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

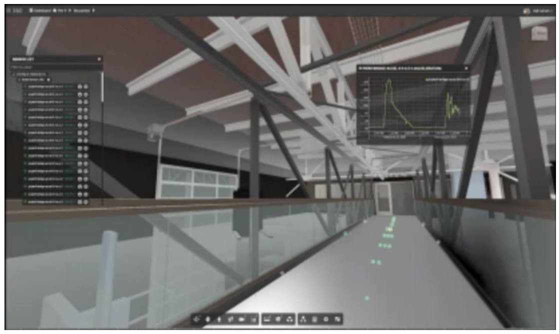


Figure A.2

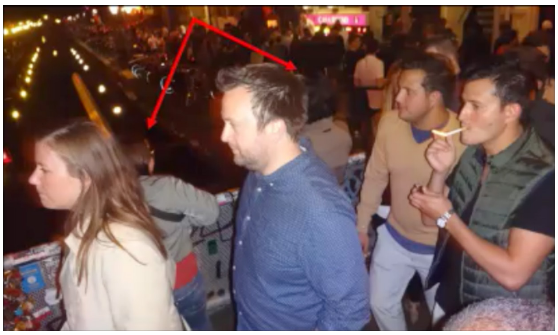


Figure A.3

Figure A.4

Figure A.5

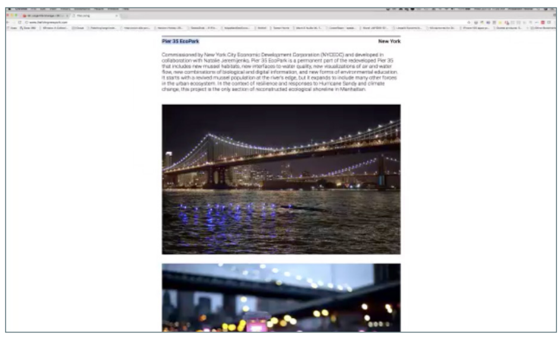


Figure A.6

Interview transcript

(00:01)
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 CO2 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 CO2. And the way our metabolism react is very sensitive to CO2. 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)

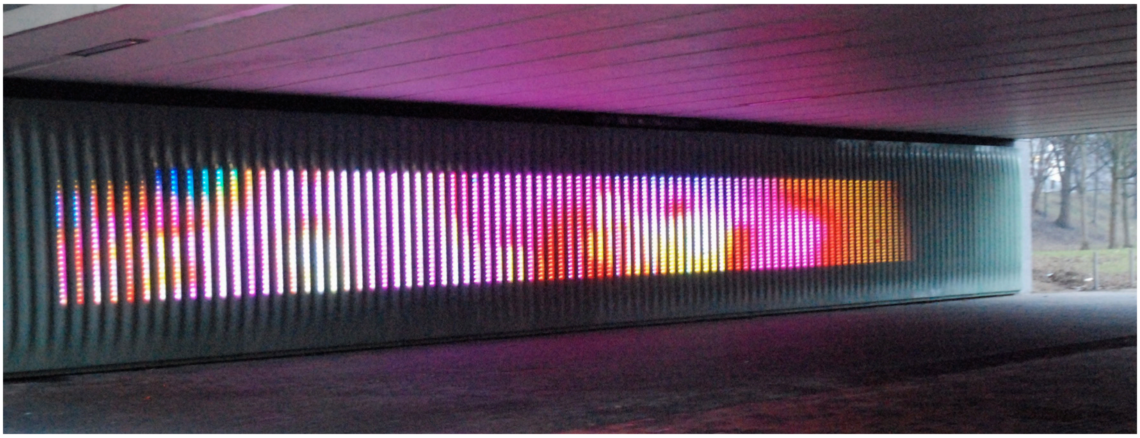


Figure B.2 Lighting design Moodwall (Wippoo, 2013)

