows for multiple use cases to be active simultaneously, a scenario that could occur when the amount of implemented context sources is increased. The lines of code under 'void loop' could be calling different use cases, for example:

```
Void loop ()
{
Lecture1();
Meeting2();
Supervised3();
Unsupervised4();
}
```

In this case, the lights in section 1 would be set to the parameters for a lecture, the second section would be set according to the parameters for a meeting, the third for a supervised project and the fourth for an unsupervised one.
Furthermore, *Figure 11* shows part of the function for section 1 of the use case 'lecture'. There are three blocks of consecutive code, each lead by a comment describing its section and the approximate location and type of fixture, e.g. '*//section 1 front spots'*. After this indication, there are several lines of code with the format '*DMXMaster.write(x, y);'*. This is the format used by the DMXMaster Arduino library [19]. The 'x' is the channel, 'y' is its value. In this case the 'front spot' is a 7-channel fixture, hence there are seven lines of code, one for each channel. The address of this fixture is 008, hence the channel in the first DMXMaster line is 8. Not all seven of its channels are used, the first three are for the red, green and blue values respectively. Which is the reason those lines are followed by a comment like '//R', which is an indication for the programmer that this line is for the red value of this fixture.

```
void loop() {

  Lecture1();
  Lecture2();
  Lecture4();
  Lecture3();




}
void Lecture1 () {

  //section 1 front spots
  DmxMaster.write(8, 20);//R
  DmxMaster.write(9, 0);//G
  DmxMaster.write(10, 255);//B
  DmxMaster.write(11, 0);
  DmxMaster.write(12, 0);
  DmxMaster.write(13, 0);
  DmxMaster.write(14, 255);//Bright

  //section 1 rear spots
  DmxMaster.write(1, 20);//R
  DmxMaster.write(2, 0);//G
  DmxMaster.write(3, 255);//B
  DmxMaster.write(4, 0);
  DmxMaster.write(5, 0);
  DmxMaster.write(6, 0);
  DmxMaster.write(7, 255);//Bright

  //Section 1 truss/floor spots
  DmxMaster.write(371, 63);//R
  DmxMaster.write(372, 0);//G
  DmxMaster.write(373, 255);//B
  DmxMaster.write(370, 255);//Bright
```

11. Figure: Example of calling use case section functions with part of use case section function

## 6.4 Implementation of schedule

The Arduino Mega, already outfitted with a DMX shield, is now also outfitted with an ethernet shield. The code for connecting to and parsing the schedule is partially based on the RelaySketch by M. Bornski [18], who made it possible to use Google Calendar to control a number of relays.

Because the SmartXp schedule as it appears on University of Twente's website rooster.utwente.nl is not directly accessible for third parties, it was exported to Google Calendar, which is only accessible through the link that is used in the system's code. Furthermore, the source code by M. Bornski was altered so that it would no longer parse the titles of events, but use their descriptions instead. This was necessary because the event type of the SmartXp schedule is indicated in the description of the event, obviously this meant that the keywords also had to be changed to the event types that the SmartXp schedule uses, so that the script could recognize certain events.

Parsing the description posed an interesting problem, as the original code would find a certain word in the data received from Google Calendar (*Appendix 3)*, for example if "TITLE:" was found, then the line after would be checked for relevant keywords and stop doing so at line ending. In the description however, keywords would not necessarily be on the same line. The solution was if the initialiser "DESCRIPTION:" was found to ignore line endings and remove spaces from the string, so that it would search the entire description for keywords. Furthermore, the code was altered so that if a keyword was found it would no longer send a signal to a relay, but instead use the DMX Master library as described above to execute functions of the relevant use cases.

