A data driven lighting infrastructure for a 3D printed bridge

Master Thesis
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Integrated Product Design

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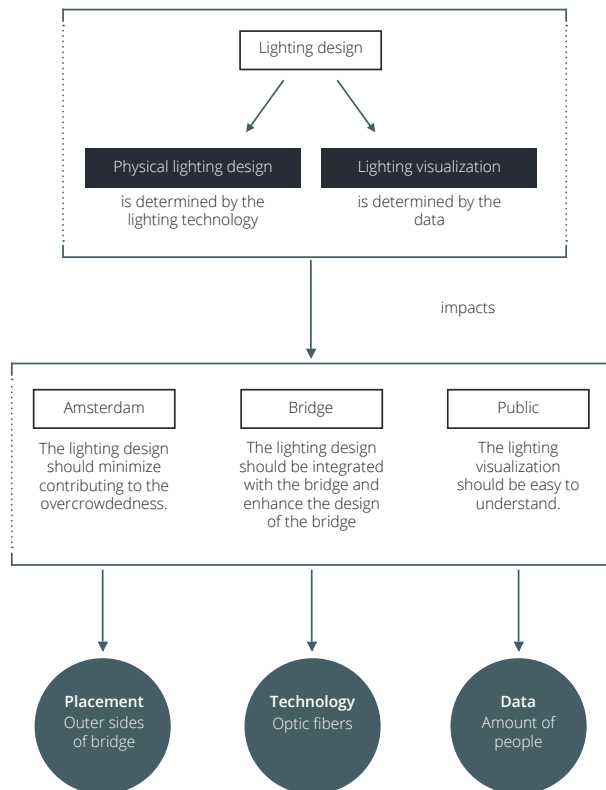Faculty of Industrial Design Engineering

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Acknowledgements

Abstract

In June 2015, MX3D announced that they were planning on building a fully functional 3D printed stainless steel bridge. The bridge will be placed on the Oudezijds Achterbrugwal located in the red light district. Because the bridge is pushing construction and modelling techniques, the bridge will also be fitted with a sensor network. The sensors will monitor the structural health and use of the bridge to ensure the bridge's lasting integrity. MX3D wants to know how the data that the bridge collects can become meaningful to a public audience. The design challenge of this graduation project is to develop a data driven lighting design for MX3D's sensor equipped 3D printed bridge, to engage a public audience with the bridge and to convey the smartness of the bridge.

Lighting design

Physical lighting design
is determined by the lighting technology

Lighting visualization
is determined by the data

impacts

Amsterdam
The lighting design should minimize contributing to the overcrowdedness.

Bridge
The lighting design should be integrated with the bridge and enhance the design of the bridge

Public
The lighting visualization should be easy to understand.

Placement
Outer sides of bridge

Technology
Optic fibers

Data
Amount of people

Through the exploration of the bridge, the location, the data and lighting technologies, multiple concepts were found using side emitting optical fibres. The final concept led from the results of a user test: A lighting design from side emitting optical fibres, that conveys the amount of people through the amount of lines that are turned on. The lighting design glows in a constant motion to convey that the bridge is a living and breathing entity, that is aware of its surroundings. The colour of the lighting design is light blue, the colour of smart technology.
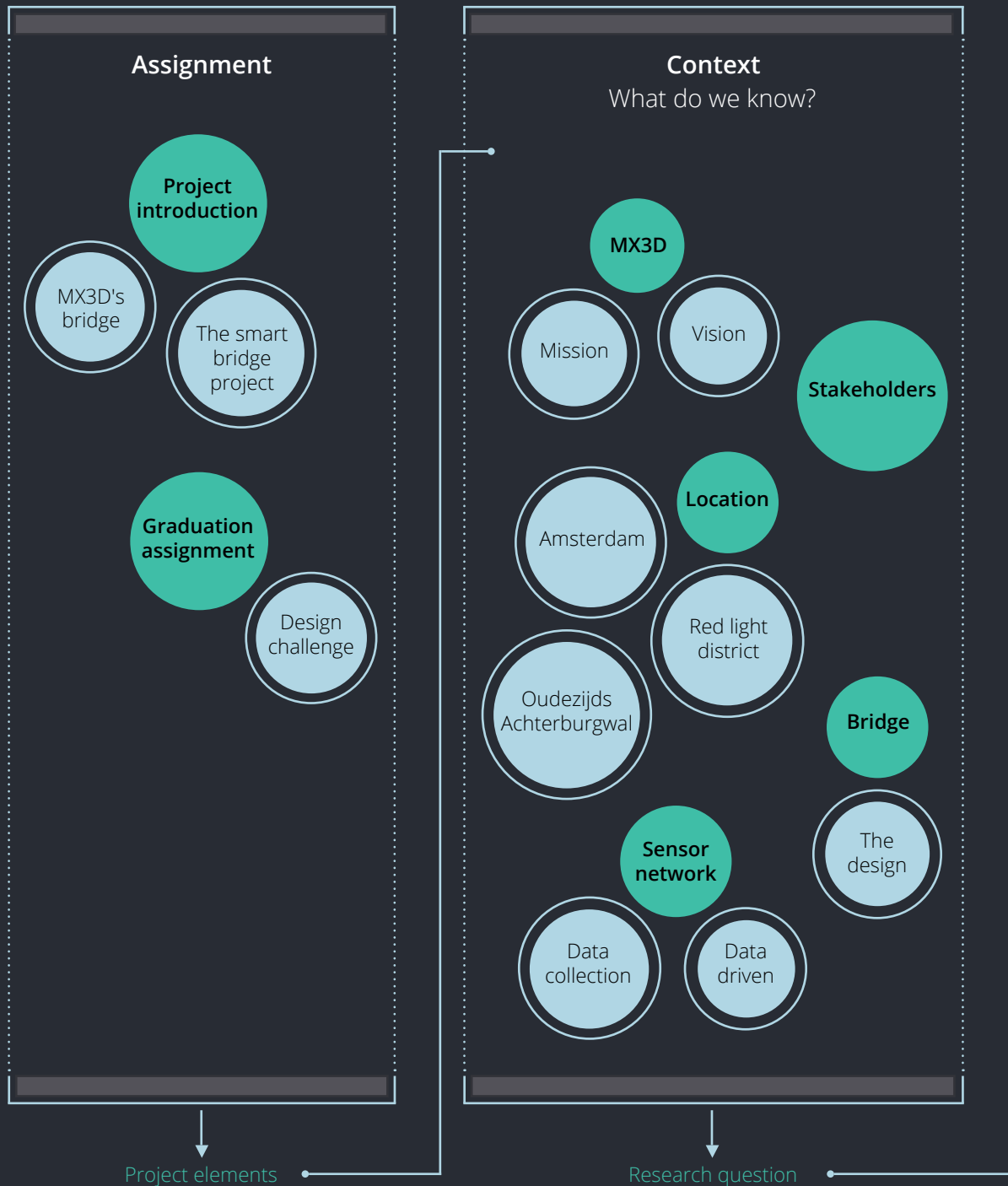
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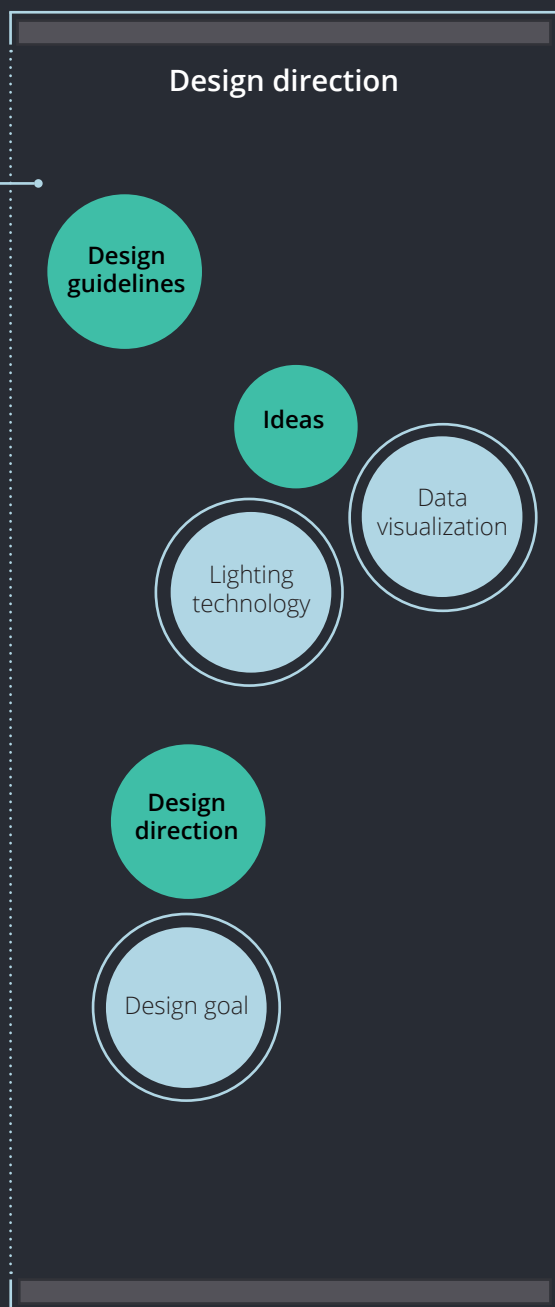
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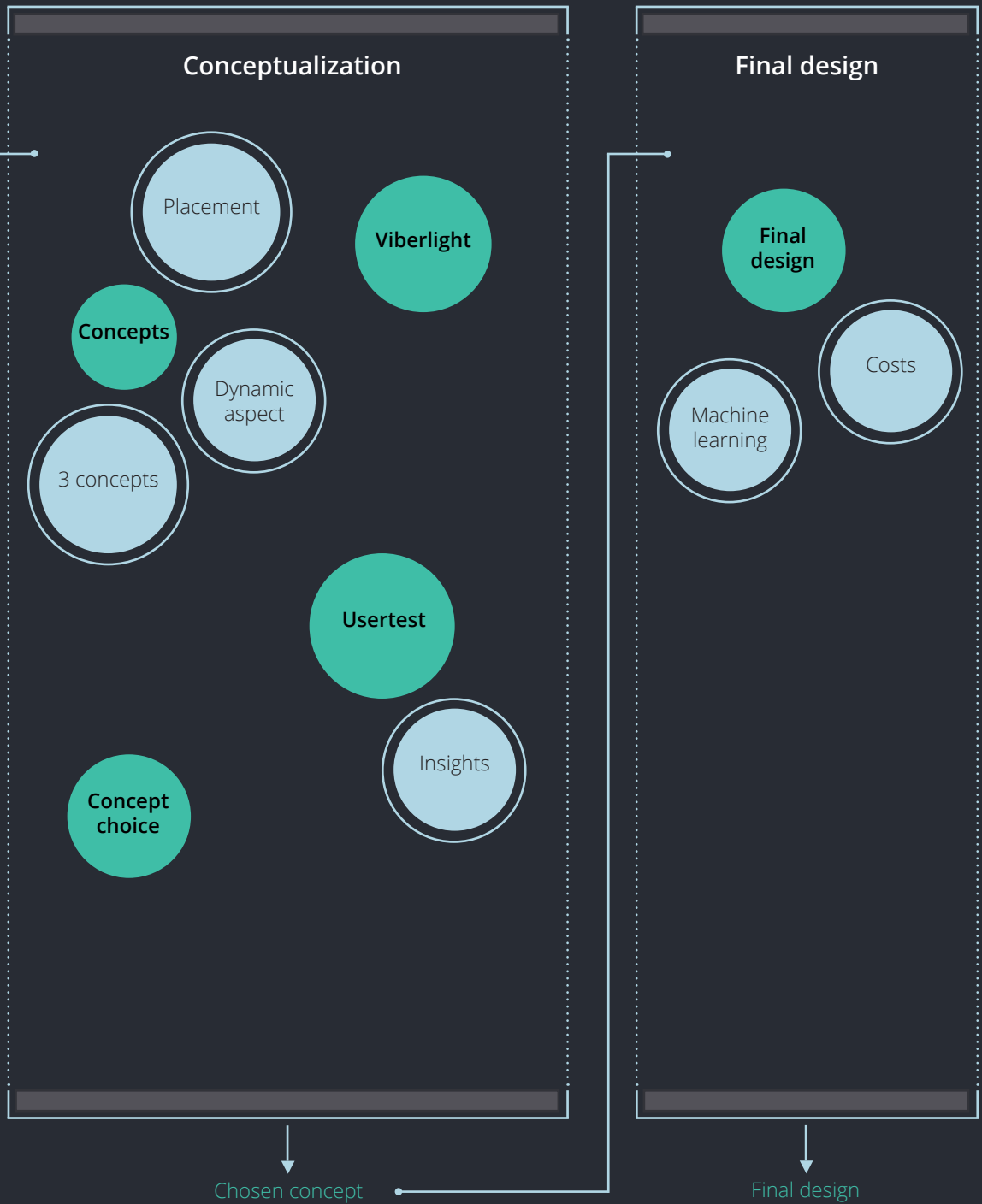
Assignment

This chapter contains information about the project and the design challenge. It briefly introduces MX3D and their 3D printed bridge and describes how this graduation project contributes to the 'smart bridge project'. The goal of this chapter is to introduce the elements that make up this graduation project.

An introduction to the graduation project

A new type of bridge

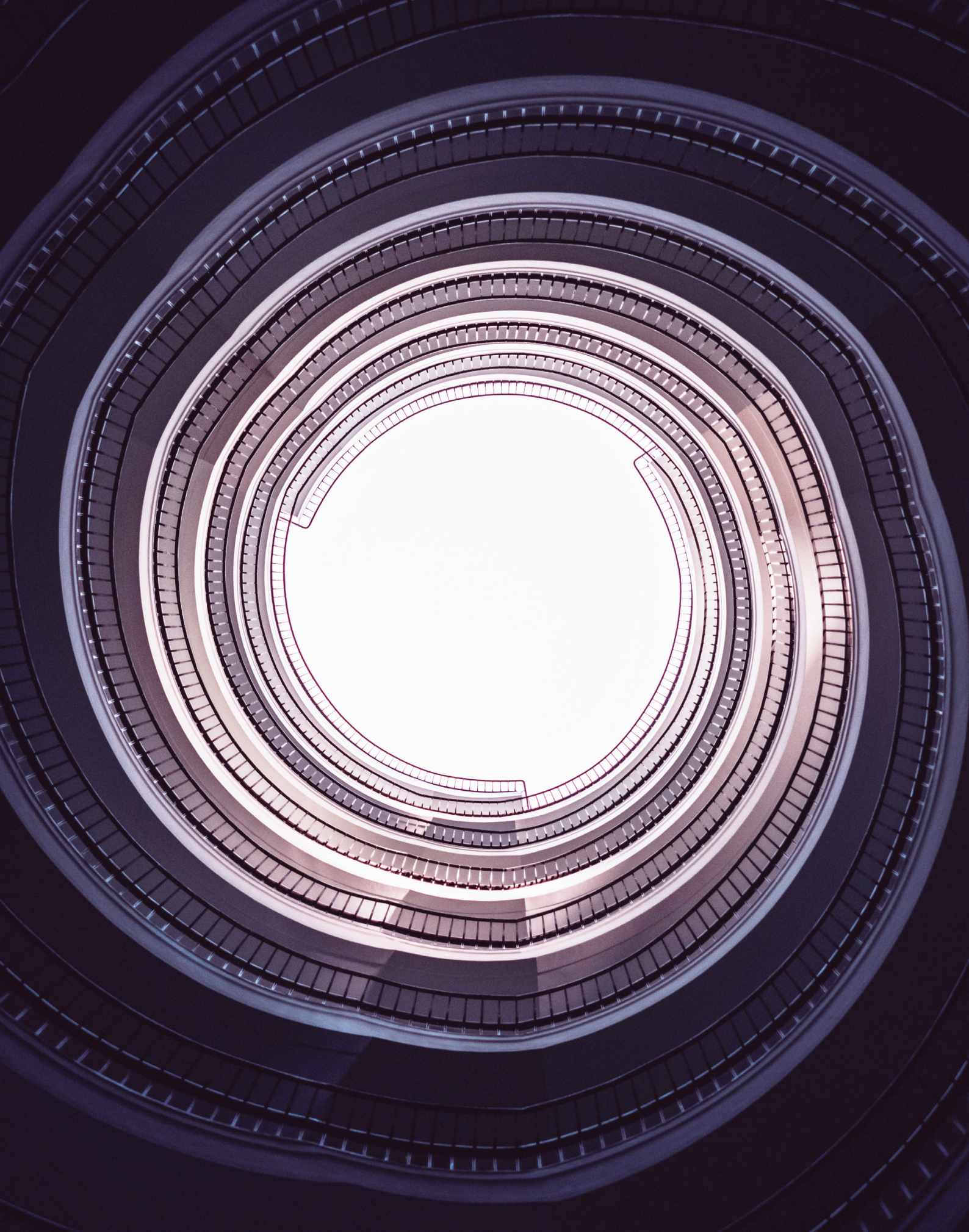MX3D is a company that specializes in robotic welding of stainless steel, also referred to as 3D printing metal. In June 2015, MX3D announced that they were planning on building a fully functional 3D printed stainless steel bridge (MX3D Bridge, 2015). The goal of the 'bridge project' is to showcase the potential applications of this manufacturing technology (MX3D, Bridge, n.d.). The bridge will be placed on the Oudezijds Achterbrugwal, one of the oldest and most famous canals in the centre of Amsterdam, located in the red light district. The bridge (*Figure 1*) is intend to be installed sometime in 2019.

Because the bridge is pushing construction and modelling techniques and real-world behaviour of a 3D printed bridge is largely unknown, the bridge will also be fitted with a sensor network. The sensors will monitor the structural health and use of the bridge to ensure the bridge's lasting integrity. MX3D refers to this as the 'smart bridge project'. The sensor data will be fed to a 'digital twin' bridge model that will help engineers understand how the bridge is performing over time and make tweaks to future designs accordingly (Estes, 2018).

The bridge project

Who: MX3D and Joris Laarman Lab, supported by 'bridge' project stakeholders.
What: A 3D printed stainless steel bridge for pedestrians.
Where: Oudezijds Achterbrugwal in the red light district of Amsterdam.
Why: To showcase the potential applications of the robotic additive manufacturing technology.

The smart bridge project

Who: MX3D supported by 'smart bridge' project stakeholders.
What: A smarter version of the 3D printed stainless steel bridge.
How: By placing sensors on the bridge and feeding the data into a digital twin model.
Why: To monitor structural health and use of the bridge.

Figure 1 Render of bridge in MX3D 's warehouse (Joris Laarman Lab, n.d.)

MX3D's bridge
A 3D printed stainless steel bridge.

The smart bridge project
Transforming the bridge into a smart bridge by integrating a sensor network that collects data about the bridge.
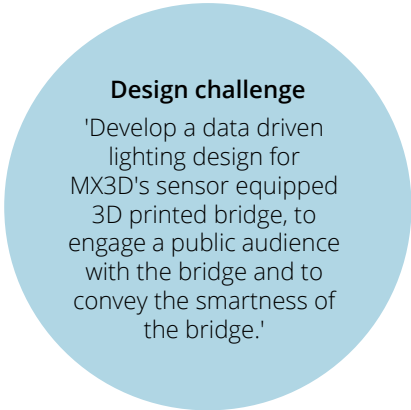
The graduation assignment explained

Design challenge

Infrastructure monitoring with sensors has become standard practice, but is not yet widespread. The collected sensor data is primarily used for monitoring structural health and predicting maintenance needs. Such data has not yet been used to engage a public audience with the infrastructure and to help create an understanding of the infrastructure and technology. As part of the 'smart bridge project', MX3D wants to know how this data can become meaningful to a public audience. The hypothesis is that a lighting design can be used to visualize data and create a meaningful experience for passersby.

The design challenge of this graduation project is to develop a data driven lighting design for MX3D's sensor equipped 3D printed bridge, to engage a public audience with the bridge and to convey the smartness of the bridge.

The term 'lighting design' refers to the physical lighting design, as well as the lighting visualisation. The focus will lie on exploring the complexity of this challenge. Different aspects will be investigated in order to determine the conditions and requirements in which such a lighting design can exist. The proposed lighting design will serve as an example of how a data driven lighting design for the bridge might look.

Design challenge

'Develop a data driven lighting design for MX3D's sensor equipped 3D printed bridge, to engage a public audience with the bridge and to convey the smartness of the bridge.'

The project approach and report structure

Project approach

The report structure and project approach are visualized on page 6, up to page 9. This project consists of eight phases: assignment, context, knowledge areas, design direction, vision, conceptualization, final design and evaluation (the evaluation phase is not visualized). The starting point of his project is the design challenge set by MX3D. Through the introduction of the project, the different project elements are defined. These project elements are discussed in more detail in the second phase: context. Everything that is already known about the project is explained here. By structuring everything that is known, it becomes easier to determine what still needs to be investigated. These question are answered in the third phase: knowledge areas. This phase provides a lot of new information, some initial ideas concerning the lighting design and provides a clear overview of the restrictions that exist within this project. These restrictions are used in phase four to define design guidelines. This phase is also used to create an overview of the most relevant options for the lighting technology and data visualisation. In the end, a design direction is decided on, which is captured in a one sentence in the design goal. In the next phase an interaction vision is created, as a guidelines during the design process of the lighting design. In the conceptualization phase six concepts for the lighting design are created. A selection of three concepts is made, which are used in the user test. The phase ends with a choice for the final concept. This concept is then further explored in the final design phase. The project ends with an evaluation phase in which the project and my process are evaluated and recommendations are made.

Project introduction

MX3D's bridge

A 3D printed stainless steel bridge.

The smart bridge project

Transforming the bridge into a smart bridge by integrating a sensor network that collects data about the bridge.

Graduation assignment

Design challenge

'Develop a data driven lighting design for MX3D's sensor equipped 3D printed bridge, to engage a public audience with the bridge and to convey the smartness of the bridge.'

Conclusion

The innovation behind MX3D's bridge is the new production technique and new material. MX3D wants to use the bridge to showcase their new technology and its possible applications. The bridge will be equipped with sensors to monitor the structural health and use of the bridge and to gather data concerning the overcrowdedness in Amsterdam. MX3D wants to know if the data that the bridge collects can also become meaningful to a public audience. Their hypothesis is that a data driven lighting design can be used to engage a public audience and convey the smartness of the bridge. This graduation project will contribute to their 'smart bridge project' by exploring this matter and developing a lighting design for the bridge. The different elements that make up this project will be discussed in more detail in the next chapter.
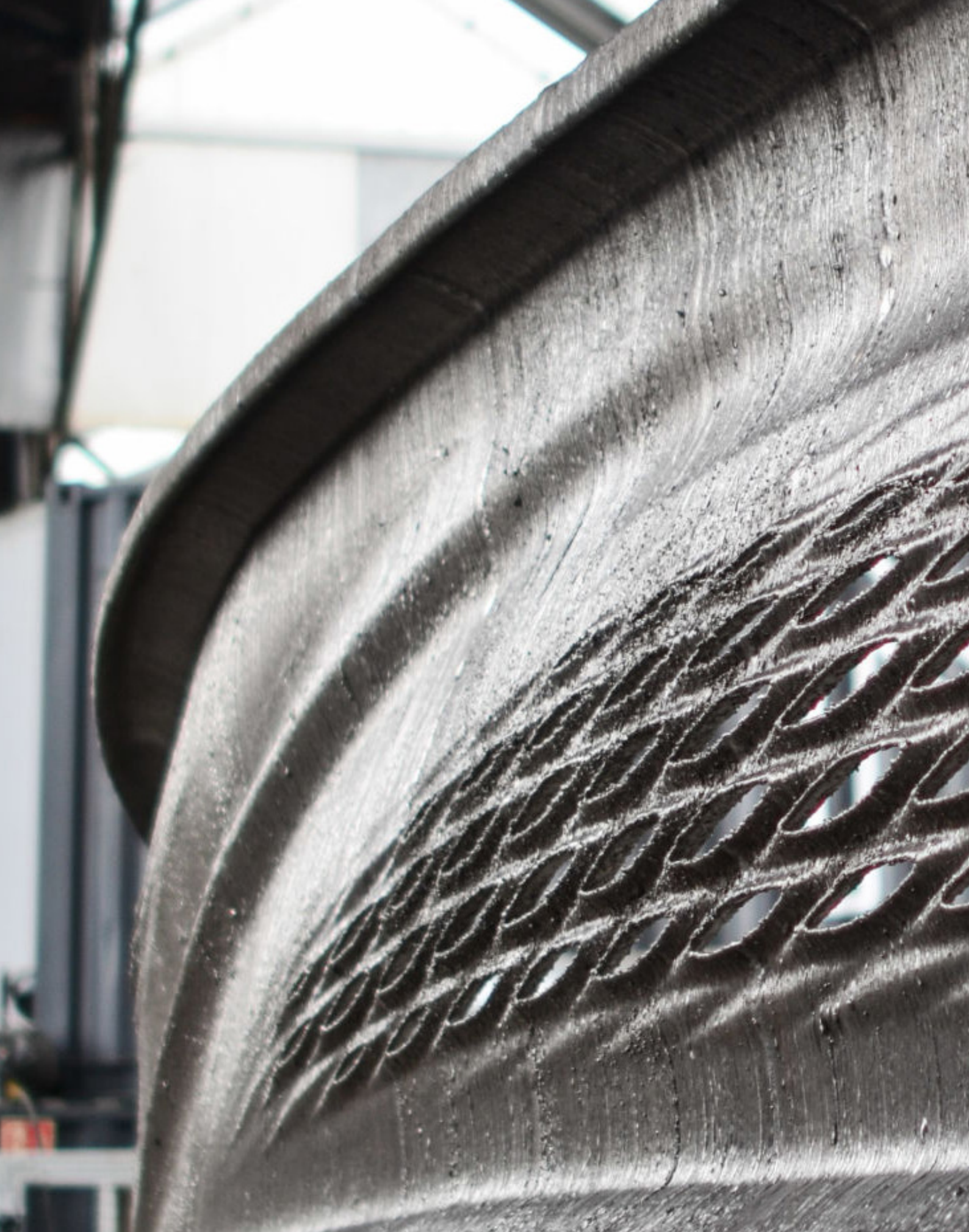
Context

This chapter focusses on the different elements
that make up this project: MX3D, the stakeholders,
Amsterdam, the bridge and the sensor network.
What do we already know? It is important to create
a better understanding of the project, in order to
determine what still needs to be investigated.

MX3D: the company behind the bridge

Introduction

MX3D is leading the consortium of companies and research organizations involved with the 'bridge project' and the 'smart bridge project'. The company has teamed up with different stakeholders to firstly develop the bridge and secondly, now that the bridge is almost finished, to turn the bridge into a smart bridge.

Their technology

The technology used to build this bridge originated at the Joris Laarman lab. It resulted from the desire to be able to print 3D objects that are larger than the box of a 3D printer. After initial experiments, it was decided that the technology would only be able to grow properly if it could stand on its own as an independent company (Joris Laarman Lab, n.d.). This led to MX3D, run by Gijs van der Velden. MX3D further investigated fast large scale prototyping. They found the solution in robotic additive manufacturing, by equipping typical industrial robots with purpose-built tools and developing the software to control them (*Figure 2*). The combination of a standard robot with a standard welding machine and MX3D's software allowed them to do free form 3D printing on a large-scale (MX3D, Bridge, n.d.). This new type of technology can print in mid-air without conventional limitations (Estes, 2018).

Their vision

With the bridge they want to showcase how far they have come with their new technology and how it can be used for actual construction. MX3D believes that automated and autonomous production of unique computer generated parts and structures will become a standard production method in the next 10 years. The company envisions their robots building constructions such as bridges and buildings in full autonomy (*Figure 3*). They see it as their mission to create intelligent, robust and easy to use robotic additive manufacturing software for industrial partners (MX3D, About, n.d.).

Vision
MX3D robots building constructions such as bridges and buildings in full autonomy.

Mission
'Create intelligent, robust and easy to use robotic additive manufacturing software for industrial partners .'

Figure 2 MX3D's printing robot (De Gruijter, n.d.)

Figure 3 Printing in full autonomy (MX3D, n.d)

Stakeholders of the smart bridge project

Introduction

The 'smart bridge project' has grown into a large scale project with multiple stakeholders (*Figure 4*). In the following text, the most important stakeholders and their roles are discussed. Other stakeholders who also contributed to the project are Lloyds Registers Foundation who is responsible for the funding of the project, Faro who provided 3D measurement and documentation expertise, Force Technology who provided sensor expertise and the University of Cambridge, University of Twente and University of Bologna, who are responsible for conducting research.

Joris Laarman Lab

The Joris Laarman Lab is a company that explores emerging technologies. They particularly focus on technologies such as 3D printing, robotics and simulation software. The company is known for multiple projects such as 'the bone chair' and 'the butterfly screen'. The Joris Laarman Lab initiated the 'bridge project' together with MX3D and has been involved with the design and development of the bridge.

City of Amsterdam

The city of Amsterdam commissioned MX3D to build a 3D printed bridge that will replace an existing bridge on one of the canals. The city has collaborated with MX3D, Arup and Imperial college to define a method for evaluating the safety of the bridge (Estes, 2018).

Arup

Arup is an independent firm of designers, planners, engineers, consultants and technical specialists, specialized in every aspect of the built environment (Arup, n.d.). Arup is the lead structural engineer of this project and is concerned with investigating the structural safety of the bridge, together with the Imperial College.

Imperial College

The Imperial College is a public research university based in London. They are involved with investigating the sensor network and the digital twin model, together with the Alan Turning Institute. The university also focusses on the structural behaviour of the bridge, investigating how the material behaves, since the bridge is built using an uncodified construction technique with uncodified material properties.

Alan Turning Institute

The Alan Turning Institute is the national institute for data science and artificial intelligence in the United Kingdom. They are responsible for designing and installing the sensor network on the bridge, to monitor the structural health and use (MX3D, Smarter bridge, n.d.). They are also responsible for the development of the digital twin model and the machine learning algorithms that will interpret the data gathered from the bridge sensor.

Autodesk

Autodesk is an international software and technology company. The company is an important stakeholder of both the 'bridge project' and 'smart bridge project'. Autodesk adds expertise in digital modelling and sensor data management with a particular focus on Dasher 360, a not yet commercial tool developed by Autodesk. Dasher360 collects, manages and visualizes sensor data and provides access to data via an application programming interface. Autodesk has a bridge in San Francisco that is used for testing, referred to as the Pier 9 bridge. This bridge is equipped with sensors and has been used for experiments in collecting and analysing data. Autodesk has made the data from the Pier 9 bridge available to partners using Dasher360. Autodesk is also working with The Alan Turning Institute researchers to develop machine learning algorithms that will enable the bridge to interpret and to react intelligently to its environment (MX3D, Smarter bridge, n.d.).

AMS Institute

The Amsterdam Institute for Advanced Metropolitan Solutions, or AMS institute, is an institute that focusses on urban challenges
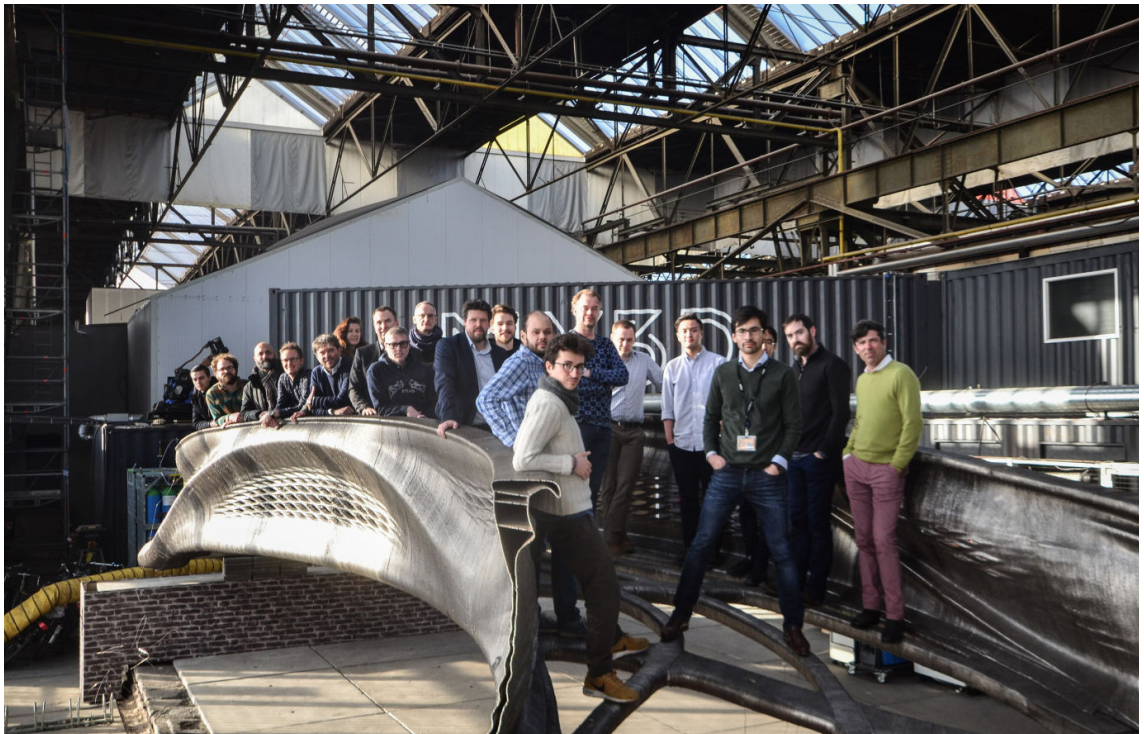
Figure 4 Smart bridge project team (De Groot, 2018)

of sustainability and quality of life, including resource and food security, mobility and logistics, water and waste management, and health and wellbeing (AMS institute, n.d.). AMS institute will be implementing new ways to use, visualize and connect the bridge's data to other sources of environmental data in the Metropolitan Area of Amsterdam (MX3D, Smarter bridge, n.d.).

Technical University of Delft

The Technical University of Delft, or TU Delft, has been granted research funding to investigate the role of smart public infrastructures in making and re-making public space. Also to explore how designers, technologists, and citizens can utilize rapid urban manufacturing and IoT technologies for designing urban spaces that express their intelligence from the intersection of people, places, activities and technology. This graduation project will contribute to that goal.

Stakeholders

There are multiple stakeholders that contribute to the smart bridge project, each focussing on their own area of expertise. The stakeholders that contribute the most to this graduation project are MX3D (bridge) and Autodesk (sensors and data).

Amsterdam: the location of the bridge

Introduction

Amsterdam is the capital city of the Netherlands. In the 17th century, during the Dutch Golden Age, the city became one of the most important ports. It was during this time that Amsterdam's famous canal ring was built: a network of intersecting waterways (I amsterdam, Amsterdam's canal ring, n.d.). In 2010 the Amsterdam Canal Ring was added to UNESCO's World Heritage List. Today, Amsterdam is known as a multicultural city with residents from 180 different countries. The city is an open and tolerant society that embraces a variety of different lifestyles, religions and beliefs (I amsterdam, Amsterdam society, n.d.). Each year, Amsterdam's canals play host to multiple major events on or alongside the water such as King's Day (formerly Queen's Day), the Gay Pride Parade, Amsterdam Light festival and the Canal Festival.

The red light district

The Red light District is one of the oldest areas in Amsterdam with many historic buildings (*Figure 6, highlighted area*). The area is mostly known for prostitutes, sex shops and coffeeshops, but the area also houses residential homes, pubs and restaurants. The Red Light District gets its name from the red neon lights that light up the windows of the brothels (*Figure 5*). There are over 400 windows in the area and the number of employed prostitutes per day is over 700 (Amsterdam.org, 2018). Prostitution in Amsterdam has enjoyed a long tradition of tolerance. The city embraces the fact that people may have preference for prostitution, soft drugs and pornography. But behind this image of acceptance lurks a different reality that at times consists of sex trafficking and forced prostitution, something the city and justice department are fighting against (Amsterdam Today, 2016). The smart bridge will be situated in the middle of the red light district on the Oudezijds Achterburgwal.
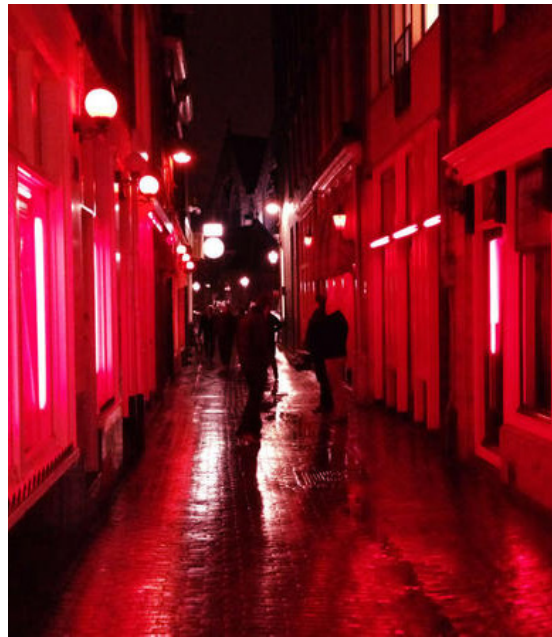
Figure 5 Red light district (Tripadvisor, n.d.)

Amsterdam

A multicultural city with residents from 180 different countries

Red light district

The name comes from the red neon lights that light up the windows of the brothels
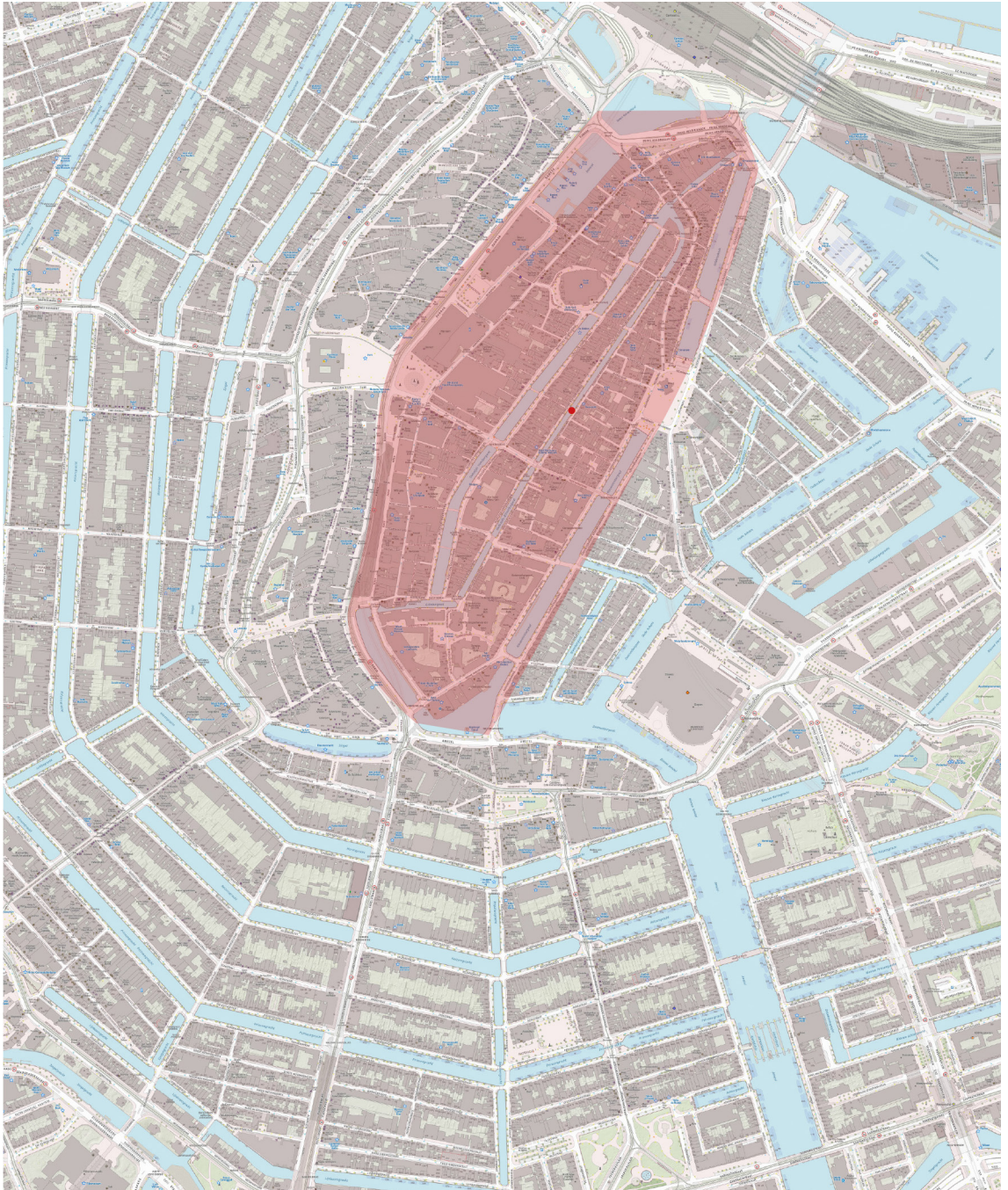
Figure 6 Map of amsterdam with red light district highlighted (OpenTopo, n.d.)