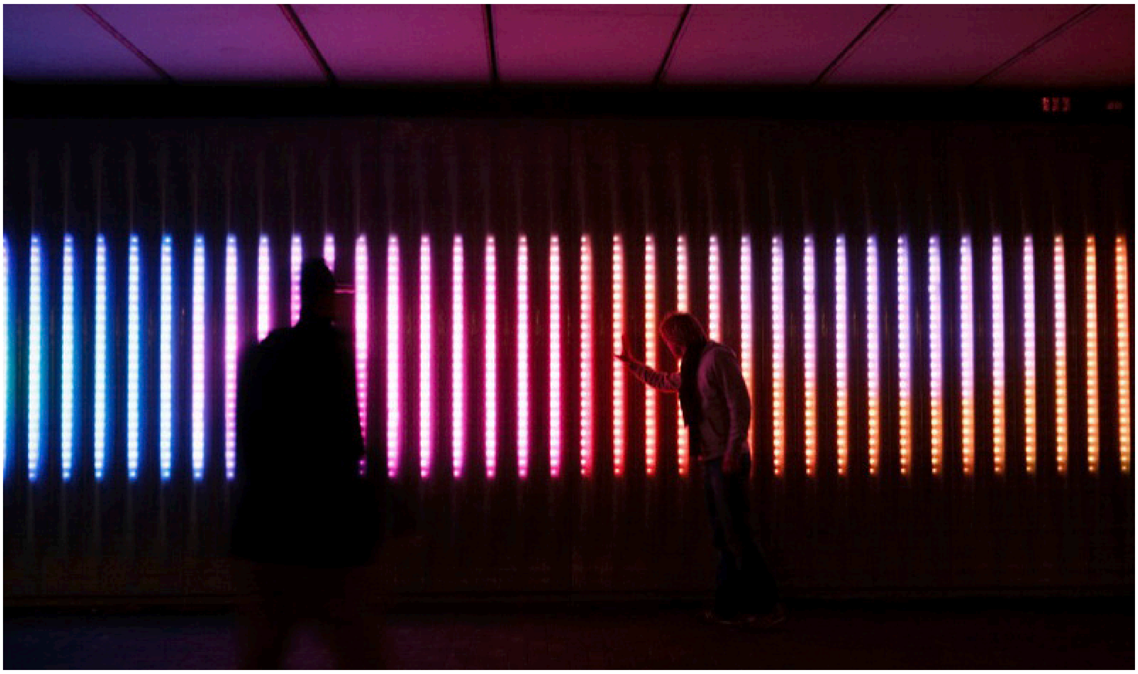


Figure B.3 People walking past Moodwall (Saieh, 2009)

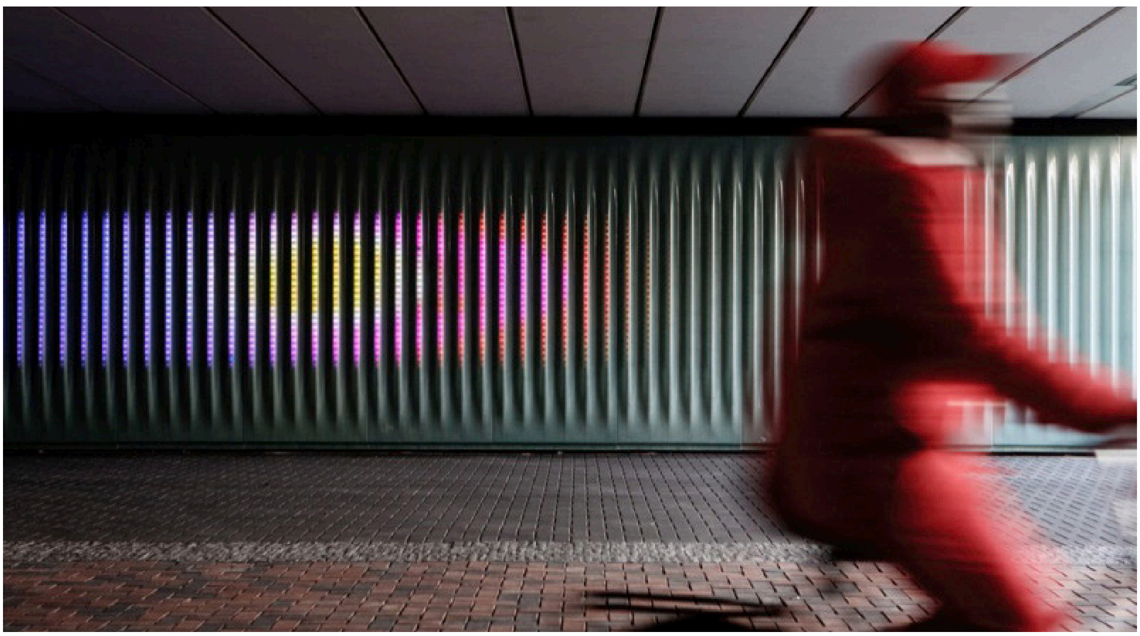


Figure B.4 Person cycling past Moodwall (Saieh,2009)

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.