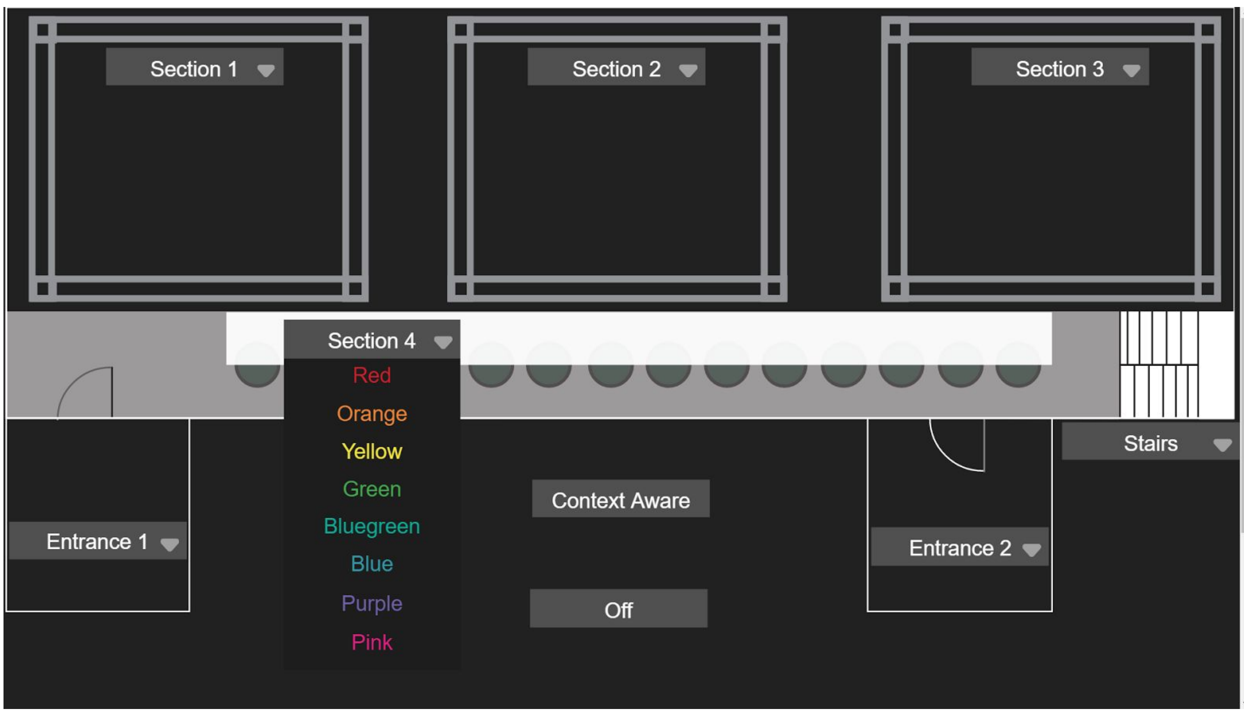
An extra use case was added for the lunch break, which isn't an event in the schedule, another method was used for calling this use case. Because the lunch break happens daily from 12:30 until 13:45, this timing was used for implementation. The method used takes the string 'now', which contains the current date and time, and copies it into two new strings 'lunchtimestart' and 'lunchtimeend', after which the section of the string which contains the time of both is replaced by '1230' and '1345'. These three strings are then used to check whether or not the value of the 'now' string is between the start and ending of lunchtime. Used in an if-loop this enables the execution of either all functions regarding schedule parsing or it directly executes the 'break' use case, depending on the time.

## 6.5 Implementation of user input

In order to implement a web-based user interface, the input of the user had to be stored so that the Arduino could interpret it, and a method of distinguishing whether to use the schedule or the user input had to be designed. The user interface *Figure 12*, which was designed by Heleen Kok, is a webpage that outputs the selected values to a php file per section and colour, see *Appendix 4* for an example. This file is parsed in similar fashion as the Google Calendar is parsed, saving a section and a colour value. A set of if-loops manage the correct section and colour allocation.

A distinguishing factor is that there is only one use case for the manual override, which uses variable red, green and blue values set by the if-loops as described above, this was a deliberate effort to decrease the length of the code. As previously described, normally use case functions consist of four sub-functions that can be called individually to enable several use cases being applied simultaneously in different sections of the SmartXp. In order to increase flexibility of the manual override, the lighting functions were divided in seven sections so that truss sections 1-3, entrance 1, entrance 2, stairs and gallery lighting could be set individually.

In order to prevent the program from constantly switching between calendar-based lighting and user input, a ‘context-aware’ button was added in the user interface, which outputs the colour of light in the php file as ‘default’. Furthermore, all lights are on ‘default’ by default. Instead of using a single boolean value to set true or false according to a light section being on default or not, a char array was used containing seven digits. This is so that each of the seven sections that can be set through the user interface have their own default or colour value and only when all seven digits are set to ‘1’ the program will go back to checking the calendar instead. In other words, a section will remain on default, even if another section is changed to a manual colour and vice versa, if not all sections are set to default the program still doesn’t return to using the scheduled lighting values.