Figure 7 Oudezijds Achterburgwal by day time (Balsing, 2010)

Figure 8 Oudezijds Achterburgwal by night time (Nwanazia, 2017)

Figure 9 Location with current bridge (Estes, 2018)

Oudezijds Achterburgwal

The bridge will be situated on the Oudezijds Achterburgwal, where the Stoofsteeg intersects with the street (*Figure 6, red dot*). The Oudezijds Achterburgwal is one of the oldest canal streets in Amsterdam and one of the main streets in the Red Light District. (*Figure 7, 8, 9*). Joris Laarman stated that a bridge over one of the old canals in Amsterdam would be a fantastic metaphor for connecting the technology of the future with the city's past, in a way that would reveal the best aspects of both worlds (Joris Laarman Lab, n.d.). Because the street is situated in the Red Light District it attracts a lot of different people. Some visit the area for the red light district, some are residents who live there and others just pass through on their way to another destination. In 2017 the Oudezijds Achterburgwal had 3.1 million visitors. On the busiest day of that year, the street had over 14000 visitors in one day (Het Parool, 2018). These numbers illustrate the crowdedness, which has become a serious issue for Amsterdam.

Oudezijds Achterburgwal

Overcrowdedness is a serious issue in the Red Light District. On the busiest day in 2017 the street had over 14000 visitors in one day

The 3D printed stainless steel bridge

Introduction

The bridge is a 12 meter long footbridge. As mentioned before, the bridge is additively manufactured using stainless steel and is built predominantly by robots. This production technique is also referred to as 3D printing stainless steel. MX3D wants to use the bridge as a medium for data visualization.

The design

MX3D and Joris Laarman Lab spent a lot of time on optimizing the design. They turned the bridge into a piece of art. The bridge has an organic design, based on the patterns of stress lines. This can clearly be seen when you compare figure 15 and 16. The metal appearance gives the bridge a futuristic feel. During construction the bridge was divided into 4 main parts: the walkway structure, the walkway path and the two sides of the bridge (*Figure 12, 13, 14*). The walkway path is made from perforated steel plates. The other three parts were printed separately, layer by layer and were later welded together. The printing layers are still visible and give the bridge it's unique texture. The cross section of the side of the bridge in figure 10 shows these printing layers. It also shows that the bridge is hollow on the inside. This saves production time and material costs and brings down the weight of the bridge. It is also a good place for integrating sensors or lighting elements into the bridge.
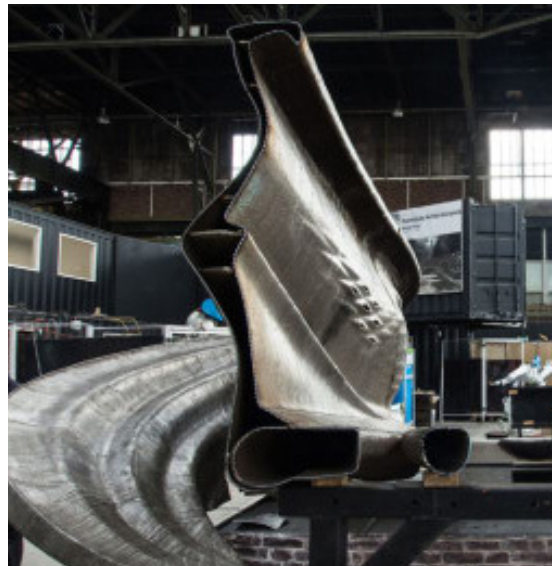

Figure 10 Hollow cross section (De Gruijter, n.d.)

Figure 11 Close up of printing layers and texture bridge (De Groot, 2018)

The organic design of the walkway structure won't be visible for pedestrians crossing the bridge, as it will be covered by the perforated steel plates of the walkway path.
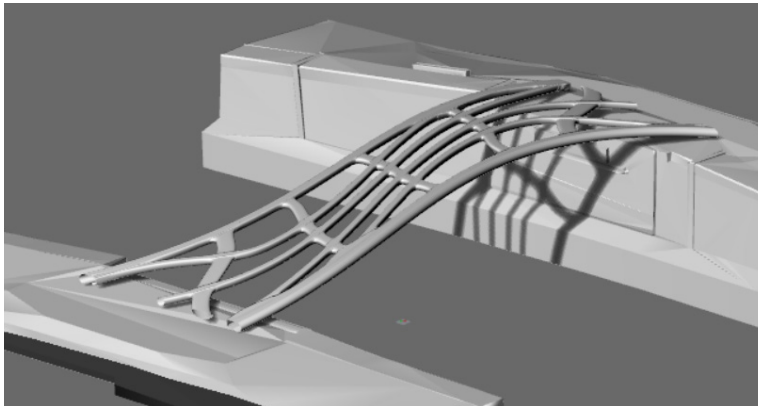
Figure 12 Render of the walkway structure

The walkway path is made from perforated steel to provide a good grip. MX3D decided not to use a see-through walkway path, as the current design is already pushing boundaries and a see-through path might scare pedestrians.
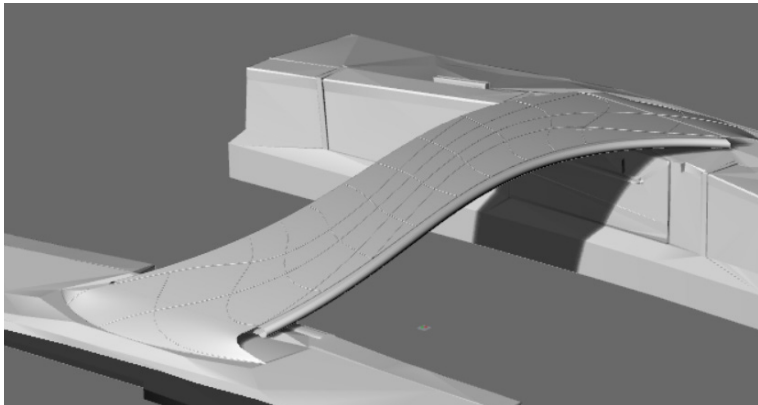
Figure 13 Render of the walkway path

The two sides of the bridge are identical to one another but mirrored, adding a certain sense of symmetry to the design.
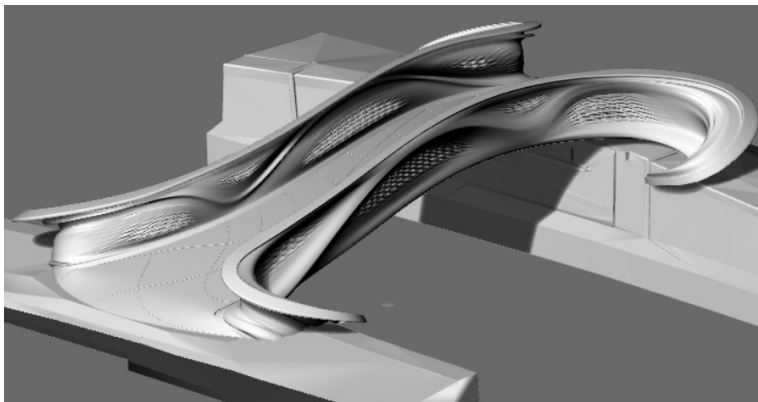
Figure 14 Render of the two sides

Figure 15 Stress lines bridge (MX3D, A smarter bridge, n.d

The bridge

The bridge has an organic design, based on the patterns of stress lines. The metal appearance gives the bridge a futuristic feel.

Figure 16 The bridge (Wolzak, 2018)

The sensor network: sensors and data

Introduction

As mentioned before, the bridge will be fitted with a sensor network. These sensors will collect structural measurements such as strain, displacement and vibration, and will measure environmental factors such as temperature and air quality (MX3D, Smart bridge, n.d.). MX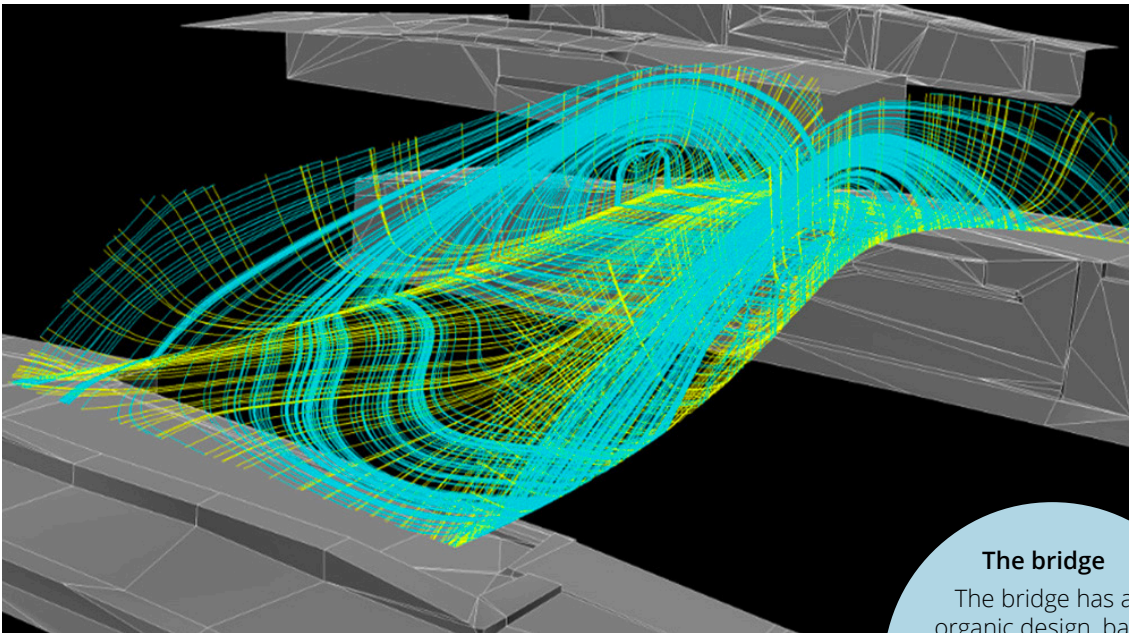3D and Autodesk are currently still working on the sensor network. Since there is no definite sensor plan for the bridge, no specifications are made in this chapter concerning the sensors and the sensor locations on the bridge. A list of potential sensors and what they can measure can be found in Appendix 6.

Why is data being collected?

- **Safety**
  The bridge was built using a new production technique. Robotic welding of stainless steel is an uncodified construction technique with uncodified material properties. To make sure the bridge is safe to use and will remain safe overtime, sensors will be added to the bridge. The sensors enable engineers to monitor the bridge's structural performance and behaviour in real time.

- **Research into the material properties**
  The bridge is pushing construction and modelling techniques and real-world behaviour of a 3D printed bridge is largely unknown. Therefore the bridge makes for an interesting research subject. The sensor data can be used to study the material behaviour and can be used to build up engineering knowledge.

- **Research into smart infrastructures**
  The data will also be used to turn the bridge into a smart bridge (*Figure 17*). The goal is to have machine learning algorithms analyse the data and learn from it what is happening: how many people are crossing the bridge and how quickly and in what direction are they going? Can a smart bridge be taught to detect that people are using it in a suboptimal way, given the current conditions, and can it be given capabilities to encourage those people to move one?

- **Research into overcrowdedness**
  The sensors on the bridge can help Amsterdam gather information about the pedestrian flow, which is important for solving the growing problem of overcrowdedness in Amsterdam. In a future scenario, the bridge could become part of a larger network of smart bridges. During an interview (*Appendix 1*) Autodesk explained the potential of having bridges in Amsterdam fitted with sensors. Alec Shuldiner (Autodesk) envisions the bridges being able to give an occupancy count at any given moment. This way traffic can be monitored throughout the whole city and the data can be used to create a heat map of the occupancy (*Figure 18*). It also allows for outliers to be detected. 'If there is especially high traffic somewhere, compared to other local bridges or compared historically to similar time periods in the past, that could indicate a problem that requires some sort of attention'.

Data collection
Safety
Material properties
Smart infrastructure
Overcrowdednes
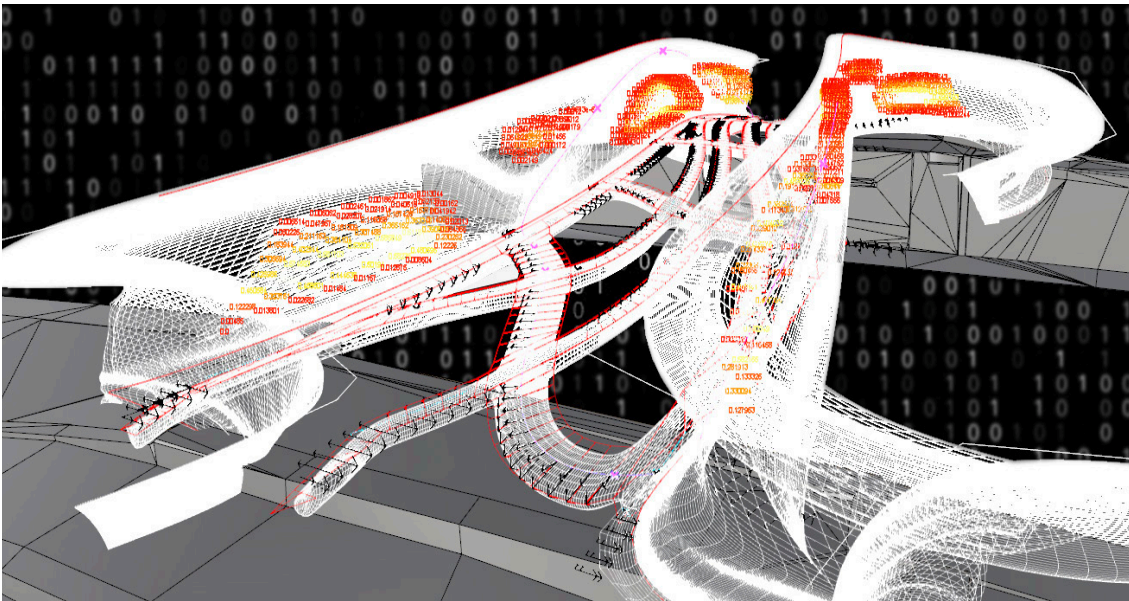
Figure 17 Visual representation of the smart bridge (MX3D, A smarter bridge, n.d.)
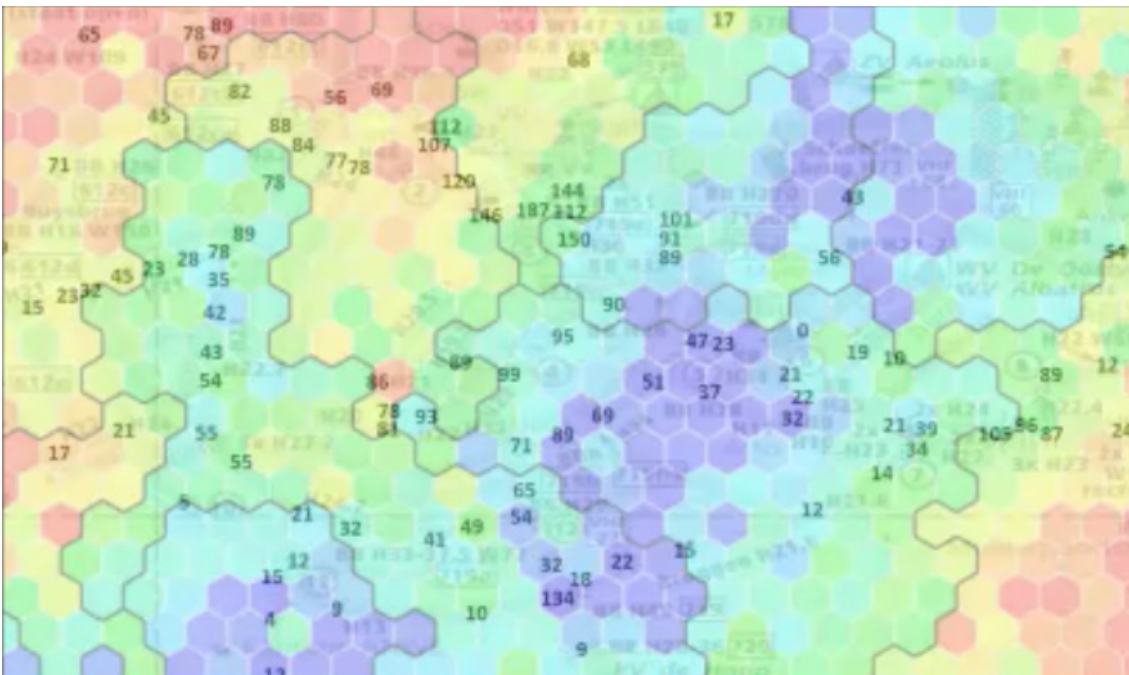
Figure 18 Example of a heat map given by Alec Shuldiner (Appendix 1)

What happens to the data?

It starts with the sensors. The sensors generate raw data, which is collected by data acquisition devices. These devices send the data to a local server, which temporarily saves the data on a local cache. From here the data is pushed into a cloud database, at a regular interval, using a rest API protocol. From here the data will be analysed and processed into meta data. A supervisory program will turn the meta data into high level operating data and store it in a historical data base. The program will also send the high level operating data back to the local server, where a local supervisor will generate an operating message that actuates the data driven lighting design.

Figure 19 Data flow diagram

Sharing the data

The raw data that the bridge collects will be processed and relevant metadata will be derived from it. Both the raw data and the higher order intelligence that the bridge generates will be available to stakeholders and partners through a data commons. Autodesk wants to collectively build an operating system for the bridge, that is modular and updatable. They envision it consisting of different layers so that different people can add to different areas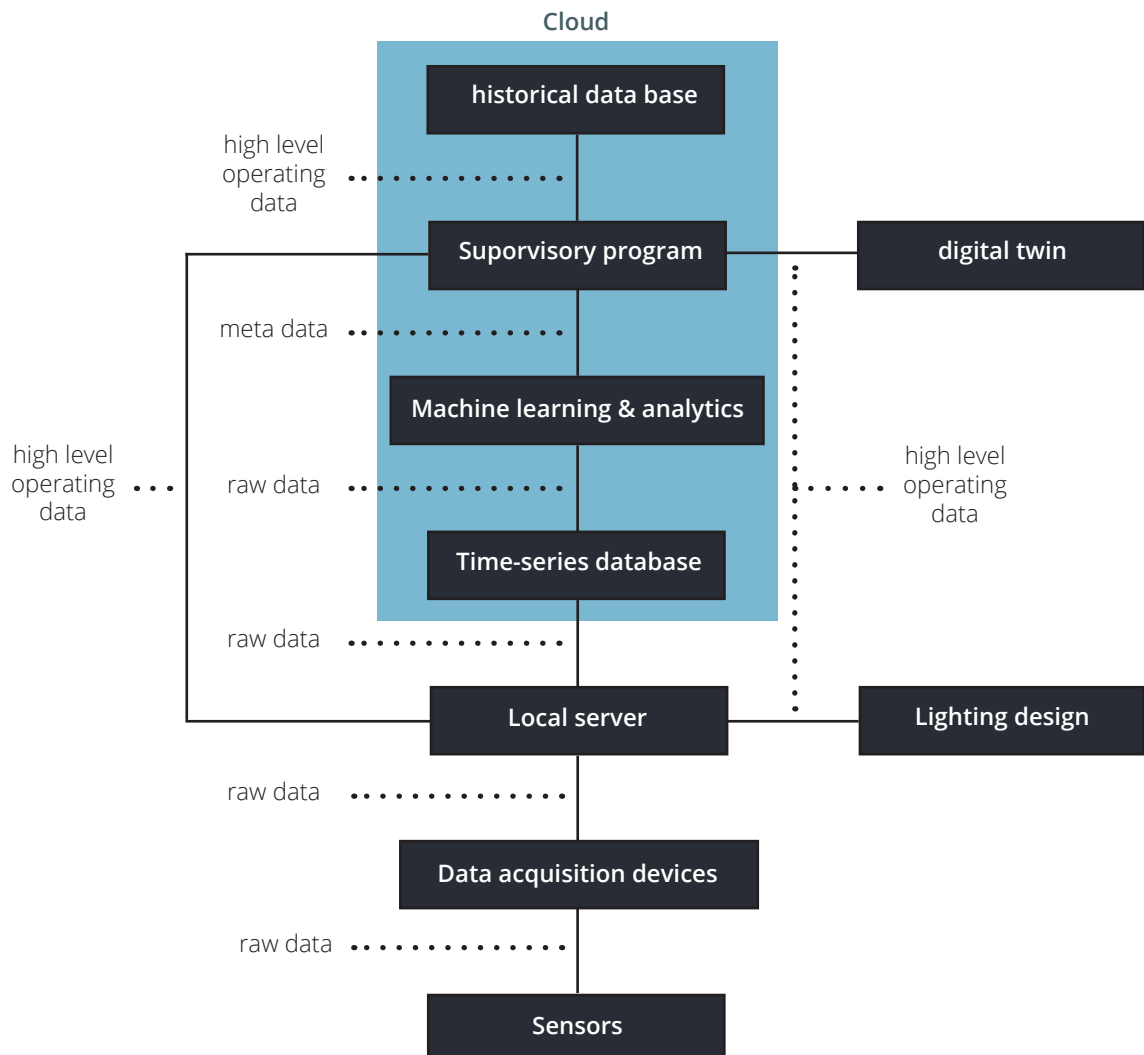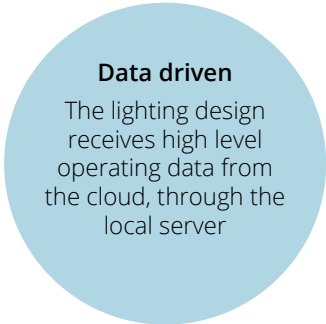, depending on their expertise. Alec Shuldiner (Autodesk): "..anybody should be able to come to the bridge and immediately understand the full capabilities in terms of what information they can get out of the bridge" (*Appendix 1*). Alex Tussier (Autodesk): "as more partners and people contribute and add more modules, the bridge will be able to see and feel and emote more kinds of detailed activities" (*Appendix 1*).

Dasher 360

Autodesk has a bridge in San Francisco, referred to as the Pier 9 bridge. It is an indoor bridge in one of their workshop spaces, that they have fitted with sensors and a visions system. They are using it as a trial run for the sensor network that they plan to install on the MX3D bridge. The Pier 9 bridge has been used for experiments in collecting and analysing data. Autodesk has used Dasher360 (*Figure 21*) to collect, manage and visualize the sensor data and to provide access to the data via an application programming interface (API). A lot of insights have been gained from the Pier 9 bridge that are relevant for MX3D's smart bridge project. The most important insights are the difficulties they experienced. These can be divided into physical difficulties (placement, calibration, wiring) and digital difficulties (noise, data filtering):

Digital twin model

To make the data more tangible, MX3D plans to create a digital twin of the bridge: a computer model that reflects the physical bridge in real time (*Figure 20*). The data that the physical bridge collects will serve as input for the model. This allows the performance and behaviour of the physical bridge to be tested against the digital model. The digital twin can contribute to the safety of the bridge, by ensuring that the bridge is safe for pedestrians and it can contribute to the material research by providing valuable insights to inform designs for future 3D printed metallic structures.

Data driven

The lighting design receives high level operating data from the cloud, through the local server
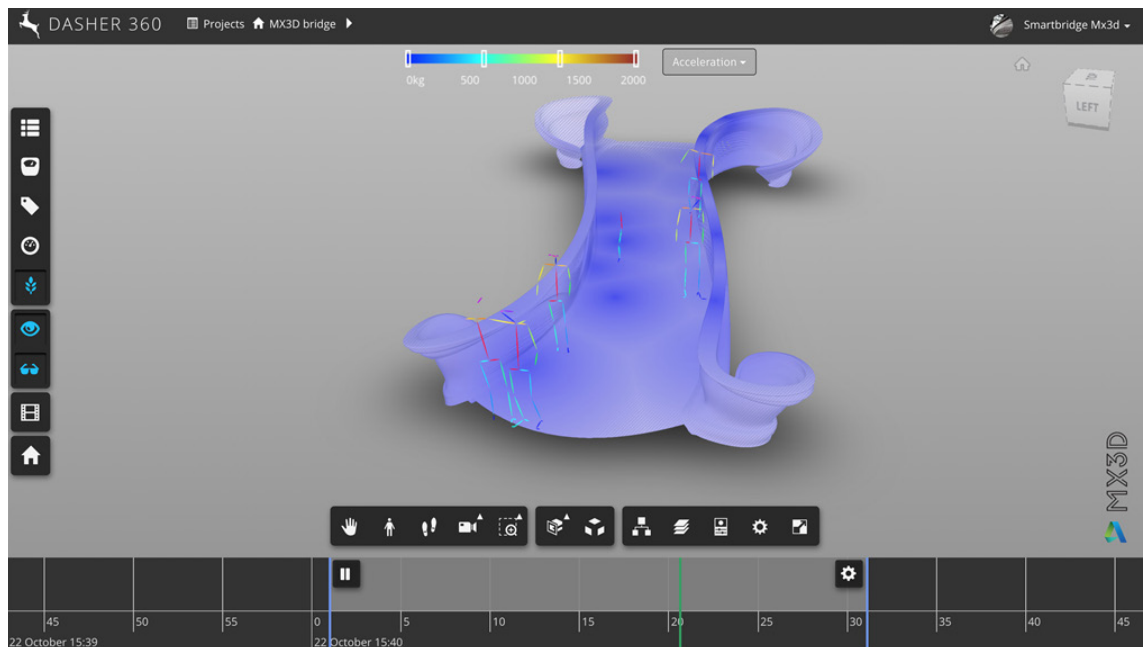
Figure 20 Screenshot of Dasher360 and the MX3D bridge with human skeletons
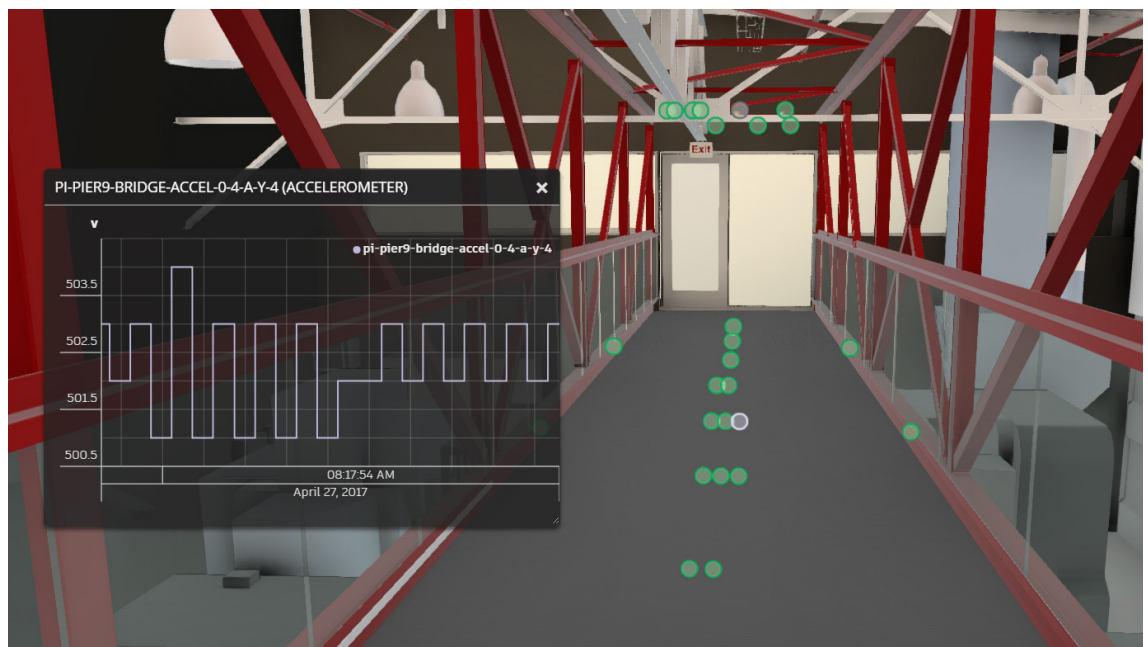
Figure 21 Screenshot of Dasher360 and the Pier 9 bridge with sensor graph

MX3D

Mission
'Create intelligent, robust and easy to use robotic additive manufacturing software for industrial partners .'

Vision
MX3D robots building constructions such as bridges and buildings in full autonomy.

Stakeholders

Stakeholders
There are multiple stakeholders that contribute to the smart bridge project, each focussing on their own area of expertise. The stakeholders that contribute the most to this graduation project are MX3D (bridge) and Autodesk (sensors and data).

Location

Amsterdam
A multicultural city with residents from 180 different countries

Red light district
The name comes from the red neon lights that light up the windows of the brothels

Oudezijds Achterburgwal
Overcrowdedness is a serious issue in the Red Light District. On the busiest day in 2017 the street had over 14000 visitors in one day

Bridge

The bridge
The bridge has an organic design, based on the patterns of stress lines. The metal appearance gives the bridge a futuristic feel.

Sensor network

Data collection
Safety
Material properties
Smart infrastructure
Overcrowdednes

Data driven
The lighting design receives high level operating data from the cloud, through the local server

Conclusion

MX3D has a clear vision for their technology and the 3D printed bridge is a first step towards the future they envision. By setting themselves the challenge to turn the bridge into a smart bridge, they have made this project even more interesting and have attracted many stakeholders who want to contribute. Now that we have a better understanding of the project, we also have a better understanding what we need to know in order to make design choices regarding the lighting design. The resulting questions will be discussed in the next chapter.

Knowledge areas

What do we still need to know? This chapter
discusses what we need to know in order to make
design choices regarding the data driven lighting
design. The first question focusses on the location
of the bridge: How are people interacting with the
current bridge? By adding a data driven lighting
design to the bridge, the bridge will transform into
media architecture. Therefore it is important to
understand: What is media architecture? What are
the challenges when designing media architecture?
But also what are the basics of light? Where on
the bridge can you add light? What are the lighting
options for the bridge? These question focus more
on light and the bridge. Lastly, there are also some
questions relating to the data: How can data be
visualised? What kind of data does the bridge
collect? Which data is interesting to visualise? The
goal of this chapter is to answer these questions,
while at the same time collecting ideas for the
lighting design.

How are people interacting with the current bridge?

Introduction

It is important to understand the context in which the bridge will be placed. In this case, that is the red light district in Amsterdam. The fact that there is already a bridge in place on the intended location of the 3D printed bridge, makes for a great opportunity. This allows us to analyze how people interact with a bridge on that particular location and make assumptions about how people will interact with the 3D printed bridge, once it has replaced the current bridge.

Observations

During two visits to Amsterdam, the Oudezijds Achterburgwal and the current bridge were observed. From this visit it became apparent that people use the bridge for other things besides crossing the canal such as a meeting point, a scenic viewpoint and a photo opportunity (*Appendix 2*). All these things come down to people standing still on the bridge. In any other city this behaviour wouldn't be a problem, but in Amsterdam and particularly the red light district it is. There is a continuous stream of people passing by, walking from one destination to another. People standing still on the bridge hinder the flow of pedestrians, causing large hold ups to occur. This is an important issue: adding lights to the bridge should not contribute to this problem. The lighting design should not require people standing still to see and observe it. It should not disrupt the pedestrian flow and should not cause crowds to gather. Achieving this will be a challenging task, since light naturally attracts people. You could therefore wonder whether this location is the best place for this bridge? There are multiple reasons why the choice to place the bridge in the red light district feels questionable. Due to its design and the technological innovation, the bridge will become a sightseeing attraction, attracting even more people to that area. Because Amsterdam and particularly the red light district are already experiencing problems with overcrowdedness, this is not an area where you want to attract more people to. Also, light already has a meaning in the red light district, so the lighting design of the bridge will need to overcome the already existing associations people have. On top of that there are already lots of lights in that area, meaning the lighting design on the bridge might not stand out. However determining whether this is the best location for the bridge is out of this projects scope. The location is a given. Nevertheless, I wanted to address these points as they contribute to what makes this project so complex. The biggest challenge of adding lights to the bridge will be to find a balance between intriguing people and making sure people don't hinder the flow of movement because they are intrigued.

Crowdedness

The area is very crowded, particularly at night. At times people on the bridge were unable to walk due to the sheer amount of people trying to be in the same place at the same time

Adding lights

The lighting design should not require people standing still to observe it, should not disrupt the pedestrian flow and should not cause crowds to gather. Achieving this will be a challenging task, since light naturally attracts people.

Figure 22 Photograph of crowdedness current bridge

Figure 23 Photograph of crowdedness current bridge

Figure 24 Photograph of crowdedness current bridge

Figure 25 Photo taken during the visit showing the crowd on the bridge

Figure 26 Photo taken during the visit showing people stopping on the bridge to take a picture

What is media architecture?

Introduction

By adding a data driven lighting design to the bridge, the bridge will transform into media architecture. It is therefore important to have a better understanding of what media architecture is and what it means for the bridge. Media architecture, placemaking and social interaction will be discussed in relation to the bridge, and some examples of media architecture will be shown.

Media architecture

Urban space is emerging as a prominent arena for digital technologies. It presents a unique set of challenges and potentials for the design of interactive systems and installations (Dalsgaard & Halskov, 2010). Media facades are an example of such installations. Media facades are architectural structures with integrated light sources and network infrastructures for distributing power and data (*Figure 30, 31, 32, 33*). It uses media based on information technologies to convey dynamic information and create a meaningful experience. Media facades is the appropriate term to describe the technical implication on a structure, while media architecture refers to the interaction between a structure as a whole and the audience (Media Architecture Biennale 2016, Media architecture). During a visit to Amsterdam I got to experience media architecture for myself when I visisted 'Moodwall', a lighting installation in a pedestrian tunnel. More information about this experience can be found in Appendix 3.

Digital placemaking

Media architecture is a form of digital placemaking. But what is placemaking? Harrison and Dourish (1996) have pointed out that a location becomes 'a place' when space becomes meaningful. This 'placemaking' happens when space becomes meaningful through cultural interactions and context. 'Digital' placemaking makes use of digital media to engage citizens and shape urban experiences. Media architecture is an example of this. Media architecture can facilitate new patterns of use and socialization, by forming a medium for interaction in public spaces. There are two types of digital placemaking: Spectacle and infrastructure placemaking (Haeusler et al., 2017). Spectacle placemaking makes use of temporary digital media installations and is a short term project. Its goal is to create a temporary destination that brings diverse people together to celebrate, inspire, and be inspired. Infrastructure placemaking makes use of situated digital media installations and is a long term project. Its goal is to enhance urban infrastructures, thus creating a sense of place as well as contributing to the liveability of cities.

Definition

Architectural structures with integrated light sources and network infrastructures for distributing power and data, that uses media based on information technologies to convey dynamic information and create a meaningful experience.

Social interaction

The interaction between the public and the media architecture is defined by the types of interface and the type of spatial lay out of the media architecture.

Types of interfaces

Media architecture that is placed in a public urban environment is meant to interact with a public audience. Hespanhol and Tomitsch (2015) argue that this interactive behaviour may emerge intuitively as a product of its level of accessibility and the type of feedback it offers. These aspects influence the type of social interaction that is encountered around urban media architecture. They propose a classification of three types of interfaces in relation to social interaction:

- Performative
  They define performative interfaces as those where the interactive zones are well delimited, yet restricted to a small number of participants, resulting in a natural division of the public into 'performers' (active participants) and 'spectators' (passive participants).

- Allotted
  Allotted interfaces share the same basic characteristics as performative ones, however are large enough to accommodate a population of participants. Participants no longer have full visibility of the interface but instead operate locally on their own section of the interface. Interaction is therefore distributed across the environment.

- Responsive ambient.
  With responsive ambient interfaces they refer to urban interfaces which track and react to the presence of people, however offer indirect and generic feedback rather than responding to specific individuals.

Types of spatial layout

The type of spatial layout that surrounds the urban media architecture also influences what type of social interaction emerges. In their research into social interaction in relation to media architecture, Dalsgaard and Hespanhol (2015) employ two categories of spatial layouts:

- Plaza
  They define a plaza as a wide, open public space where a large number of citizens potentially congregate, facilitating social encounters as well as passive social practices as people watching or loitering (*Figure 28*).

- Thoroughfare
  A thoroughfare, by contrast, is a transit area connecting plazas, therefore characterized by the continuous flux of passers-by walking from one destination to another (*Figure 29*).

Figure 28 Example plaza (Caligari, n.d.)

Figure 29 Example thoroughfare (Stolk, n.d)

Figure 30 'Greenpix' media wall (Giostra, 2008)

Figure 31 Intelligent wall by F/B office (Grozdanic, n.d.)

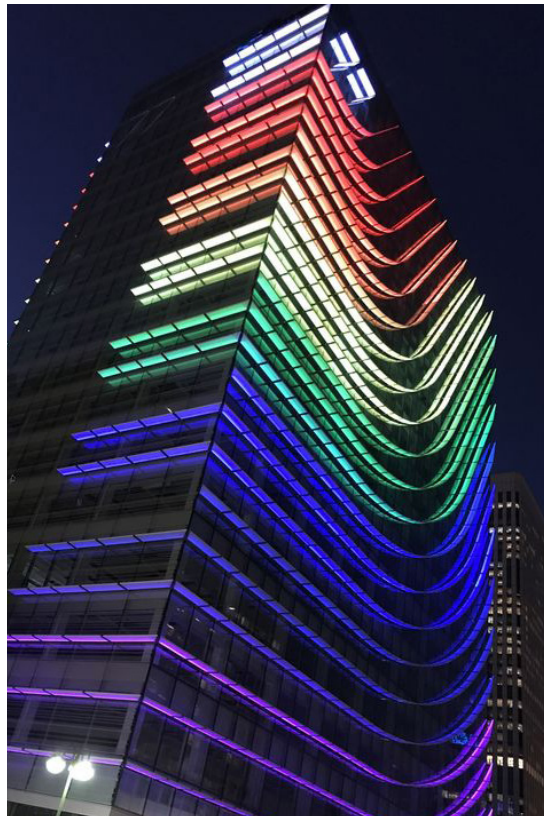Figure 32 Media wall of Casino Bregenz by Zumtobe

Figure 33 'Castellana 77' by iGuzzini illuminazione

Display technologies

There are different ways of turning a building or structure into media architecture. Haeusler (2009) categorized six different display technologies that can be used:

- Front projection façades
  Façades that have digital media projected on to them from the front of the façade by video projectors.

- Back projection façades
  Façades that have media content projected on to translucent areas integrated into the façade from the back of the façade by video projectors.

- Display façades
  Facades that use large screens integrated into the façade to show media content (*Figure 32*).

- Window animations
  Façades that use windows as pixels by illuminating them (*Figure 33*).

- Illuminant or light-emitting façades
  Façades that integrate light emitting elements into the façade (*Figure 30, 31*)

- Mechanical façades
  Façades that integrate mechanically moveable elements into the façade.

Examples of bridges

The San Fransisco Bay Bridge
A successful example of a bridge turned in to media architecture is the San Francisco Bay Bridge, where artist Leo Villareal created a temporary (2013-2015) lighting installation called the Bay Lights (The Bay lights, n.d.). It was turned into a permanent installation in 2016, after the bridge proved to be a succes. The installation is visible from a great distance and shows changing patterns (*Figure 34*) based on data from the environment, such as the flow of water, or fish swimming by.

The Rachel carson Bridge
Another interesting example is the lighting installation 'Energy Flow' on the Rachel Carson Bridge in Pittsburgh, created by environmental artist Andrea Polli and wind turbine manufacturer Ron Gdovic (Riverlife, n.d.). Energy Flow was a temporary (2016–2018) lighting installation powered by wind turbines that showed a real-time visualization of wind speed and wind direction using 2700 multicolored LED lights positioned along the bridge's vertical cables (*Figure 35*).

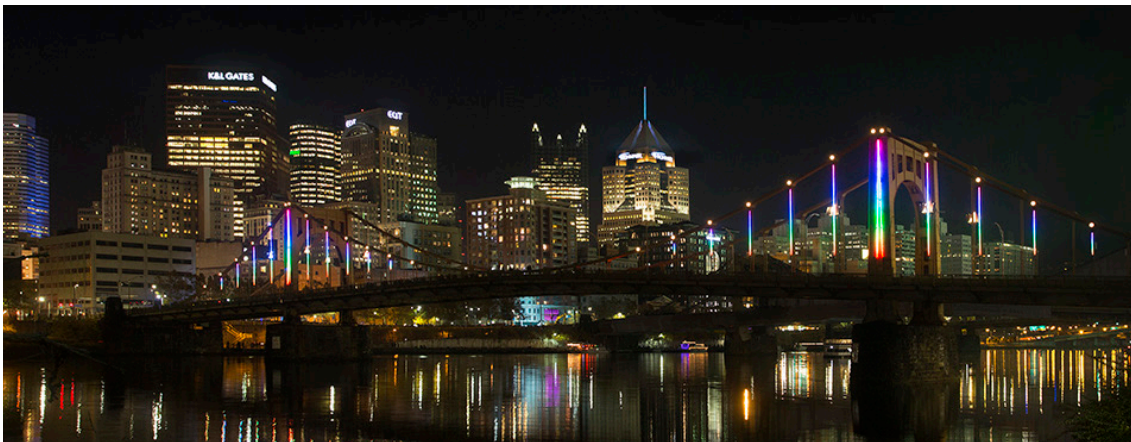*Figure 34 'Bay lights' on San Fransisco Bay Bridge (The Bay Lights n.d.)*

Figure 35 'Energy Flow' on Rachel Carson Bridge (Rippel, n.d.)

MX3D's bridge as media architecture

Display technology
Adding a data driven lighting design to the bridge, will turn the bridge into a media façade. When designing the lighting design, the existing design of the bridge needs to be taken into account. The display technology needs to be suitable for the design of the bridge. This limits the display technologies that can be used to turn the bridge into a façade. Taking the existing design of the bridge into account, the bridge could be turned into a front projection façade or a light-emitting façade, or a combination of both. Turning the bridge into a display façade is technically possible, but is not a desirable option. The display will disrupt the organic design of the bridge since it can't be integrated into the design. A back projection façade is not possible as the bridge has no back side and no integrated translucent areas. A mechanical façade doesn't use light to alter the appearance of the façade and is therefore not relevant to use on the bridge.