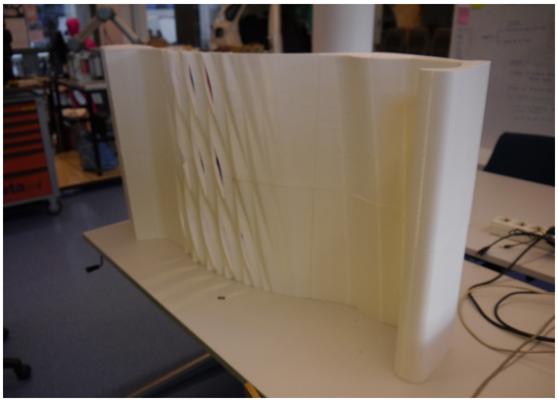


Figure C.1 3D printed full-scale model

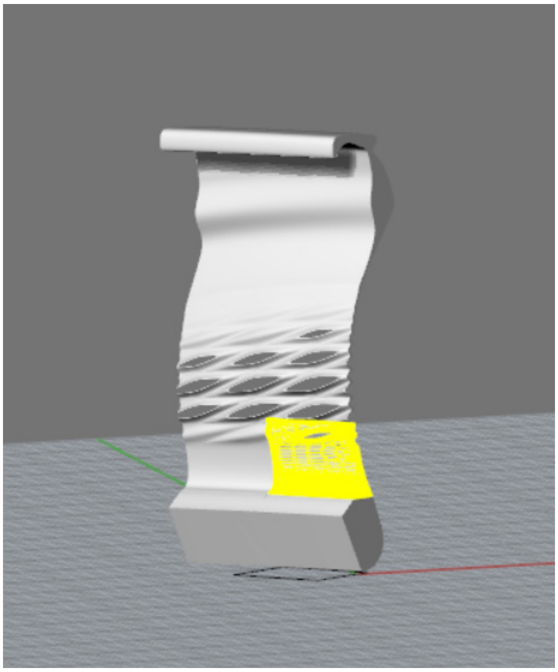


Figure C.2 Extracted part in Rhino

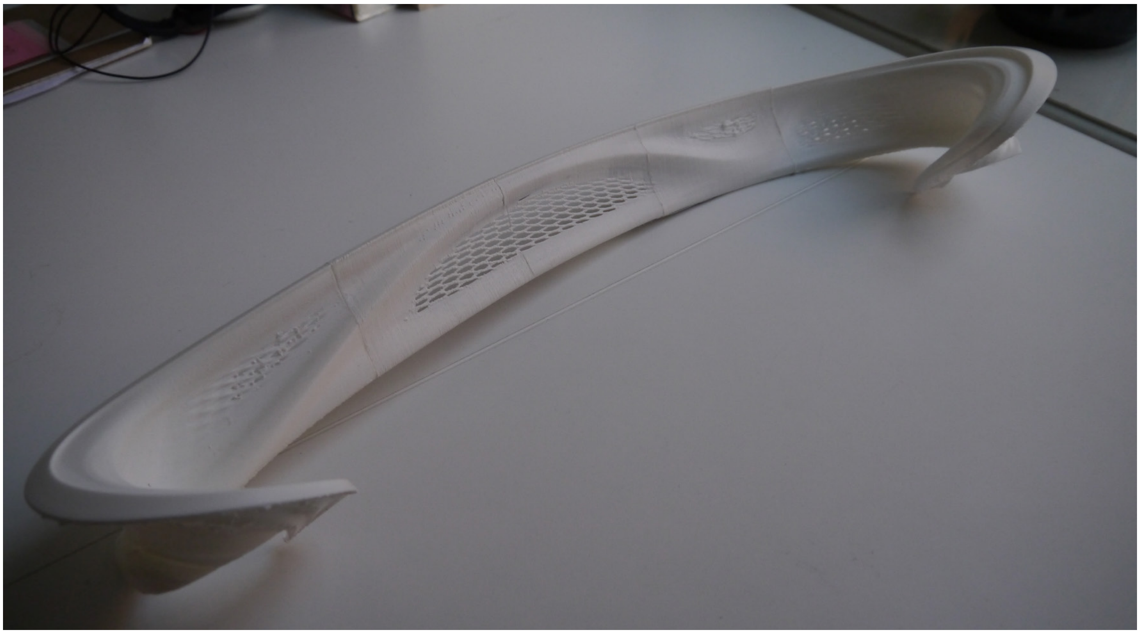


Figure C.3 3D printed scale model