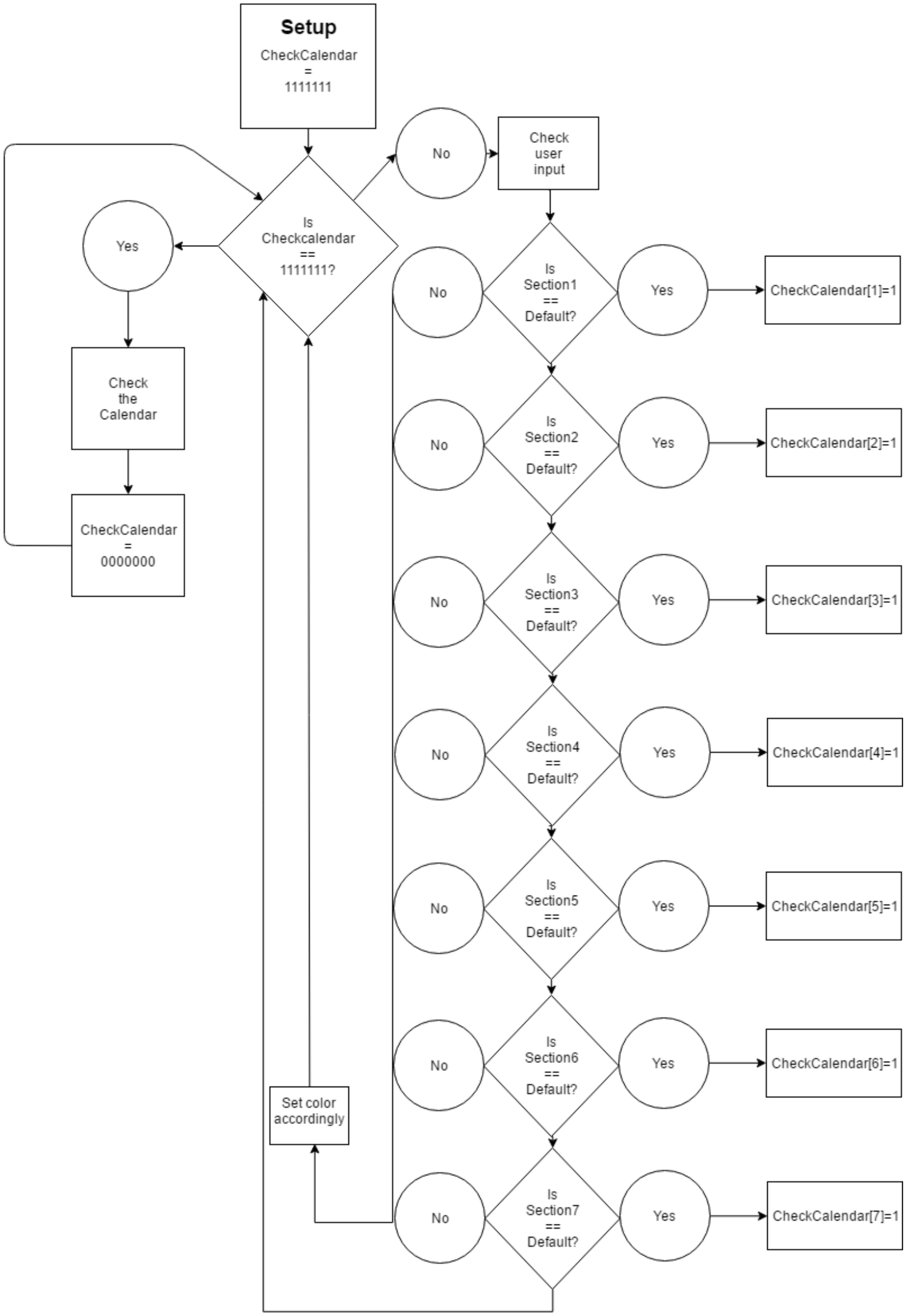



12. Figure: Manual override user interface

### 6.6 Functionality

*Figure 13* describes how the Arduino switches between checking the calendar and checking the user input. The flowchart shows that when the calendar is checked, a value ‘checkcalendar’ is set to ‘0000000’. This byte is used by the program to keep track of whether the SmartXp’s schedule should be checked for use cases, or the settings from the manual override should be applied. Instead of a boolean that can only be true or false, ‘checkcalendar’ is a byte that consists of seven digits. Each of these seven digits represents one of the sections of which lights can be adjusted in the user interface.