Placemaking
MX3D wants to add a lighting design to the bridge to display data driven digital media, with the goal to engage the public audience with the bridge. By doing so, they will shape the urban experience of the bridge and the surrounding area, thus contributing to digital placemaking. The lighting design is supposed to become a permanent fixture on the bridge and will continue to create a sense of place for a long period of time. This can be distinguished as infrastructure placemaking.

Social interaction
The location where the bridge will be placed can be defined as a very busy thoroughfare. The flow of movement of pedestrians passing by should not be disrupted by social interaction with the bridge. Therefore it is desirable to turn the bridge into a responsive ambient interface. Responsive ambient media architecture can be used as a way to enhance the experience of thoroughfares without disrupting the environment. This type of interface offers indirect and generic feedback and doesn't require active participants, who might hinder other pedestrians.

Display technology
Front projection
Light-emitting

Placemaking
Digital infrastructure placemaking

Social interaction
Responsive ambient media architecture can be used as a way to enhance the experience of thoroughfares without disrupting the environment

What are the challenges when designing media architecture?

Introduction

Designing media architecture is a challenging task. Dalsgaard, Halskov and Wiethoff (2016) have looked into the challenges that arise when designing media architecture and have provided a structured overview of these challenges. As discussed in their work, the challenges can be divided into two overarching categories: namely those related to the product, meaning the media architecture and those related to the process. In the following text the challenges will be explained and discussed in relation to the bridge, to increase the understanding of the circumstances in which we are trying to design a lighting design. It is important to understand which issues might arise during the design process and how they contribute to the complexity of the project.
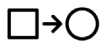
Product related

Novel interfaces

Integration

Robustness & stability

Social transformations

Emergent use

Content

Process related

Stakeholder involvement

Situational diversity

Design process model

Technical expertise

Evaluation

Product and process related challenges

Challenge 1: Novel interfaces
Media architecture installations can be seen as a new type of interface. The displays that are used differ from traditional displays that have pixels organized in a matrix. They differ in terms of scale, resolution, brightness, exposure etc. There is not yet a standardized way of organizing pixels. Media architecture has a variety of input and output configurations.

The bridge has a complex organic shape and can be viewed from different distances and angles. Different viewing locations require a different resolution and brightness, which makes organizing pixels a complicated task. A first step in tackling this problem is choosing a viewing location from where the lighting design should be visible. Depending on the distance to the bridge, a choice can then be made for the resolution and brightness.

Challenge 2: Integration into physical structures and surroundings
Media architecture installations have to be integrated into the existing physical surroundings of a city. The architecture of existing buildings, plaza's and streets needs to be taken into account, as well as the multiple viewing perspectives and distances and the spatial layout of the interaction zones.

The lighting design for the bridge has to be integrated into the existing design of the bridge. It is important that it doesn't disrupt the design, but enhances it. Creating such a cohesion will be challenging since the bridge is already printed. The lighting design can't be built into the bridge but will have to be added on to it. The lighting design also has to integrate with the surroundings of Amsterdam. The classical design of the canal houses differs from the futuristic design of the bridge. Here a choice has to be made: the lighting design can be used to either emphasize the difference or to minimize it.

Challenge 3: Robustness and Stability
Media architecture can be exposed to harsh weather, therefore light and weather conditions need to be taken into account. Furthermore, users may not feel a sense of ownership when dealing with the installation, and may be less gentle in their use. Vandalism and theft may also present challenges. Designers may need to come up with a strategy to prevent this or with a plan on how to repair installations when this happens. The different life cycles of architecture and the digital components will also need to be taken into account.

The bridge will be placed outside and will be used by thousands of people every day. That means the bridge and the lighting design need to be wear- and weatherproof. This will be challenging for the lighting design, since it can't be built into the bridge. To minimize the chance of breakage or vandalism, the power supply of the lighting design should be kept out of reach of pedestrians, for instance under the bridge or under the paving stones, and the individual lighting elements should be properly attached to bridge. It is also important to choose a lighting technology that is durable and has a weatherproof rating of ip67.

Challenge 4: Transforming social relations
The introduction of media architecture in an existing public setting can cause disruptions and can transform established social relationships and interaction patterns, or create new ones. Often this is the specific purpose of an installation: to change the existing public space. But this may have negatives consequences. Therefore all possible social transformations need to be taken into account.

A possible negative social transformation that could come from turning the bridge into media architecture, is the disruption of the pedestrian flow. The goal is to engage passersby with the bridge without crowds gathering, because the location of the bridge is already very busy and highly trafficked. In that sense, adding light to the bridge feels like a contradiction, as light naturally attracts people, especially when it conveys a meaning. The challenge will be to find a balance between engaging the public while maintaining the pedestrian flow.

Challenge 5: Emerging and unforeseen uses of places and systems
Media architecture installations are likely to be used, perceived and adopted by users in different ways than designers intended or anticipated. This can happen both short-term and long-term. Therefore it is important that designers also consider new patterns of use and socialization that may occur over time.

The bridge that is currently in use on the location in Amsterdam is already being used in unintended ways. The new bridge will likely be used in those same ways. It is not unimaginable that the new bridge will become a landmark for tourists, who will want to take photos of and on the bridge, turning the bridge into a photo opportunity. People stopping on the bridge disrupt the flow of movement and can cause traffic jams on the bridge. To make sure the lighting design doesn't contribute to the display of such behaviour on the bridge, the lighting design should be placed somewhere that doesn't require people standing still on the bridge to view it. Making the bridge interactive could also create another problem: people actively interacting with the bridge and exploring the boundaries of the interactive bridge. If for example the bridge responds to load, this could trigger people to jump on the bridge. It's important to keep this in mind when choosing the data that will be visualized.

Challenge 6: New forms of content for a novel medium

A key challenge when designing content for media architecture is to find a balance between supporting the communicative and interactive intentions, while also taking into account the situational circumstance and the qualities of the display, such as scale, shape, pixel configuration.

The goal of the lighting design for the bridge is to visualize data. Data visualization is a special form of content. Contrary to an image or movie, where you need a certain amount of pixels, data visualization can be done in a simple and abstract manner. The biggest restriction for designing data visualization content, is the light placement on the bridge. The shape of the bridge is very complex and light can't be placed everywhere. This influences the shape and pixel configuration options. Nevertheless, with all the different technologies and light solutions that exist, there are still many options.

Challenge 7: Aligning stakeholders and balancing interests

The introduction of a new media architecture in a public space often affects a broad range of people. There are clients, companies and institutions with different agendas and interest and a variety of citizens and citizen groups who use the public space. It is important to explore, negotiate and balance stakeholder interests.

The smart bridge project has a lot of project stakeholders, each focussing on a different aspect of the bridge. From all of the project stakeholders, the interests from MX3D are the most important to take into account, since they are the project owners. Equally important are the interests of the users of the bridge, since some of them might be affected by the bridge on a daily basis.

Challenge 8: Diversity of situations

Media architecture is located in urban settings where a wide variety of situations occur and overlap with each other. The variety of people and activities changes over the course of time. This can be in a day, a week, a year or in accordance with specific events. These existing situational patterns need to be uncovered to develop an installation that can confirm, extend or change existing situations, depending on the aim of the installation

The bridge will be located in an urban setting where a lot of different situations occur. The bridge will collect data of the people and activities that take place and will monitor changes that occur over time. A machine learning algorithm will analyse this data and can detect existing situational patterns. This information can be used to adjust the media installation to help the bridge confirm, extend or change existing situations.

Challenge 9: Adopting design process models
Since the field of media architecture is still relatively novel and emerging, there are no standardized design process models for designing media architecture installations. Designers face a challenge adopting a systematic and structured design process, especially concerning the fact it often needs to balance the wishes of multiple stakeholders and cover multiple areas of expertise.

In the smart bridge project there are multiple elements that come together: the bridge, the location, the sensors network, the data, the lighting design. Together they form the media architecture. When one of these elements changes, it influences the other elements. For instance, the choice for a certain lighting technology will influence the placements options on the bridge and the type of data visualisation that is possible, and vice versa. In this project, all elements can serve as a starting point for making design decisions. It is important to go through multiple design cycles and iterations, exploring all elements.

Challenge 10: Aggregating technical skills and expertise
Media Architecture as the symbiosis of media and the built environment demands highly specialized expertise in multiple areas such as electrical engineering, architecture, lighting design, urban planning and coding.

MX3D has gathered a large group of project stakeholders that each have their own specialized expertise (see 'The stakeholders'). By working together, MX3D can combine their knowledge to create a smarter bridge and to turn the bridge into media architecture.

Challenge 11: Contextualizing and evaluating interaction
In every stage of the process of designing media architecture, the challenge arises how to evaluate. Because the experience of media architecture differs from the experience of other forms of media and other products, it is a challenge to identify appropriate evaluation methods.

There are multiple evaluation methods that can be used to test the lighting visualisation of the lighting design. A few examples are light projection mapping on a scale model, prototyping on a 1 on 1 model, prototyping with Arduino, digital visualisations and animations. The choice depends on which aspect needs to be evaluated.

What are the basics of light?

Introduction

MX3D wants to use light to visualize data. A first step towards desiging with light is understanding the basics. What is light and how is light used? Also what is the lighting situation at the location of the bridge?

What is light?

According to Collins English Dictionary, light is the brightness that lets you see things. Technically speaking, light is electromagnetic radiation that falls within the visible part (*Figure 36*) of the electromagnetic spectrum, meaning it can be perceived by the human eye. It is a form of energy that can behave as both a wave and a particle. This dual nature of light is referred to as the wave-particle duality. The eye interprets the different wavelengths as colours – moving from red, through orange, green, blue to violet as wavelength decreases (Philips, 2008).

The fourth dimension

Nowadays lighting isn't just used to improve the visual perception, but also to create a pleasant atmosphere. It plays a central role in architectural design. Light makes our surroundings visible and allows us to see space and structure. Light determines how we perceive an environment and influences our well-being and the aesthetic and emotional effect of a space (Erco, 2006). Therefore, light is often considered to be the 'fourth dimension' of architecture. Light can be used to accentuate the functional and decorative qualities of a space, and its proportions (*Figure 37, 38, 39*).
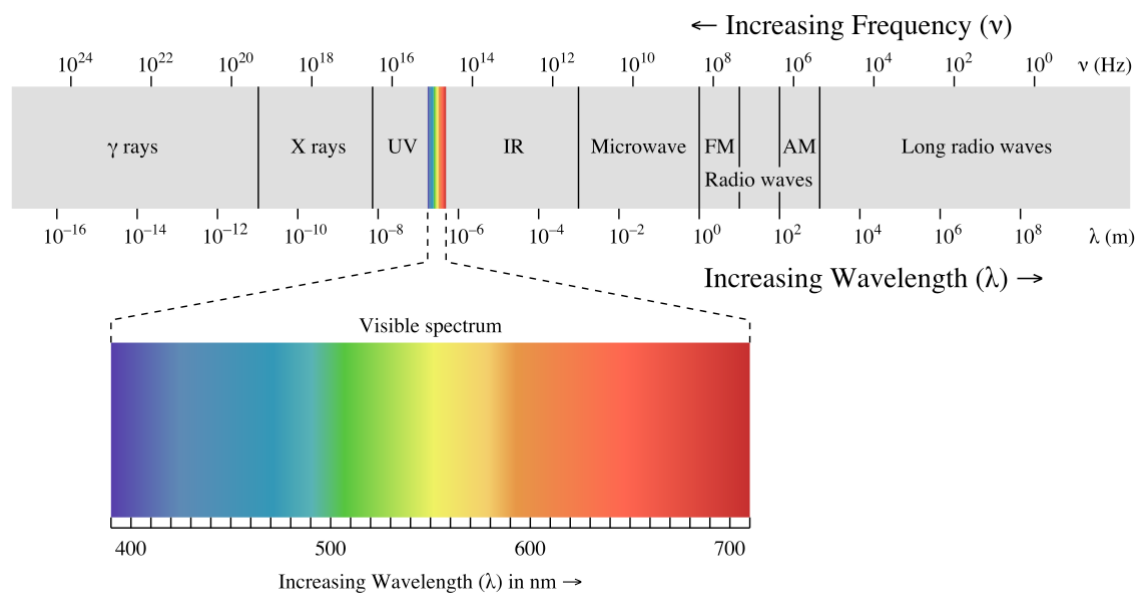

Figure 36 Visible spectrum of electromagnetic radiation (Ronan, n.d.)

Figure 37 Creo Hall (Akira Sakamoto, 2005)

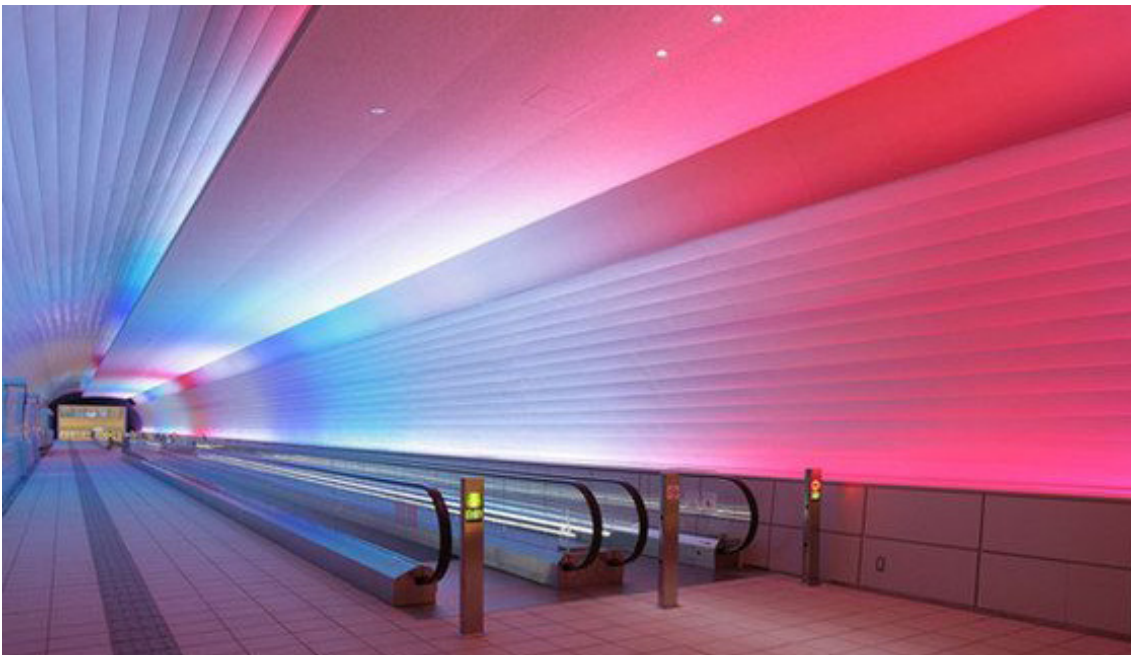*Figure 38 Guggenheim museum (Turrel, 2013)*

Figure 39 Kyushu National Museum (Chickada, 2005)

The three principles

In the 1950s, the lighting designer Richard Kelly borrowed ideas from perception psychology and theatrical lighting and combined them into a uniform concept for lighting design (Erco, 2012). He separated the qualities of light into three principles:

Ambient luminescence
General lighting of the surroundings. It responds to the basic requirement for physical orientation within a space and serves to provide a basis for more advance lighting.
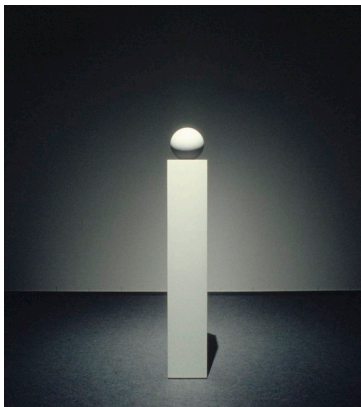
Focal glow
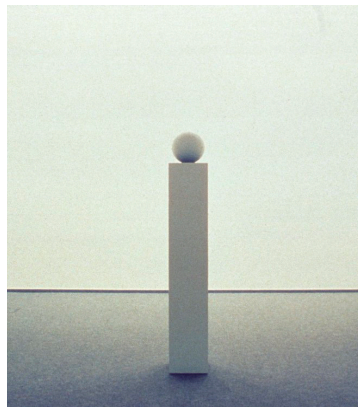Directed light used to emphasise objects. It accentuates features and creates hierarchies of perception.

Play of brilliants
Decorative lighting effects. It is light as an aesthetic end in itself, by using colours, patterns and dynamic changes to create atmosphere and visual attraction.
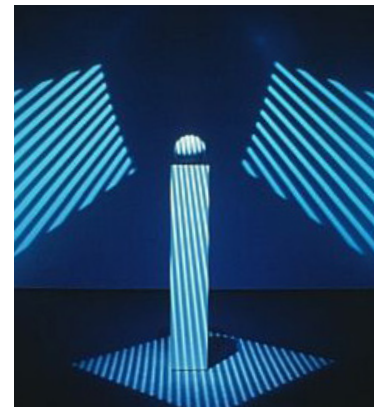
Figure 40 (Erco, 2012) *Figure 41 (Erco, 2012)* *Figure 42 (Erco, 2012)*

To experience the different types of lighting, a small experiment was conducted using the full scale prototype (Appendix 4) and different lighting set ups (Appendix 5). The experiment explored different possibilities where light was used to highlight the design of the bridge.

Light and bridges

Light can also be applied to bridges, both for functional and aesthetic purpose. For instance, traffic and pathway lighting on the bridge ensure sufficient illumination for drivers, cyclists and pedestrians to safely cross the bridge. But light can also be used to accentuate certain design elements of the bridge (*Figure 43, 44*). Lighting designers usually pick the static characteristics of the construction: the girder, truss, arch or suspension. It can highlight the architecture and can creates a characteristic appearance at night, which is often visible from far away. Bridges above water make for fascinating views when their illuminated structure is reflected in the water (Erco, 2012).

Figure 43 Nhât Thân bridge (Philips lighting, 2017)

Figure 44 Meydan bridge (Philips lighting, 2015)

Existing lighting conditions

The existing lighting circumstances at the location of the bridge have also been investigated. These form the basis on which the lighting design of the bridge will be designed. As can be seen in figure 45 and 46, there is a lot of light coming from the street lights, from inside the surrounding buildings and from the signs of the establishments in the street. The lighting which will be added to the bridge will not be functional lighting in the sense that it needs to provide visibility and safety. The street lights already take care of this. The lighting on the bridge is more for aesthetic purposes. Therefore it doesn't need to meet certain standards. It just needs to be bright enough to be visible when walking down in the street. A general indication for the amount of lumens required for the lighting design of the bridge lies somewhere between 50 and 200 lumens, based on the recommendations for path lighting, step lights and hardscape lights.

Figure 45 Photograph of the lighting in the street

Figure 46 Photograph of the lighting in the street

Existing light conditions
Street light
Lights from buildings
Lightsigns

Where on the bridge can you add light?

Introduction

What are potential locations on the bridge where lighting can be integrated? Different viewing locations require a different resolution and brightness. The placement of the lighting also determines the amount of space there is for data visualization.

Lighting locations

An overview of all the lighting locations on the bridge can be seen in figure 47. These are further visualized in figure 48 to 53. As previously discussed, the placement of the lighting should not disrupt the pedestrian flow. Therefore the lighting design should be placed somewhere on the bridge that doesn't require people standing still on the bridge to see it. Ideally you would have people experience the lights as they are walking down the street towards the bridge. That way they don't have to stand still to see and observe the bridge, but they can do so while walking. The following options for the placement of the lighting are therefore most ideal: in or under the handrail, on the outside of the bridge, under the bridge, on the canal wall projected onto the bridge.
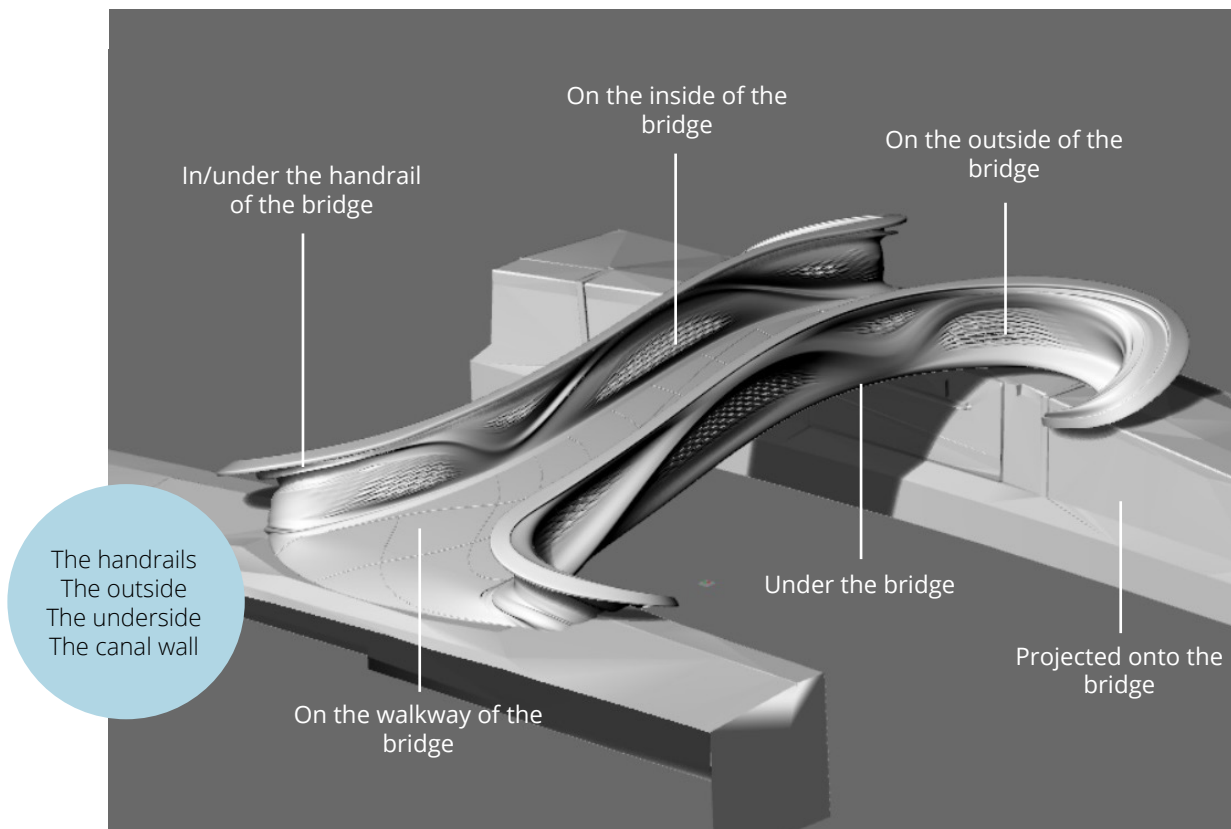

On the inside of the bridge

On the outside of the bridge

In/under the handrail of the bridge

The handrails
The outside
The underside
The canal wall

Under the bridge

Projected onto the bridge

On the walkway of the bridge

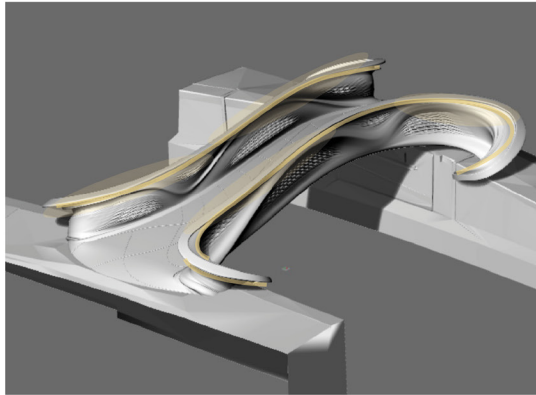*Figure 47 Overview lighting location*

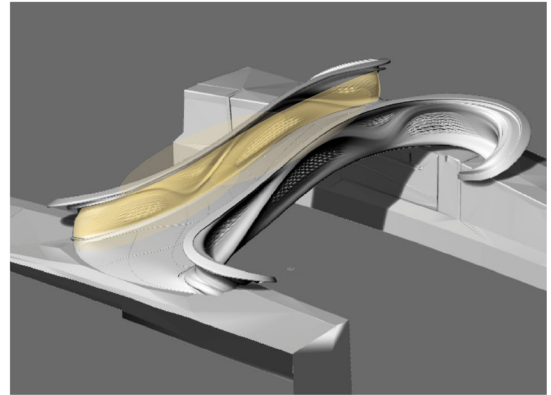*Figure 48 In/under the handrail of the bridge*

Figure 49 On the inside of the bridge

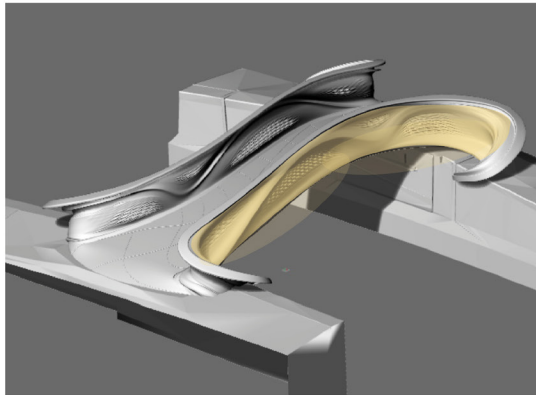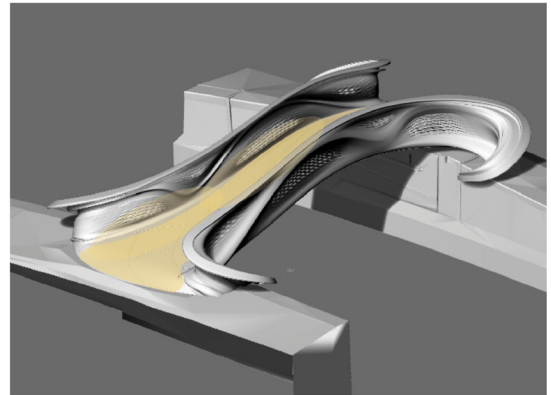*Figure 50 On the outside of the bridge*

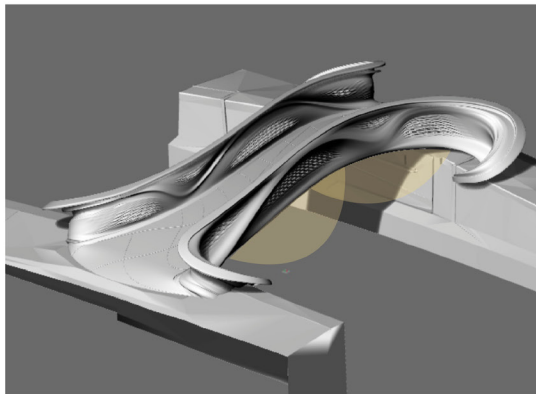*Figure 51 On the walkway of the bridge*

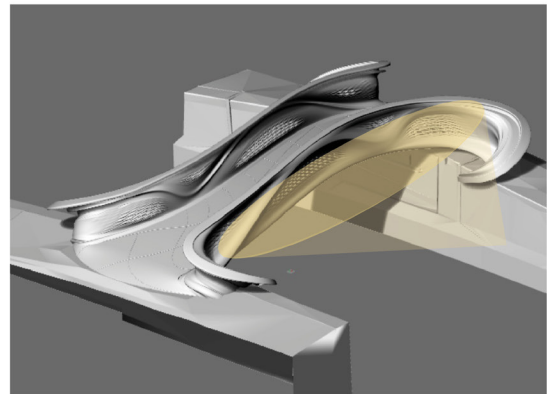*Figure 52 Under the bridge*

Figure 53 Projected onto the bridge

What are the lighting options for the bridge?

Introduction
There are three elements that influence the aesthetics of the lighting design for the bridge. These are: the lighting technology, the lighting effect and the placement pattern. Together they determine the appearance of the lighting design. Therefore all three elements have been investigated. The different possibilities that exist are mentioned below.

Lighting technologies
A selection has been made of the lighting technologies that could potentially be used on the bridge to visualize data. They differ in shape and physical appearance.

Aesthetics
Lighting technology
Lighting effect
Placement pattern
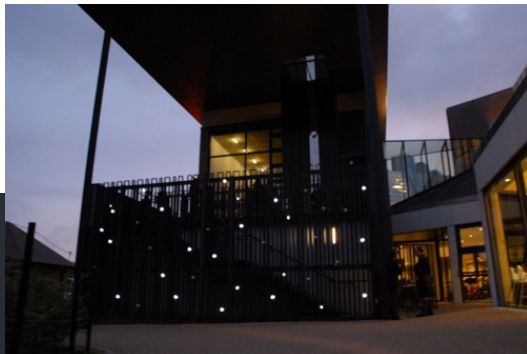
LED's   *(DistanceLab, 2008)*

LED ring   *(Burgess, n.d.)*

LED strip   *(Adafruit, n.d.)*

LED net   *(Iamtheweather, 2009)*

LED tiles *(Adafruit, n.d.)*

Light spots *(LetsLed, n.d.)*
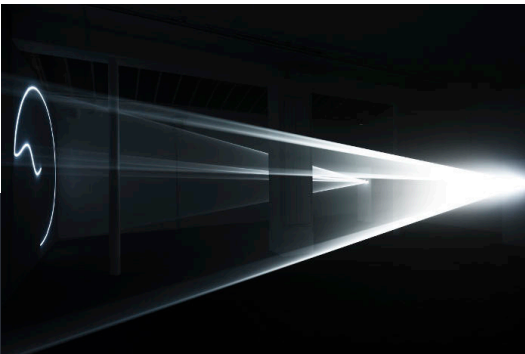
Projector *(Mccall, 2016.)*

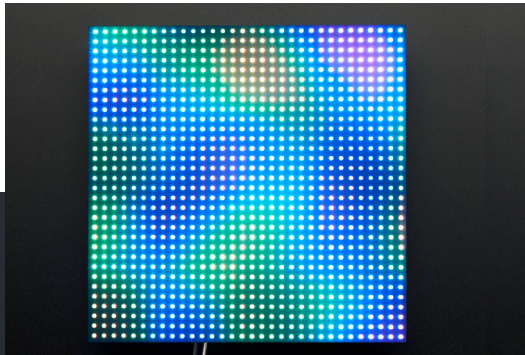Screen *(Hild, n.d.)*
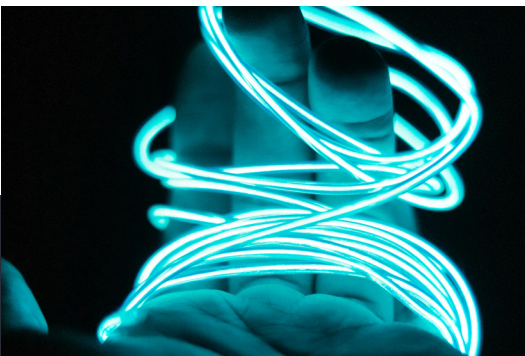
EL wire *(Gill, n.d.)*
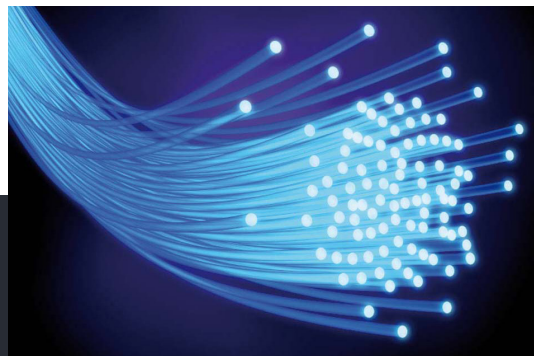
Optic fibers *(Pharrel.fr, 2017)*

Lighting effects

Lighting effects refers to the way light is used to create a certain effect. The lighting effects mentioned below could potentially be used on the bridge to visualize data. Some of these light effects only apply to a certain lighting technology: Emitting light (all lighting technologies), illuminating bridge parts (light spots), projection on bridge parts (projector), reflecting light on the water (all lighting technologies). Of course all lighting technologies emit light. What I mean here with 'emitting light' is that the source of the light itself is used as part of the design, while with the other effects the focus lies more on the illuminating effect of the light.

Illumination   *(Philips, 2015)*

Projection   *(Phormatik.org, 2013)*

Reflection   *(Adire, 2018)*
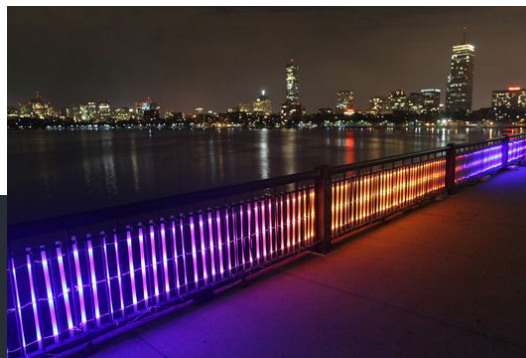
Emitting light   *(Seitinger, 2013)*

Placement patterns

Placement patterns refers to the placement of light on the bridge. The following images are examples of placement pattern used in interior design. There are many different options for the bridge, depending on the lighting technology that is used. Placement patterns can differ in terms of:

· Resolution (number of pixels)
· Density (size and spacing of pixels)
· Visual field (style of pixels)
· Structure (flat or dimensional pixels)
· Graphic arrangement (type of pattern)

Lines   (Koerner, 2017)
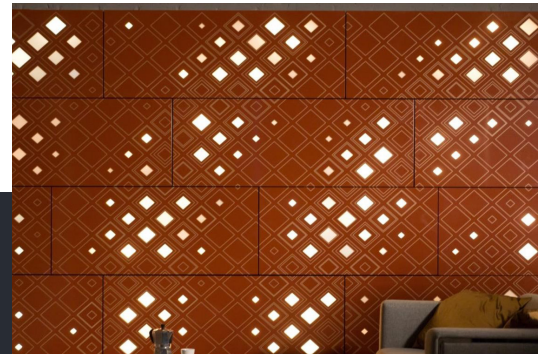
Squares   (Philips, n.d.)
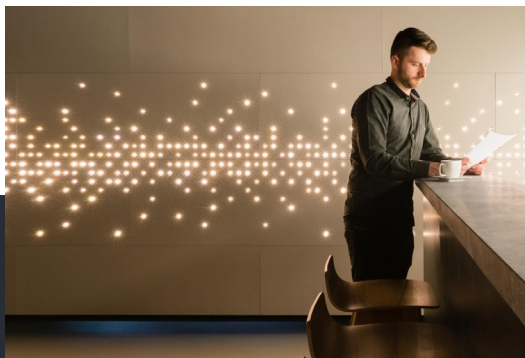
Circles   (Koerner, 2017)
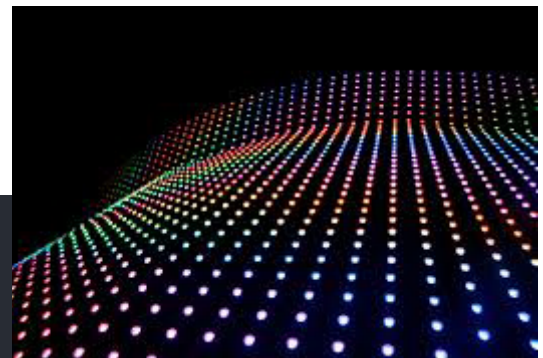
Circles   (Downloadapkfree, n.d.)

Technology prototyping

To gain a better understanding of the lighting technologies, some of them were explored through prototyping. The insights during this exploration are discussed below. Some intial ideas are visualised on the left page. The placement of the different lighting technologies on the bridge was also briefly explored. This can be found in appendix 9.

Example of neopixel jewel (Adafruit, n.d)

Example of neopixel ring (Adafruit, n.d)

Example of ledstrip (Kiwi-electronics, n.d.)

Example of matrix panel (Adafruit, n.d.)
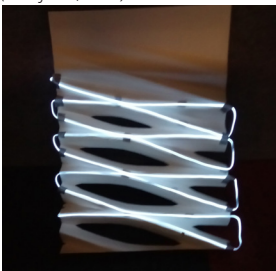
Prototype with EL wire

Single RGB LED
One LED on its own is not that interesting. It becomes interesting when you place multiple in a pattern. You can place as many as you want as close together as you want. This leaves a lot of possibilities for the lighting design. The only downside is that that requires lots of wiring and you would have to address each LED individually.
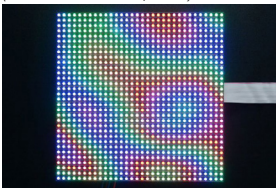
Neopixel jewel
Is similar to the single LED's. It is almost the same only with more LED's in one place. You can use the LED spot as a whole or use the individual LED's. When assigning the individual LED's different colours, it is hard to make a distinction between the different colours from a distance.

Neopixel ring
Interesting shape to incorporate in the lighting design. The LED's are already placed in a pattern so to speak: in an open circle. This can be used to make interesting lighting design patterns. The circles come in a variety of sizes.

LED strip
Because the strip is flexible you can make multiple shapes. On top of that the LED's can be addressed individually. The combination of these two properties allows you to create lots of different lighting design options.

LED Matrix panel
With a small LED's matrix panel you can make very dynamic visualisation. You can even show letters and numbers. A downside is that the shape doesn't provide many options for integration into the bridge.

EL wire
The dynamic options of EL wire are limited. It can be turned on and off. An advantage of EL wires is that you can make clean lines that run across the whole bridge, with less wiring. This was tried out on part of the 3d printed model of the bridge.

Outward movement created
with multiple rings
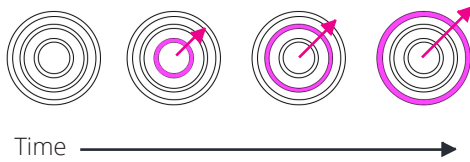
Circular movement
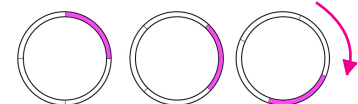
Time

Time

Light can be passed
on from one circle
to another through
circular movement
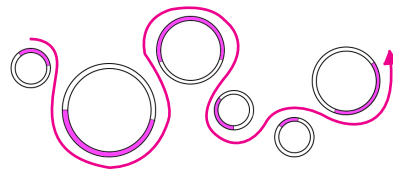
Linear movement
with LED strip
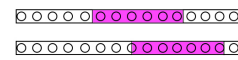
Alternating the location of light.
Can also be done with LED strip

Can be used to
show an increase
or decrease in
data, or show
vibrations
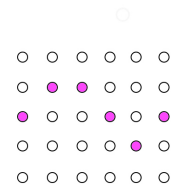
A grid of lights
can be used to
create all sorts of
shapes

Wave motion

Wave motion
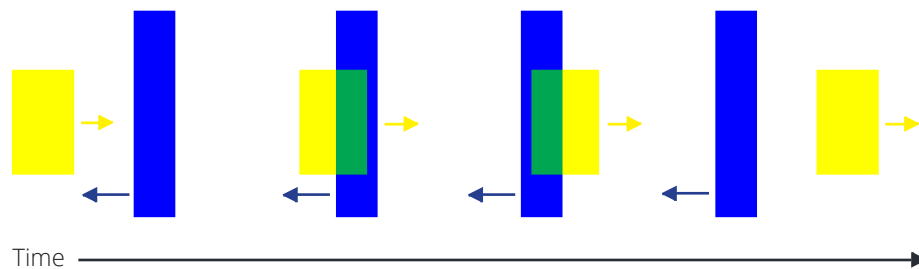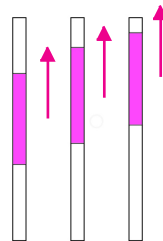
Use of colours. The colours move in different
direction. Were they meet their colours overlap
creating a new mixed colour.

Time

How can data be visualised?

Introduction
Data visualization is the graphical representation of information and data. MX3D wants to use the bridge as a medium for visualizing data through light.

Data visualisation

There are two ways in which the lighting design can be made data driven:

- The light visualization can represent the data
- The light visualization can respond to data

In the first case, the light symbolizes the data. It represent a quantity or a state. The lights could, for instance, show the wind direction or the amount of people. It can represent real time information.

In the second case, the light only reacts to the data, it doesn't represent it. The light represent a change in the situation and has no additional meaning in itself. An example would be if a light changed colour each time someone shouts or someone crosses the bridges. It would only show that something happened not what or when.

For the bridge it is more interesting to explore a light visualization that represent data. Visualizing data can be done in a simple and abstract manner. A nice example of this 'EmotiCannes (*Figure 47*), a kinetic data sculpture made from small computer screens, positioned to represent the Lion: the icon of the Cannes Festival of Creativity (SEGD, n.d.). The Lion responded to tweets from festival attendees. A tweet would be graded and weighted as being positive or negative. The data visualization would then change colour in response, informing people about the mood of the festival crowd. It is a playful demonstration of how data can become physical.

The lighting design for the bridge needs to have a dynamic factor that can convey a change in the visualized data. There are multiple options to do this. These are visualized on the next page.