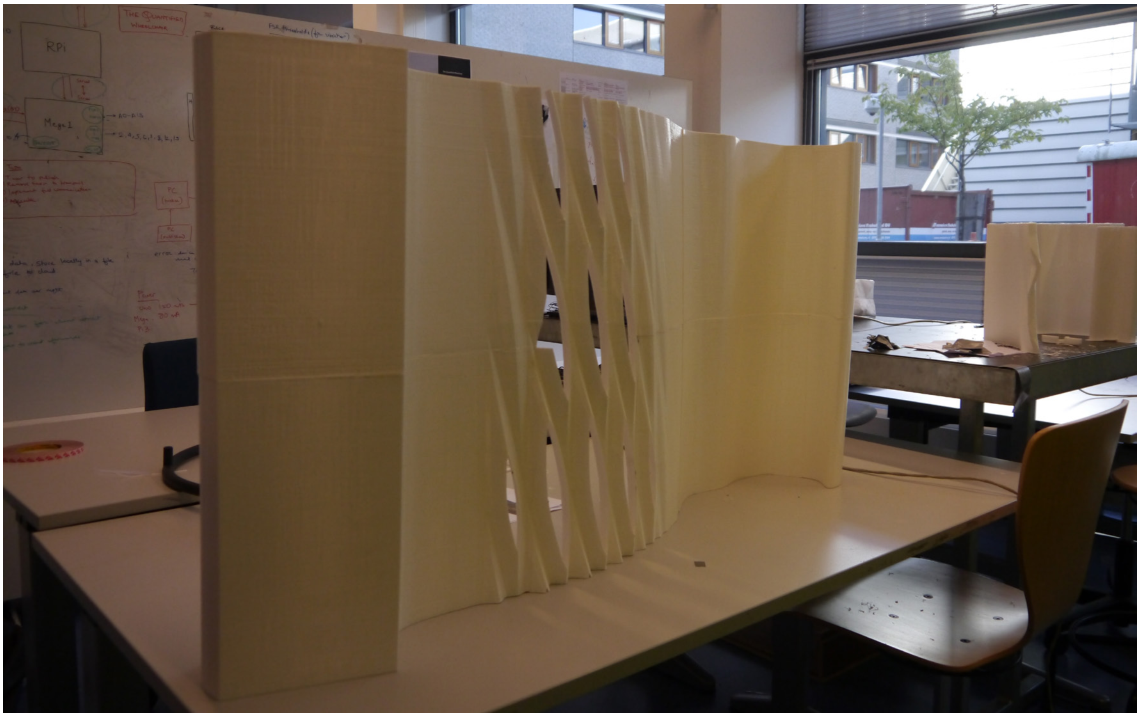


Figure C.4 3D printed full-scale model

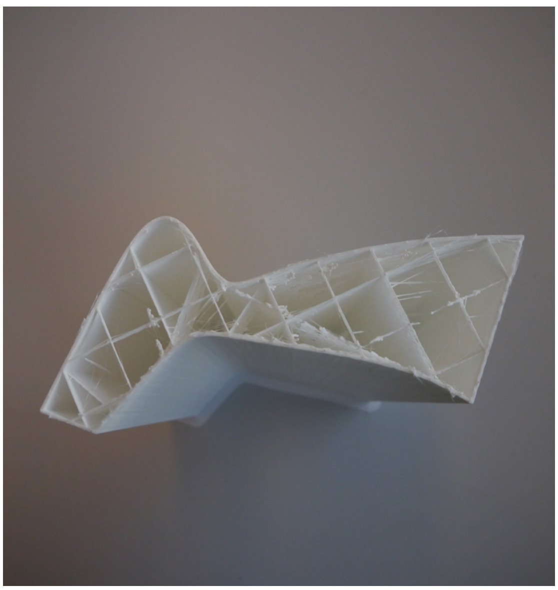


Figure C.5 Cross section individual part

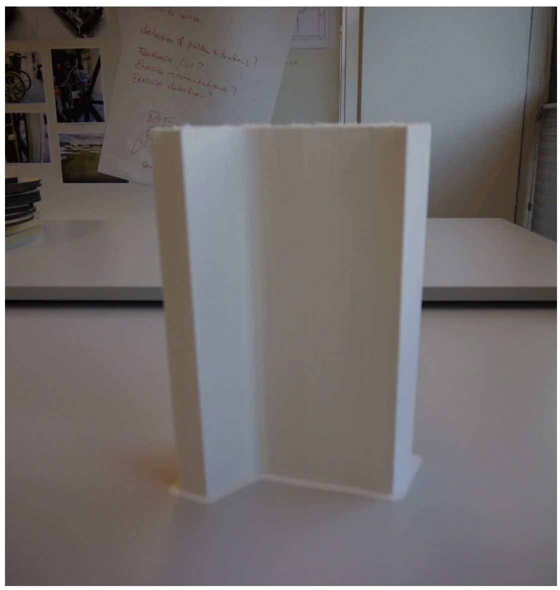
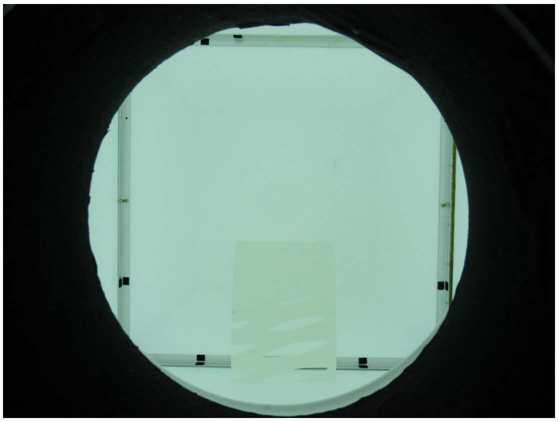