In the user input php file that is parsed by the Arduino, a section may be set to a colour or to ‘default’. If a section is set to default, its corresponding byte value will be set to ‘1’. For example if only section 3 is set to default in the manual override, the byte string will be ‘0010000’. Following the flowchart, the calendar will be checked again if the value of ‘checkcalendar’ equals ‘1111111’. This means that if a number of sections, but not all sections, are set to default, the lights in those sections are set to the values of the use case last obtained from the schedule. Only if all sections are set to default, the value of ‘checkcalendar’ will be ‘1111111’, the calendar will be parsed again and the values of the obtained use case are applied to all sections. After the calendar has been parsed, ‘checkcalendar’ will be re-set to ‘0000000’, re-starting the cycle that checks manual override data.




13. Figure: Flowchart: software switching between calendar and override

# 7. Evaluation

The purpose of the evaluation phase is to check whether the prototype was successfully built according to the requirements set in the ideation and specification phase. As described in chapter 3.1.4 functional evaluation was applicable in this part of the project and as such it is discussed in this chapter. See *Table 7* for evaluation results.

7. Table: Requirement evaluation

| **Requirement** | **me t** | **Remarks** |
|---|---|---|
| All use cases analysed under chapter 4.4.1 *must* be included in the system. | yes | All included with the addition of use cases for lunch break and manual override. |
| It *must* be possible to at least activate the lighting conditions set for each use case manually in software for Heleen Kok's testing purposes | yes | All use cases can be called from the Arduino's main loop function. It is no longer easy to do this, but at the time of testing it was. |
| The use cases *should* eventually all be linked to context parameters that determine the use case in question to be active. | yes | All use cases are activated by at least one keyword that can be indicated as an event type by the scheduler. |
| There *must* be a comprehensible form of signalling, e.g. some sort of traffic light, that indicates which SmartXp access and staircase users may use. | yes | Even though users sometimes choose to ignore the signals, they are present in hallways, along the railing in section 4 and at the staircase, from a technical point of view they are working correctly. Each signal light is accompanied by a poster with all possible signal light colours explained, thus making it comprehensible within the scope of functional evaluation. |
| According to the client, the system *should* make use of existing hardware components, such as light fixtures and attachments, and infrastructure such as signal distributors and cabling. | yes | All previously used light fixtures are used by the newly developed system, as well as cables and trusses. More fixtures and cables were added. |
| At least two of the context sources described in chapter 4.3 *must* be implemented. | yes | User input and SmartXp schedule have both been implemented. |
| Switch between use cases by autonomously checking the SmartXp's schedule. | yes | The system parses the schedule correctly. However, the schedule has to be exported from rooster.utwente.nl to google calendar manually after each period. |

| | | |
|---|---|---|
| Allow user to manually set lighting conditions through an interface, preferably online. | yes | The user interface is web-based. |

# 8. Conclusion

In this chapter conclusions are drawn based on the research questions stated in chapter 1, followed by future work and recommendations.

### 8.1 Answering the research question

The research question for this project was;

- How to develop a context-aware lighting system that supports the different use cases of the SmartXp?

With the sub-questions;

- What are the SmartXp's use cases?
- 'Which generic light plan can be used for all SmartXp use cases?
- 'What light conditions are best suitable for each use case?'.

The first sub-question has been answered, as use cases have been determined in the ideation phase and implemented successfully in the realisation phase and tested through functional evaluation. The second question was answered in the specification phase, when all use case light plans were overlaid and, after some modifications through the realisation phase, the final general light plan was realised, see *Figure 8*. The third question is partially answered in this report as most use case light plan requirements were discussed in the specification chapter. However, details about the exact lighting values were determined by Heleen Kok as they belong in her part of the project and thus, they can be found in her project report.
Due to the nature of the main research question, which is a 'how-to' question, there is no single answer to it, as it describes a process. The process of developing a context-aware lighting system that suits different use cases must consist of at least the following steps, in approximately this order; determine stakeholders, determine use cases, determine lighting conditions per use case, design light plan, determine context sources, prioritize context sources, choose suitable hardware controller, implement use cases and output to lights, implement context source hardware and software. Omitting any of these steps from the project would be likely to leave or create flaws in the system.