Dynamic factor
On/off
Location light
Colour light
Intensity light
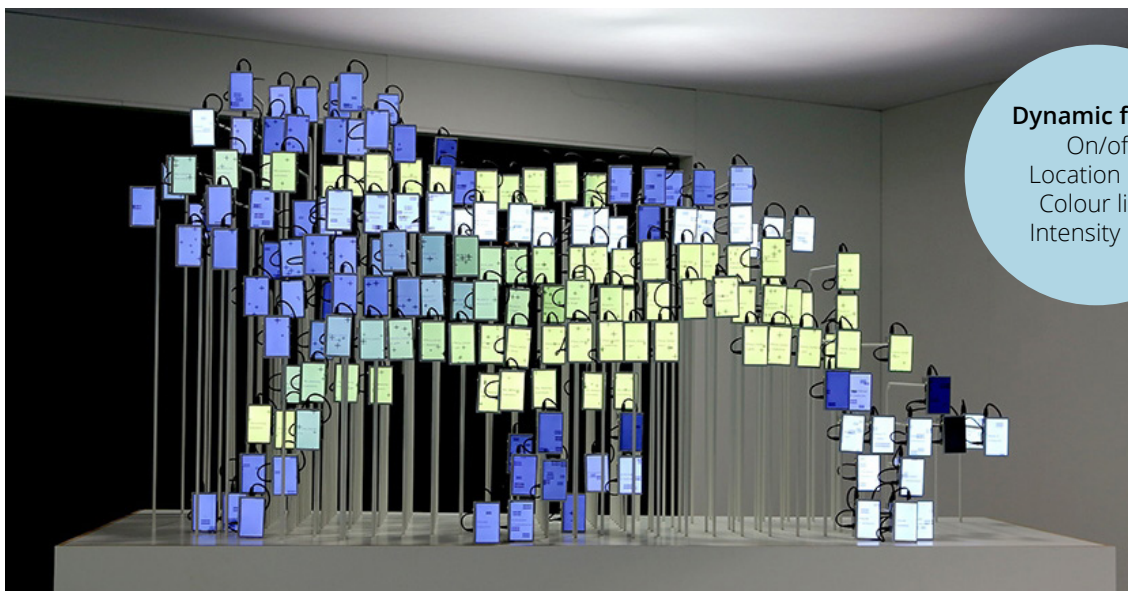
Figure 47 EmotiCannes: a kinetic data sculpture (SEGD, n.d.)

On/Off

Location of light

Colour of light

Intensity of light

What kind of data does the bridge collect?

Introdution

MX3D and Autodesk are currently still working on the sensor network. Since there is no definite sensor plan for the bridge, a list was compiled of all potentially interesting sensors. The sensor are divided into: environmental sensors, structural sensors and human-structure sensors. For each sensor, data insights from the sensor data were investigated. These were divided into momentary, hourly and daily patterns. The results can be found in Appendix 6.

Structural sensors

Strain gauges
Load cells
Inclinometers
Accelerometers
Displacement transducers
Pressure cells
Thermistors

Environmental sensors

Thermometer
Hygrometer
Anemometer
Rain gauge
Barometer
CO2 meter
Sound level sensor
Direct/ambient light sensor

Human-structure sensors

Accelerometers
Camera vision system
Wifi

Sensors
Structural
Environmental
Human-structure
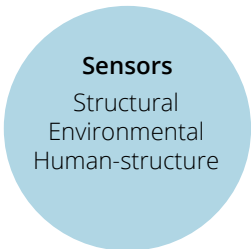
Which data is interesting to visualise?

Introduction

To find out which data insights people might find interesting, a creative session was held. Students got to give their input on which data they thought would be meaningful to visualize for the public.

Creative session

The creative session was held at the Technical University of Delft, department of Industrial Design Engineering, with six students. The session started out with word associations. Participants were asked to write down word associations that came into mind. Afterwards they were asked to discuss HKJ's in a group context and cluster the ideas they came up with. The best ideas were translated into a concept which they presented on a A3 poster to the group. The complete set up of the creative session and the results can be found in Appendix 7. The most interesting results are mentioned here.

Content
General info
Amsterdam
Internal bridge
External bridge

General information
Time
Temperature
Weather forecast

Amsterdam related information
Heartbeat of Amsterdam
I Amsterdam bridge
Daily revenue of prostitution
Interactive arousal meter (body heat)

Internal bridge information
Vibrations of bridge (auditory/visual/ haptic)
Stress and strain of the bridge

External bridge information
Amount of (tourist) suitcases
Dynamic two directional walkway path
Movement of people
Heartbeat of people

Figure 48 Creative session

Interaction

Crowdedness
The area is very crowded, particularly at night. At times people on the bridge were unable to walk due to the sheer amount of people trying to be in the same place at the same time

Adding lights
The lighting design should not require people standing still to observe it, should not disrupt the pedestrian flow and should not cause crowds to gather. Achieving this will be a challenging task, since light naturally attracts people.

Display technology
Front projection
Light-emitting

Definition
Architectural structures with integrated light sources and network infrastructures for distributing power and data, that uses media based on information technologies to convey dynamic information and create a meaningful experience.

Media architecture

Social interaction
Responsive ambient media architecture can be used as a way to enhance the experience of thoroughfares without disrupting the environment

Challenges

Product and process related challenges

Placemaking
Digital infrastructure placemaking

Basics of light

Existing light conditions
Street light
Lights from buildings
Lightsigns

Lighting options

Lighting locations

The handrails
The outside
The underside
The canal wall

Aesthetics
Lighting technology
Lighting effect
Placement pattern

Data visualisation

Dynamic factor
On/off
Location light
Colour light
Intensity light

Data collection

Sensor
Structural
Environmental
Human-structure

Interesting data

Content
General
Amsterdam
Internal bridge
External bridge

Conclusion

In this chapter questions about interaction, media architecture, light and data were investigated. The insights that were gathered will help define design guidelines for the lighting design. These guidelines are needed in order to make design choices. Another goal of this chapter was to collect ideas that could potentially be used for the lighting design. By combing different ideas, design directions can be created. The design guidelines and the design directions will be discussed in the next chapter.

Design direction

This chapter summarizes the restrictions for the lighting design that were found in the previous chapter and defines the design guidelines. The design guidelines help narrow down which ideas are relevant for this project. Ideas for the data visualisation and the options that exist for the lighting technology are discussed. The lighting technologies are compared to one another based on 4 aspects. In the end a design direction is chosen, leading to a clear design goal.

Design guidelines

Restrictions

The exploration of the questions in the previous chapter helped identify restrictions for the lighting design. To provide a clear overview, they have been summed up below. Behind the restriction, between the parenthesis, is mentioned on which aspect of the lighting design the restriction has the most influence.

- The overcrowdedness of the location
  (for the light placement and the data visualization)
- The possibility of vandalism
  (for the infrastructure and light placements)
- The existing aesthetics of the bridge
  (for the appearance and light placement)
- The existing structure of the bridge
  (for the design and light placement)
- The complex design of the bridge
  (for the light placements)
- The sensor constraints
  (for the data visualization)
- The required power supply
  (for the infrastructure)
- The required wi-fi connection
  (for the infrastructure)
- Future maintenance
  (for the infrastructure and light placements)

Design guidelines

The restrictions combined with other insights gathered in the previous chapter lead to the following design guidelines for the lighting design.

The lighting design...

- should not cause crowds to gather
- should not disrupt the pedestrian flow
- should not trigger undesirable behaviour with the visualized data
- should be placed somewhere that doesn't require people standing still on the bridge itself to view it
- should not disrupt the design of the bridge
- should be connected to the bridge without having to make structural adaptions to the bridge
- should be robust and wear proof
- should be weather proof rating ip67
- should have its power supply placed out of reach of pedestrians

The restrictions lead to 9 design guidelines for the lighting design

Ideas

Design explorer

There are different aspects that make up the lighting design. Throughout this report multiple options for these aspects have been discussed. An overview of all the existing possibilities for the bridge can be found in the design explorer in Appendix 8. The design space explorer is a tool that can help structure large quantities and varieties of information.

Options for data visualization

Data visualization has been investigated through the data exploration and through the creative session. The most interesting data insights are explained below:

Shadows of people.
People are represented by coloured shapes that follow them depending on their direction. When two people walk past each other, the colours overlap and become their mixed colour.

Amount of people
Lights can be used to represent the amount of people on the bridge. This visualization relates to the public as it is about them, the people, and less about the bridge.

Heartbeat of the city
A collection of data can be used to create the heartbeat of the city, for instanced by combining the amount of people, the amount of sound, the hour of the day. It can be an sine wave representing the heartbeat of something that simulates the pattern of beating (change in light intensity or colour).

Footsteps
Light represents people's footsteps. Each individual gets their own representation that responds to their pace and follows them. Based on vibrations and location.

Stress in the bridge
Light represents the stress division in the bridge. This light visualisation relates to most to the smart bridge concept: the main reason of implementing sensors was to keep track of the stresses in the bridge with regards to safety.

Vibrations of the bridge
Light is used to visualize the vibrations in the bridge. This can be done by visualizing a sine wave that responds to things happening in the environment and people who cross the bridge.

Options for lighting technology

The technology options that were found during the exploration are rated to one another, to find out which is most suitable to be used on the bridge:

	Aesthetic impact	Integratability	Dynamic options	Robustness	Score
LED's	+/-	-	+	-	-
LED ring	+/-	-	+/-	-	-
LED net	-	-	+	-	-
LED tiles	-	-	+	-	-
LED strip	+	+	+	-	+
Light spots	+	+	-	+	+
Projector	+/-	+	+	+	+
Screen	-	-	+	-	-
EL wire	+	+	-	+	+
Optical fibers (side-emitting)	+	+	-	+	+

Aesthetic impact on the bridge
The lighting design should enhance the bridge, not disrupt the design. The design of the bridge should still be visible.

Integratability
The lighting technology should be easy to integrate with the structure of the bridge. As little wires, cables and connections as possible.

Dynamic options light
The lighting technology should provide different dynamics options to convey data.

Robustness
The lighting technology should not be fragile and should not be easily destroyed by people. If it does break is should be easy to repair, without having to replace the whole lighting design.

Explanation overview

LED strip, light spots, projector, EL wire and light fibers, all have a positive score.

Everything that uses LED's has been given a negative mark for integratability (except LED strip) and robustness. That is because LED's require a lot of wires to be connected to each other and to a power source. This makes them more vulnerable to breakage. Also, replacing an LED is more work than replacing a light fibre or light bulb in a light spot. The wires also effect the aesthetics of the bridge.

The aesthetic impact of LED's and LED rings depends on the placement on the bridge. The aesthetic impact of the projector depends on the content that is projected and on the size of the projected area. If the projection would cover the whole bridge, the beauty of the bridge would be lost.

There are two types of optical fibres: end-emitting (only shines from the end) and side emitting fibres (shines through-out its length). Only the latter is suitable for the bridge. In this comparison we therefore only use side emitting optical fibres.

EL wires and side-emitting optical fibres are similar in appearance. The main difference is that the fibres are brighter than EL wires. Also, the source of light for optical fibres is placed at the beginning of each fibre, while for EL wire the light source runs through the wire. EL wire is therefore more vulnerable to breakage than a optical fibre.

The results

The technologies most suitable to be used on the bridge are:

· Led strip
· Light spots
· Projector
· Light fibres

Data visualization

Shadows of people
Amount of people
Heartbeat of city
Footsteps
Stress in bridge
Vibrations

Lighting technology
Led strip
Light spots
Projector
Optical fibres

Design direction

Design direction

The goal of the design direction is to determine the purpose of the lighting design. Which information will be visualized. Where on the bridge will the data be visualized? And what lighting technology will the data visualization use? The lighting design will have an impact on Amsterdam, the bridge and on the public.

For Amsterdam, the lighting design shouldn't worsen the overcrowdedness, or at the very least contribute as little as possible to the problem. The best way to do this is by placing the lighting design on the outer sides of the bridge. This way people can experience the lights as they walk down the street towards the bridge. They don't have to stand still to see and observe the bridge, but they can do so while walking.

For the bridge it is important that the lighting design doesn't disrupt the design of the bridge. In my opinion, the best technology to use on the bridge, is side emitting optical fibres. Optical fibres can easily be attached to bridge, using glue or a simple suspension system. The light source for the fibres can be placed safely under the bridge, as the fibres only require a laser at the beginning of the fibre. They have a more refined appearance than a LED strip and don't require any additional wiring. Optical fibres are easy to maintain and minimally invasive for the structure of the bridge. Projectors and light spots just shine light on the bridge, they don't enhance the design, while optical fibres can be integrated with the design to add an additional layer to the bridge.

For people, the lighting visualization needs to be understandable. Preferably something people can also sense for themselves. That way it is easier for them to verify if they understand what the lights mean. The most simple data visualization would be to show the amount of people on the bridge. People can then see for themselves how the light correlates to the amount of people. The camera vision systems can provides this data to the bridge.

Design goal

The design challenge was: 'develop a data driven lighting design for MX3D's sensor equipped 3d printed bridge, to engage a public audience with the bridge and to convey the smartness of the bridge.'

I intend to do this by visualizing the amount of people on the bridge, using side emitting optical fibres on the outer sides of the bridge.

> **Design goal**
> 'Visualize the amount of people on the bridge by placing side emitting optical fibres on the outer sides of the bridge.'

How does this engage people and convey the smartness?

· Engage people
People can see the lights change and can influence the light. This way people become involved with the bridge.

· Convey smartness
The light changes according to data collected by the bridge. This is communicated back to the public through light. The lighting design conveys the smartness of the bridge by communicating information and responding to change.

> **Design goal**
>
> 'Visualize the amount of people on the bridge by placing side emitting optical fibres on the outer sides of the bridge.'

```
┌─────────────────────────────────────────────────────────────┐
│                      Lighting design                         │
│                                                              │
│    Physical lighting design          Lighting visualization  │
│                                                              │
│       is determined by the             is determined by the │
│       lighting technology                     data          │
└─────────────────────────────────────────────────────────────┘
                              │
                              │  impacts
                              ▼
┌─────────────────────────────────────────────────────────────┐
│     Amsterdam              Bridge              Public        │
│                                                              │
│  The lighting design   The lighting design   The lighting   │
│  should minimize       should be integrated  visualization  │
│  contributing to the   with the bridge and   should be easy │
│  overcrowdedness.      enhance the design     to            │
│                        of the bridge          understand.   │
└─────────────────────────────────────────────────────────────┘
        │                     │                     │
        ▼                     ▼                     ▼
   Placement             Technology              Data
  Outer sides           Optic fibers          Amount of
   of bridge                                    people
```

Design guidelines

The restrictions lead to 9 design guidelines for the lighting design

Ideas

Data visualization

Shadows of people
Amount of people
Heartbeat of city
Footsteps
Stress in bridge
Vibrations

Lighting technology

Led strip
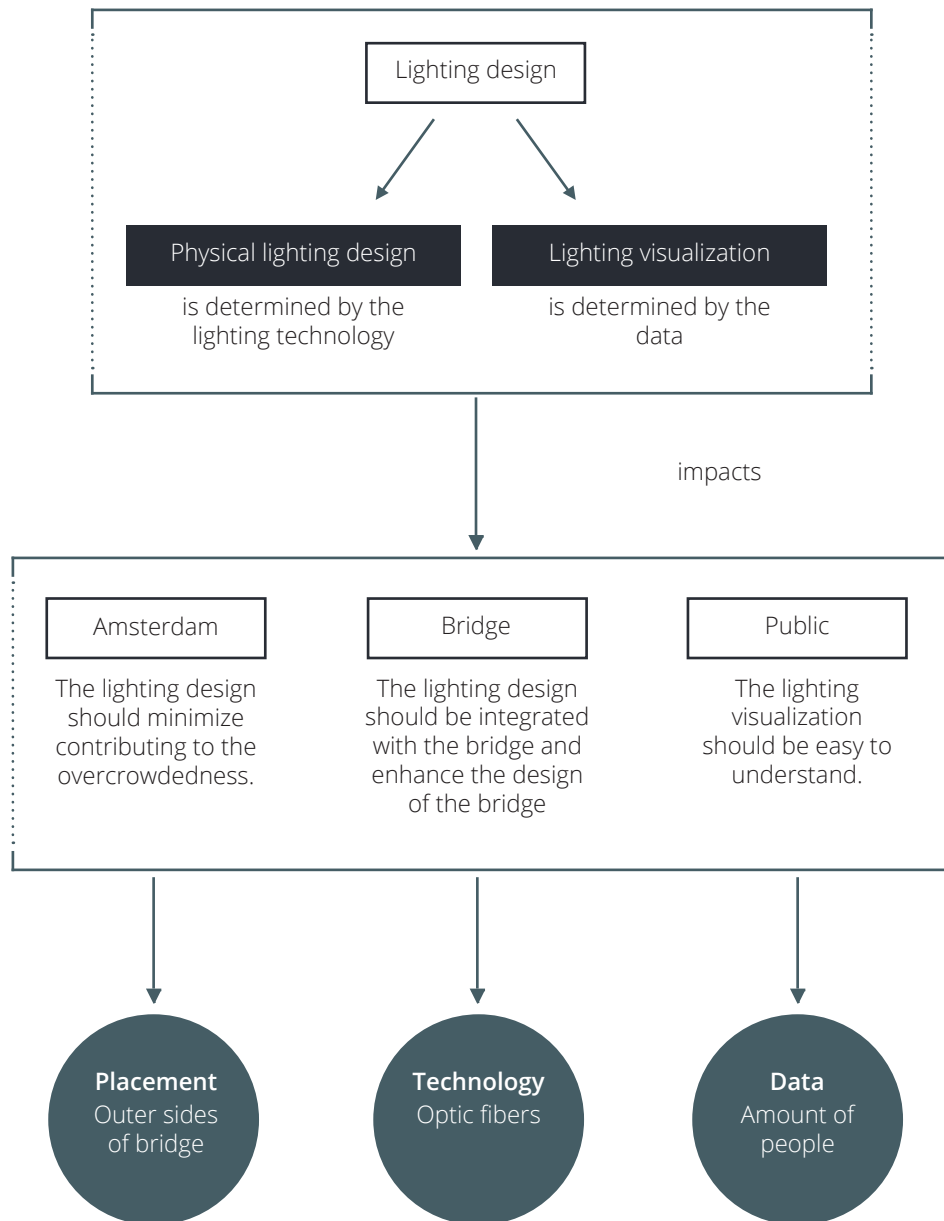Light spots
Projector
Light fibres

Design direction

Design goal

'Visualize the amount of people on the bridge by placing side emitting optical fibres on the outer sides of the bridge.'

Conclusion

The most interesting data insights were collected
and discussed. Based upon analysis of the design
tech-nologies against 4 aspects such as aesthetics
impact, integratability, dynamic options and
robustness, the amount of lighting technologies
were narrowed down to 4 options. The final choice
about the lighting technology, the data visualization
and the placement of light on the bridge was made
based upon what would we best for Amsterdam,
the bridge and the public.
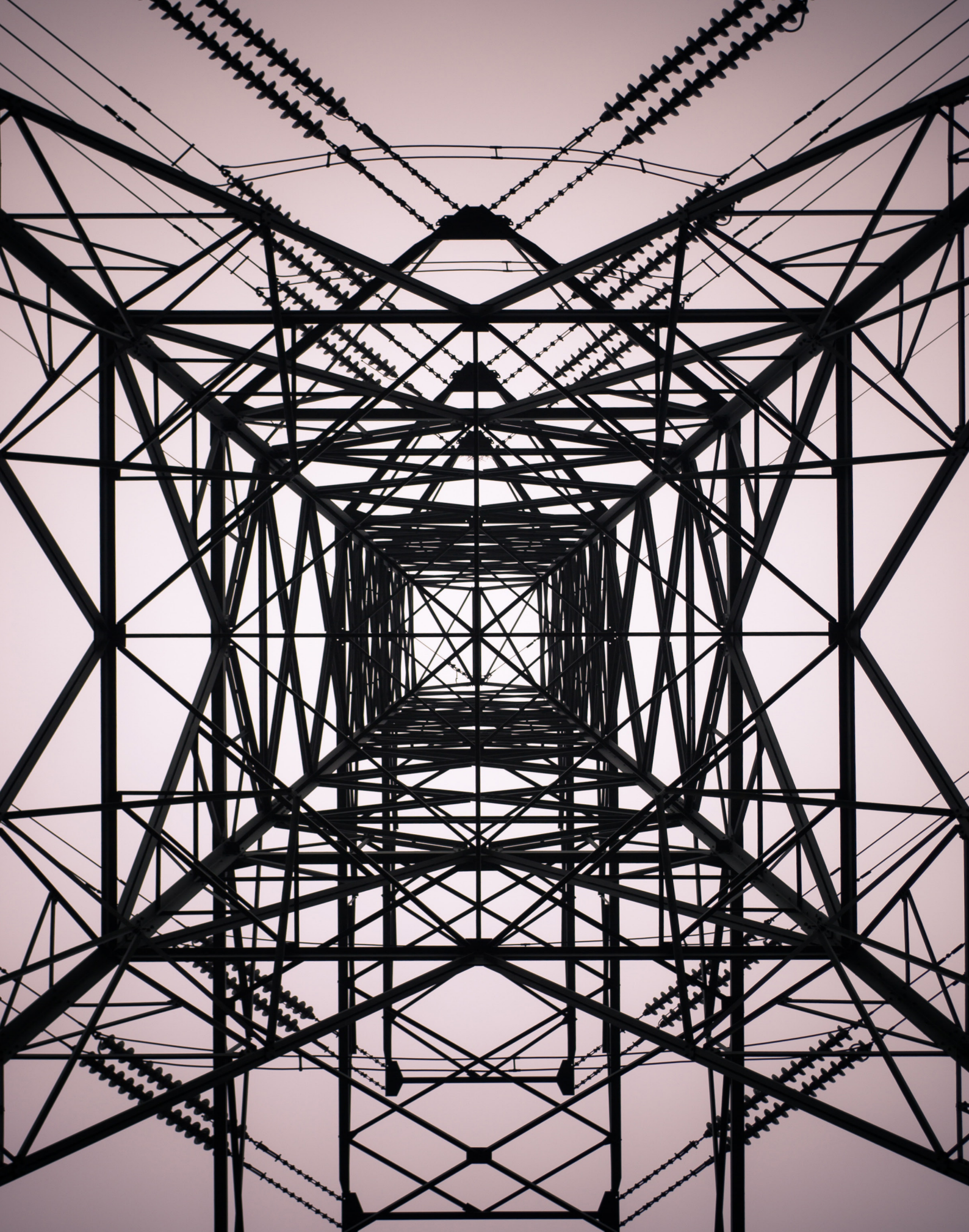
Vision

In this chapter an interaction vision will be created.
An interaction vision can be used to express
and identify the qualities of the user-product
interactions. The vision can help during the
conceptualization phase, when design decisions
need to made.

Vision

Introduction

An interaction vision can be used to express and identify the qualities of the user-product interactions. The goal is to create a representation of the feelings and experiences that the interaction with the bridge and the lighting design should bring for people passing by or crossing the bridge.

Interaction vision

The desired character of the interactions is captured in figure 49 and in the following textual statement:
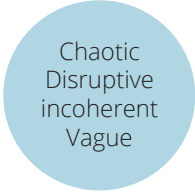
'Unravelling layers'

The lighting design reveals hidden layers of the bridge. Information that usually isn't visible. This statement symbolizes what the media architecture intends to achieve. At the same time it also represent the envisioned user experience of the media architecture. Through their interaction with the bridge, the public audience will uncover the meaning of the data visualization. First they sees the lighting design, they'll notice change, they'll observe the media architecture to find reason for the change, then they'll uncover the meaning. These steps can be seen as layers of the experience, where each layer brings more knowledge.

Desired interaction qualities that follow from this vision are:

Surprising
Intriguing
Effortless
Impressive

Undesired interaction qualitites are:

Chaotic
Disruptive
incoherent
Vague

From the desired and undesired interaction qualities, the following desired product qualities are derived:

Simplicity
Elegance
Clean lines
Luminous

The qualities expressed in this vision will be used during ideation to find a meaningful purpose for the lighting design and a suitable lighting technology.

Figure 49 Unravelling layers (Vuing, 2013)
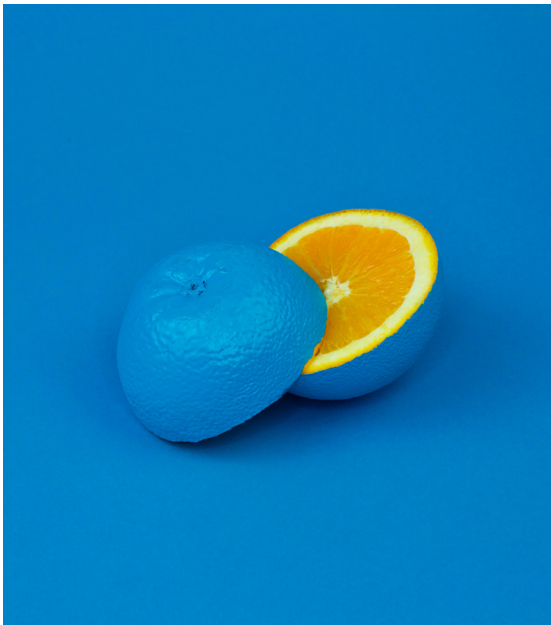
Suprising

Intriguing

Effortless

Impressive

Simplicity

Elegance

Clean lines

Luminous

'Unravelling layers'

Interaction vision

Desired interaction qualities
Surprising
Intriguing
Effortless
Impressive

Desired product qualities
Simplicity
Elegance
Clean lines
Luminous

Undesired interaction qualities
Chaotic
Disruptive
incoherent
Vague
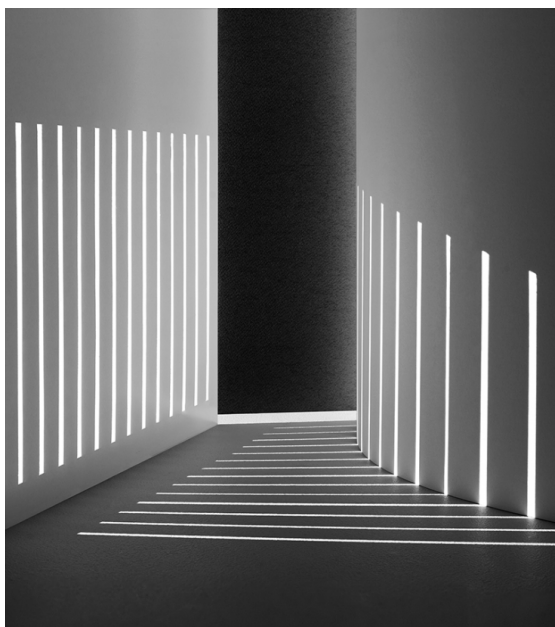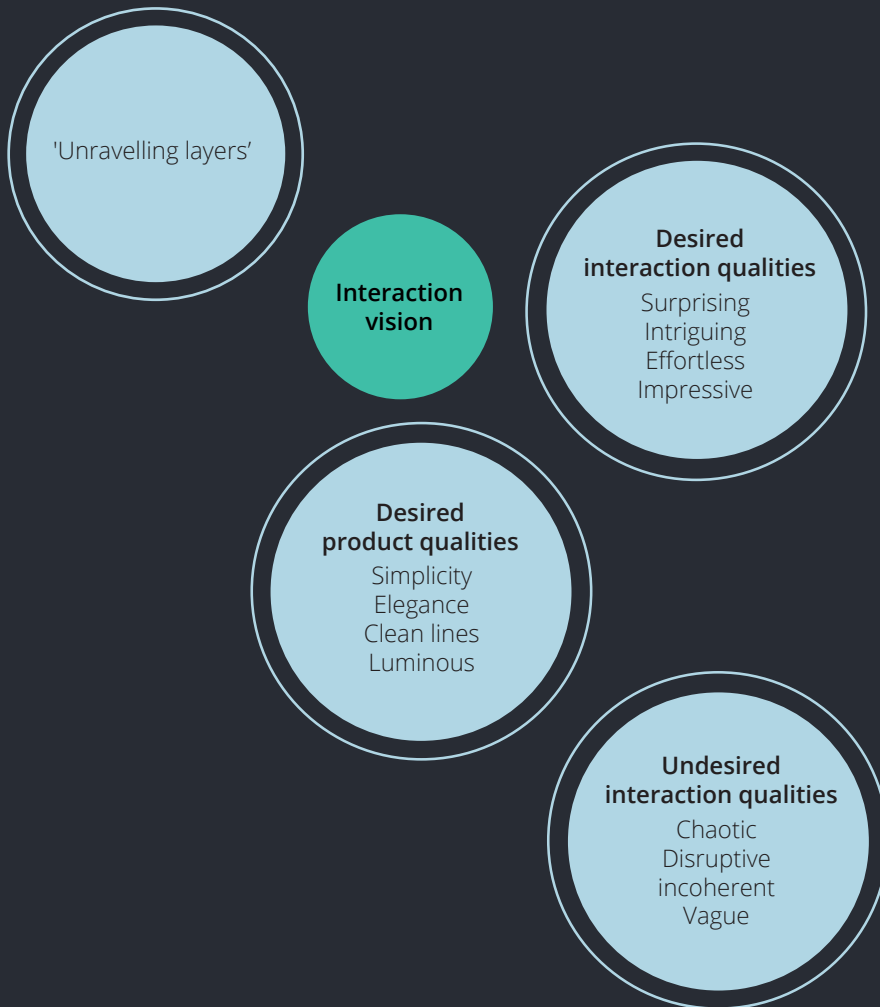
Conclusion

This chapter introduced the interaction vision
and the desired interaction and product qualities.
These will be used when making design choices
concerning the concepts in the next chapter.
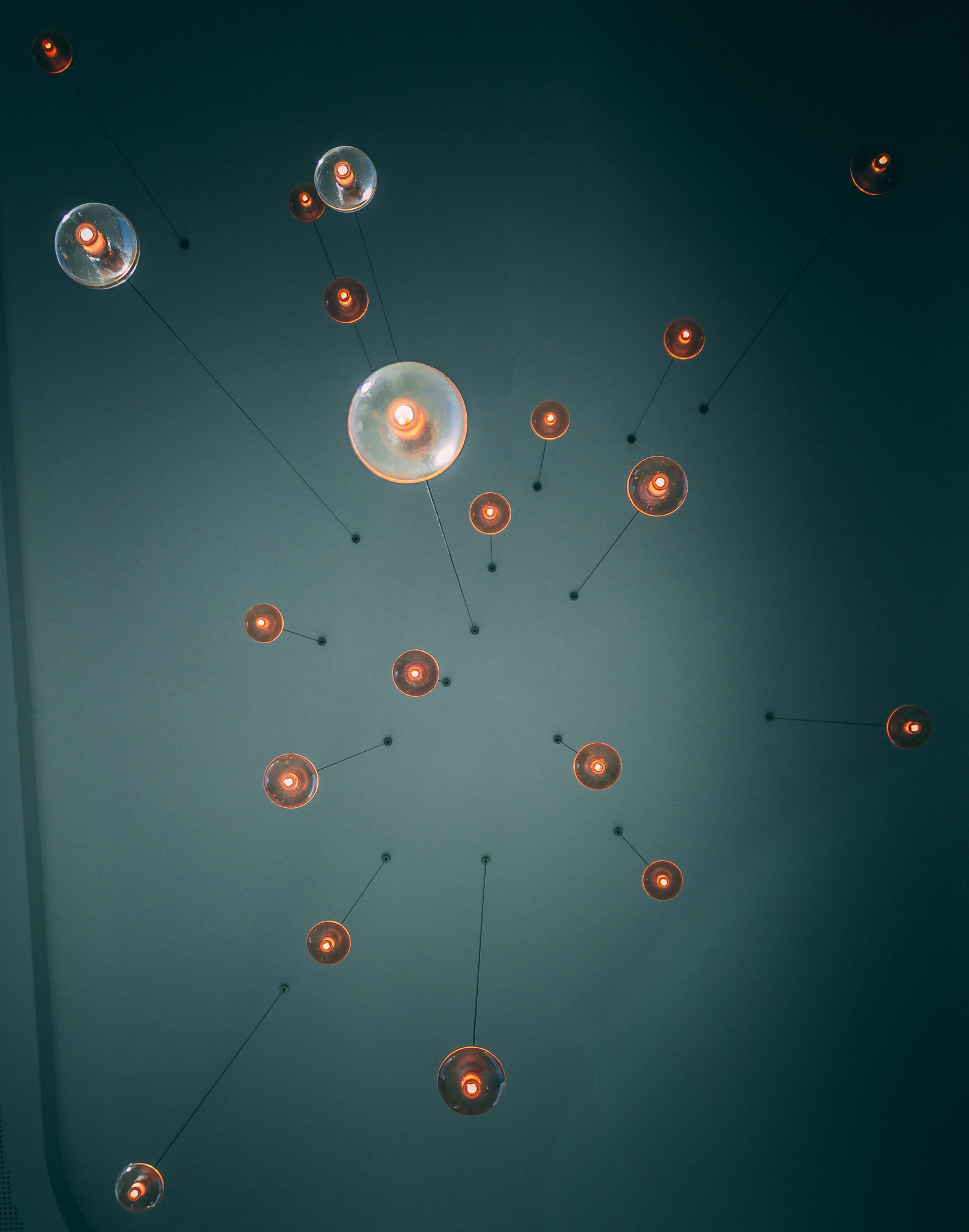
Conceptualization

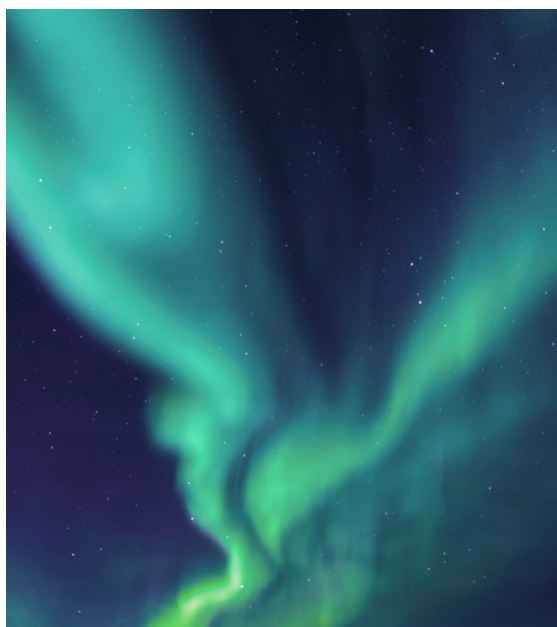In this chapter we explore ways to achieve the design goal. First we take a look at Viberlight, a company that specializes in side emitting fibres. A visit to the company and prototyping with an actual fibre leads to more knowledge about the technology. Knowing what the fibres are capable of, was useful when deciding on the placement of the fibres on the bridge. The dynamic options of the technology are explored through a morphological map. This results in six concepts. From these concepts, a selection of three concepts is made. They are used in the user test, aimed to find out if people understand the lighting visualisation and if they recognize the design intentions of a concept. The user test leads to a lot of insights that are used when a final concept is chosen.

Viberlight

Introduction

In a previous chapter it was explained that the lighting design of the bridge will use side-emitting light fibres. However there is a big quality difference in the types of fibres and light sources that can be used. A company that specializes in high quality side emitting light fibres is Viberlight. Viberlight is a company that provides integrated solutions using Corning® Fibrance™ Light-Diffusing fibres, Versalume RGB Multi-Color Laser Modules and the Viberlight intelligent laser enclosure (ILE).
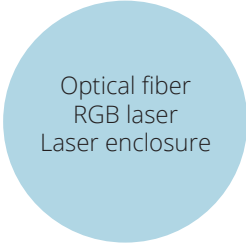
The fibres

Optical fibres were originally designed to send digital data from point A to point B, as an alternative to electrical wires. However, it turned out the fibres had additional properties and are now also used for aesthetic lighting purposes. Side emitting optical fibres have a modified outer layer that has been processed using nanotechnology. The added nanostructures cause the light to 'leak' from the fibre. The light is diffused out of the sides of the fibre and along the length of the fibre without any energy loss. Meaning the illumination effect remains intact throughout the entire length of the fibre. Corning's 'Fibrance' optical fibres have a diameter of 0,23mm and can light up a thin cable over a distance of more than 50 meters (Viberlight, n.d).

The laser module

Viberlight uses Versalume RGB Multi-Color Laser Modules, that include integrated red, green, and blue lasers combined into one light stream. The lighting technology produces little heat. RGB laser can generate any colour, even white is supported. The more laser power, the higher the brightness. The technology can be used during the day, but as with any light technology the outdoor experience gets less during daytime (Viberlight, n.d.). The laser module has a fibre optic connecter (FC connector) with a screw mechanism. The fibres can easily be screwed onto the laser module, allowing for easy maintenance. The module is powered by 12V DC input.

The laser enclosure

The ViberLight Intelligent Laser Enclosure allows for simple and easily accessible maintenance. It has been designed to be used in indoor and outdoor environments. It has AC and DC powering based models and can support up to 12 laser (Viberlight, n.d.). The laser enclosure does not have to be placed near the lighting design as fibres can be used to transfer the light to the side emitting optical fibres. This means the enclosure can be placed somewhere safe and somewhere that allows for easy maintenance.

Optical fiber
RGB laser
Laser enclosure
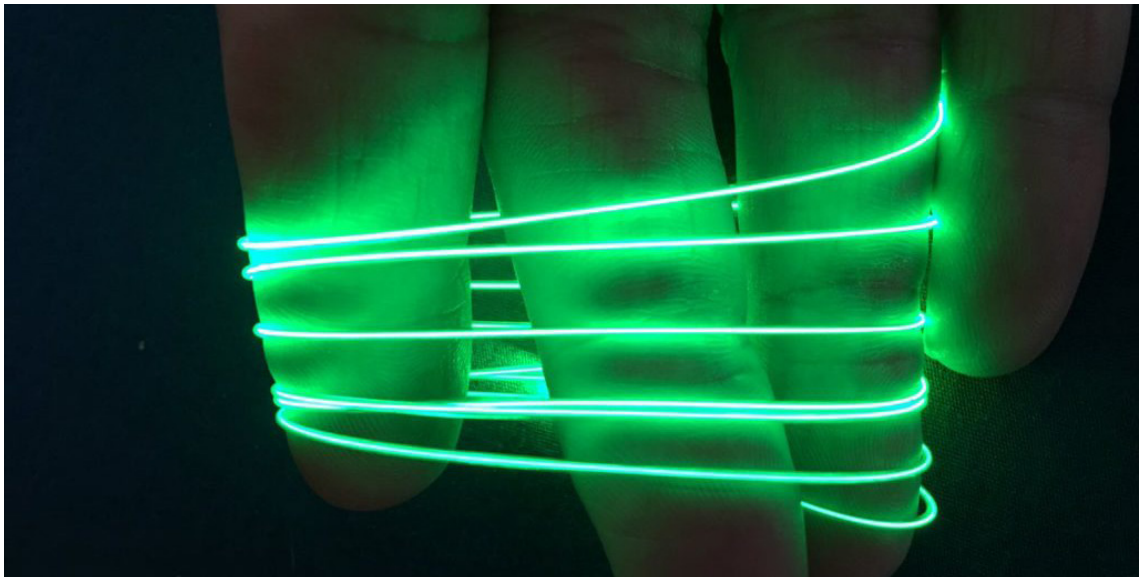
Figure 50 Close up of fibre (Viberlight, n.d.)

Figure 51 Automotive example (Viberlight, n.d.)

Characteristics technology

- ultrathin and light material
- tight-bend capability
- bright clear colour
- emits continuous uniform light
- waterproof
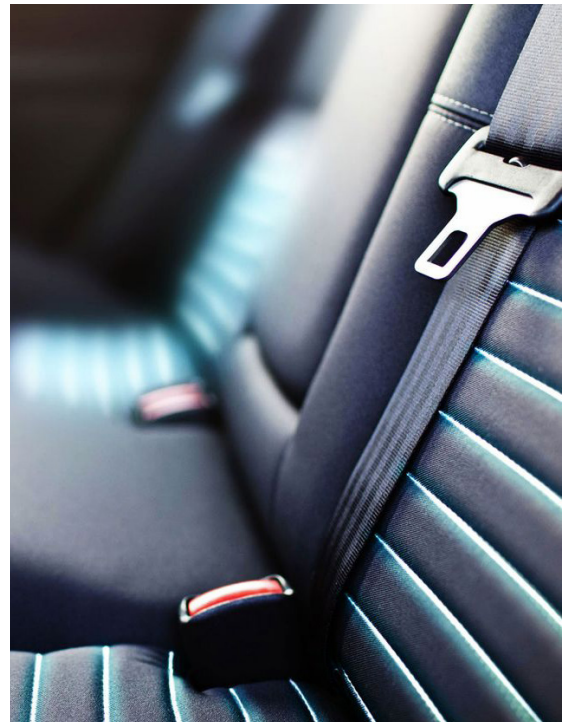
Figure 52 Corning Fibrance in car seat (Corning, n.d.)