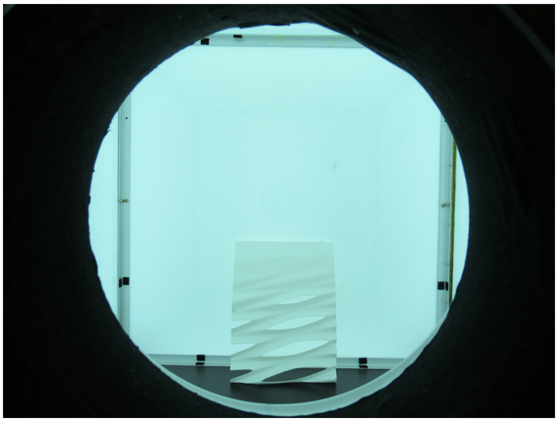
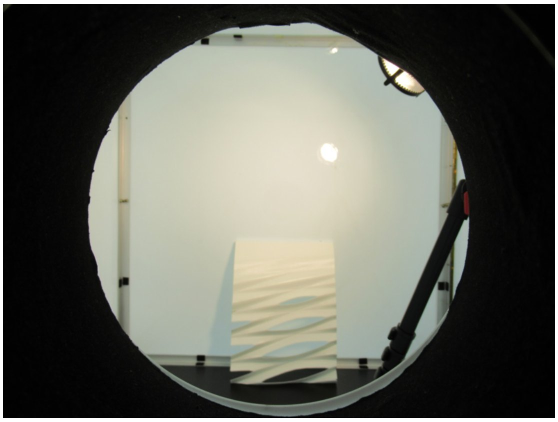


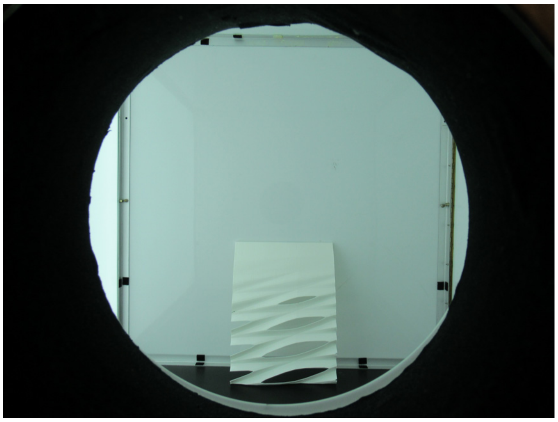
Figure C.6 One part of the model

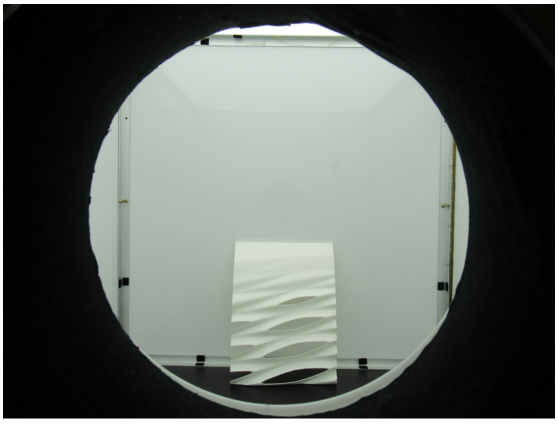
Appendix 5: Light experiment with full scale model bridge