### 8.2 Future work and recommendations

Even though the code per use case is currently divided into different sections, the system is not yet able to identify several use cases at once. In order to increase flexibility and carry out use case hybrids the amount of context sources must be increased and per-section use case determination is required. The recommendation regarding this, is to research to what extent each context source can be used to identify per-section use cases and start by implementing those with the highest accuracy. Furthermore, the user interface can be expanded to more accurately set lighting conditions by adding buttons for use cases and perhaps for individual lights as well. Another improvement that can be made to the user input settings is checking the calendar per section instead of only after all sections are set to default, so that single sections set to default will continue to be updated if not all are.

Implementing more context sources means implementing more hardware sensors and handling more variables both on a software and hardware level. In order to reduce strain on the Arduino microcontroller, firstly the code should be further optimized to increase efficiency and secondly, processing of hardware input should be divided over several processing nodes, e.g. several Arduino's. If an Arduino microcontroller is used to process the raw data of a single context source, it can then output commands to an Arduino that acts as a hub to process and prioritize context data and control the lighting output.

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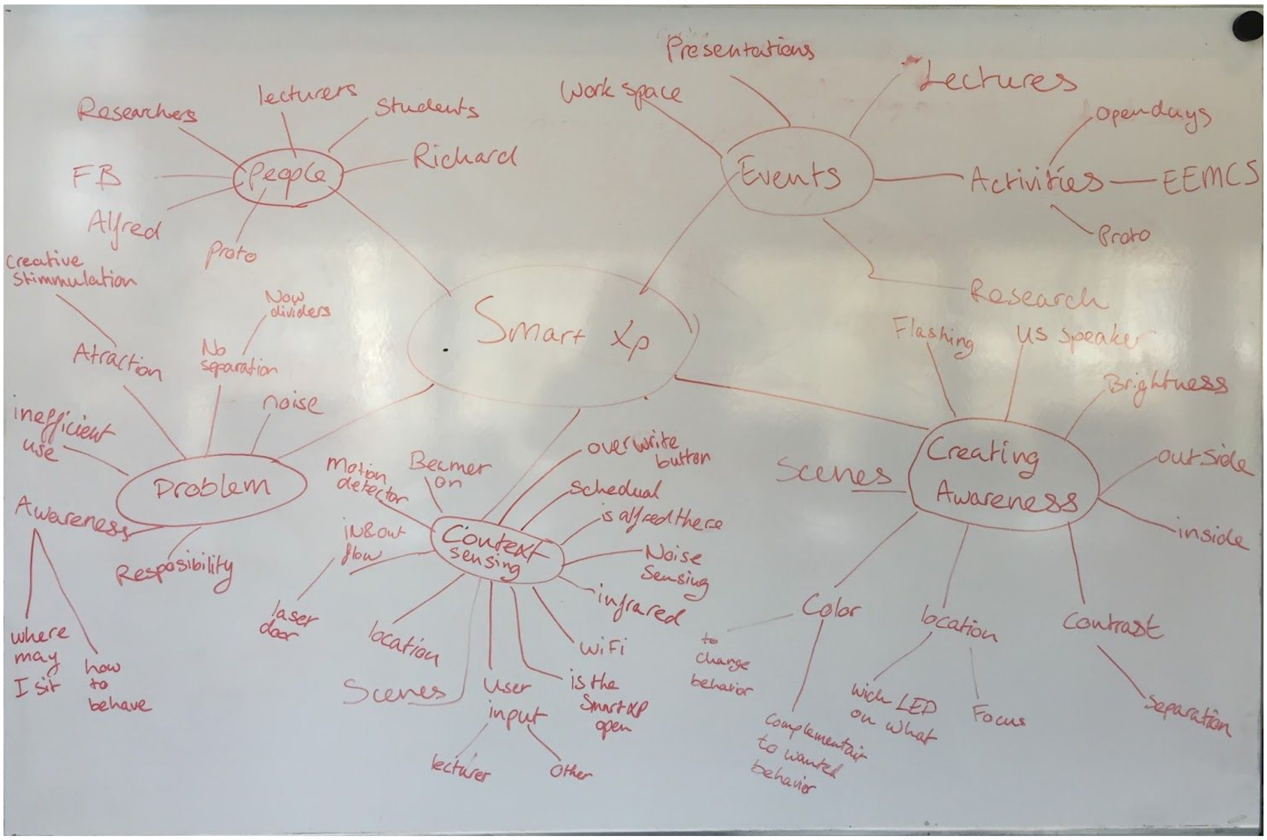
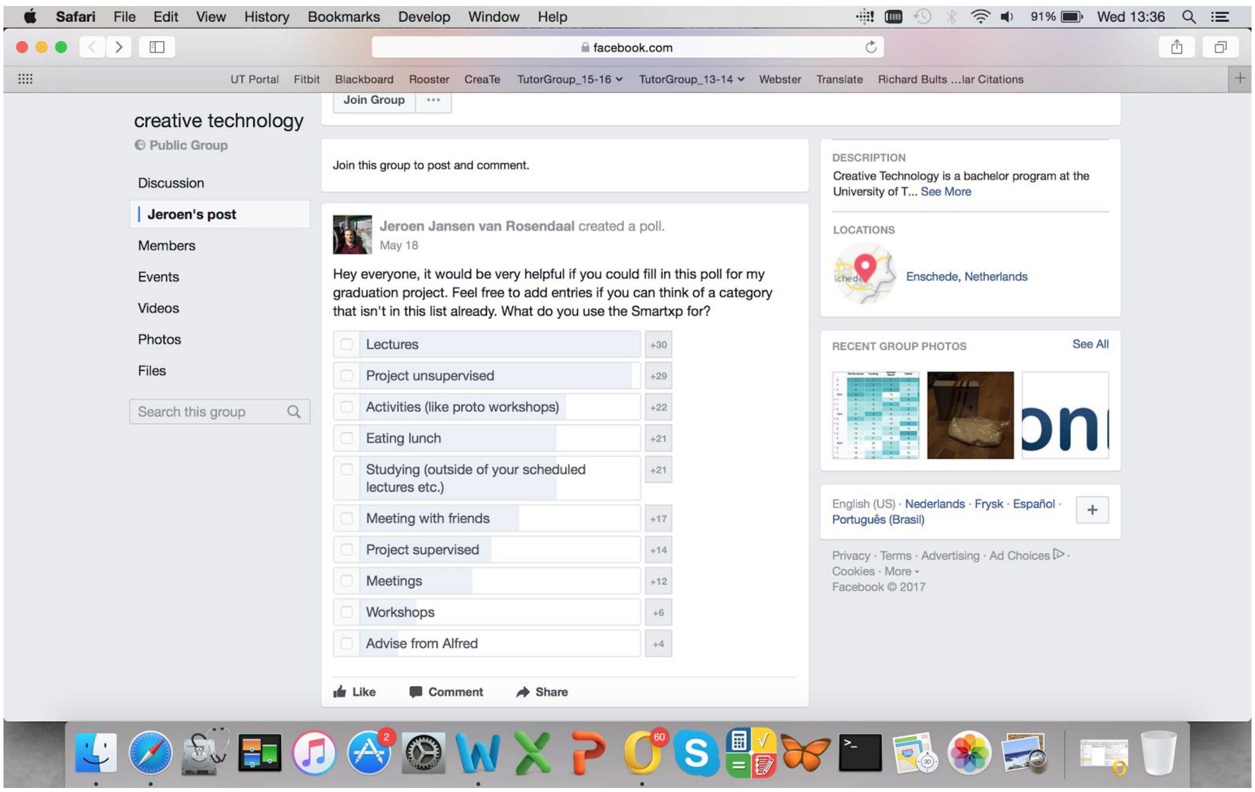
# Appendix 1