Technology prototyping

To get more information about the lighting technology, I visited Viberlight and was able to borrow one of their fibres and a blue laser. This helped me to get a better understanding of the possibilities of the technology and to see how the technology looks on the bridge.
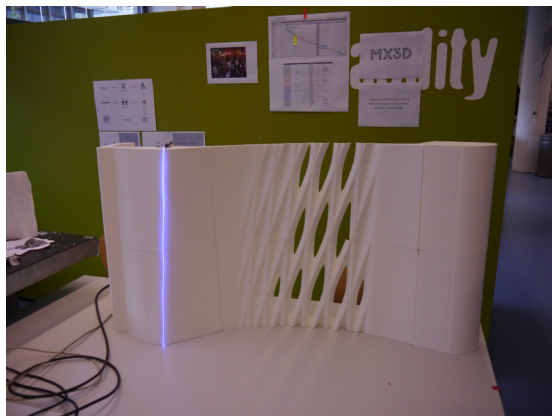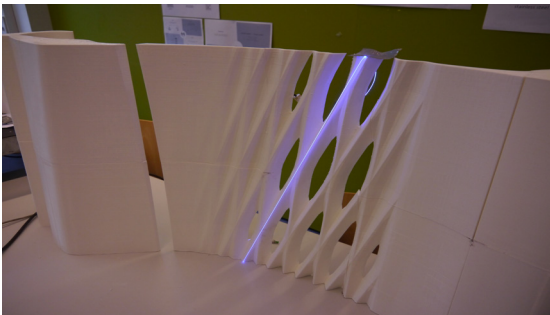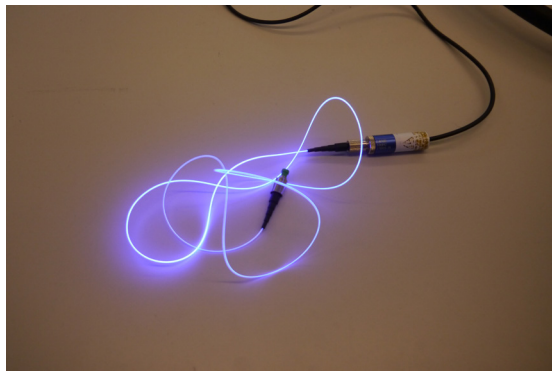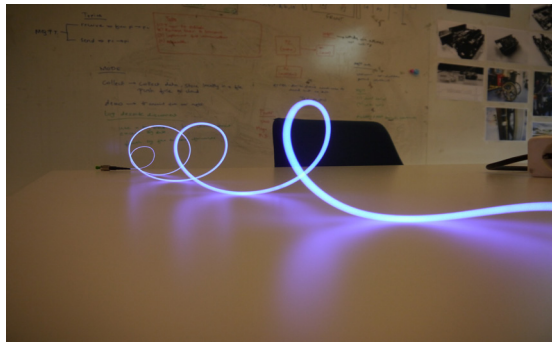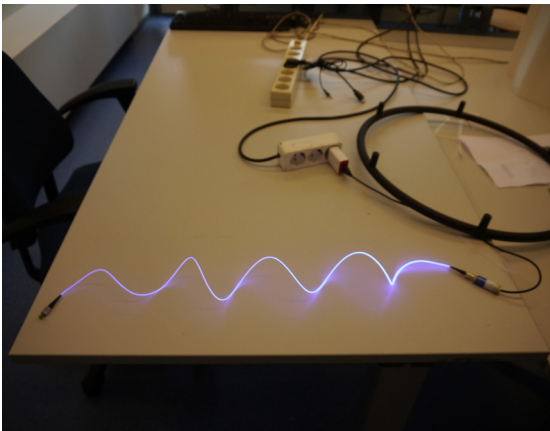
Concepts

Introduction

The goal of the lighting design is to visualize the amount of people. Lighting design concepts can differ from each other in their fibre placement and the dynamic aspect that is used to convey the amount of people. These two elements were further explored, in order to create different concepts. A choice was first made about the placement of the fibres on the bridge.

Placement

Simplicity, elegance and clean lines. With these product qualities in mind, a design was created that follows the design of the bridge. Five organic lines flow over the side of the bridge (Figure 53).
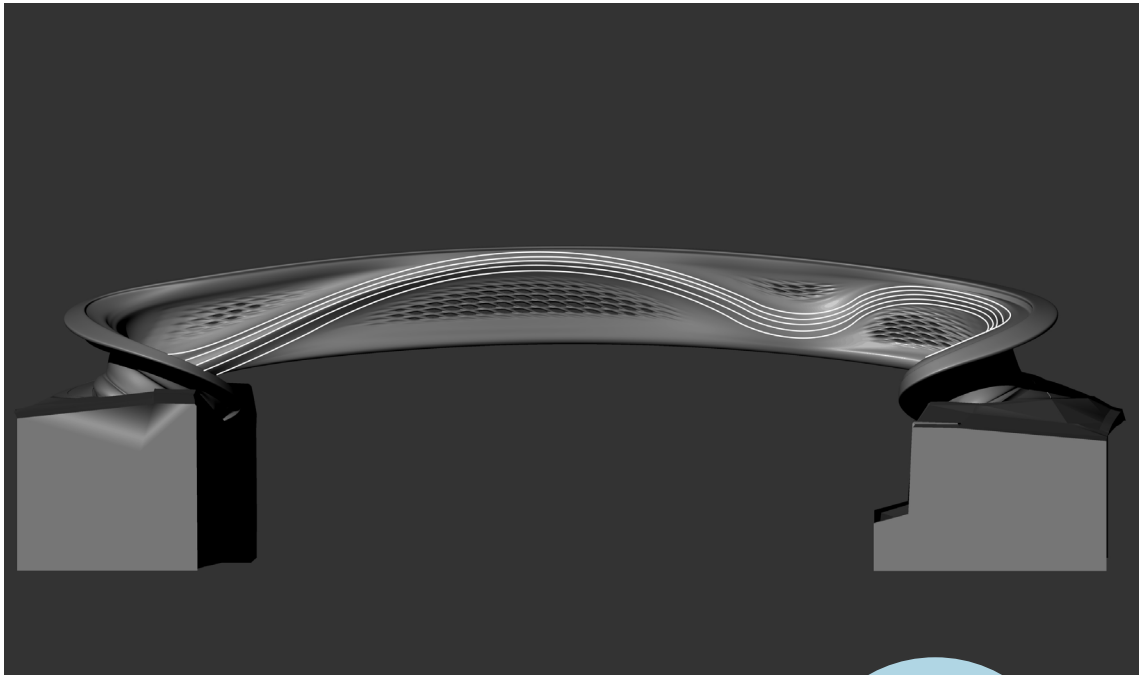
Figure 53 Placement of the side emitting optical fibres

Placement
5 organice lines flow along the side of the bridge

Dynamic aspect

This morphological map presents an overview
of all the different options the bridge has for the
colour of the lines, the amount of lines that are
turned on at a given moment, the brightness of
the lines and the light effects. The bridge has a
static mode (aesthetic purpose) and a dynamic
mode (functional purpose). The dynamic mode
changes over time and conveys the meaning of
the information. The colour, the amount of lines,
the brightness and the light effects can all be used
to convey the amount of people on the bridge
(dynamic mode). The light effects in static mode are
meant to convey the 'smartness' of the bridge: the
fact that the bridge is sensing and monitoring itself
and its environment. Each concept derived from
the morphological map needs at least one dynamic
aspect to be able to communicate different
meanings. The different static and dynamic aspects
are explained on the following pages.

Dynamic aspect
Colour
Lines
Brightness
Effects
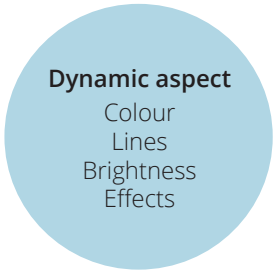
Morphological map

Colour	1 colour (static)	2 colours (static/dynamic)	multiple colours (dynamic)	
Lines	all lines on (static)	varying amount of lines on (dynamic)		
Brightness	1 brightness level (static)	alternating brightness level (dynamic)		
Effects	Glowing (static/dynamic)	Moving (static/dynamic)	Flickering (static/dynamic)	No effect (static)

Colour	1 colour (static)	One colour that stays constant over time.
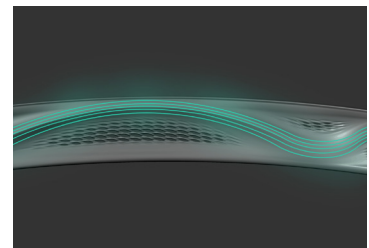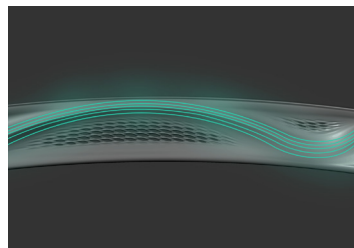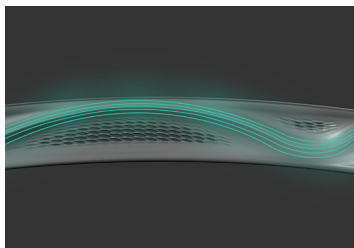
(time)

no changes

Colour	2 colours (static)	Colour gradient of two colours, that stays constant over time.
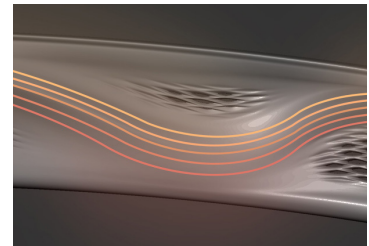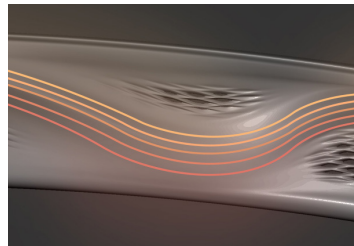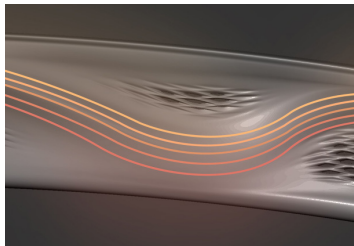
(time)

no changes

Colour	2 colours (dynamic)	Colour changes over time into another colour.
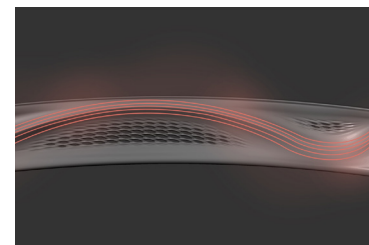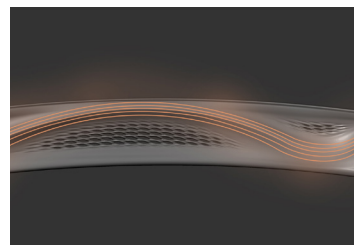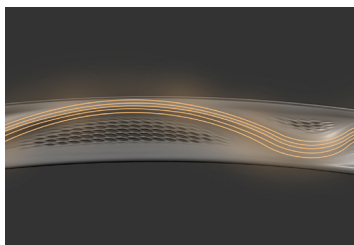
(time)

Colour	multiple colours (static)	Multiple colours that are constant over time.

Rainbow

⟶ (time)

no changes

Random
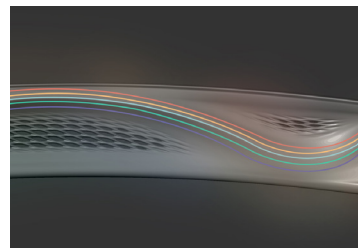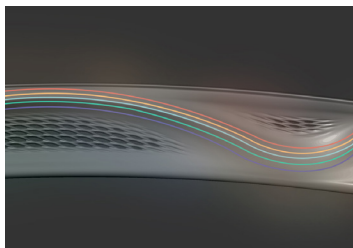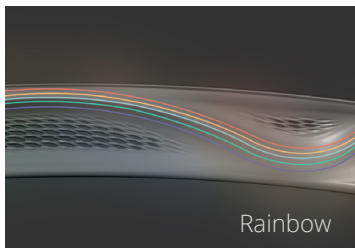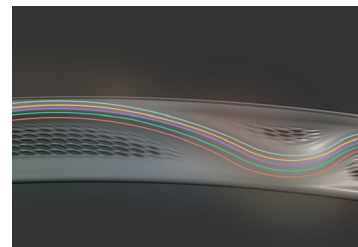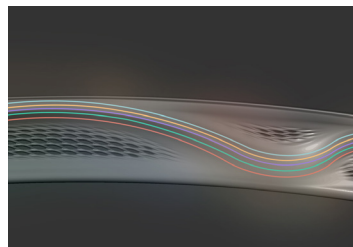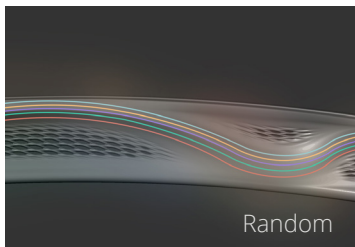
⟶ (time)

no changes

Colour	multiple colours (dynamic)	Colour changes into other colours over time.
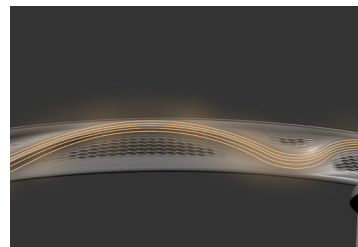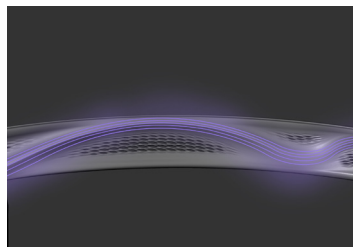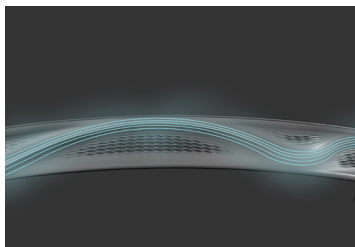
⟶ (time)

Lines	all lines on (static)	Amount of lines is constant over time.
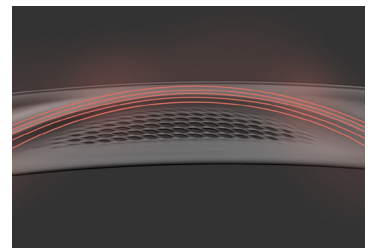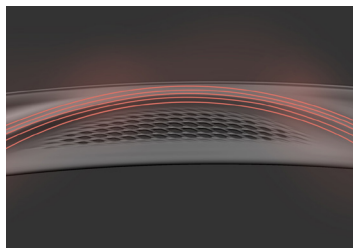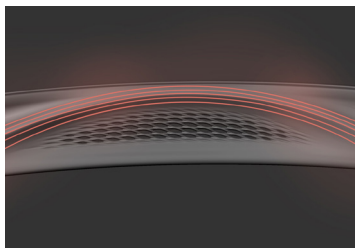
(time)

no changes

Lines	varying amount of lines on (dynamic)	Amount of lines change over time.
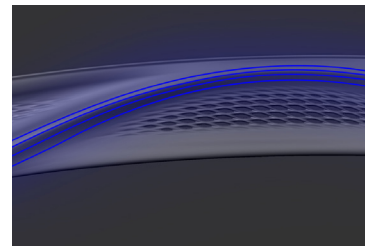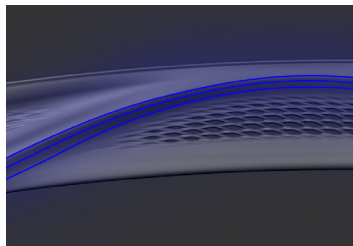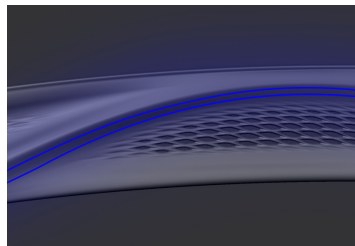
(time)

| Brightness | 1 brightness level (static) | Brightness remains constant over time. |
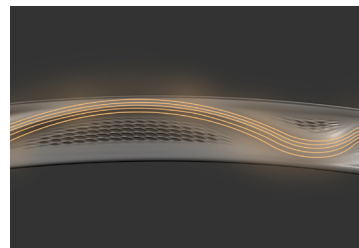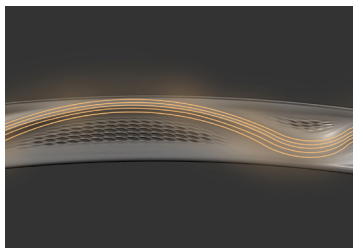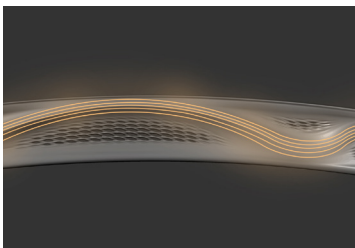
(time)

no changes

| Brightness | alternating brightness (dynamic) | Brightness changes over time. |
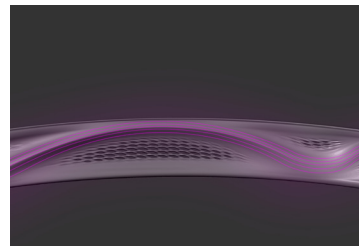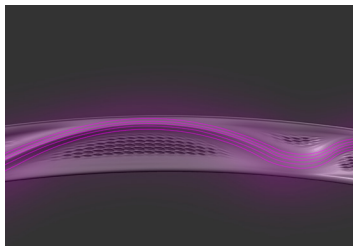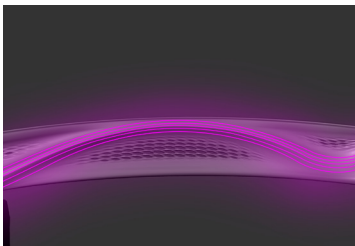
(time)

| Effects | Glowing (dynamic) | Brightness changes in a constant pattern to create a glowing effect. |
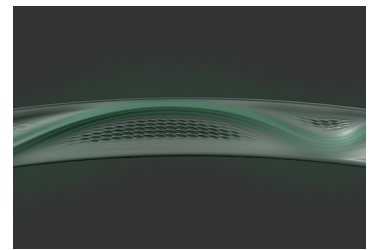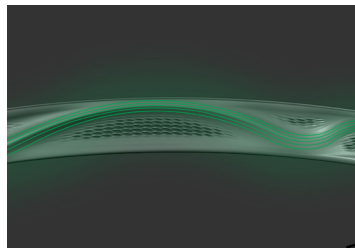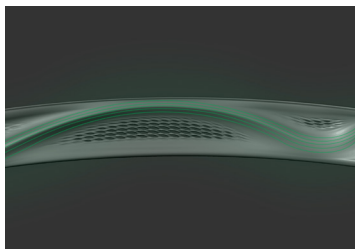
(time)

| Effects | Moving (dynamic) | By turning lines on and off a movement is created. |
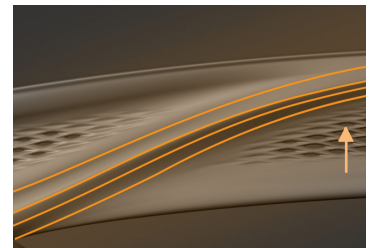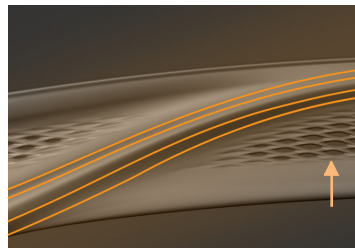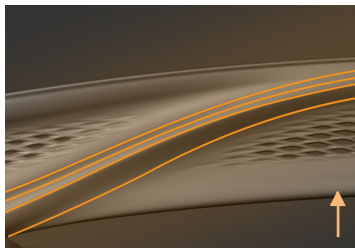
(time)

| Effects | Flickering (dynamic) | The lines go on and off in a certain pace. |
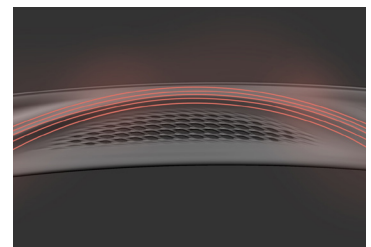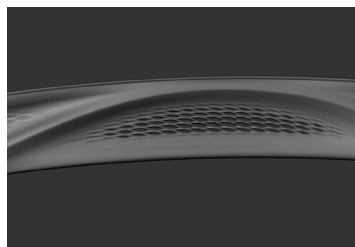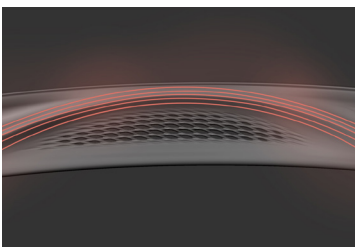
(time)

Concepts

After exploring the options presented in the morphological map, the different aspects were combined to form concepts. Out of all the concept that were created, there were six concepts that made the most sense. These are discussed below.

Concept 1: Light blue + varying amount of lines + glowing
The amount of lines represents the amount of people. Light blue is the colour of smart technology and artificial intelligence. The colour represent the smartness of the bridge. As does the glowing effect, which was inspired by a breathing motion.

(7wdata, n.d)

Concept 2: **Rainbow colours + varying brightness**
The intensity of the brightness represent the amount of people. The rainbow refers to Amsterdam's tolerance to the LGBT community.
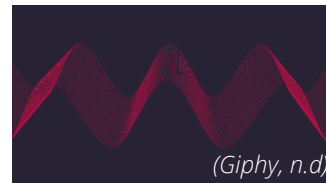
Concept 3: Varying colours + flickering
The colour represent the amount of people. The colour order is based on the colours used in a FEM analysis to calculate the stress and strain. It's a reference to the internal structure monitoring. The flickering was inspired by the blinking of hardware lights.

(Giphy, n.d)

Concept 4 : Varying colours
This concept is similar to concept 3, only it does not flicker. The colour represent the amount of people and the order of the colours is based on the colours in a FEM analysis.

(Coleman, n.d)
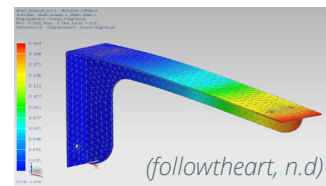
Concept 5: **Red + upward movement**
The speed of the movement represent the amount of people. The more people, the faster the upward movement. The colour red represent the red light district. The movement was inspired by the loading movement on a computer.

(followtheart, n.d)

Concept 6: **Red + amount of lines**
The amount of lines represent the amount of people. The colour red represent the red light district.

(Gerritsen, 2018)

Colour	Lines	Brightness	Effects	Concept 1
1 colour	varying amount of lines on	1 brightness level	glowing	
(static)	(dynamic)	(static)	(static)	

Colour	Lines	Brightness	Effects	Concept 2
Multiple colours	all lines on	alternating brightness level	no effect	
(static)	(static)	(dynamic)	(static)	

Colour	Lines	Brightness	Effects	Concept 3
Multiple colours	all lines on	1 brightness level	flickering	
(dynamic)	(static)	(static)	(static)	

Colour	Lines	Brightness	Effects	Concept 4
Multiple colours	all lines on	1 brightness level	no effect	
(dynamic)	(static)	(static)	(static)	

Colour	Lines	Brightness	Effects	Concept 5
1 colour	all lines on	one brightness level	movement	
(static)	(static)	(static)	(dynamic)	

Colour	Lines	Brightness	Effects	Concept 6
1 colour	varying amount of lines on	1 brightness level	no effect	
(static)	(dynamic)	(static)	(static)	

Concept selection

The concepts were turned into animations. This brought the concept more to life and was very useful for making decisions. The animations led to important insights, that are based on my opinion.

The biggest influence on the appearance/ perception of the concept is the dynamic aspect. I have found that movement and flickering are too disruptive and chaotic to be used as ways to communicate change (undesired interaction qualities). Also communicating change through brightness is not distinctive enough. It's very vague (undesired interaction quality). People might not recognize that the lighting design changes over time. It is not effortless enough (desired interaction quality). On the contrary, using the amount of lines or the colour of the bridge as a way to communicate change is very clear and effortless (desired interaction quality). Concepts that use these dynamic factors are perceived as more calm. Finally, the glowing effect is intriguing and calming, not disruptive.

I want to verify these insights through a user test and test the design intentions behind the concepts. The three best concept are concept 1, 4 and 6. These will be tested in the user test.

Concept 1:
+ Clear way of communicating changes
+ Calm
+ Glowing is intriguing

Concept 2:
- Brightness not distinctive.

Concept 3:
+ Clear way of communicating change.
- Flickering is disruptive.

Concept 4:
+ Clear way of communicating change
+ Calm

Concept 5:
- Movement is disruptive

Concept 6:
+ Clear way of communicating
+ Calm

3 concepts
Glowing light blue lines
Red lines
Multiple colours

User test

Set up

A user test was set up to test if participants understand the lighting visualisation, if they recognize the design intentions behind the concepts. A detailed overview of the questions and the images supporting the questions can be found in appendix 10. The three animations that were used, have been captured in images on the next page. The test consisted of four parts:

Part 1
Find out if participants understand what the lighting visualisation means:
· The amount of people on the bridge

Part 2
Find out if they think the lighting visualisations convey the amount of people in a clear way

Part 3
Finding out if participants understood the design intentions.
· The red light relates to the red light district.
· The light blue light that glows represents innovation, smartness and intelligence.
· The colours relate to the colours representing forces in a force analysis.

Part 4
Find out which animations participants like best and why.

Hypothesis:
I expect that participants are able to connect the change of the lighting to the change in the amount of people.

Hypothesis:
I expect that participants will think that the lighting visualisations conveys the amount of people in a clear way. I expect that participants will have a preference for a specific dynamic aspect (either change in colour or change in amount of lines) and will rate that aspect higher.

Hypothesis:
I expect that participants will be able to connect the red light to the red light district. I expect that participants will choose words such as intelligent, innovative, smart and calm to describe the lighting design. I expect that participants are not able to connect the colours of the bridge to colours used to represent forces. The colours are similar to colours that can be found in a rainbow.

Hypothesis:
I expect that people will prefer either concept 1 or concept 3. I expect that they won't prefer concept 2, as red isn't often used in lighting.
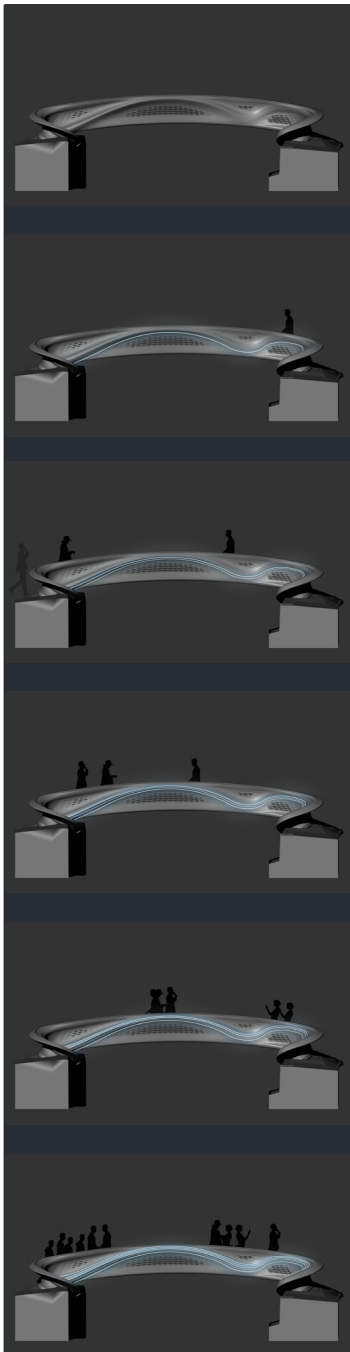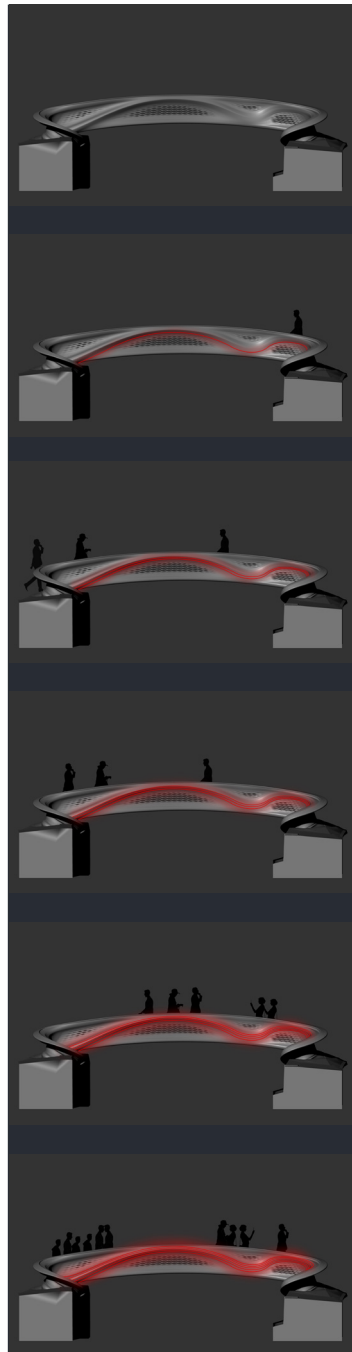
Animation 1   Animation 2   Animation 3
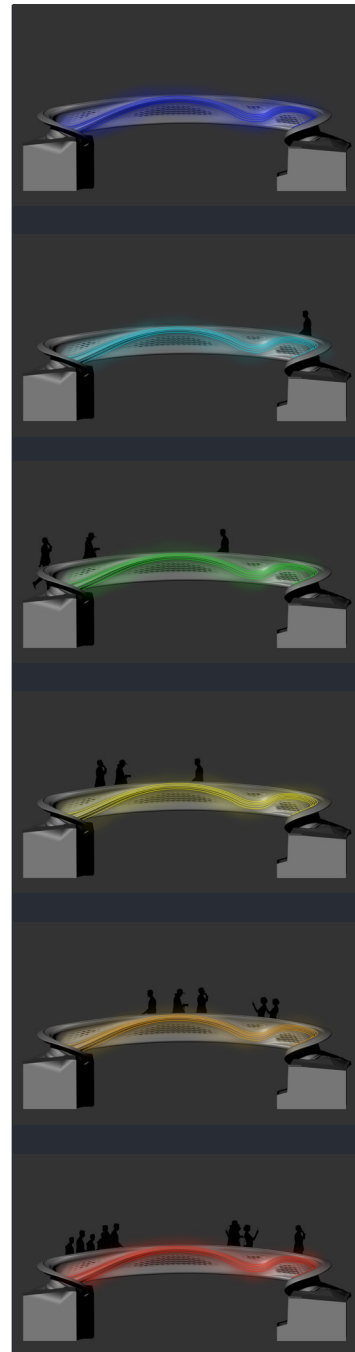
The results

Question 1
- 6 out of 30 people did not understand what the lighting design meant.
  [*2 people looked at concept 1 / 1 person looked at concept 2 / 3 people looked at concept 3*]

- 16 out of 30 people did understand what the lighting design meant.
  [*3 people looked at concept 1 / 7 people looked at concept 2 / 6 people looked at concept 3*]

- The other 8 understood that it was related to the amount of people but wasn't sure how. They recognised that the change signified an increase that had something to do with the people on the bridge. However not everyone related this to the amount of people. Some thought it signified an increase/decrease in the load or the stresses on the bridge.
  [*5 people looked at concept 1 / 2 people looked at concept 2 / 1 person looked at concept 3*]

Question two
- When all the ratings are added up, concept 1 has 171/210 points, concept 2 has 173/210 points and concept 3 has 120/210 points. This is significantly lower than concept 1 and concept 2.

- 7 people gave concept 1 the highest rating.
  5 people gave concept 2 the highest rating
  5 people gave concept 3 the highest rating
  3 people rated all concept equally
  10 people gave concept 1 and 2 the highest rating

Question 3
- 5 people linked concept 2 to image 1
  16 people linked concept 2 to image 2
  9 people linked concept 2 to image 3
  No one linked concept 2 to image 4.

Question 4
- Amount of times a word was chosen:
  Romantic   1
  Intelligent   19
  Expensive   7
  Joyful   1
  Respectful   5
  Innovative   15
  Adventurous   2
  Ordinary   1
  Unpleasant   0
  Friendly   1
  Boring   0
  Funny   0
  Serious   2
  Smart   13
  Calm   16

- 5 out of 30 people would use the same words to describe the other lighting designs
  25 out of 30 people would use different words to describe the other lighting designs.

Question 5
- 4 out of 30 people linked concept 3 to image 1
  21 out of 30 people linked concept 3 to image 2
  5 out of 30 people linked concept 3 to image 3

Question 6
- 21 out of 30 people liked concept 1 the best.
  1 out of 30 liked concept 2 the best
  8 out of 30 liked concept 3 the best.

- Explanation for preference concept 1:
  Clean, calm, simple, neutral, clear, the light suits the design of the bridge.

- Explanation for preference concept 3:
  More fluent, more noticeable, more ambient way of representing

Conclusion

In total 24 out of 30 participants understood that the lighting design had something to do with the amount of people, even if they didn't understand the specifics. The most important thing is that they understood that the bridge responded to an event and tried to communicate a change through the lighting. The means the smartness of the bridge was successfully conveyed.

Apparently participants found animation 3 the most unclear. Since animation 1 and 2 had a much higher score and were very close to each other, the conclusion can be drawn that using the amount of lines as a dynamic factor is preferred over using the colour as a dynamic factor.
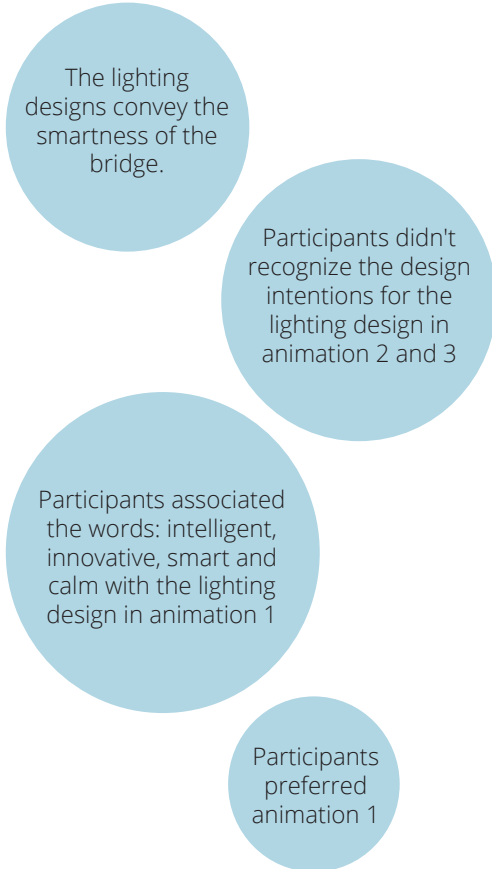
Only 16 people linked the red lights to the red light district. The reason why the other participants chose another image is unknown. It could be that they didn't recognise image 2 as the red light district, or it could be that they thought the futuristic design of the bridge belonged in a more futuristic city (image 3, appendix 10). It appears that the participants didn't recognise the design intention for this concept.

The design intentions for the concept in animation 3 were also not clear for the participants. However this was expected as the colours are similar to colours that can be found in a rainbow. For this concept the design intentions needs to be explained to people, in order for them to appreciate it.

The design intentions for the concept in animation 1, however, were clear. Participants chose the intended words to describe the design: intelligent, innovative, smart and calm. Unexpected was that participants also associated the word expensive with the lighting design.

I think the results from question 6 were also very clear: 21 out of the 30 participants liked concept 1 the best. The reasons they gave for why, were: it's clean, calm, simple, neutral, clear. The light suits the design of the bridge.

It's interesting to note that 8 out of 30 participants liked concept 3 the best, considering this concept scored very low in part two. Only 1 participant preferred concept 2.

The lighting designs convey the smartness of the bridge.

Participants didn't recognize the design intentions for the lighting design in animation 2 and 3

Participants associated the words: intelligent, innovative, smart and calm with the lighting design in animation 1
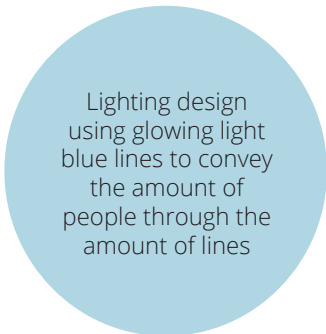
Participants preferred animation 1

Concept choice

Chosen concept

The chosen concept for the lighting design of the bridge, is the light-blue coloured lighting design that conveys the amount of people on the bridge through the amount of lines that are turned on. This choice was made because I think this concept best reflects the smart character of the bridge. In the user test, participants affirmed this by describing the chosen design as intelligent, innovative and smart. The lighting design glows in a constant motion to convey that the bridge is an almost living and breathing entity, that is aware of its surroundings. The lighting effect helps people to understand that the bridge is a smart bridge. The more people on the bridge the more glowing lines, when the number of people on the bridge remains constant the lines will not increase but they will still glow. People will still be able to see that the bridge is sensing because of the glowing effect. When there are no people on the bridge the lines will no longer glow. This also enhances the feeling of engagement with the bridge.

This lighting design was also selected by the majority of participants as being their favourite. Participants perceived the bridge as calm and neutral. These are positive associations, since Amsterdam is already very busy and loud. The lighting design can balance this out, minimizing its contribution to the overcrowdedness.

Lighting design using glowing light blue lines to convey the amount of people through the amount of lines

Placement
5 organice lines flow along the side of the bridge

Viberlight

Optical fiber
RGB laser
Laser enclosure

Concepts

Dynamic aspect
Colour
Lines
Brightness
Effects

3 concepts
Glowing light blue lines
Red lines
Multiple colours

The lighting designs convey the smartness of the bridge.

Usertest

Participants associated the words: intelligent, innovative, smart and calm with the lighting design in animation 1

Participants didn't recognize the design intentions for the lighting design in animation 2 and 3

Concept choice

Lighting design using glowing light blue lines to convey the amount of people through the amount of lines

Participants preferred animation 1

Conclusion

In this chapter a selection of three concepts was made, which were tested on participants during a user test. The insights from the user test helped decide which lighting design was the better choice for the bridge. The final design for the bridge is the lighting design based on the light-blue lines that glows in constant motion. In the next chapter more details are discussed about the final design.

Final design

In this chapter more details are discussed about the final design of the lighting design. It is explained how the amount of people influences the bridge and what the costs of the lighting infrastructure are.

Machine learning

As mentioned before, the lines represent the amount of people on the bridge. The amount of people per level will be determined by the machine learning algorithm. If the bridge collects enough data, a machine learning algorithm can be used to detect patterns in the data. If, for instance, it's very busy every Tuesday afternoon, with crowds of 30, 40 and 50 people crossing the bridge at a given time, then on Tuesday afternoon the amount of people per level needs to become higher. Change should occur with every additional 10 people that step on the bridge. While on a very slow Thursday morning, when there are no more than 4 to 10 people on the bridge at a given time, the amount of people per level needs to become lower. Change should happen with every additional two people that step on the bridge. The lighting design needs to stay dynamic and relevant. From the data, the bridge could learn daily, monthly and hourly patterns, that are relevant for the lighting design.

Costs

The lighting design consists of 5 light lines. For each light line, two side emitting optical fibres are placed inside a plastic tube. This tube keep the fibres together and protects them. The tubes can be mounted onto the bridge. The fibres are connected to RGB lasers. These are controlled by a control unit that responds to the incoming data as explained previously in figure 19. The costs of the lighting infrastructure are calculated below. This is a price estimation given by Joop van Aard (Front office team of Viberlight) during our meeting.

2 x 5 multi-colour laser = 10 x €180	= €1800
2 x 5 fibers = 10 x €17	= €170
5 see through tubes to hold the fibers	= €20
Color mixing software	= €200
1 control unit	= €945
Raspberry Pi + Arduino + accessories	= €150
Total	= €3285

Figure 54 Impression final design
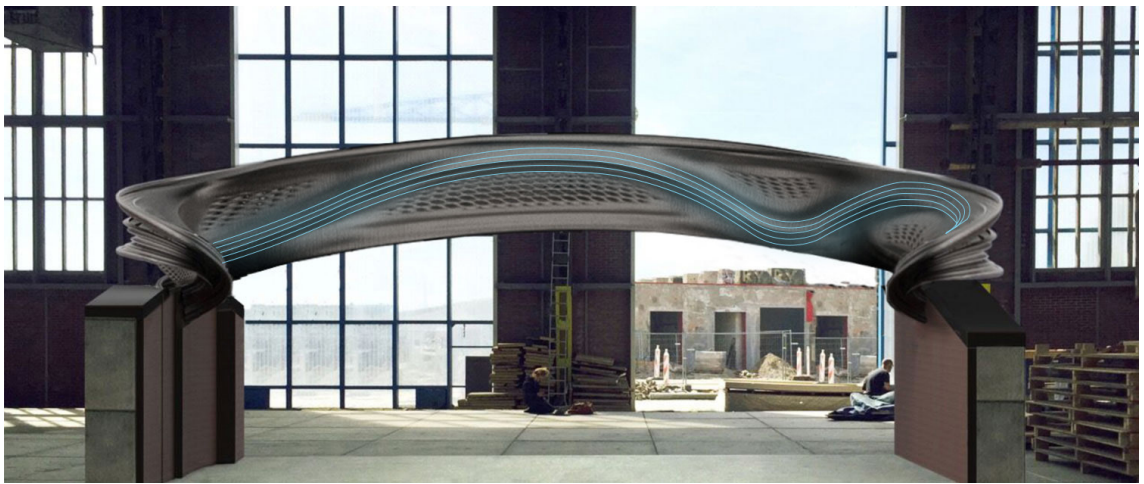
Figure 55 Impression final design
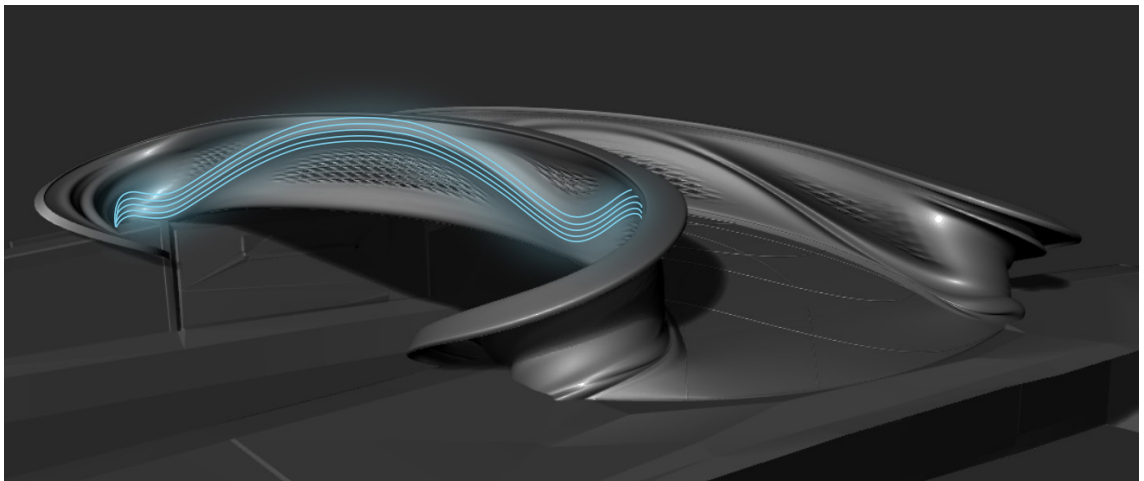
Figure 56 Impression final design
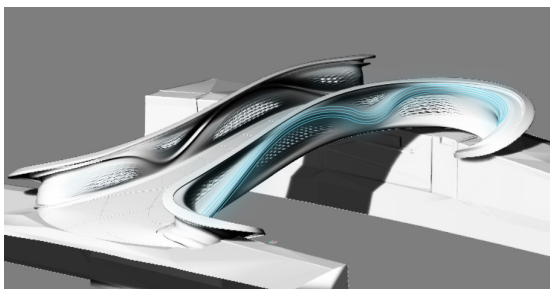
Figure 57 Impression final design (day time)   *Figure 58 Impression final design (night time)*
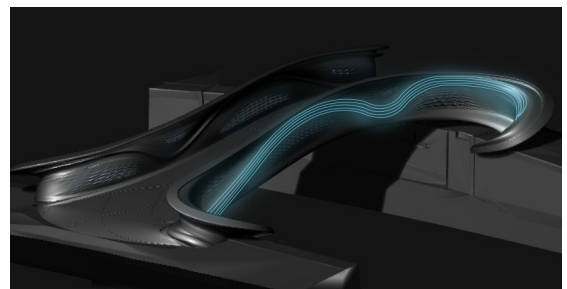
Final design

The amount of people per level will be determined by the machine learning algorithm.