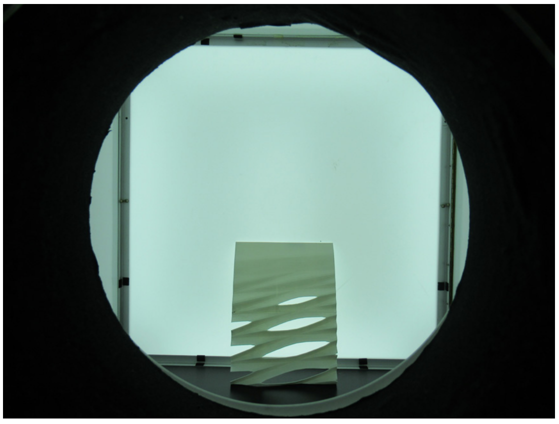

D.1 Set up 1

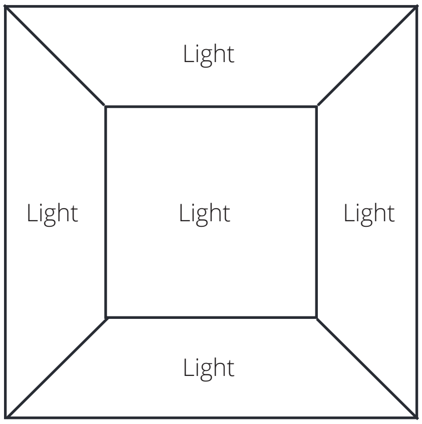

D.2 Set up 5


D.3 Set up 14

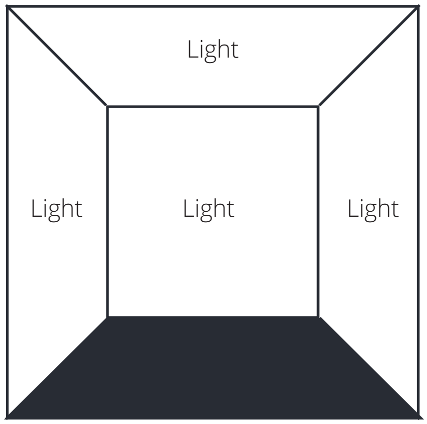

D.4 Set up 17


D.5 Set up 18

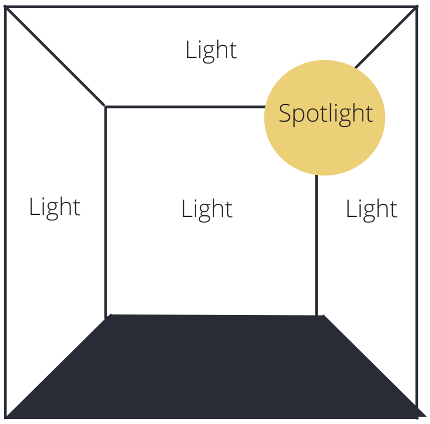

D.6 Set up 19



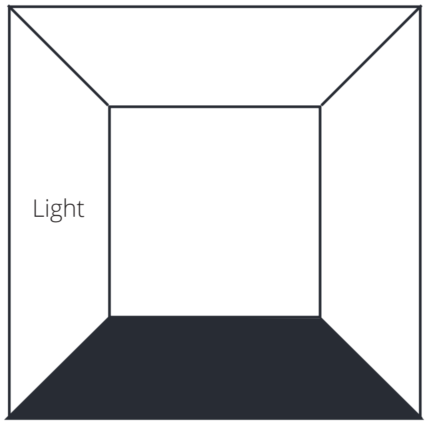
Set up 1



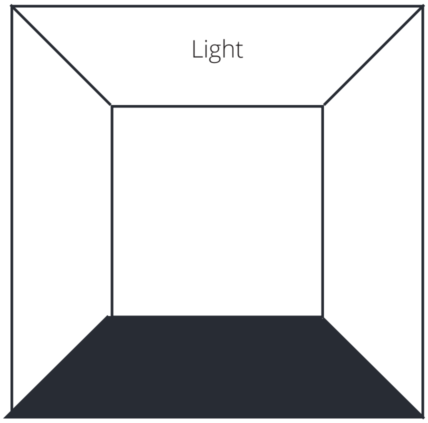
Set up 5



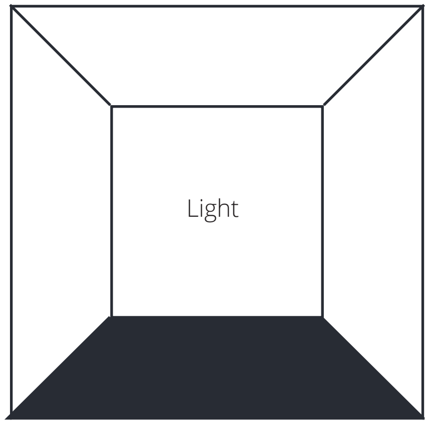
Set up 14



Set up 17



Set up 18



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

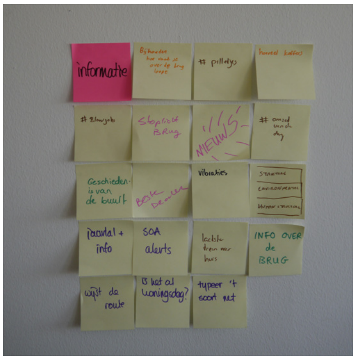


Figure E.5 Information

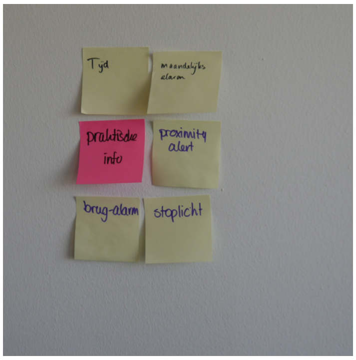


Figure E.6 Practical information

Figure E.7 Information for everyone

Figure E.8 Information for tourists

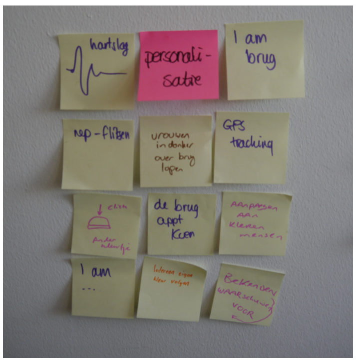


Figure E.9 Personalisation

Figure E.10 Gamification

Figure E.11 Behaviour influencing

Figure E.12 Implementation

Figure E.13 Interaction

Figure E.14 Uncategorized

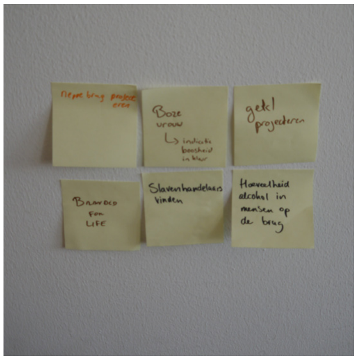