## Mind map



# Appendix 2

## Screenshot Facebook survey



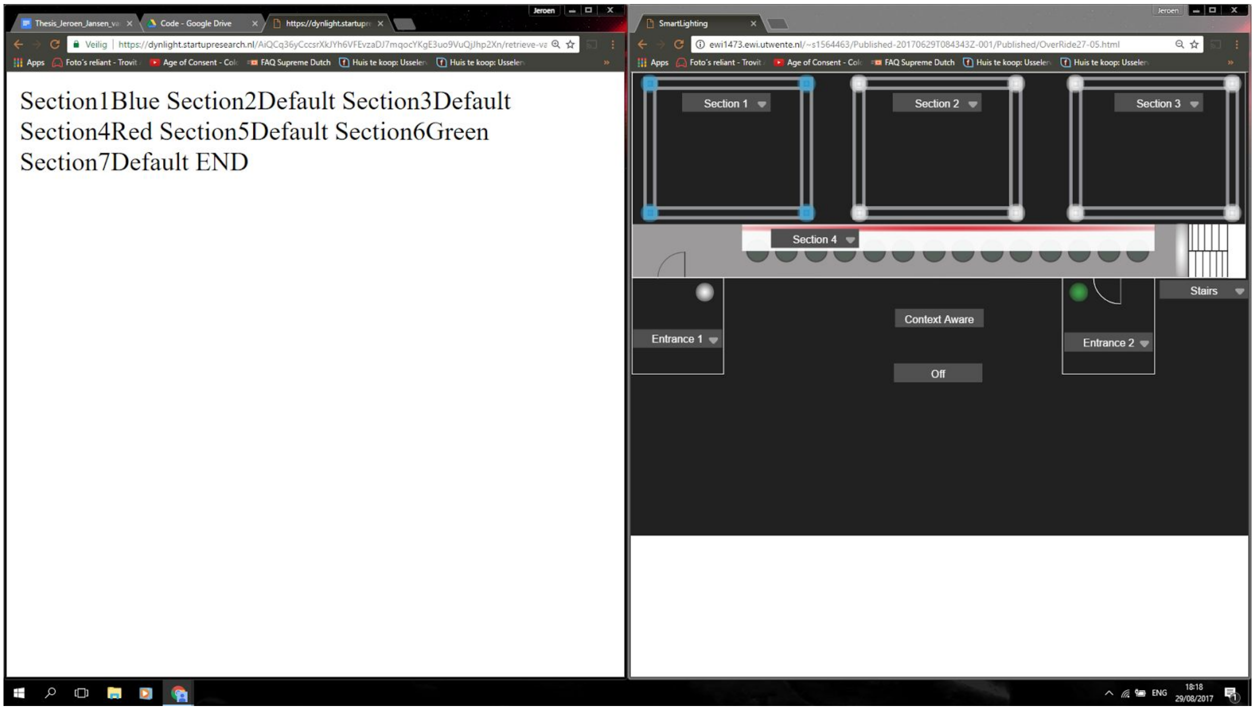
# Appendix 3

Example of data received from Google calendar (SmartXp schedule), containing one event.

BEGIN:VCALENDAR
PRODID:-//Google Inc//Google Calendar 70.9054//EN
VERSION:2.0
CALSCALE:GREGORIAN
METHOD:PUBLISH
X-WR-CALNAME:University of Twente personal location timetable - s1564463
X-WR-TIMEZONE:Europe/Amsterdam
X-WR-CALDESC:University of Twente personal location timetable - s1564463
BEGIN:VEVENT
DTSTART:20170830T064500Z
DTEND:20170830T153000Z
DTSTAMP:20170829T173644Z
UID:2016!2413DA58EC0E4040C7519B14A05CF712-20170830@rooster.utwente.nl
CREATED:20170829T063729Z
DESCRIPTION:Type: Other\n\nLast synchronised on 2017-08-29 at 08:37 CEST
LAST-MODIFIED:20170829T063729Z
LOCATION:ZI A 138
SEQUENCE:0
STATUS:CONFIRMED
SUMMARY:Kick-in voor Proto
TRANSP:OPAQUE
END:VEVENT
BEGIN:VEVENT
….

# Appendix 4

- Left side of image: PHP output file (user interface back-end), viewed in web-browser
- Right side of image: Corresponding user interface, opened in web-browser



# Appendix 5

Code

The code that is uploaded to the Arduino is over 80 pages in A4 format, therefore instead of including it in this document it can be found in a separate file accompanying this PDF (if not printed) or may be obtained by contacting jeroenjvr@outlook.com.