Total cost estimation €3285

Conclusion

This chapter explained how the amount of people
can vary per day, according to the patterns
the machine learning algorithm detects. It also
explains how the cost estimation of the lighting
infrastructure was calculated.
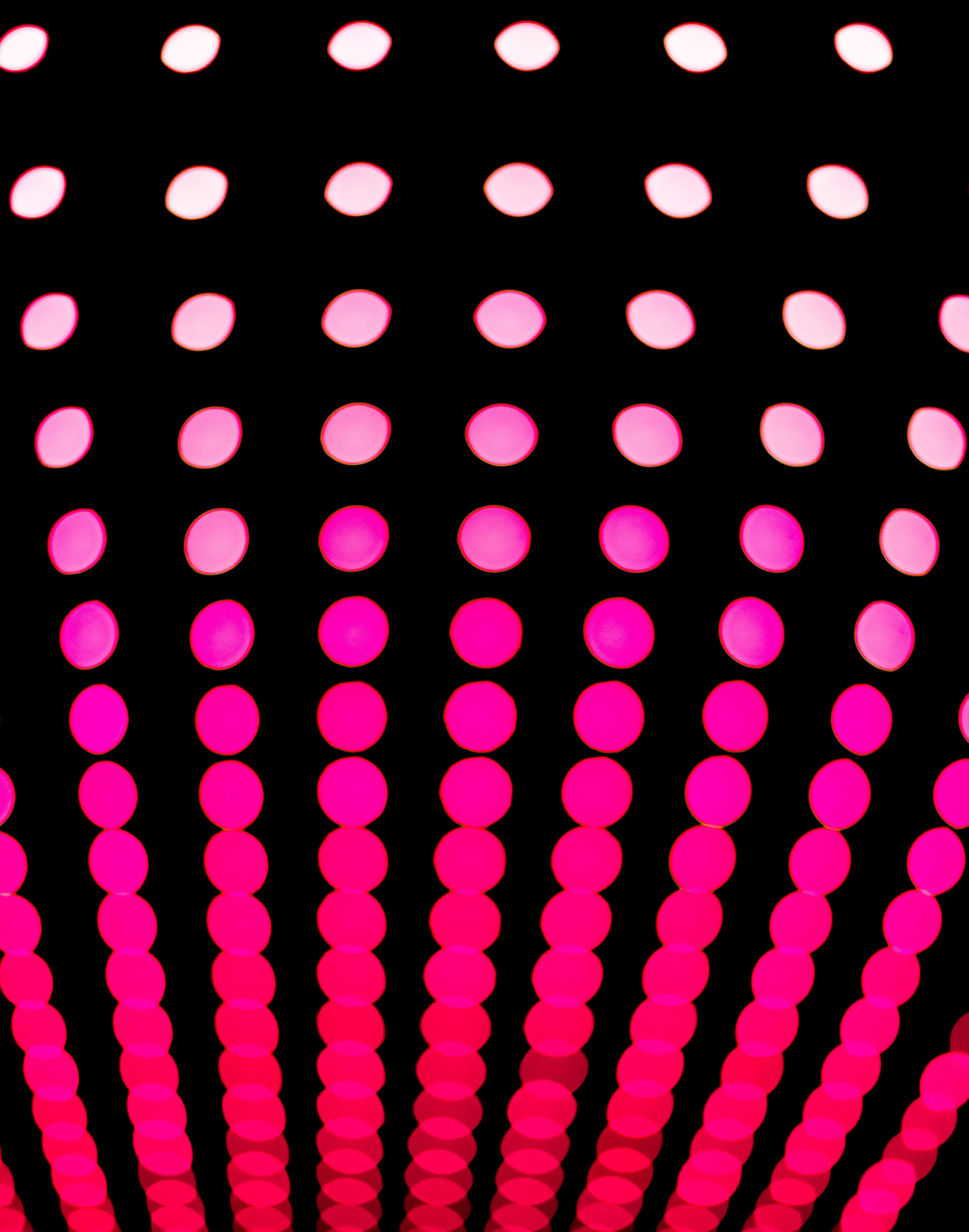
Evaluation

In this chapter the project and the process are
evaluated and recommendations are made.

Evaluation

Project evaluation

The design challenge was the starting point of this project: develop a data driven lighting design for a 3D printed bridge to engage people with the bridge and convey the smartness of the bridge.

In the chapter about the concept choice I already explained why I believe the final design fulfills this challenge. The bridge can sense its environment and collect data. This makes the bridge smart. But how can this smartness be conveyed to people? By visualizing data through light. Light is used to reveal a hidden layer of the bridge, namely the sensor network. All lighting designs that visualize data are per this definition smart. People need to be able to determine that the bridge is smart. Simply having lights change color does not necessarily imply data driven, it could be lights that have a preprogrammed sequence. Having data that directly corresponds to the engagement with the bridge, be the data that determines the lighting, allows people to observe that the bridge lighting responds to peoples interaction on the bridge, this conveys the element of sensing and responding making the bridge smart.

So how can you determine which lighting design does this the best? The 'colour' concept visualized data and therefore conveyed the smartness of the bridge. However, some people mentioned during the user test that they found the use of colours childish. Does this not make the lighting design smart anymore? The lighting design should convey the smartness of the bridge, by visualizing data, but it should also by itself convey a certain smartness, otherwise the data visualization is less convincing. That is why the final design concept was chosen. Through the use of colour and a glowing affect, the lighting design was associated with intelligence, innovation and smartness.

Another aspect of the design challenge is that part that mentions engaging people: by looking at the bridge and observing what is happening people are engaging with the bridge, a structure they would normally cross without thinking twice. The fact that they can also influence the lighting visualisation by crossing the bridge, means that people can be engaged with the bridge in multiple ways. This is something the final concept also achieves.

But here I would like to point out a risk associated with this project: should we even want to engage people with the bridge? I can't ignore the fact that Amsterdam has a problem with overcrowdedness and that by placing a lighting design on this show-pony of a bridge we would be adding to this problem. Just placing the bridge there will in all likelihood already create an increase in visitors. It will be even worse when the bridge has lights. Not only are people attracted to light, they will also start to interact with the bridge and explore the boundaries of the interaction, or they will wait for just the right moment to have a photo taken of them on the bridge. Only two months ago, tourists destroyed a field of rare pink grass in Hangzhou city due to the selfie craze. Who assumes the responsibility for the consequences of modern technology?

Process evaluation

During this project there were a lot of times when I got stuck. Especially at the beginning when the project was still very broad. I found it hard to make decisions because I wasn't sure on what to base them. That's why in the first two months I clung to the literature I had found on media architecture, when is should have just tried out things with light. I kept going back to what is meaningful? And meaningful for who? I took small steps forward but it took a few months before in finally made a decision about the lighting design and lighting technology. Once this decision was made, things progressed a lot faster (still not super fast though). It need to work on making more iteration steps during the design process and I need to work on communication my process to others.

Recommendations

Before the lighting design be implemented, the data side of the story needs to be developed more. A lot of things concerning the smartness of the bridge are still hypothetical. The cloud infrastructure still needs to be built and Autodesk is still exploring machine learning with some of the other stakeholders.

Ideally, the bridge would have been designed around the sensor network and the lighting infrastructure. If such a smart infrastructure project was to be repeated I would recommend taken these aspects into account from the beginning. This way more durable and sustainable smart infrastructure can be created.

I also recommend exploring other options than light to communicate the smartness of the bridge. But if the smart bridge team does decide to continue with light, I recommend exploring projection mapping, as this is a great tool to create complex data visualisation.

Shelf 1 (top):

No.	Label
218	Skulpturen-garten am Funkturm
217	Fassaden-gestaltung Spandauer Damm
216	Britzer Damm
216	Britzer Damm
215	Brunnen Breitscheid-Damm
214	Lazarus-Krhs. und Paul-Gerhardt-Stift
214	Lazarus-Krhs. und Paul-Gerhardt-Stift
214	Lazarus-Krhs. und Paul-Gerhardt-Stift
214	Lazarus-Krhs. und Paul-Gerhardt-Stift
214	Lazarus-Krhs. und Paul-Gerhardt-Stift
214	
213	Theodor-Heuss-Platz
212	Nasses Dreieck
211	Leuchten-familie für Berliner Straßen (LTF)
211	Leuchten-familie für Berliner Straßen (LTF)
211	Leuchten-familie für Berliner Straßen (LTF)
210	
210	Städtebaul. Verdichtung Müllerstraße
209	Karl-Bonhoeffer-Nervenklinik "Festes Haus"
209	Karl-Bonhoeffer-Nervenklinik "Festes Haus"
209	Karl-Bonhoeffer-Nervenklinik "Festes Haus"
209	Karl-Bonhoeffer-Nervenklinik "Festes Haus"
209	Karl-Bonhoeffer-Nervenklinik "Festes Haus"

Shelf 2:

No.	Label
231	Lutherplatz (Kunst)
231	Lutherplatz (Kunst)
231	Lutherplatz (Kunst)
231	Lutherplatz (Kunst)
231	Lutherplatz (Kunst)
231	Lutherplatz (Kunst)
230	Kranold-platz (Kunst)
228	OSZ-Oberstufen-zentren an 8 Standorten (Kunst)
228	OSZ-Oberstufen-zentren an 8 Standorten (Kunst)
228	OSZ-Oberstufen-zentren an 8 Standorten (Kunst)
228	OSZ-Oberstufen-zentren an 8 Standorten (Kunst)
227	TU-Erweiterung Spreebogen
225	Grund- und Sonder-schule Nehringstraße
225	Grund- und Sonder-schule Nehringstraße
225	Grund- und Sonder-schule Nehringstraße
225	Grund- und Sonder-schule Nehringstraße
224	
223	Klinik Wiesengrund im Humboldt-krhs. (Kunst)
223	Klinik Wiesengrund im Humboldt-krhs. (Kunst)
223	Klinik Wiesengrund im Humboldt-krhs. (Kunst)
223	Klinik Wiesengrund im Humboldt-krhs. (Kunst)
223	Klinik Wiesengrund im Humboldt-krhs. (Kunst)
222	Krankenhaus Zehlendorf / örtl. Bereich Heckeshorn
222	Krankenhaus Zehlendorf / örtl. Bereich Heckeshorn

Shelf 3:

No.	Label
243 / 244 / 245	BUGA 1983 Brunnen / Grabeschen / Farbmöbe
243 / 244 / 245	BUGA 1983 Brunnen / Grabeschen / Farbmöbe
243 / 244 / 245	BUGA 1983 Brunnen / Grabeschen / Farbmöbe
243 / 244 / 245	BUGA 1983
243	
242	
241	Parkachse 1/ Kieler Platz BUGA 1983
241	Parkachse 1/ Kieler Platz BUGA 1983
240	Brunnen an d. Müritzer Allee BUGA 1983
239	Karl Foerster-Skulptur BUGA 1983
238	Skulptur Vorplatz Pro. Die Welt
237	Krhs. St. Marien Maria Trost
237	Krankenhaus St. Marien / Maria Trost
237	Krankenhaus St. Marien / Maria Trost
237	Krankenhaus St. Marien / Maria Trost
236	Skulp-turen Flug-hafen Tegel
235	Land-gericht Tegeler Weg
234	Oranienburger Tor (2. Stufe)
234	Oranienburger Tor (2. Stufe)
233	Platzgestaltung Karl-Marx-Platz Richardplatz
233	Platzgestaltung Karl-Marx-Platz Richardplatz
233	Platzgestaltung Karl-Marx-Platz Richardplatz
233	Platzgestaltung Karl-Marx-Platz Richardplatz

Shelf 4 (bottom):

No.	Label
261	
259	Kindertages-stätte Emser Straße
258	Esplanade
255	Frauennotruf-einstell Plötzensee
246 / 247 / 250	
254	BUGA 1983
253	OSZ Bau / Holz Kunst am Bau
253	OSZ Bau / Holz Kunst am Bau
253	OSZ Bau / Holz Kunst am Bau
253	OSZ Bau / Holz Kunst am Bau
253	OSZ Bau / Holz Kunst am Bau
253	OSZ Bau / Holz Kunst am Bau
251	Crelle-straße
250	Klein-garten-krhs
249	Gestaltung von Fassaden am Lok-Angeles-Platz
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
248	BUGA 1983 Franziskus-krankenhaus Erweiterung
247	Franziskus-krankenhaus Erweiterung

References

References

Adafruit (n.d.) LED strip [Image]. Retrieved on August 23, 2018 from https://www.adafruit.com/product/2439

Adafruit (n.d) LED tile [Image]. Retrieved on August 23, 2018 from https://learn.adafruit.com/adafruit-rgb-matrix-plus-real-time-clock-hat-for-raspberry-pi?view=all

Adafruit (n.d.) Matrix panel Retrieved on August 23, 2018 from https://www.adafruit.com/product/2026

Adafruit (n.d.) Neopixel jewel [image] Retrieved on August 23, 2018 from https://www.adafruit.com/product/2226

Adafruit (n.d.) Neopixel ring [image] Retrieved on August 23, 2018 from https://www.adafruit.com/product/1768

Adire, S (2018) Reflection (Darling Harbour) [Image]. Retrieved on August 23, 2018 from http://fountain.cutewheat.site/darling-harbour-fountain-show/

Akira Sakamoto Architect (2005). Creo Hall [Photograph]. Retrieved October 8, 2018, from https://www.world-architects.com/en/akira-sakamoto-architect-and-associates-osaka/project/creo-hall

Alam, R. (n.d.) Technical support [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

AMS institute (n.d.) AMS FAQ. Retrieved May 9, 2018 from https://www.ams-institute.org/institute/#faq

Amsterdam.org (2018, August 24). Facts and figures. Retrieved September 17, 2018 from https://amsterdam.org/en/facts-and-figures.php

Amsterdam Today (2016) World famous: the Amsterdam Red Light District. Retrieved September 17, 2018 from https://amsterdamtoday.eu/world-famous-the-amsterdam-red-light-district/

Arup (n.d.) Our firm. Retrieved May 8, 2018, from https://www.arup.com/our-firm

Balsing, H (2010) Oudezijds Achterburgwal [Photograph]. Retrieved September 17, 2018 from http://fotos.serc.nl/noord-holland/amsterdam/amsterdam-33115/

The Bay Lights (n.d.) The Bay Lights Bridge [Photograph]. Retrieved on May 24, 2018 from http://thebaylights.org/

Caligaris, C. (n.d.) Palazzo della Regione a Torino in piazza Castello {Photograph]. Retrieved Au-gust 6, 2018 from https://unsplash.com/photos/SjhF0GMI0zY

Castro, B. (n.d.) Sharing [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Chickada, R (2005) Kyushu National Museum [Photograph]. Retrieved October 8, 2018 from https://www.architonic.com/en/story/architonic-the-fondazione-targetti-s-lighting-academy-shines-brighter-with-architonic/7000646

Coleman (n.d) Smart technology [Image] Retrieved on December 1, 2018 from https://www.lsainsider.
com/google-smart-technologies-are-going-to-change-how-we-do-business/archives

Corning (n.d.) Car seat [Image]. Retrieved December 2, 2018 from https://www.corning.com/media/
worldwide/csm/images/4B-Fibrance-Auto.jpg/jcr:content/renditions/retina_676.jpg

Cresnar, G. (n.d.) Integration [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Dalsgaard, P. & Halskov, K. (2010). Designing urban media façades: cases and challenges.
Proceedings of the SIGCHI Conference on Human Factors in Computing Systems – CHI '10. doi:
10.1145/1753326.1753670

Dalsgaard, P., Halskov, K. & Nielsen, R. (2008). Towards a design space explorer for media facades.
Proceedings of the 20th Australasian Computer-Human Interaction Conference, OZCHI 2008. doi:
10.1145/1517744.1517816

Dalsgaard, P., Halskov, K. & Wiethoff, A. (2016). Designing media architecture: tools and approaches for
addressing the main design challenge. Proceedings of the SIGCHI Conference for Human-Computer
Interaction – CHI '16. Doi: 10.1145/2858036.2858318

Dalsgaard, P. & Hespanhol, L. (2015). Social interaction design patterns for urban media architecture.
Human-Computer Interaction – INTERACT 2015, 596-613. doi: 10.1007/978-3-319-22698-9_41
De Groot, A. (2018) The MX3D team standing on its 3d printed bridge [Photograph]. Retrieved April 25,
2018 from https://gizmodo.com/the-first-3d-printed-steel-bridge-looks-like-it-broke-o-1824252512

De Gruijter, O. (n.d.) MX3D's printing robot [Photograph]. Retrieved April 25, 2018 from https://3dprint.
com/188541/mx3d-bridge-update/

DistanceLab (2008) LED's (Urban pixels) [Image]. Retrieved on August 23, 2018 from http://www.
agamanolis.com/distancelab/news/2008.php

Dowload APK free (n.d.) Circle [image] Retrieved from https://downloadapkfree.com/com.
ipmobilesolutions.wallpapersblackabstract

Erco (2012). Light in the outdoor area. Retrieved October 8, 2018 from https://www.erco.com/download/
content/30-media/lightintheoutdoorarea/erco-light-in-the-outdoor-area-en.pdf

Erco (2006). Lights and scenography. Retrieved October 8, 2018 from https://www.scribd.com/
document/125533930/20113929-Lighting-Handbook-ERCO-Light-and-Scenography

Estes, A. C. (2018) The first 3D printed steel bridge looks like it broke off an alien mothership.
Retrieved April 25, 2018, from https://gizmodo.com/the-first-3d-printed-steel-bridge-looks-like-it-
broke-o-1824252512

Estes, A.C. (2018) The future location of the MX3D bridge over the Oudezijds Achterburgwal canal in
Am-sterdam [Photograph]. Retrieved September 14, 2018 from https://gizmodo.com/the-first-3d-printed-
steel-bridge-looks-like-it-broke-o-1824252512

Farias, B. (n.d.) Weight [Icon]. Retrieved December 2, 2018 from   https://thenounproject.com/search/?q=weight&i=1414023

Fundhouse (2013) Impressive [image] Retrieved on August 23, 2018 from https://www.fundhouse.co.za/article/independent-industry-research/trends-in-european-asset-management-3/

Followtheart (n.d.) Fem analysis [image] Retrieved on December 1, 2018 from   http://followtheart.info/kareff-Tue_4_11.html

Gerritsen, R (2018) Red lights [image] Retrieved on December 1, 2018 from https://renzogerritsen.nl/wp-content/uploads/2018/03/Red-Light-District-Amsterdam.jpg

Gill, d (n.d.) Hand [image] retrieved from https://unsplash.com/photos/VW1xJfuOj2g
Hild, J (n.d.) Girl [image] retrieved from https://unsplash.com/photos/WjZ4eaHq9G4

Giostra, S. (2008) Greenpix media wall [Photograph]. Retrieved April 25, 2018 from http://sgp-a.com/#/single/xicui-entertainment-center-and-media-wall/.

Giuditta-Valentina-Gentile (n.d.) Footsteps [Icon]. Retrieved December 2, 2018 from https://thenounproject.com/search/?q=footsteps&i=112452

Giphy (n.d.) Breathing motion [Image] Retrieved on December 1, 2018 from https://giphy.com/gifs/loop-sine-wave-mE7HsXGDe2aRi

Grozdanic, L. (n.d.) E/B Office [Photograph]. Retrieved May 16, 2018 from http://www.evolo.us/architecture/dynamic-performance-of-nature-eb-office/

Haeusler, M. H. (2009). Media Façades : History, Technology, Content. Ludwigsburg: Avedition.

Häusler, H., Hespanhol, L., Tomitsch, M., & Tscherteu, G. (2017). Media Architecture Compendium - Digital placemaking. Stuttgart: Avedition.

Harrison, S. & Dourish, P. (1996) Re-Place-ing Space: The Roles of Place and Space in Collaborative Systems. Proc. of CSCW, ACM.

Hespanhol, L., Tomitsch, M. (2015) Strategies for intuitive interaction in public urban spaces. Interacting with computers, 27 (3), 311-326. doi:10.1093/iwc/iwu051

Iamtheweather (2009) LED net [Image]. Retrieved on August 23, 2018 from http://iamtheweather.com/?p=956

I Amsterdam (n.d.) Amsterdam's canal ring. Retrieved September 14, 2018, from https://www.iamsterdam.com/en/about-amsterdam/overview/history-and-society/canal-ring

I Amsterdam (n.d.) Decoding Amsterdam's city symbols. Retrieved September 14, 2018, from https://www.iamsterdam.com/en/about-amsterdam/overview/history-and-society/city-symbols

I Amsterdam (n.d.) Amsterdam society. Retrieved September 14, 2018, from https://www.iamsterdam.com/en/about-amsterdam/overview/history-and-society/society

I Amsterdam (n.d.) I Amsterdam letters. Retrieved September 14, 2018, from https://www.iamsterdam.com/en/about-amsterdam/overview/i-amsterdam-letters

iGuzzini illuminazione (n.d.) Castellana 77 [Photograph]. Retrieved May 16, 2018 from https://architecten-web.nl/projecten/project.aspx?ID=35069

Jiang, W. (n.d.) Data [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Joris Laarman Lab (n.d.) MX3D Bridge. Retrieved March 19, 2018, from http://www.jorislaarman.com/work/mx3d-bridge/

Koerner. B (2017) Circles [Image] Retrieved on August 23, 2018 from https://lucept.files.wordpress.com/2017/06/gile-2017-thinklight-brad-koerner-embedded-lighting.pdf

Koerner. B (2017) Lines [image] Retrieved on August 23, 2018 from https://lucept.files.wordpress.com/2017/06/gile-2017-thinklight-brad-koerner-embedded-lighting.pdf

Kiwi-electronics (n.d.) LED strip [image] Retrieved on August 23, 2018 from https://www.kiwi-electronics.nl/digitale-rgb-ledstrip-ws2813-30-led-1m?lang=en

Laymik (n.d.) Process [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Lenthall, S (n.d.) Simplicity (shadow spaces) [image] Retrieved on August 23, 2018 from http://owengildersleeve.com/showcase/shadow-spaces

LetsLED (n.d.) Light spot [Image]. Retrieved on August 23, 2018 from https://www.letsleds.nl/product/led-rgb-spot-67mm-kantelbaar-3watt-rond-dimbaar/

Light [Def. 1]. (n.d.). In Collins English Dictionary Online, Retrieved October 8, 2018, from https://www.collinsdictionary.com/us/dictionary/english/light

Luck, Y. (n.d.) Transformation [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Magicon (n.d.) Brickwork [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Magicon (n.d.) People [Icon]. Retrieved December 2, 2018 from https://thenounproject.com/search/?q=people&i=258554

Magicon (n.d.) Shadow [Icon]. Retrieved December 2, 2018 from https://thenounproject.com/search/?q=shadow&i=456804

Mccall, A (2016) Projector [Image]. Retrieved on August 23, 2018 from http://www.martineaboucaya.com/anthony-mccall-leaving-with-two-minute-silence/

Media architecture. (2016). In Media architecture biennale. Retrieved May 15, 2018 from http://catalog. mediaarchitecture.org/#main

MX3D (n.d.) About. Retrieved March 19, 2018, from http://mx3d.com/about-2/

MX3D (n.d.) MX3D Bridge. Retrieved April 24, 2018, from http://mx3d.com/projects/bridge-2/
MX3D (n.d.) A smarter bridge. Retrieved April 26, 2018, from http://mx3d.com/smart-bridge/

MX3D Bridge (2015, June 11). MX3D to print steel bridge in Amsterdam [video]. Retrieved April 24, 2018, from https://www.youtube.com/watch?time_continue=1&v=pZNTzkAR1Ho

Nwanazia, C (2017) Amsterdam red light district area [Photograph]. Retrieved September 17, 2018 from https://www.beejonson.com/single-post/2017/11/02/Amsterdam-Red-Light-District

OpenTopo (n.d.) Amsterdam Centrum [Image]. Retrieved September 17, 2018 from https://upload. wikimedia.org/wikipedia/commons/a/a3/Amsterdam-centrum-OpenTopo.jpg

Het Parool (2018) 3,1 miljoen bezoekers Oudezijds Achterburgwal in 2017. Retrieved September 17, 2018 from https://www.parool.nl/amsterdam/-3-1-miljoen-bezoekers-oudezijds-achterburgwal-in-2017~a4569451/

Pharrel.fr (2017) Optic fibers [Image]. Retrieved on August 23, 2018 from https://www.pharrell.fr/ comment-savoir-si-on-est-eligible-a-la-fibre.html

Philips (n.d.) Squares (Luminous patterns). [image] Retrieved on August 23, 2018 from http://www.lighting. philips.com/products/luminous-patterns

Phillip Burgess (n.d.) LED ring [Image]. Retrieved on August 23, 2018 from https://learn.adafruit.com/ assets/30702

Philips (2008). The basics of light and lighting. Retrieved October 8, 2018 from http://images.philips.com/ is/content/PhilipsConsumer/PDFDownloads/China/ODLI20150914_001-UPD-zh_CN-basics_of_light.pdf

Philips lighting (2015) Meydan bridge [Photograph]. Retrieved October 8, 2018 from https://www. ledinside.com/lighting/2015/9/dubais_the_meydan_bridge_brilliantly_illuminated

Philips lighting (2017) Nhât Thân bridge [Photograph]. Retrieved October 8, 2018 from https://www. ledsmagazine.com/articles/2017/07/philips-turns-modern-hanoi-bridge-into-a-colorful-light-display.html

Philips (2015) Illumination (Big four bridge) [Image]. Retrieved on August 23, 2018 from https://www. philips.com/a-w/about/news/archive/standard/news/press/2015/20150219-Big-Four-Bridge-Shines-a-Light-on-Louisville-Waterfront-Revitalization-Efforts-with-Connected-LED-Lighting-from-Philips.html#. VbbxqhOqpBc

Phormatik.org (2013). Projection (A bridge to develop) [Image]. Retrieved on August 23, 2018 from https://cargocollective.com/phormatik/3D-Projection-Mapping
brad.koerner@philips.com

Plaster, S. (n.d.) Diversity [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Prado, L. (n.d.) Bridge [Icon]. Retrieved on September 19, 2018 from https://thenounproject.com

Rippel, L (n.d) Energy Flow Rachel Carson Bridge [Photograph]. Retrieved September 17, 2018 from http://riverlifepgh.org/riverfront-guide/energyflow/

Riverlife (n.d.) "Energy Flow" Lighting on the Rachel Carson Bridge. Retrieved September 17, 2018 from http://riverlifepgh.org/riverfront-guide/energyflow/

Ronan, P. (n.d.) Visible light [Image]. Retrieved October 8, 208 from https://en.wikipedia.org/wiki/Visible_light_communication#/media/File:EM_spectrum.svg

Saieh N. (2009) Moodwall Studio Klink and Urban Alliance [Photos]. Retrieved September 19, 2018 from https://www.archdaily.com/23239/moodwall-studio-klink-and-urban-alliance

SEGD (n.d.) EmotiCannes – an evolution of data visualization. Retrieved November 30, 2018, from https://segd.org/emoticannes%E2%80%94-evolution-data-visualization

Seitinger, s (2013) Emitting light (LightBridge) [Image]. Retrieved on August 23, 2018 from http://theatrum-mundi.org/library/lightbridge/.

Stolk, G. (n.d.) [Photograph]. Retrieved May 16, 2018 from https://citiesintransition.eu/publication/amster-dam-anticipating-the-future

Sykes, R. (2009) Moodwall by Urban Alliance. Retrieved April 20, 2018 from https://www.dezeen.com/2009/03/05/moodwall-by-urban-alliance/

Three-Six-Five (n.d.) Heartbeat [Icon]. Retrieved December 2, 2018 from https://thenounproject.com/search/?q=heartbeat&i=1016881

Tripadvisor (n.d.) Private red light district tour [Image] Retrieved September 17, 2018 from https://www.tripadvisor.nl/AttractionProductDetail-g188590-d12470727-

Turrel, J (2013) Guggenheim New York [Photograph]. Retrieved October 8, 2018 from http://www.patriciasendin.com/2013/07/aten-reign-james-turrells-new-space-at.html

Vande Moere, A. & Wouters, N. (2012). The role of context in media architecture. Proceedings of the 2012 International Symposium on Pervasive Displays – PerDis '12. doi: 10.1145/2307798.2307810

Vectoriconset10 (n.d.) Vibration [Icon]. Retrieved December 2, 2018 from   https://thenounproject.com/search/?q=vibration&i=1659503

Viberlight (n.d.) Automotive [Image]. Retrieved on December 3, 2018 from https://viberlight.com/inspiration/product-integration/

Viberlight (n.d.) Close up fibre [Image]. Retrieved on December 3, 2018 from https://viberlight.com/

inspiration/product-integration/

Viberlight (n.d.) Technoloy. Retrieved August 10, 2018 from https://viberlight.com/technology/

Vuing (2013) Unravelling layers [image] Retrieved on August 23, 2018 from http://vuing.com/3d-effects-by-layers-of-color/

Wan, W., Buchanan, C. & Gardner, L. (2018). Finite element analysis of the MX3D Bridge (Revision 1.0). Imperial College London, Department of Civil and Environmental Engineering.

Wippoo, M. (2013) Moodwall [Photo]. Retrieved September 19, 2018 from http://www.meiawippoo.com/blog/moodwall/53

Wolzak, T. (2018) The MX3D bridge [Photograph]. Retrieved April 25, 2018 from https://gizmodo.com/the-first-3d-printed-steel-bridge-looks-like-it-broke-o-1824252512

Zumtobel (n.d.) Casino Bregenz with Capix LED [Photograph]. Retrieved May 16, 2018 from http://www.lightlive.com/en/20140919-excitement-rises-as-darkness-falls/

7wData (n.d.) Smart car [image] Retrieved on August 23, 2018 from https://www.7wdata.be/big-data/connected-car-data-is-the-new-oil/

Appendices

Appendix 1: Interview with Autodesk

Set up
On June 13 2018 two of the stakeholders from Autodesk were interviewed. The purpose of the interview was to create a better understanding of the sensor network and data collection of the smart bridge. The interview was semi-structured and conducted through a conference call on Skype. The semi-structured quality of the interviews allowed flexibility in the order in which the questions were asked and the amount of time that was spent discussing a certain topic.

Questions
Which sensor will be used?
Why are these specific sensors used?
How are the sensors attached to the bridge?
What are the steps in the process of data collection?
What insight do you want to gain from the sensor data? Both short term and long term?
How will these insights be used?
What do you want to achieve with the self-learning algorithms?
How is the bridge 'smart'?

Topics
The topics that were discussed are:
· Autodesks internet of things (IOT) perspective on the bridge.
· Pier 9 bridge project update.
· The potential of a data model for the MX3D bridge.
· Difficulties experienced with the sensors of the Pier 9 bridge.
· The steps in the process of data collection.
· Digital twin
· Data ownership and privacy
· The future of the technology
· The autonomy of the smart bridge
· Sensor attachment to MX3D's bridge
· Purpose of the CO2 sensors
· Autodesk's lighting design ideas

Participants
Juline Wilkinson (student), referred to as 'J'
Ruben Baldewsing (student), referred to as 'R'
Gerd Kortuem (chair), referred to as 'G'
Alec Shuldiner (Autodesk), referred to as 'A1'
Alex Tessier (Autodesk), referred to as 'A2'

Screenshots

The following images were discussed during the interview. They are screenshot from the video recording of the interview
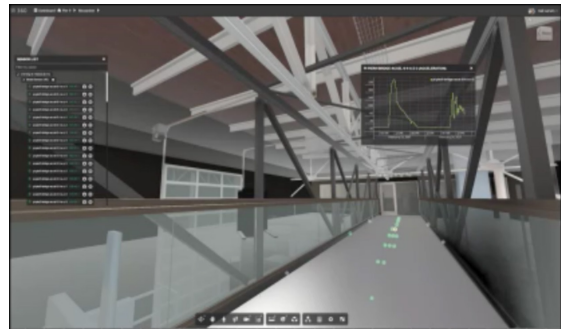

Figure A.1

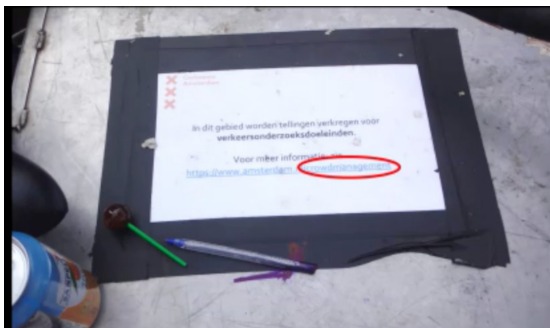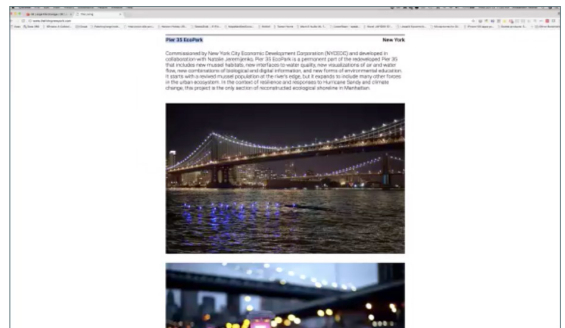
Figure A.2

Figure A.3

Figure A.4

Figure A.5

Figure A.6

Interview transcript

A1: Okay, so this is a presentation, I'm jumping in a bit in the middle, that I've given a number of times at internal conferences and to various groups inside the company. And what I point out to them is that what we're doing with this bridge, the way that we're printing it is basically creating a completely new structure. So we see here *(Figure D.1)* three rods, one is an aluminium, one's steel, they're at the bottom and the top and in between is a printed rod of the sort using the sort of technology we're using to build the bridge and we know everything we need to know about how those other two rods will perform right, metallurgy is thousands of years old and the industrial processes that make these go back way over a century, but we know almost nothing about what will happen when with temperature changes and stresses and load how the rod in the middle will perform and how it will fail to perform or what will happen when it fails to perform under various circumstances. So the inspiration originally for this project came from the thought that you know we don't really know what's going to happen and we should be collecting data from the bridge that we can start to build up a corpus of engineering knowledge that will allow us to eventually get to a point where we can look at that rod and know how it will perform like the others and then of course, feel free to interrupt by the way as I go, then of course there is the fact that we are building a bridge and you know bridges when they are not well enough understood when they are sort of pushing the boundaries of bridge building technologies or even when bridges we think we understand are put in new places, sometimes disastrous things can happen and we really want to avoid that, so that is what a lot of the data collection on this project is really about. It's about engineering jobs and about the fact that MX3D wants to be able to understand how any given structure is going to perform overtime, not just this particular bridge that we're building, so I then tell them about the pier 9 prototype that we've done and the technology that's the bridge that I think I've certainly talked to you about before Gerd, and the work we've done in our workshop and how we prototyped that bridge and set it up and some work we've done around that. These visualisations *(Figure D.2)* I think you're familiar with now from your work with dasher 360 and the set up we have, the technologies we use, the software we use to power that bridge and which we'll be using to power the mx3d bridge as well. And the fact that it then, you know we've now taught this bridge how to count how many people are one it in any given point of time, give us an occupancy count. So I then explain to people that we are planning to replace this particular bridge here in the red light district in Amsterdam. And I point out that this is going to be a very different challenge then that little red bridge that we have back in our offices, it's about the same size but it doesn't see anything like this kind of traffic and we have no idea how well we'll be able to get machine learning to perform, to do things like occupancy counts when the occupancy is this intense. But then I start to talk about, and this is the part that I think is the most interesting for our conversation today, the question of what good would it be, assuming that we can get a bridge like that to understand that there are people on it and where they're going and how many of them there are, what good would that really be? And so one use case that I present for that purpose is to point out that people don't use a bridge, necessarily use a bridge, the way you expect them to. So in this picture *(Figure D.3)* we see this incredibly dense population of people all through the red light district and mostly at this time, these are almost all tourists, no sane Amsterdammer is going to come to the red light district at you know 11 o'clock on a Saturday night in the summer. And so we have here a bunch of tourist and they've come to see the red light district and in fact what most of these people are seeing is the backs of each other's heads and what happens I think is these two you see here pointed out by the arrows, they get to the bridge, they walk out on it and they realize that here they finally have a chance to see the red light district, right, they can look across the water, they can see the buildings on either side, they can see the crowds, so they stop, which is not what we think of as the use case of a bridge right, we think a bridge is to get people from one side of

something to another and in fact they are using it as a viewing platform. This is a real problem as well because it also chokes up the flow of traffic and when you have traffic flows this heavy in the neighbourhood, that's actually dangerous and a concern for the local police and for the Amsterdam city planners. So one possibility is, can a smart bridge be taught to detect that people are using it in a suboptimal way given the current conditions and can it be given capabilities to encourage those people to move one, audio cues, vibrational cues, people have suggested super heating, localized super heating of the structure. I mean I don't know what the right answer is but. A bridge that could attend to it's own flow and ensure that there was always a constant flow or at least in peek trafficking times there was a constant flow across it, would be a better bridge then a dumb bridge that could not do that. So that's one sort of IOT story I tell around the bridge. And I talk a bit about how in fact a lot of infrastructure and a lot of buildings and a lot of constructions face these same problems. This is the Sagrada Familia [Figure D.4] in Barcelona which is both a place of worship and a tourist destination and has been and will continue to be I'm sure for decades more a construction site. None which get along very well with each other. You know, could this building be made smart enough to sort out these conflicting use cases. I then run back to Amsterdam *(Figure D.5)* to point out that next to the bridge there is a junction box and on top of that there is this sign, which you can read quite well but which I for my English speakers point out is really about studying crowd management, right, it's that issue with those incredible dense crowds in the red light district that people want to address and that research has been done for. But as we can see in this description, it is a temporary study, it is being done in only a few places, it's a very episodic and narrow way to study the problem of crowding in the red light district or for that matter in the city of Amsterdam, which is experiencing worse and worse crowding over the years. So that study is happening here but if we imagine and this is now the other big IOT story that I tell, if we imagine that we are able to do this for all the bridges in the inner city of Amsterdam, and of course there are quite a lot of those bridges, then something very nice would happen, so pretend that we're getting from all the bridges, as we are getting from the mx3d bridge, just a simple occupancy count at any moment in time so here's a moment in time, it's maybe the middle of the day or something and all the bridges are telling us how many people are on them. This bridge has none which turns out not to be a problem, it's a draw up bridge which is open. There shouldn't be anybody on it, but here our outlier detection shows us that there's especially high traffic here compared to other local bridges or compared historically to similar time periods in the past and that indicates a problem that requires some sort of attention. But the other really great thing this does is it provides us a heat map of occupancy throughout the city on what could potentially be a real time basis and with almost any degree of granularity you would whish to have. And that something that would be incredibly useful to city planners to people who are interested in commercial property investments and things in that nature. So these are, and I think these are the only two, the main things that I you know that I regularly talk about in terms of the IOT applications of a bridge of this sort. So I'll stop now. That's not as far, you know we've talked about lots and lots of things, but that's as far as sort of a developed thinking around what a bridge of this sort might be used for.

(08:06)
R: Okay, thank you. Shall we start with asking some questions?

(08:18)
J: Yes. So we've prepared some questions, so we're just going to go through them and some may seem less relevant then others but just go with it, bear with us.

(08:26)
A1: Great

(08:28)
J: You can start Ruben.

(08:31)
R: Okay. We, first of all we were interested in the current status of the Pier 9 bridge project. And mainly what kind of insights you got from the data and maybe the machine learning and if you have examples of those data insights. You've already talked about counting people.

(09:00)
A1: Yes so I think Alex can give you the very latest on that. Maybe you want to, Alex I think you're on mute, but if you want to jump in and tell us how the machine learning is going on the study that you're doing right now on the bridge, that would be great.

(09:16)
A2: Sure, can you guys here me.