Figure E.15 Uncategorized

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

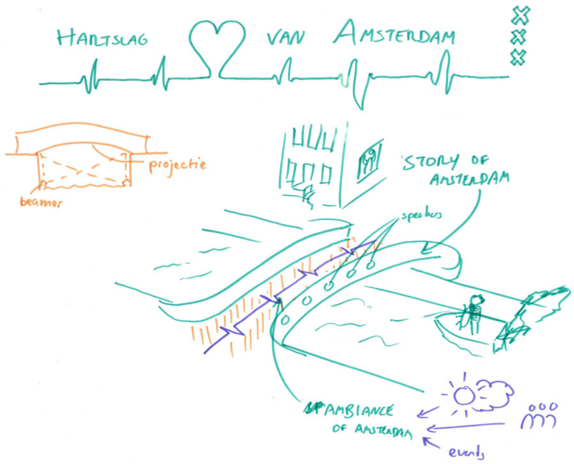
Light (technology)

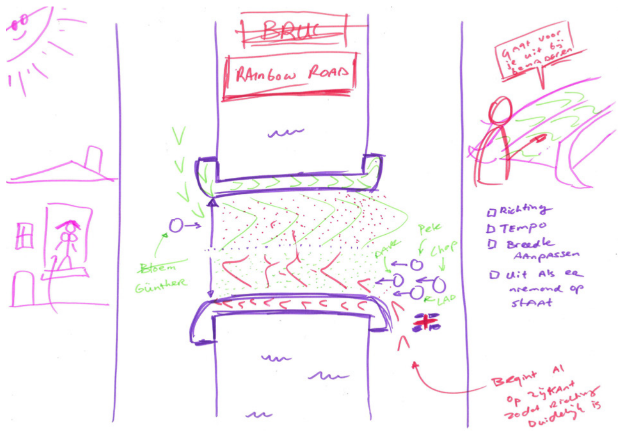
- Saturation/ light intensity
- Colours
- On/off speed
- Hologram bridge
- Projecting patterns
- Glow in the dark
- Matrix board
- Light reflecting in water
- Reflecting mirrors
- LED tiles

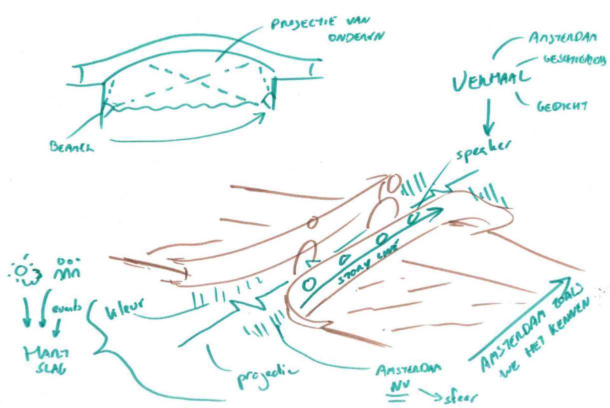
Interaction

- 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


HARTSLAG VAN AMSTERDAM
projectie
beamer
STORY OF AMSTERDAM
speakers
AMBIANCE OF AMSTERDAM
events


BRUG
RAINBOW ROAD
Richting
Tempo
Breedte Aanpassen
Uit als er niemand op staat
Begint al op zijkant zodat richting duidelijk is


PROJECTIE VAN ONDEREN
BEAMER
VERHAAL
AMSTERDAM
GESCHIEDENIS
GEDICHT
speaker
STORY LINE
kleur
events
HARTSLAG
projectie
AMSTERDAM NU
sfeer
AMSTERDAM ZOALS WE HET KENNEN

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)