(09:18)
R: Yes
A1: Yeah
J: Yes

(09:19)
A2: Right so I mean, one of our main tasks has been to try to count pedestrians without the use of the camera's. we're using the camera's as a base line, we're using a various set of computer vision techniques. Some are very modern, that can actually skeletonize people. But we begin this sort of conservative labelling of the data. So our initial attempts, we looked at just the accelerometer array, we used variance as a feature in our training and we just did a basic binary logistic compression where we would just try to detect do we have signal, or do we not have signal. The sensors that we have a very noisy and we got about 89 percent accuracy on that particular test using variance. We then tried some different kinds of feature engineering to see if we could tell more things about the accelerometer signal, so we used a variety of FT's (*Fourier transforms) in the frequency domain. I don't have the details on me right now, I'd have to dig into them a little bit but I think we created an additional 8 features per sensor using different kinds of Fourier transforms and I think we got the accuracy up only a few more percent, but really what we decided was that the quality of the sensors that we have on our prototype for accelerometers weren't good enough and most recently we have been mostly just focusing on the strain gauges to see what we can do, so we're actually trying a set of combinational networks in a graph like arrangement and we're also increasing the amount of data, initially we only used 48 hour periods which I think had about 80 crossings. Crossings would be like events where people cross the bridge or when people sit or walk on the bridge and we're also working on augmenting the labels for the data sets which we could probably use some help with, but then there are some issues because it uses the camera data. We're actually trying to label not just when people are walking but when they're stopping and holding on to the barrier and so on. So we made sort of a basic set of labels and ontologies and we're currently trying to add that to our data set. We're looking at creating a more sanitized data set in about six weeks, which should have a few thousand crossings in it and that's what we're currently using in our data prep for the convolutional

neural net. So that's sort of where we are right now. I got an email yesterday from one of our partners who did milau- (*?), who said he has a post doc available to consult. We haven't set up a meeting yet but maybe that's something we could do. But our goal here is to try to create a set of standardized messages that can be used by other people who want to study things about the bridge, in a sort of modular but updatable way. So not everyone is going to have to look at all the raw data all the time, you'll get a message say when the number of counted people on the bridge exceeds or maybe a rough location of where they are. With the computer vision we can give quite an accurate prediction, but that all has to be done anonymously. So one of the things I thought I would want to talk about with this group is what are the sets of meta data that you would want to see derived from the raw sensor data. So think of it as you will, we're collectively building an operating system for the bridge, which is a set of messages and derived meta data rather then just providing raw sensor data all the time, right. We have this layer on top that gives you, that's a data model for activity on the bridge. What does that data model need to look like, what are the things that you want to see in there, what are the things you want to, what's the kind of information that you'd want to use, to give the kind of feedback that alec was talking about, about traffic on the bridge or nudging people to move or encouraging them to move or other scenarios like that. So that's the conversation I would really like to have but Alec, anything to add?

(13:47)
A1: I would just ask if the concept of a data model is something you're familiar with?

(13:54)
J: You're asking us?

(13:55)
A1: Yes

(13:59)
R: Not really

(14:01)
J: Well I understand sort of what you're explaining, but I haven't really worked with anything like that.

(14:06)
A1: So I think establishing a formal data model for the bridge and alex is asking you for your requirements for that, which can come in any form at all, we'll figure that out, but our goal would be to then produce a document which says here are all of the different attributes that you can see and here's what each one means and here's what causes them to be populated, maybe some information on the degree of variance you see in them or some other information that characterizes specific data that would show up or maybe the confidence we have if we're providing an occupancy score or something like that, an occupancy count, but it should be a document that allows anybody to come to the bridge and to read that document and to immediately understand the full capabilities in terms of what information they can get out of the bridge.

(14:56)
A2: Yeah and also to add to that, that will be a living and breathing entity. So that as more partners and people contribute and add more modules, the bridge will be able to see and feel and emote more kinds of detailed activities right. What we need is sort of nucleus to start and so typically what a data model is, is

sort of like a, as small as possible but complete set of parameters that express the kinds of things that we want to build our interactions on top of. I don't know if that helps.

(15:33)
J: So for instance if I would want to know how many tourists cross the bridge with their suitcase, you would compile that into meta data, that's what you mean right?

(15:42)
A1: Correct

(15:43)
J: And label that kind of data so I could access it really easily. Okay.

(15:48)
A1: So you would then look at the data model and you would see ah okay, occupancy, so that tells me the number, I would look to that to find out how many people were on their and then it turns out that occupancy has characteristics, those characteristics include you know has luggage or has baggage with them or does not, you know, we have some how know is native to Amsterdam is foreign and then you would be able to do okay now I'm going to say what I'm interested in are the subset occupants that have baggage which are non-native. And the data model would tell you how to look at the data to get that out of it. It's kind of like labels for columns in excel.

(16:30)
J: I get it. I'm not sure if I would be able to tell you right now what I would need. I'm not sure what you think Ruben?

(16:36)
R: No not right now.

(16:40)
A2: Well it's a conversation that we can continue to have because we haven't built the interactive things yet and on our side it's one way to sort of guide the direction of, so we're doing a lot of the basic machine learning stuff right now but we're going to need to do more and more and more as time goes on and this will help guide what those efforts are. Now, the raw data will always be accessible to partners if they want to do this themselves but what we're trying to do is organize things in the right number of layers, so that people with the right expertise can contribute the most to different areas, so it's also sort of a framework for this kind of collaboration, right, where we can help each other in a most efficient way.

(17:24)
G: Yeah, Juline and Ruben, we can work on that. We can try to come up with a small list of what the data model might look like based on some initial ideas that you have and then we'll send it over and start a conversation around that from there.

(17:44)
J: Yeah. Are you okay with that Alec and Alex?

(17:48)
A1: Yes absolutely. So you have to understand, the way I conceive of this relationship, so my role on this bridge project is something of a product manager, right, so I view the bridge as a product, it needs to be able to do certain things for certain people and I've got to figure out how to express those requirements back to Alex who is basically the development manager, he controls the resources, who are going to figure out how to get the bridge to do these tricks. So what I'm looking for and I'm delighted to be having this conversation with you, is I'm looking for stakeholders who are going to say well these are the things we actually need it to be able to do and the more richly you can communicate back to me and back to Alex what you need the bridge to do, the better we can start to formalize those requirements and ensure that the bridge can actually do the things that you all really hope it will do. And those conversations between us and you, they need to be fairly rich stuff, it's not like we're expecting you to come back and just say here's the list and we're all set and we go away. No it's a highly iterative process. So it's great that we've started but it's really just a start.

(19:00)
A2: Yeah. And if we can let's start small and then grow big, right so think of it as an onion and we're starting at the centre and we'll add these layers and you know, in a year or two years or whatever, we'll have what we ultimately would have wanted.

(19:14)
J: Okay. are you okay with us asking some more questions, some general questions?

(19:23)
A1: Bring it.

(19:27)
J: Well. Shall we just continue with the list? We wanted to know the difficulties you experienced with placing the sensors for the pier 9 bridge. And this is just more so we can get a general impression of everything that is going on with the sensors and the data and how it works.

(19:42)
A2: So the difficulties placing them or just overall?

(19:46)
J: Just overall, like the sensor placement, or the noise, or like you said accuracy or false positives, whatever you have.

(19:53)
A1: Well we can start with placement. We've done it twice now, because we did it one time and then we pulled them all off again and had to put them back on because we sort of wanted to change how it looked really, uhm so it turns out bridges are really really dirty. Uhm, working underneath a bridge is really unpleasant. You're getting all this dust and stuff and it's in a workshop space so it turns out there's this finely milled metal dust and ughh it's awful. So, uhm, you know, I think this is something I've had in the back of my mind the whole time when MX3D's talking about oh well we'll install the sensors, oh pff boy you guys have no idea how unpleasant attachment is going to be. So it's, it is really a difficult thing doing that. It's a really hard thing to do with precision. Right, so we have these nine, I think it's nine plates in the bridge and ideally the accelerometer would go exactly in the middle of the plate. Uhm, good luck,

you know if you'd thought of it before you would have built the plate in such a way that it has a measuring point at it's center but of course that's not there so you know, oh I guess it's here and you're using a sharpie to draw a circle to put it back in the same place and you know it's a messy process, it's a very difficult process to do with any precision. You're working over your head on the underside of a bridge, it's very tiring. So it's, it's, what we're doing here is really incredibly primitive in the sense that this sort of thing should be built into the design in the first place and ideally should be manufactured into the bridge. Have the whole thing built so that it's ready to go, you know. And we're getting there. As advanced as the MX3D bridge is, the way we're approaching it right now is really very primitive. Uhm, so, it will be quite a task getting sensors on the bridge. It has been a surprisingly difficult task, in our controlled environment, to keep the sensors on, to keep the data flowing. Uhm, the cleaning crew comes through and they just unplug stuff. People, you know, need to get an extra something in and they move wires around or conductivity drops . Alex you may have a total up-time percentage or something but it definitely is not reliably you just get the thing turned on, and it's on. So there's some sort of physical maintenance of the bridge that's required. Uhm, the noise and such, I mean Alex that's your bailiwick so if you like to speak to that.

(22:09)
A2: Sure, sure. Just to add to Alec's description of the physical challenges of placement, positioning, uhm, you know there is, we've skipped some very normally very critical calibration aspects and one of the reasons was we wanted to see if we could work around that with the software and the machine learning algorithms and the other techniques we are going to use would be robust to changes in the signal quality and in the signal characteristics. So, you know, we planned to bake that in there. We haven't really decided if that's what we're going to do with the MX3D bridge. I mean certainly for the, um, we sort of broken the sensor net into two major divisions. The first is structural monitoring, the other one is what Alex calls the secondary sensor net. So we will most certainly have to calibrate the primary sensor net, the structural sensor net, however calibrations change over time, right instruments sway over time and need to be re-calibrated and it's very much uncertain if we're going to be able to do that on the regular basis necessary to keep the MX3D bridge, when it's over the canal, properly calibrated. So again, that's why we sort of let our sensors be sloppy from a calibration perspective to see if we could sort of handle that, so that's one aspect. And the other one that I really can't over emphasize enough, the physical challenges, is just in the wiring and wire routing and Alec knows we've been going back and forth with our partners, but the routing of the cables, I mean the reason we're using cables is for reliability and robustness. Wi-fi is fantastic in all of the experiments that we've done in our living lab environment in Toronto. Whether we've used mesh networks or advanced wi-fi or redundant wi-fi, it's never really mattered, but wi-fi has always been far less reliable than a wired network. So we always try to push for, you know, that nervous system analogy, the wiring of these things. But there's not a really good set of tools, techniques to do that, and on the MX3D bridge where you have this very rough surface and a lot of sharp edges and a lot of tight corners, this is a huge challenge for all of us on the distributed team. So if I had to identify a pain point, I would say it's wiring. We have some simulators at Autodesk which we've developed which can simulate wires quite well. You know, the bending and twisting and so on, but there is a whole area of HCI where well, because you have the simulator but what is the right kind of design tool. How do you run that through, how do you, uh, what phase of the design do you add that to. So for us there is a whole like mountain or iceberg of issues around wiring for these kinds of things. So that's an interesting question. To the, let's place ourselves in the digital domain. We've had a lot of constraints with our prototype. We had to basically design, build it and install it in less than four weeks. So as a result we re-used a lot of sensor equipment and technology which we had previously used and that's why our accelerometers where very noisy. The sources of this noise come a lot from the equipment that we're using. But also the

environment that the equipment is in. So the equipment in pier 9 is, as Alec described, is in a machine shop basically, where you have large blades and mills and you know, not to far away there is welding equipment so this creates a lot of radio frequency noise. On the MX3D bridge there will be a lot of cellphone interference because you're going to have, in that scene, I mean how many of those tourist you think are going to have cellphones. Probably every single one of them, right. So that's in a specific domain probably, the 2.4 Gigahertz range or the 5 Gigahertz range, but that will still sort of bleed into some of the sensors, most likely. So were going to have to be aware of that. So there's always going to be some sort of electrical noise. There's always things like street cleaners, or because it's outside there will be activity from electrical storms. But I also see these things as opportunities and the data where, you know even though, you know, you can view this as a parasite inside of the signal that you're getting, you could also use it as an opportunity where, well if, now we have enough of these spikes or signatures of I don't know, a street cleaner or an electrical storm, maybe we can then go back and measure things about that. So that's another reason to not be to fastidious with filtering these things out. Right, so again in that operating system layer we don't want to over calibrate, we don't want to over sanitize the raw data, we want it to be available so we can tease these things out. So that's part of the philosophy here.

(27:46)
A1: A couple of examples of that sort of thing on the bridge at pier 9, there is the, uh, when additional electrical generation capability comes on in the bay area net, so that's in network for all of the San Francisco region, you can actually see that in the sensors, you can see the change in, I guess it's the change in voltage, average voltage level or something, across the entire bay area network, you see that phenomenon there. It has nothing to do with anything that is happening in the workshop or on the bridge, but the bridge is a meta sensor for it's environment in this sense. You can see earthquakes on the bridge, so you know, that sort of thing, you don't want to filter out. You want to recognize that there's something external to the bridge that's happening causing this event. And you know you could imagen somebody saying well I want to check is Amsterdam actually keeping it's street cleaner frequencies to the degree that they're supposed to. And the fact that those whirling blades generate, the whirler scrubber brushes on the street cleaners generate a particular electronic signal, interference signal on the bridge, would allows us to count the frequency of those, of the passages of those machines for example.

(28:57)
A2: Yeah, I mean we need to see the equipment as a giant antenna that can pick up all sorts of different things and so we need to be conscious but we cannot properly filter those things out.

(29:12)
G: Okay, just, Juline and Ruben, you need to aware of the time, so you need to prioritize your questions and focus on what you, what you want to get out of it today.

(29:25)
J: Well I think one of our main questions that we had is the steps in the process of data collection, right.

(29:34)
R: Yeah, I want to address the same.

(29:37)
J: So we were just wondering, because we know that there are sensor that collect data and there's a digital twin somewhere, but we were wondering if you could go through the steps that the data takes,

because that's still unclear for us.

(29:49)
A2: Okay, so you mean from like raw signal generation and all the major sort of chunks of a pipeline that we have today, or the one that we are going to build for MX3D or both?

(29:58)
J: Well the one that we are going to build for MX3D.

(30:02)
A2: Right. So we are still building it. So I mean I'll use ours as a proxy. So on every single data acquisition

device, which on the pier 9 bridge is a raspberry pi with a dac, there's a little program running. We call it the programmable data router and it's job is to cache locally and memory as much data as is necessary and then it pushes it up into a cloud data base using a rest API protocol. The difference between our bridge and what we're going to do at MX3D is that the raspberry pi's themselves don't maintain a long historical record. And the reason they don't do that is because the actual physical hardware, uh each raspberry pi uses a rewritable memory chip which is basically an sd card which we have in our phones and camera's but they are only designed to take on so many cycles of reading and writing before they wear out. So we try to keep everything in ram and then push everything up to the cloud. On the bridge we're going to have a set of workstations that will have a local distributer file system that will maintain a local cache but we're also going to push as much of that data up to the cloud as possible. So the programmable data router that interfaces with the data acquisition devices, which are running analog-digital converters or digital-digital converters which talk to the raw sensors, they get pulled at a frequency at a regular interval. They may or may not aggregate some of that data into an average and look at a detection, that's called change of value, they may just pull raw values and what they'll do is they'll throw it into the local data lake which will then get pushed up into the cloud. In terms of, uh so that will be sort of the raw data layer. Which will come in at different frequencies for different sensors. Processing that in a string you're going to have a set of different algorithms, heuristics, that will be, looking at those different things and creating different sorts of temporal meta data, which will then get consumed by another layer which will then get put into that data model that we're talking about. So at that layer there's going to be sort of a supervisory level program, that is taking and aggregating the results of all of these different analytics they're running on different systems, some of which will be running on the cloud, some of which will be running locally. Then it will aggregate those into these sets of operating system messages, that will then get ready for broadcast and distribution but will also be serialized and stored in another historical data base. So, uhm, if you, ideally you would have an interactive program running that would watch you, you know, color the bridge with light or activate speakers or shake a section of the bridge that we add on afterwards. It would actually talk to this local supervisory program on one of the servers on the bridge and ask permission and then once an encryptions is formed, and then get notifications pushed to it, you'd list it on a socket, you would get that high level operating data. So that's sort of the rough architecture of how this will , uhm, how the data goes from the raw device into all the different processing and streaming layers and then back to the consumer which will be a program. Where things like dasher it will actually go directly into the cloud and then just look at the historical data and then other clients can do that as well through a rest protocol.

(34:08)
J: And how does the digital twin fit into this

(34:12)
A2: So, uhm the digital twin is also going to be served through the cloud. Uhm, I mean digital twin is not a well defined regulated entity. So for the bridge it will initially take the form of a building information model, probably an IFC or a relic of some sort, which will also integrate with a set of GIS files and infoworks files. Most of these initially we plan to manage with our A 360 and Dim 360 systems, but as more models come in they will have to be added as different kinds of data formats and then unified through a cloud interface. So that's work to be developed on so know that the real purpose of the digital twin is to be in fact similarly, not just in the shape but also in the behavior of the actual system that's running and we don't have all of those pieces yet. That is something that we will be developing with Turin, ourselves and other people. But the initial starting point will be a physical digital model of the shape of the area, the shape of the bridge, perhaps some structural analyses and that will be sort of the center of it. It will all be hung of on a building information model, through IFC or Dim.

(35:41)
R: Uhm, I have two more questions. The first one is on the topic of data ownership and privacy. How do you guys think about the privacy and who owns this data?

(36:04)
A2: Alec you want that one?

(36:06)
A1: Sure. I mean fundamentally MX3D owns the data, it's their bridge. The principle that we've operated under since the beginning of the project however is that the data will be open. The goal is to make both the raw data and the higher order intelligence that the bridge generates or that anybody chooses to generate from the bridge, that that get's contributed back to a data commons around the bridge and is available to anybody who joins that commons. What we've been doing on the bridge in pier 9 is we've been trying to push to find out how much insight you can get from the data in order to identify if there are any obvious privacy concerns that we need to be aware of. An extreme example of this and I don't think on, well we certainly don't have enough sensor density on our current bridge and I don't think we're going to end up with enough sensor density on our MX3D bridge, but you know an example is potentially that we could identify an individual by their gate, by the pattern of footfalls as they walk across the bridge right, that would be unanticipated privacy impacting potential from the bridge. So we are hoping to use our bridge as sort of, to keep ahead of the MX3D bridge to identify issues of that sort. Right now we are not aware of anything that would be PII, personally identifiable information, other than the camera information itself which is already being collected in that area by the police, by this camera that got set up by, I think it was Delft. So we're going to create a camera group a some point and I think that group is going to have to address these issues quite specifically but at the moment we don't see other than the camera information, we don't see anything that the bridge is collecting that is potentially PII.

(37:51)
R: Okay. And the last question I have was how do you see the future of this technology, in say 10 years from now. What do you think is possible and what can you do with it.

(38:06)
A1: So I think there are two things, to my mind important things that we should see change around this technology. One of them is that these issues that make it so hard to do, the fact that you have to apply it after the fact, that we don't have good modelling that tells us what information you're really going to get

back if you put in the investment, Autodesk and other companies are working to get past these issues, to make it easy to, or even just part of the normal work flow to design something, to design sensor in, and to get a simulation of what those sensors will then tell you through using machine learning, once they are embedded and built into the thing and operative. So I think it will become much easier for this thing to happen, which is the first thing and because it will become much easier for it to happen it will be happening much more often. And the result of that is that we are going to get basic information out of the internet of everything around us, right, the things will start to deliver on this promise of IOT that we've talked about, which will allow us to have smart cities and, well they will start with smart streets and smart neighborhoods , I hope the red light district comes as an example of that, using the bridge, and that we will find that these things are happening without for example having to rebuild the entire city right, that as objects start to appear and their sensors for their areas, our awareness through the IOT starts to grow and get broader and deeper over time.

(39:31)
R: Okay.

(39:33)
J: I was actually wondering do you envision this sort of thing that we are trying to do with the bridge, will it be completely autonomous or will we need like a human influencer or human control in the whole process?

(39:47)
A2: I think initially we will need some human intervention, I don't think our, my personal goal is to not make it fully autonomous. I see this as a big science experiment and also a big social experiment. So the purpose of this bridge isn't to achieve autonomy. The purpose of this bridge is to answer fundamental questions around IOT , cyber infrastructure, smart systems, city systems that will lead us to perhaps having autonomous things but the purpose of this bridge is very much as a big science experiment and social experiment. So our goal isn't to do that, isn't to achieve sentient or fully automation but to do something that respects people's privacy, while teasing out the kind of information that can enhance the urban experience in a city, that can enhance the societal experience and that maybe can improve traffic flow and energy flow and other kinds of things. So really it's a big science experiment for us.

(40:59)
J: Okay. So I think we sort of went through all our questions.

(41:07)
R: Yeah I think we touched all the important ones.

(41:11)
A1: Well, we could say a bit more about a couple of these, uhm, you know we talked about privacy a bit , the fact that there are camera's in the red light district right now is pretty problematic to my point of view. The woman who work in the red light district, by law are not allowed to be filmed, there at work and you're not allowed to be filmed at work in the Netherlands, as best I understand things. I understand why the police need to have camera's in the red light district but my hope is we will ultimately be in a position where the things themselves are providing the intelligence that the police need or the other authorities that have a responsibility to monitor the area need without having to have camera's there. So far from something that contributes to privacy issues, I'm hoping this approach to the internet of things

can actually start to solve some of the privacy issue that we're struggling with righ now. I agree with Alex, I don't think there is any, there's been any thought about autonomy. I mean some of our more far thinking colleagues have envisioned situations where you know, the bridge is built by robots and robots will come out at night and they'll take it down or they'll move it some place else that the autonomous intelligence of the city has figured is more optimal for the flow of the bridge. Or we will monitor an even higher level, economic flows into the shops of the red light district and the bridge will self-optimize to improve the economic health of its environment. You can imagen these very high order, sci-fi type of outcomes and you know maybe we'll get there but I think that sort of thing is very far in the future, so it's definitely not in the scope of this project but the autonomy, I mean it's not really, it's not autonomy, that's not what you mean but where I would love to see this becoming a so deeper part of what we do that we're kind of unaware of it, is in the design process itself, right. The intelligence that we get back from this bridge should inform how future bridges get built and that should do that by becoming deeply embedded into the design technicalities that are used to make these bridges or make smart infrastructures in general. I do think there is a lot of stuff that we are doing here right now, very self-consciously and frankly at times painfully. I hope a bunch of that stuff disappears but to make the bridge itself a truly autonomous entity of some sort, that's, I don't know, maybe, that's google's goal, that's nor really our goal.

(43:45)
A2: Yeah I think this, for me this could be a stepping stone towards that. There's a lot of, in fact I was at smart geometry a few weeks ago and was asked to key note there and part of my key note was on the evolution of intelligence in us, in genetic or biological systems. And you know, if you go back to the Precambrian explosion, what really kicked off the Precambrian explosions wasn't the emergence of intelligence, it was the emergence of sensors and how sensors and sensing the environment in order for predator to escape pray, or you know to move towards sun light when the UV intensity wasn't so great to produce more food for yourself and then get away from it when the UV was to, this is what exactly developed brains, that the sensors and nervous systems produced brains and intelligence. So that's really what we're focusing on with this bridge, is the sensors and the nervous system and the information that we can get out of it. So it's not to say that through various reinforcement learning techniques over time the bridge could sort of develop some sort of plant-like or maybe even basic animal-like intelligence, but that's really not our goal, our goal is on creating this platform to ask these sort of questions over time and that's why the flexibility of the platform and the openness of the data is so important and that's why we want you to help us explore all these different areas

(45:33)
J: Well I actually just thought of two random smaller questions, which are just out of curiosity. How are you planning on connecting the sensors to the bridge, to MX3D's bridge. Because it could be interesting for us.

(45:48)
A2: So you mean physically?

(45:50)
J: Yeah.

(45:52)
A2: Yeah, so we're still hashing that out in the groups. Different sensors have different mounting requirements. Some of them will be fastened with epoxy residence, some of them we will need to grind

certain areas of the bridge or build up metal coupons with the welding process to grind it down to fix those sensors. Others can just be strung along, and then with sort of the equivalent of an acoustic seal that's always flexible we put down, and sort of fix it that way . The wires will have to be pulled using various techniques that electricians use, which is you know like rigid tubes or flexible tubes that you pull through the structure. So it really depends. Some of them will be bolted or mounted to the bridge. If we do the little cells at the end, the bridge will be resting on top of those just to sort of contact the situation. So they vary quite wildly and until we actually get our hands on the sensors there's a lot of physical stoke solutions that are going to happen to these things and we don't have all the answers yet.

(47:05)
J: Okay.

(47:07)
R: So for a lighting infrastructure which probably uses different lights, it is also possible to make alterations, small alterations to the bridge itself.

(47:22)
A2: Yeah I think so. I think you might be able to screw into it in some case but we'll have to discuss that with the structures group and MX3D, in other case we might have to develop clips. I don't know what phase the metal has but there may be some opportunities to use magnetism in some cases. So it's going to vary wildly, but the challenges of that area in the red light district for any of the, let's call them systems, that we put on there is going to be, you know, can maybe be temper proof from the general populous right. If it's an art exhibition the last two to three days then you can have a security guard there to say hey hands of right, like at the louvre or something. But if you want it to be there for weeks and months then it's going to have to be robust and temper proof. That's also some of the issues we have on the MX3D bridge that we don't have on the pier 9 bridge, where we don't have to worry about vandalism right or somebody..-

(48:26)
A1: Well you say that but people keep unplugging the thing right haha

(48:30)
A2: Haha. Yeah, well but at least it can be plugged back in, right.

(48:38)
J: I had another question about the sensors. Because we saw some documents which had some sensors mentioned. One was strain and accelerometer. That makes sense but why do you choose to put a CO_2 meter. Did you think of all the sensors that could be useful or do you already have a sort of purpose in mind?

(48:59)
A2: So I mean the purpose is mostly historical from our experiences building a living lab, so a lot of the ideas and technologies that Autodesk brings to this, comes from our early experiments with dasher. Studying human occupancy and human behavior inside a building. One of the great influences of that is the environment, so uh humans, you can measure the number of humans in a room for example by looking at CO_2. And the way our metabolism react is very sensitive to CO_2. We're actually trying to put other gas meters on the bridge to measure the environment. So alec has pointed out many times that

you know, there's boat traffic underneath. A lot of that boat traffic is diesel, diesel creates nitroxide, can we meter, measure, smell the boat traffic and what it's influence may be on the people or the area, right, so there's interplay of environment of the businesses of the social behavior. That's all part of that data set. We want our bridge to feel but it's also important to have it smell and listen. So we're really trying to copy as many human senses as possible. Because ultimately it's humans that drive all design and all behavior. So it's really that interaction that's interplay with the design that we're more focused on.

(50:28)
J: Okay. Well I don't have any further questions.

(50:33)
R: Me neither.

(50:36)
G: Maybe I can inject a question. So the students are working on a lighting infrastructure and visualization in some form. For Autodesk, just sort of from the top of your head, what are the three immediate greatest ideas you might have, what such a lighting infrastructure might actually display?

(51:05)
A1: Well we've worked a little bit, we talked a little bit with a group that does digital projection mapping called obscura digital. I don't know if you're familiar with them or with digital projection mapping in general, but it's the use of these very high powered projectors to change the visual appearance of a structure or of a space. And so one of the ideas early one was, you know I actually used to live in the red light district and it is constant problem in the red light district, coming home with your bicycle, you have got a ton of groceries hanging on the cargo rack in the front and somebody stops on the bridge in front of you to take, some tourist inevitably, stops on the bridge in front of you to take a picture. Could the bridge with project mapping or some other form of lighting illuminate a bicycle lane? Now this was before we understood that there wasn't actually any bicycle traffic on the bridge, so that was an early example. But you know we talked a bit with them about the potential of using that data from the bridge to drive in real time the projections that are on the bridge. You can imagen for example when we have to many people stopping on the bridge at a bad time that again there's a projection onto the bridge that warns them, the people of that or if not a projection then a set of LED's near where they are standing turn red or something or you know in some way give them a visual cue that they should move on. So a lighting design that would actually feed of on the intelligence of the bridge not just the raw data not just reprojecting the data flows in the bridge but which would actually respond to the intelligence generated, oh there's a problem or oh there are to many people or oh something has stopped by giving a visual cue that to my mind would be a really great solution. I think something that also, that did just work, the digital skin that you mentioned early on, or the luminous skin I think you called it, that's a lovely idea. It's somewhere between an art work and something having real utility in the sense that it gets people to understand that they are on a smart object, that's useful and nice but I warn you that when people know that data is being collected about them, they behave differently. So when started to tell people that there were sensors on the bridge at pier 9, even though there was no way to see them people where not noticing them, there wasn't feedback from them, even when you show that sort of thing people would start to behave differently on the bridge. The tour guides would take groups out on the bridge and they would all jump at once on the bridge. Now that's not a problem, it's some interesting data events but you know we are expecting that if you make it clear to people that the bridge is responding to them by visual feedback they will start to play with the bridge, I'm sure of that .

(54:12)
J: Yeah.

(54:15)
A1: So Alex has a nice thing here on the screen [Figure D.6].

(54:18)
A2: Yeah so this is from our sister group in New York, who's an architectural practice called the living and there part of our complex systems team. They have done various things with lights in the past, so this particular example here is called pier 35 eco park. They basically built these water sensors that could detect tide and water quality and other things and they would display a light show floating in the water. They also look at water particle quality by harvesting, by using mussels and they put sensors on all these individual mussels to measure how much they open and how much they close and how much water is filtering through them and again adding that to the light show, so there's some pretty fun ideas there so you can get an idea of the water quality based on the way these lights behave as they float around. They have also done this living light pavilion, that was commissioned in Seoul and I think there's a video on the internet of this. So yeah, we've played around with a lot of different ideas but it think we're most interested in the cool stuff that you guys are going to come up with.

(55:32)
R: Yeah this is nice for inspiration.

(55:35)
A2: I think you'll find a lot of stuff in interactive architecture out there that can lead towards that sort of inspiration.

(55:47)
G: All right. Ruben, Juline, anything else?

(55:54)
J: Not for me

(55:56)
R: No, I'm also good.

(56:00)
G: All right.

Appendix 2: Behaviour count during location visit

Behaviour count

On Tuesday the 21th of August 2018 the behaviour of people on the old bridge was counted for 1 hour starting at 20:00 and ending at 21:00. During this hour the average amount of people on the bridge was around 5 to 10. The maximum amount of people during this time was 20.

Observed behaviour	Amount of times observed
Stopping to get something out of bag:	3
Stopping to hang out on the bridge (0 – 30 sec)	8
Stopping to hang out on the bridge (30 – 60 sec)	3
Stopping to hang out on the bridge (1 – 5 min)	5
Stopping to enjoy the view (0 – 30 sec)	14
Stopping to enjoy the view (30 – 60 sec)	8
Stopping to enjoy the view (1 – 5 min)	2
Stopping to take a picture	28
Stopping to kiss on the bridge	1
Stopping to discuss walking directions	16

Appendix 3: Insights from media architecture experience

Moodwall

During a trip to Amsterdam I visited the location of 'Moodwall'. 'Moodwall' is a pedestrian tunnel turned into media architecture. The lighting design interacts with people passing by, improving the atmosphere in the tunnel and making people feel happier and safer. The interactive urban wallpaper is made from 2500 LEDs behind a ribbed semi-transparent wall' (Syskes, 2009). The installation is based on shadow play. When the wall senses people passing by, lights start to follow them. The installation uses multiple colours of light and patterns and is fun to interact with. The contextual integration of the installation is on point. The installation suits the location and carrier, as the Bijlmer has a reputation of being and unsafe neighbourhood. The meaning of the content was understandable up to a certain level. It was clear that the lights follow people passing by, but the meaning of the colours and patterns were unclear. An explanation sign next to the installation could help increase the understanding.

Figure B.1 Location Moodwall (Saieh, 2009)
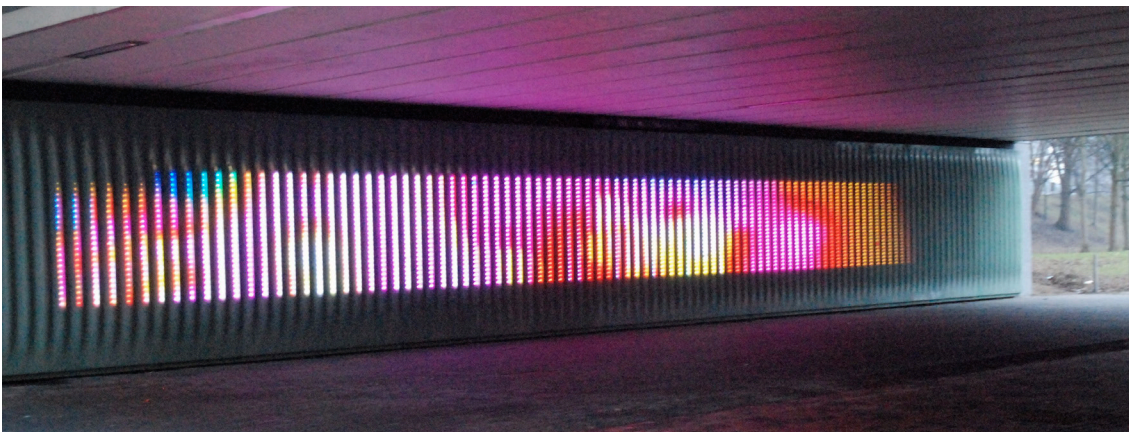
Figure B.2 Lighting design Moodwall (Wippoo, 2013)
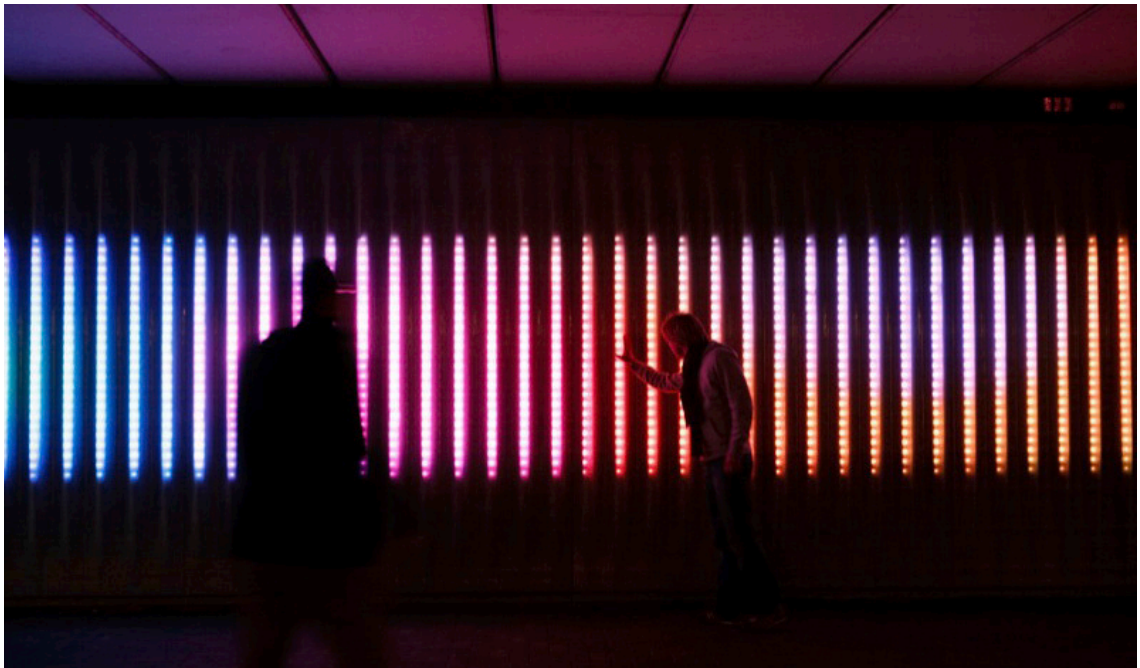
Figure B.3 People walking past Moodwall (Saieh, 2009)
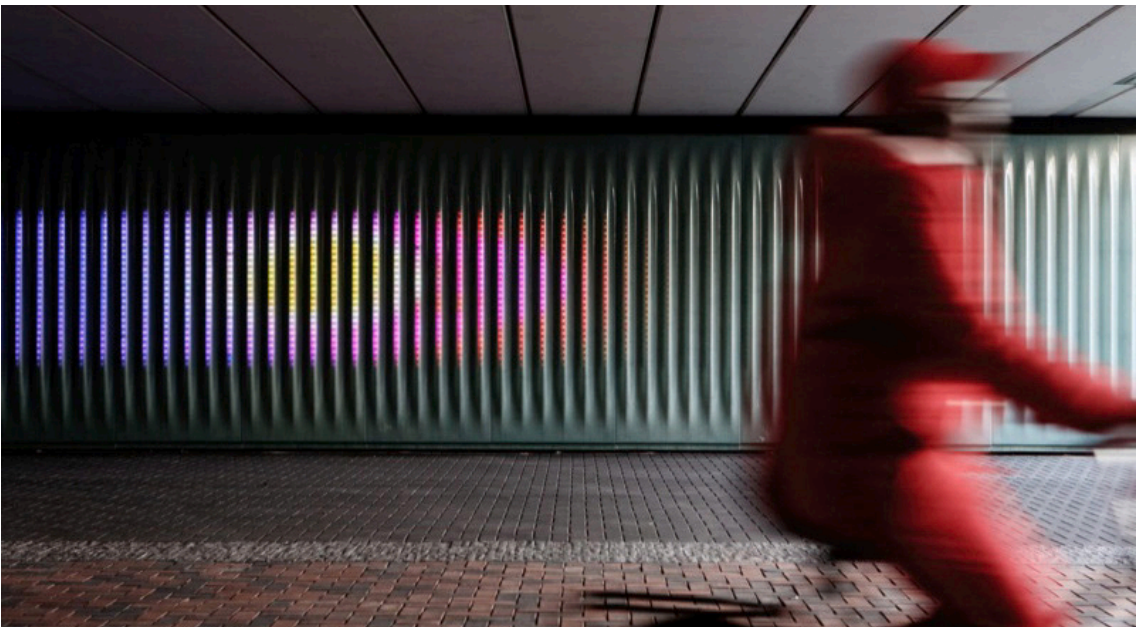
Figure B.4 Person cycling past Moodwall (Saieh,2009)

Appendix 4: Models of the bridge

The models

Two models were made of the bridge: a scale model and a full-scale model. The first, to gain a better understanding of the design and to have a physical representation of the bridge at hands. The latter, for testing purposes. Both were extracted from the Rhino model of the bridge and were 3d printed.
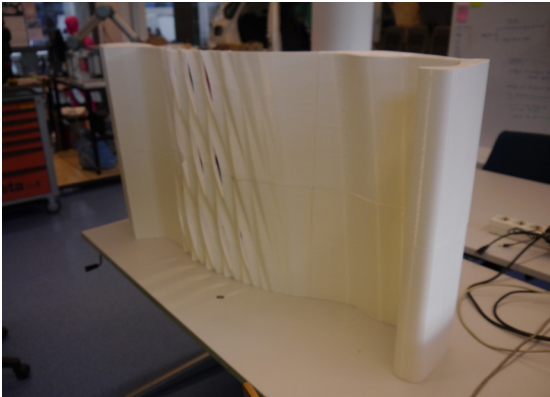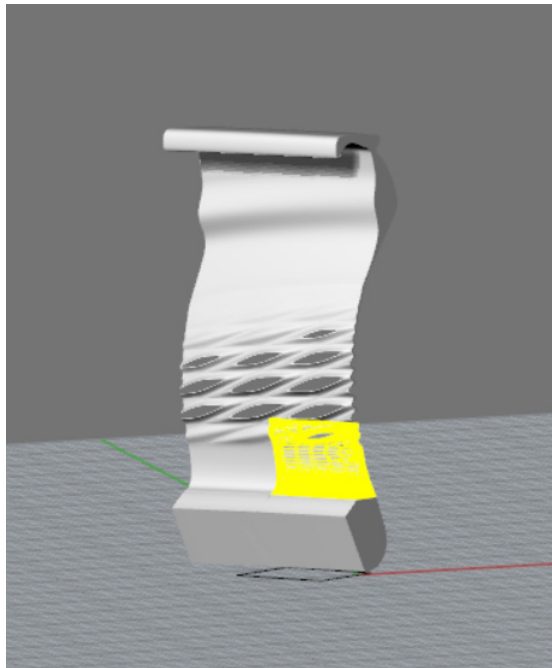

Figure C.1 3D printed full-scale model

Figure C.2 Extracted part in Rhino
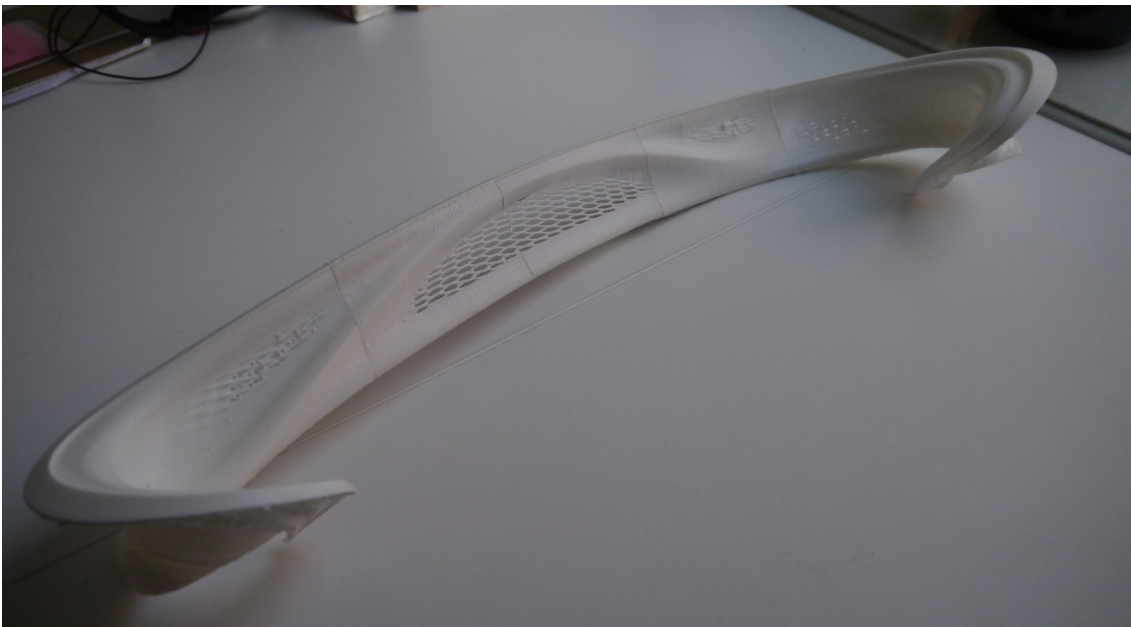
Figure C.3 3D printed scale model
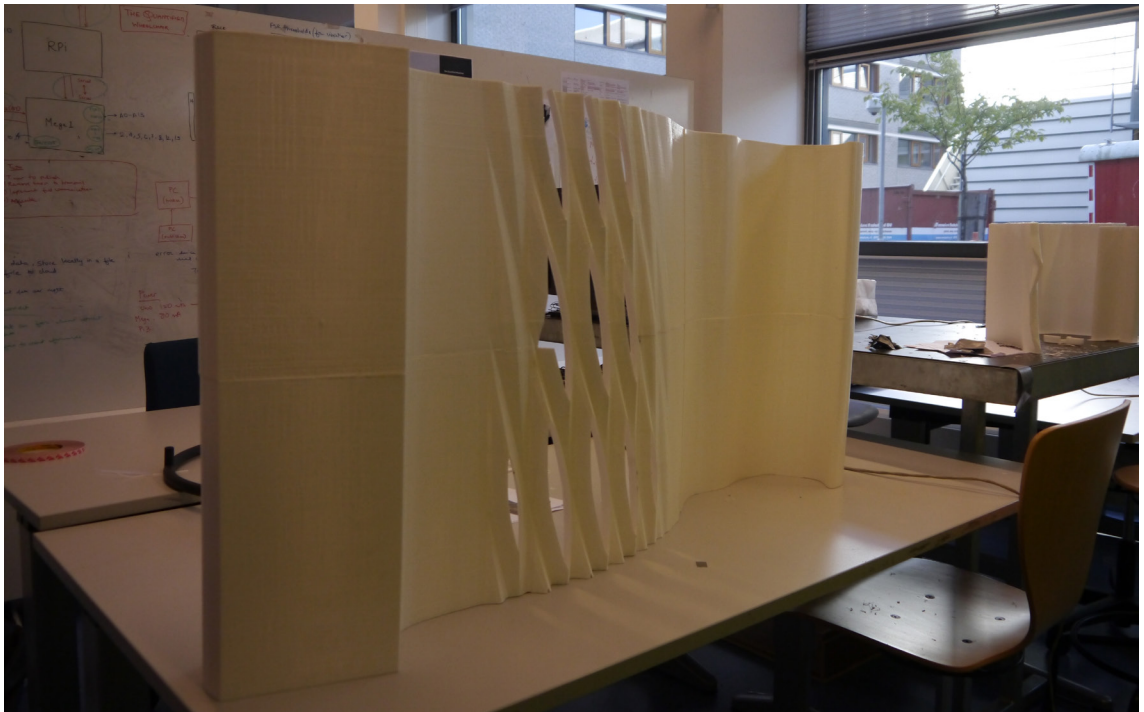
Figure C.4 3D printed full-scale model
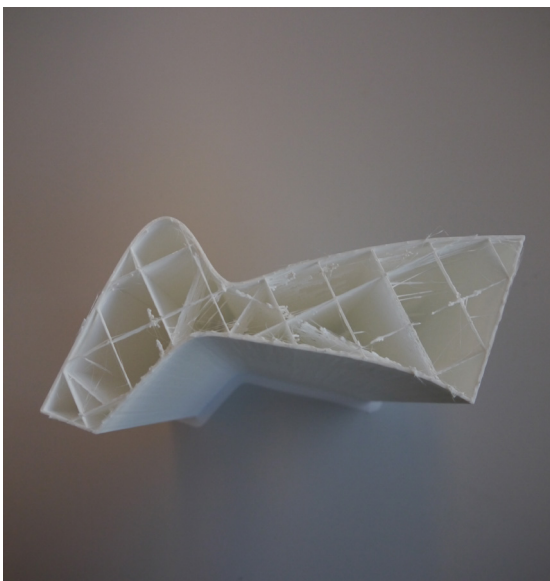
Figure C.5 Cross section individual part
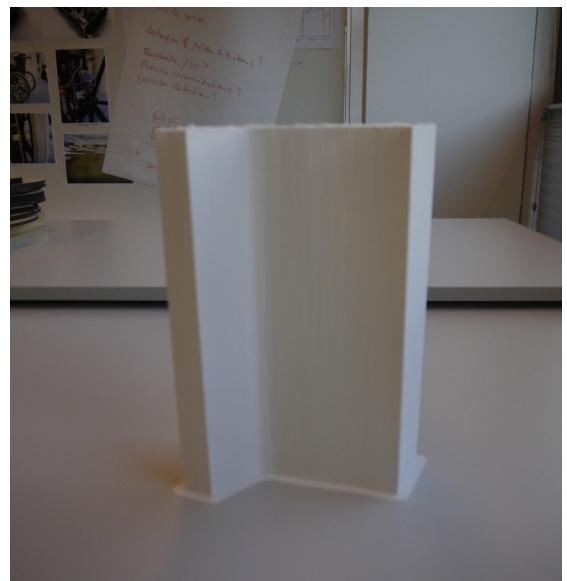
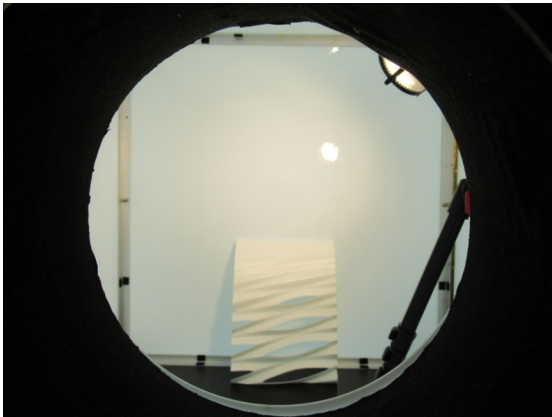

Figure C.6 One part of the model
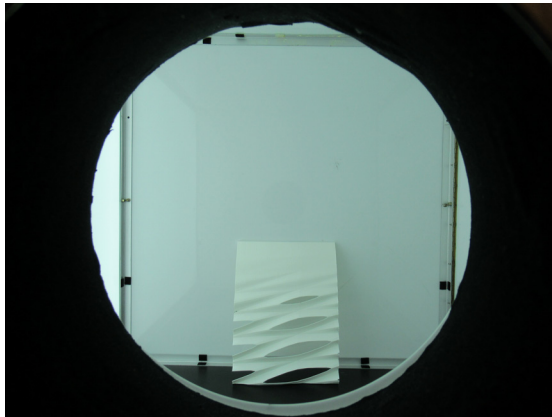
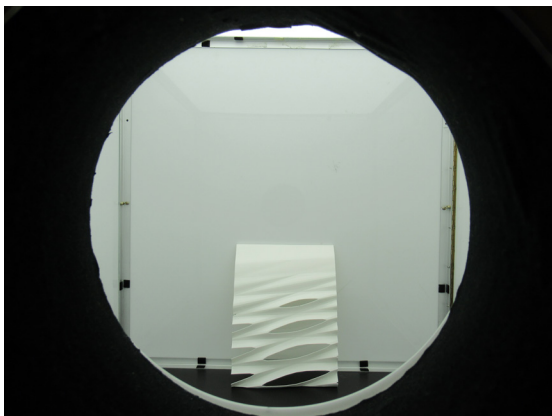# Appendix 5: Light experiment with full scale model bridge
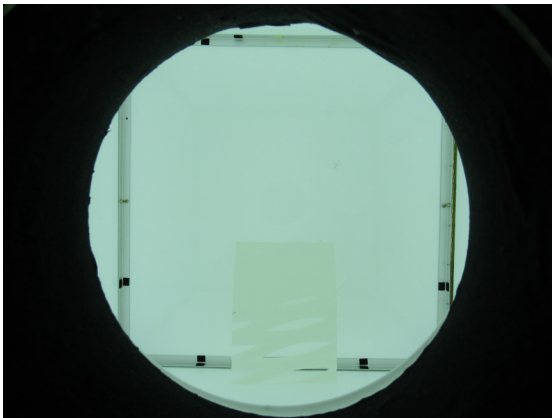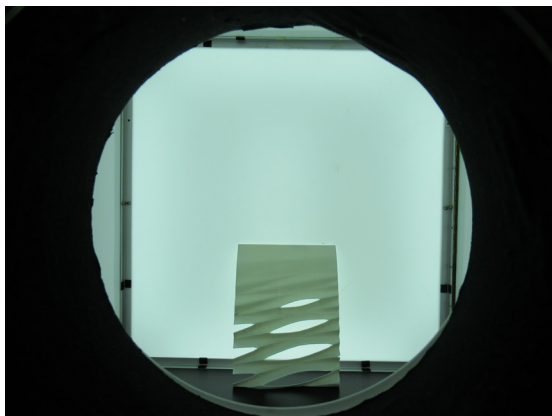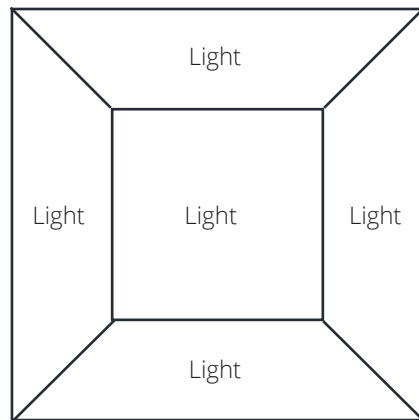

D.1 Set up 1
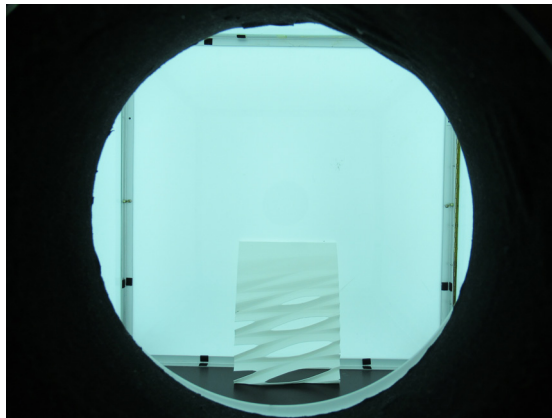
D.2 Set up 5

D.3 Set up 14

D.4 Set up 17

D.5 Set up 18

D.6 Set up 19

Light

Light   Light   Light

Light

Set up 1

Light

Light   Light   Light

Set up 5

Light

Spotlight

Light   Light   Light

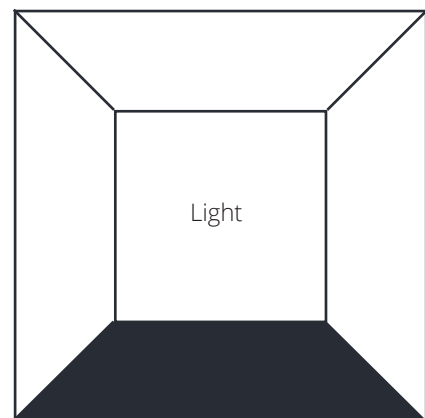*Set up 14*

Light

Set up 17

Light

Set up 18

Light
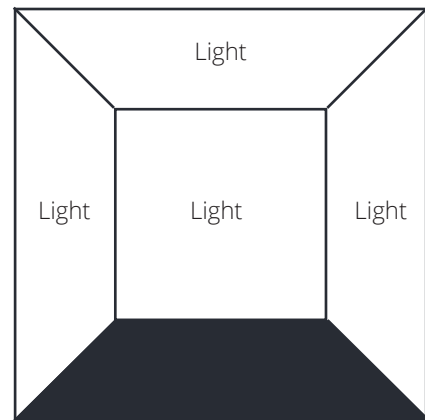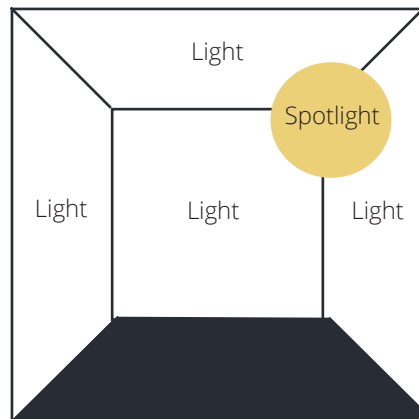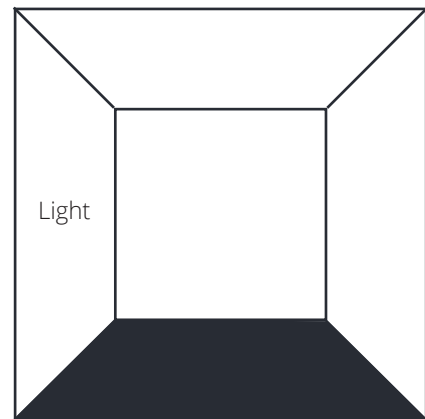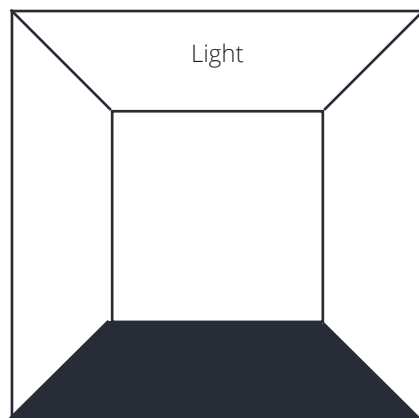
Set up 19

Appendix 6: Data exploration

Structural sensors

Sensors	Momentary patterns	Hourly patterns	Daily patterns
Strain gauges	Stress in a specific point on the bridge Strain in a specific point on the bridge Stress of total bridge Strain of total bridge Division of stress over points Division of strain over points Location of people on the bridge Are people walking over the bridge: yes/no Are people leaning on the hand rails: yes/no Stress safe for stress limits: yes no Strain safe for strain limits: yes/no	Change in stress Change in strain Average stress Average strain Maximum/minimum amount of stress Maximum/minimum amount of strain Derive the walking speed of persons Derive the walking direction of persons Derive the walking route persons Derive the location a person stopped Time spend standing still	Busiest hour during the day How many people crossed the bridge in total Most common walking direction Average walking speed Most common walking route Most common stopping locations Average time spend standing still Most commonly used side of the bridge Difference day time night time behavior Outliers
Load cells	Load in a specific cell Load of people on bridge Load of total bridge Division of load over 4 cells Location of people on the bridge Load safe for structure: yes/no	Change in load Average load Maximum/minimum amount of load	Busiest hour during the day
Inclinometer/ tilt meter	Angle at specific point Angle in handrail Angle in deck Angle of whole bridge	Change in angle Average angle Maximum/minimum angle	
Accelerometers	Vibrations at specific points Vibrations in handrail Vibrations in deck Vibrations of whole bridge Are people walking over the bridge: yes/no	Change in vibration Average vibration Highest/lowest vibration Walking speed person Walking direction person Walking route person (combination with camera?) Location a person stopped Time spend standing still	Busiest hour during the day How many people crossed the bridge in total Most common walking direction Average walking speed Most common walking route Most common stopping locations Average time spend standing still Most commonly used side of the bridge Difference day time night time behavior Outlier
Displacement transducers	The amount of deflection Direction of deflection		
Pressure cells	Amount of pressure		
Thermistors	Temperature of bridge structure Difference in temperature throughout the bridge Difference weather and bridge temperature Temperature safe for structure: yes/no Temperature safe for touch: yes/no		

Human-structure sensors

Sensors	Momentary patterns	Hourly patterns	Daily patterns
Camera/vision systems	Number of people on the bridge Walking direction of a person Walking speed of person Walking route of person Location of person correlated to sensor activity	How many people crossed the bridge in total Most common walking direction Average walking speed Most common walking route Most common stopping locations Average time spend standing still Most commonly used side of the bridge Difference day time night time behavior Outlier	
Wifi?	Number of phones with wifi		

Environmental sensors

Sensors	Momentary patterns	Hourly patterns	Daily patterns
Thermometer	Temperature of weather Hot/cold weather Apparent temperature (humidity & wind speed) Normal temperature for day/month: yes/no	Change in temperature Average temperature of hour Highest/lowest temperature in an hour Difference in predicted and actual temperature	Change of temperature over the day (per hour) Average temperature of the day Average temperature during day time Average temperature during night time Hottest/coldest hour of day Comparison historical temperature of day Normal temperature for the day: yes/no
Hygrometer	Relative humidity	Change in humidity Average humidity of hour Highest/lowest humidity in an hour Difference in predicted and actual humidity	Change of humidity over the day (per hour) Average humidity of the day Average humidity during day time Average humidity during night time Highest/lowest humidity of day Comparison historical humidity of day Normal humidity for the day: yes/no
Anemometer	Wind: yes/no The wind speed The wind direction	Change in wind speed Change in wind direction Average wind speed of hour Average wind direction of hour Amount of wind gusts Highest wind gust	Change of wind speed over the day (per hour) Change of wind direction over the day (per hour) Average wind speed of the day Average wind speed during day time Average wind speed during night time Average wind direction of day Average wind direction during day time Average wind direction during night time Highest/lowest wind speed of day Amount of wind gusts Highest wind gust Comparison historical wind speed of day Comparison historical wind direction of day Normal wind speed for the day: yes/no Normal wind direction for the day: yes/no
Rain gauge	Rain: yes/no Amount of rain per time period (rain intensity)	Change in rain intensity Total amount of rainfall in hour	Change in amount of rainfall over the day (per hour) Total amount of rainfall in day Highest/lowest amount of rain per hour Comparison historical amount of rainfall of day Normal rainfall for the day: yes/no
Barometer	The barometric pressure	Change in barometric pressure Average barometric pressure of hour	Change in barometric pressure over the day (per hour) Average barometric pressure of the day Average barometric pressure during day time Average barometric pressure during night time Highest/lowest barometric pressure of the day Comparison historical amount of bar. pressure of day Normal barometric pressure for the day: yes/no
CO2 meters	Air quality Air quality good: yes/no	Change in air quality Average air quality hour	Average air quality of the day Highest/lowest air quality of the day Comparison historical air quality of day Normal air quality for the day: yes/no
Sound level sensor	The decibel level High/low sound level	Change in activity Highest/lowest sound level	
Direct/ambient light sensor	Amount of ambient light Day/night time		

Appendix 7: Creative session with students

Set up

Date: April 19, 2018   Time: 11:00 – 13:00

11:00 Walk in (10 min)

11:10 Warm up (5 min)
Participant have to throw a stuffed animal over to each other. When they catch it, they have to make an association with one of the following things:
•   A bridge
•   The red light district
•   Light
This is done to help participants feel at ease around each other and prep them for the next parts of the creative session.

11:15 Introduction (10 min)
The project is introduced. The smart bridge is explained and it is mentioned that MX3D wants to engage people with the bridge through the use of light. During the explanation participants are asked to write down words that come into their mind. The result is a word web with words associated with the project (*Figure A.3*).

11:25 HKJ's (25 min)
A couple of 'how can you's' have been prepared beforehand. These are:
•   How can you engage people with the bridge through light?
•   How can you communicate information to people through light?
•   How can you show that the bridge is interactive?
•   How can you use the data of the bridge is to stimulate interaction?

Participants are asked to discuss these in a group context. They can write down anything they come up with on a post-it. During the brainstorm images of the bridge were used as probes. The results were four A3 papers filled with post-it concerning a specific HKJ.

11:50 Break (15 min)

12:05 Clustering post-it's (20 min)
Participants are asked to cluster the ideas they generated with the HKJ's, by sticking the post-its on the wall in groups (*Figure A.4*). The results were eleven clusters of post-its.

12:25 Hits and dots (10 min)
Participants are asked to judge the ideas on creativity and feasibility by placing a sticker on the best ideas. They are given four stickers, two for creativity and two for feasibility. After all the stickers have been stuck on the post-its, they post-its with the best ideas are placed on the table and re-clustered.
The results were twenty-so post-its with stickers on them.

12:35 Poster (15 min)
The participants are asked to make a poster in groups of two. They can combine the resulting post-it into a concept for a lighting design. When they have finished the poster, they are asked to present the posters to each other. The result were three posters.

12:50 End of session (10 min)

Figure E.1 Photo of participants writing down word associations

Figure E.2 Photo of participants clustering ideas on the wall

Results of word web

The words in the word web (*Figure A.5*) can be organized into three groups:
· Words associated with the location
· Words associated with the 3d printed bridge
· Words associated with light and the lighting design

A lot of words are very obvious, but there are some words that hint towards more interesting ideas. Such as turning the bridge into an actual 'theme park' attraction, or have the content of the bridge relate to the red light district or Amsterdam. Another unconventional idea is to make the bridge glow in the dark or to use a hologram next to the bridge to showcase sensor data. Lastly, having the

Associated with the location
· Amsterdam
· Prostitution
· Sex
· Red light
· Money
· Experience
· Attraction (amusement park)
· Tourists
· Amsterdam light festival
· Crowdedness
· Pedestrians
· Love locks on bridges

Associated with the 3d printed bridge:
· Metal
· Sensors
· Smart
· Data
· Information
· New production technique
· Failure of millennium bridge
· Resonance
· Vibrations

Associated with light and the lighting design:
· Lights
· Interactive
· Engaging
· Changing colours according festival (light festival, king's day, gay pride)
· People can change light colours
· Light projections
· Glow in the dark
· Water & light
· Movement & light
· Team vs team (light) battle
· 3d light / hologram

Figure E.3 Photo of word web made by participants

Results of clustering

The initial clustering during the creative session (*Figure F.4*) led to the following clusters:
- Information (*Figure F.5*)
- Practical information (*Figure F.6*)
- Information for everyone (*Figure F.7*)
- Information for tourists (*Figure F.8*)
- Personalisation (*Figure F.9*)
- Gamification (*Figure F.10)*
- Behaviour influencing (*Figure F.11*)
- Implementation (*Figure F.12*)
- Interaction (*Figure F.13*)
- Uncategorized (*Figure F.14 & F.15*)

These clusters were re-organized after the creative session, because some of the clusters were very similar. This led to the following list:
- General information
- Amsterdam and the red light district
- Bridge related information
- People oriented information
- Tourist related information
- Warnings and alarms
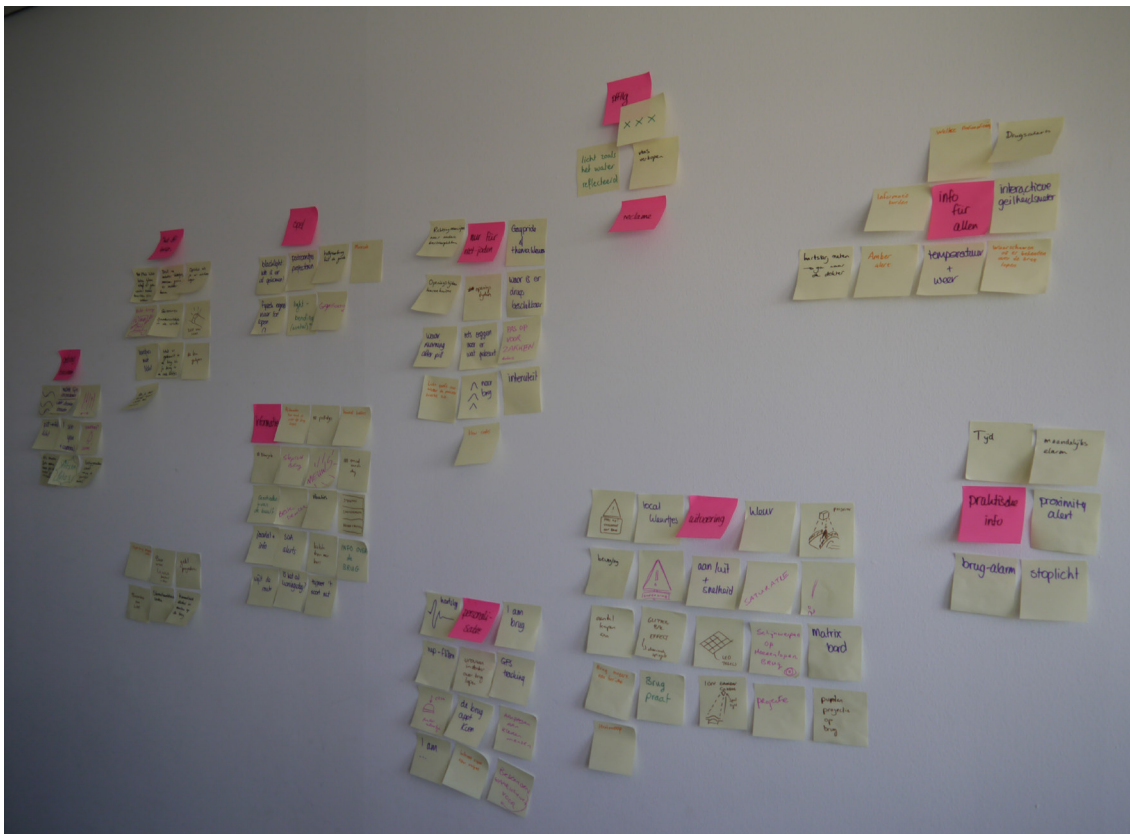- Light and interaction
- Uncategorized

Figure E.4 Photo of idea clustering on the wall

General information
- Trains leaving (time, last train home)
- Directions guide
- Time
- Temperature
- Weather forecast

Amsterdam and red light district related information
- History of the neighbourhood
- Year + historic information
- STD alert
- Daily revenue of prostitution
- Amount of drugs sold
- Amount of blowjobs given
- Interactive arousal meter (body heat)
- Opening hours brothels
- Directions guide to weed shops
- Heartbeat of Amsterdam
- I Amsterdam bridge
- Blacklight on bridge

Bridge related information
- Amount of (tourist) suitcases that have crossed the bridge
- Vibrations of bridge
- Information about bridge
- Light indicates where the most stress and strain is
- Two directional walkway path

People oriented information
- Heartbeat of people
- Adapting colour to colour of peoples clothes
- Movement of people
- Projecting straight walking lines to see if someone is drunk
- Wearables and phones light up when they cross the bridge
- Publicly shaming someone if they are being annoying
- Bright light whenever people try to take photos on the bridge

Tourist related information
- Is it kings day (yes/no) for the tourists
- Directions guide to tourist attractions

Warnings and alarms
- Drugs alert
- Amber alert
- Monthly air alarm
- Warn for pickpocketing

Light and interaction
- Light arrows going towards the bridge
- Changing light intensity
- Colour codes
- Special days and festival colour
- Vibrations to convey interactiveness
- When touching the bridge or a button it changes colour
- Hologram bridge
- Projecting patterns
- Glow in the dark
- Colour
- Matrix board
- Saturation as a variable
- On/off speed
- Local colours
- Light reflecting in water
- Reflecting mirrors
- LED tiles
- Talking bridge
- Warning sign interactive bridge
- Spotlight on bridge
- Reversed interaction, more people less lights, so people aren't attracted towards the bridge
- Bridge lights up if someone walks over it
- Seasonal lighting effect

Uncategorized ideas
- Breaking news
- Traffic light bridge
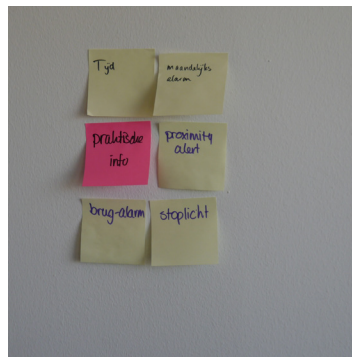- Three x's representing Amsterdam

Figure E.5 Information

Figure E.6 Practical information

Figure E.7 Information for everyone

Figure E.8 Information for tourists

Figure E.9 Personalisation

Figure E.10 Gamification

Figure E.11 Behaviour influencing

Figure E.12 Implementation
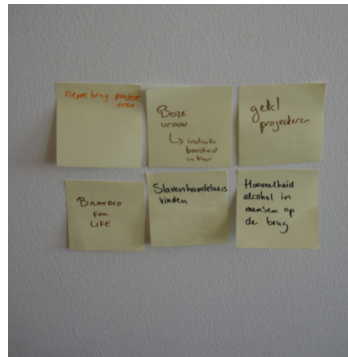

Figure E.13 Interaction

Figure E.14 Uncategorized

Figure E.15 Uncategorized

Re-clustering

The results were filtered and re-clustered again. Information that was considered irrelevant or inappropriate was removed. These were mostly sex-related things but also information that is static in nature, instead of dynamic over time. Only ideas that are actually interesting for the lighting design are left over. These were divided into two categories:

Ideas for content

General information
- Time
- Temperature
- Weather forecast

Amsterdam & red light district related information
- Heartbeat of Amsterdam
- I Amsterdam bridge
- Daily revenue of prostitution
- Amount of blowjobs given
- Interactive arousal meter (body heat)

Internal bridge information
- Vibrations of bridge (auditory/visual/ haptic)
- Light indicates where the most stress and strain is

External bridge information
- Amount of (tourist) suitcases crossings
- Dynamic two directional walkway path
- Movement of people
- Heartbeat of people

Ideas for implementation

Light (technology)
- Saturation/ light intensity
- Colours
- On/off speed
- Hologram bridge
- Projecting patterns
- Glow in the dark
- Matrix board
- Light reflecting in water
- Reflecting mirrors
- LED tiles

Interaction
- Dynamic light visualisation
- Light arrows going towards the bridge
- Vibrations to convey the interactiveness of the bridge
- When touching the bridge or a button, the bridge changes colour
- Talking bridge
- Warning sign to indicate the bridge is interactive

Posters
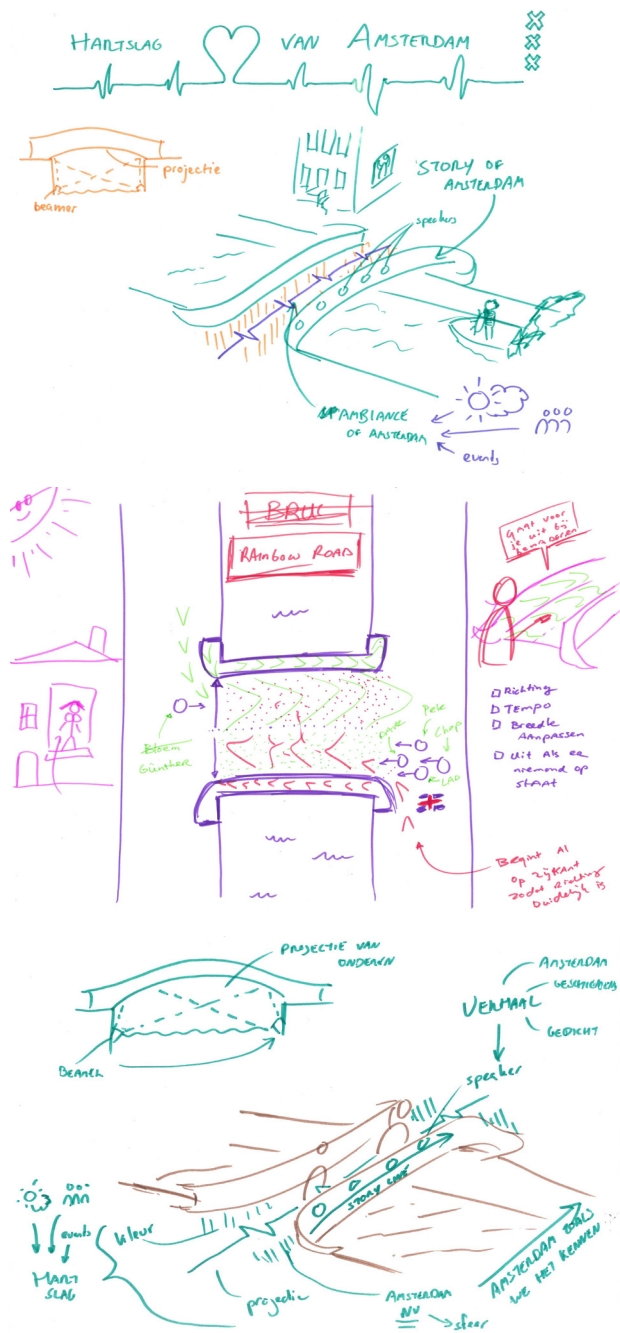
Appendix 8: Design space explorer

What is a design space explorer?

Dalsgaard, Halskov and Nielsen (2008) have found a way to create an overview of the key aspects surrounding the design space of media architecture. They have created a tool called the 'Design Space Explorer' (Figure F.1). The tool is case-specific, so for each new design process, new design aspects need to be defined. Figure F.2 and F.3 are examples of concepts created using a design space explorer.

This tool was used to structure the large quantity and variety of information that was gathered during the exploration, the context research and the ideation.

Fixed parameters

As in most design projects, there are a number of parameters in this project that are fixed:

- MX3D (project owner)
- The bridge (design, dimensions, material)
- The location (Amsterdam, red light district, Oudezijds Achterburgwal)
- Spatial lay out (thoroughfare)
- The use of light (lighting design)
- The use of data (data driven)

These elements cannot be changed and influence the options that exist for the aspect surrounding the design of the lighting infrastructure.

Material	Form	Combination	Location	Situation	Interaction sensing	Interaction style	Format	Content
Water Electricity Air	Tile Dot Tube Wire	Matrix Line	Plaza Metro Parking lot Entrance Exhibition space Corridor Wall Floor Ceiling	Passing by Arrival Resting Self-expression Departure Playing Observing Exploring Sharing	Autonomous Passive Active	Movement Gesture Touch Input device	Film Image Text	Information Ornamentation Guidance Data visualization Reflection

Figure F.1 Design Space Explorer in the Warsaw MoMA (Dalsgaard et al, 2008)

Material	Form	Combination	Location	Situation	Interaction sensing	Interaction style	Format	Content
Electricity	Tile	Matrix	Exhibition space Wall	Passing by Observing	Autonomous	None	Image	Ornamentation Data visualization

Figure F.2 Concept 1 for the Warsaw MoMA (Dalsgaard et al, 2008)

Material	Form	Combination	Location	Situation	Interaction sensing	Interaction style	Format	Content
Electricity	Wire	Line	Plaza Entrance	Passing by	Passive	Movement	Image	Ornamentation Guidance

Figure F.3 Concept 2 for the Warsaw MoMA (Dalsgaard et al, 2008)

Design aspects

Display technology
Type of lighting technology that can be used to turn the bridge into a display.

Front projection façades
Light-emitting façades

Interaction style
Type of input that is used to interact with the bridge.

Movement
Sound
None

Discoverability
Ways how the interactiveness of the bridge is conveyed

Visual feedback
Dynamic lighting
Light arrows going towards bridge
Information sign
Warning sign

Auditory feedback
Sounds
Auditory information

Haptic feedback
Vibrations

Sensors
Type of sensors that will be placed in and around the bridge.

Strain gauges
Load cells
Inclinometer/ tilt meter
Accelerometers
Displacement transducers
Pressure cells
Thermistors
Thermometer
Hygrometer
Anemometer
Rain gauge
Barometer
CO_2 meters
Sound level sensor
Direct/ambient light sensor
Camera/vision systems
Mobile apps
Wi-fi

Technology Specific technology used to light the bridge.	LED's LED ring LED strip LED net LED tiles Light spots Projector Screen EL wire Light emitting fibers
Pattern The pattern/ shape of the lights.	Grid Lines Circles Dots Squares Other shapes
Illumination Light effects that can be achieved with the lighting technology and lighting design	Emitting light Illuminating bridge parts Projecting of bridge parts Reflecting light on the water
Dynamic factor The way light communicates a change.	On/Off Light location Light colour Light intensity Speed on/off Speed of colour change Speed of location changes Speed of intensity change
Lighting locations Locations on the bridge were the lighting infrastructure can be placed	In or under the handrail On the outside of the bridge Under the bridge Projected onto the bridge

|	
Data insights Insights gathered from the sensor data.	See momentary, hourly and daily patterns in appendix 6 and the results of the creative session in appendix 7.
Interface Type of media interface the bridge can be based on interaction.	Responsive ambient interface
Interaction sensing Type of sensing the interaction is based on.	Passive

Appendix 9: Placement different lighting technologies
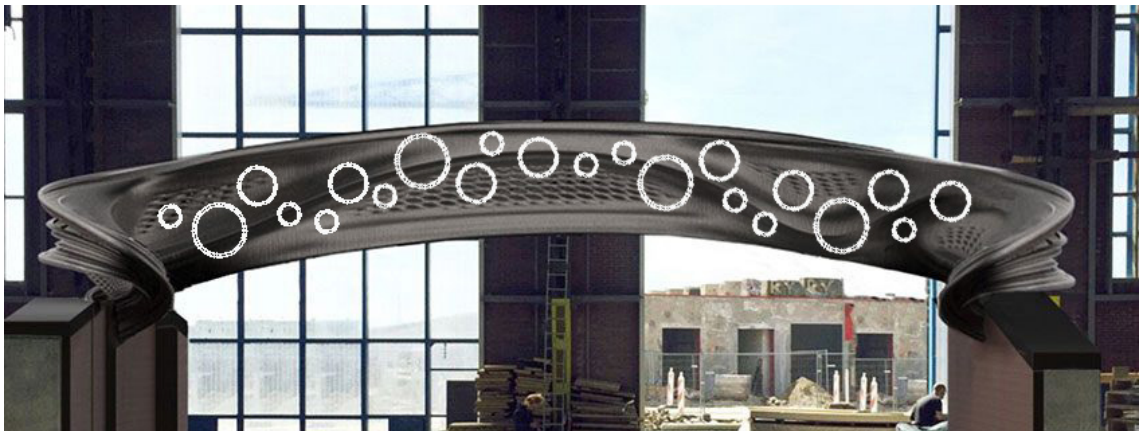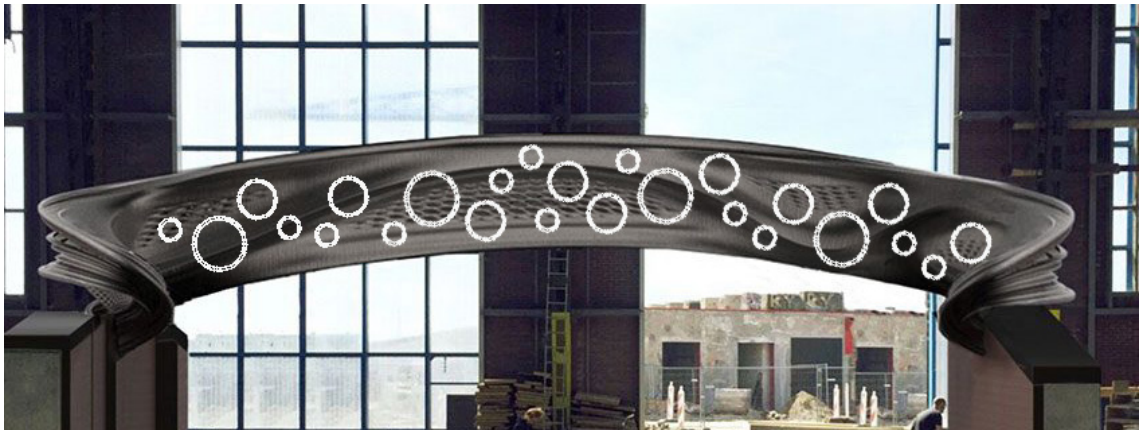
Appendix 10: user test

Questions

Question 1:
In your opinion, why do you think the lights change?

> Answer:

Question 2:
Please rate the following statement for all three animations:
'It is clear that the lighting visualisation relates to the amount of people on the bridge.'

	Totally disagree			Neutral			Totally agree
	1	2	3	4	5	6	7
Animation 1	o	o	o	o	o	o	o
Animation 2	o	o	o	o	o	o	o
Animation 3	o	o	o	o	o	o	o

Question 3
Which neighbourhood do you associate with the lighting design in this animation?

o The neighbourhood in image 1
o The neighbourhood in image 2
o The neighbourhood in image 3
o The neighbourhood in image 4

Question 4
Choose 2 or 3 words that you associate with the lighting design in this animation:

o romantic   o innovative   o boring
o intelligent   o adventurous   o funny
o expensive   o ordinary   o serious
o joyful   o unpleasant   o smart
o respectful   o friendly   o calm

Would you use the same words or different words to describe the other animations?
o the same words
o different words

Question 5
Which image corresponds best to the change in colours?
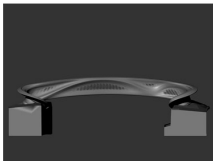
o Image 1
o Image 2
o Image 3

Question 6:
Which one do you like best and why?

o Animation 1
o Animation 2
o Animation 3

> Because: …

Images

Have a look at the following images and fill in question 3 concerning the animation below.

Animation

Image 1

Image 2

Image 3
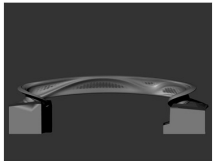

Image 4

Back

Next

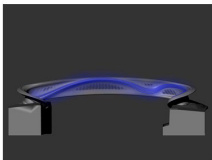Have a look at the following words and fill in question 4 concerning the animation below.

Romantic
Intelligent
Expensive
Joyful
Respectful
Innovative
Adventurous
Ordinary
Unpleasant
Friendly
Boring
Funny
Serious
Smart
Calm

Back

Next

Have a look at the following images and fill in question 5 concerning the animation below.

Image 1

Image 2

Image 3

Back

Next