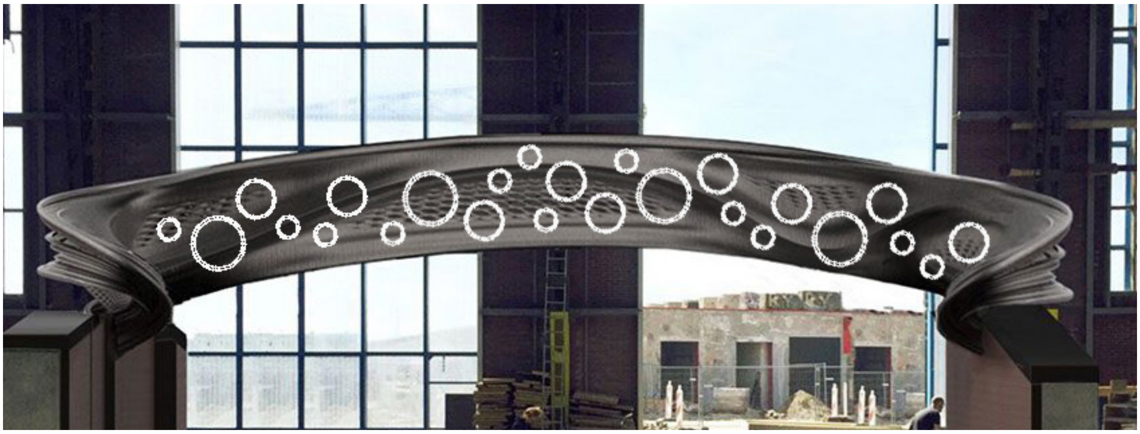
Design aspects

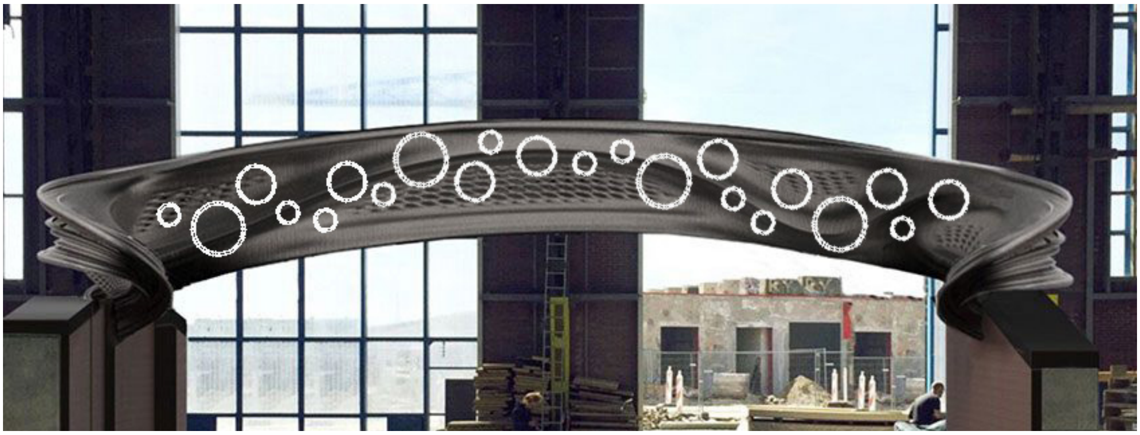
Display technology Type of lighting technology that can be used to turn the bridge into a display.	Front projection façades Light-emitting façades
Interaction style Type of input that is used to interact with the bridge.	Movement Sound None
Discoverability Ways how the interactiveness of the bridge is conveyed	<u>Visual feedback</u> Dynamic lighting Light arrows going towards bridge Information sign Warning sign <u>Auditory feedback</u> Sounds Auditory information <u>Haptic feedback</u> 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 CO2 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 1	2	3	*Neutral* 4	5	6	*Totally agree* 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 intelligent
- o expensive
- o joyful
- o respectful
- o innovative
- o adventurous
- o ordinary
- o unpleasant
- o friendly
- o boring
- o funny
- o serious
- o smart
- 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

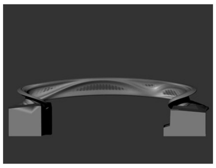
Question 6:
Which one do you like best and why?

- 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

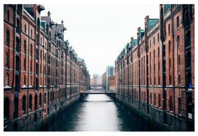


Image 1

Image 2

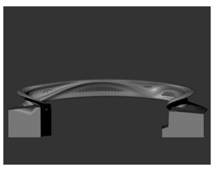
Image 3

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.

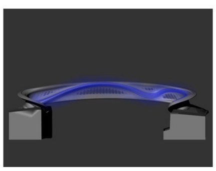


Image 1

Image 2

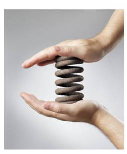


Image 3

Back

Next