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From Footsteps to Data to Art: Seeing (through) a Bridge

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From Footsteps to Data to Art: Seeing (through) a Bridge

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Abstract
While the guiding vision for IoT (Internet of Things) suggests that technology withdraws to the background, this paper explores the case of a physically visible, IoT-enabled footbridge to be placed in Amsterdam in summer 2020. The question is, how do aesthetic relationships with the bridge shift as knowledge of its IoT capabilities increase? The outcomes of user observation and two community design workshops are discussed, focusing on 1) what individuals desire to know about the bridge's IoT capabilities, 2) how to best inform users that the bridge is collecting data, and 3) what capabilities people would want a smart bridge to possess and be made explicit. It is found that a postphenomenological lens might help address changing aesthetic relationships between people and the bridge. This revelation might be useful to apply to other "smart" infrastructures.

Key Words
citizen-centered design; data; IoT; postphenomenology

1. Introduction

One promise of Internet of Things (IoT) technology is to remove humans as the intermediary between processes.[1] Rather, "things" will be able to autonomously capture, generate, and communicate data, so that the data quantity and quality accumulated by the IoT will no longer be undermined by the time limits, poor attention spans, or inaccuracies of people.[2]

While the guiding vision for IoT suggests that the technology withdraws to the background, this paper explores the specific case of a highly visible, IoT-enabled, footbridge to be placed in Amsterdam late 2020. To be more precise, the bridge, as a material object, is visible while the embedded sensor network remains invisible. Furthermore, the data acquisition and outcome of the processing will be revealed, at least to those who engage with the data.

This project is an anomaly. Most IoT projects operating in Amsterdam keep the sensor networks, data processing, and outcomes invisible to the general public. By exposing the sensing capabilities and its outcomes in real time, hopefully the project can stimulate debate on the use of IoT in public space. However, this introduces a question for aesthetics: How to allow users of the bridge to view it as an IoT object and not just an ordinary, elaborately designed, 3D printed bridge?

From the postphenomenological perspective, bridges constitute background relations. In other words, a bridge does not invite the users to directly interact but rather becomes part of the world, albeit a part which co-shapes behavior and perception of the environment. When making everyday use of a bridge, one may only notice it if poor condition or design flaws draw attention to the object.[3]

From observational research and workshop feedback, described in detail in Sections 1.1, 4, and 5, it seems that the identity of the structure and, therefore, the relationships between users and the bridge might change with added access to the sensor system. For example, when users are aware that the structure is collecting data, in simplistic terms or with basic feedback, the relationship may shift to an alterity relation, in that it becomes a plaything to stomp on or a surveillance tool to avoid. Alternatively, when the bridge “explains” the data, a hermeneutic relationship may be established and users may start to read the world through the bridge.

Thinking further, if sensors output the wrong data or the system goes out, it might affect conceptions of the physical bridge, both the interactions happening on it and the structural integrity of the material object. This could have deeper consequences if, in the future, the data is used for governance purposes.[4] Simultaneously, it is possible that, as the novelty factor wears off, the bridge might return to a background object for most users, given that, at its core, it is still a stationary infrastructure instrumental to crossing a canal.

This paper begins by outlining the research methodology and contextualizing the bridge's physical and sensor network origins. Next, the metaphysics of the bridge are explored. Finally, we address observations from Dutch Design week and the outcomes of two workshops on user expectations and desires towards the IoT-enabled bridge. From footsteps (interaction) to data (sensor readings) to art (data representation and utilization), participants attempted to see through a bridge.

1.1 Methodology

Field work for this paper includes behavioral observations from Dutch Design Week, October 20-28, 2019 and two workshops. Both workshops took place at Tankstation (http://tankstationenschede.nl/), a creative nonprofit in Enschede, the Netherlands, between April and May 2019 and lasted for about an hour and a half each.[5]

During the first workshop, "Data in the City: Ethics," thirteen participants were presented the bridge described in this paper as a case study. They were asked a series of questions on whether they would 1) want to know about data collection; 2) have the right to know; 3) have the right to know its purpose; 4) have a right to access the data, raw and processed; and 5) have the right to not be recorded. In one group of five and two groups of four, participants designed systems for data awareness for the MX3D bridge and then for universal data awareness. Groups presented their designs and individuals voted on their favorites.

In second workshop, "Data in the City: Design," twenty-one participants consented to contribute to research and were asked 1) What does "city" mean to you? 2) What aspects of a city do you find important? 3) What would you improve about Enschede? 4) What sort of information could you obtain from a smart bridge? 5) If a bridge could talk what would you want it to say? and 6) what if it could communicate with other infrastructures?

This workshop concluded with six teams designing an application that would use bridge sensor data to improve Enschede.[6] Each group came up with differing ways to utilize bridge data that while perhaps extraordinary reveal not only underlying values and conundrums of city users but also perspective changes towards responsive bridges. Participants voted on which design they would most want to implement in Enschede and their favorite overall.

1.2 Context

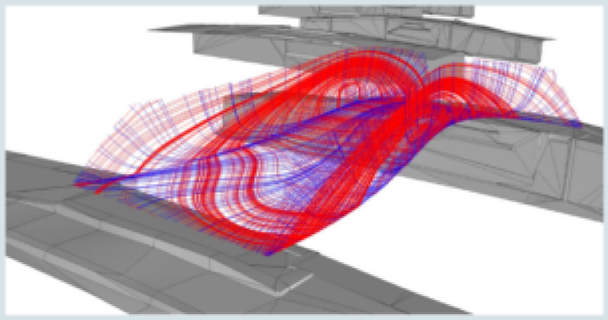
In 2014, after already 3D printing chairs, designer Joris Laarman decided that it was time to print metal. This led to the creation of metal printing robots and a freestanding multiple axis 3D printing company, MX3D. After brainstorming what structure to build to showcase their new technology, they eventually decided 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."[7]

Bridge in Process of Construction in MX3D Warehouse, by Oliver de Gruijter

As innovative as the MX3D bridge may sound, it is not the first 3D printed infrastructure in the Netherlands. The world's first 3D printed concrete bridge was installed in 2017, in Gemert, Netherlands; it is eight meters long, primarily for cyclists, and can bear the weight of two tons.[8] Currently, research is underway to 3D print the inner and outer walls of Dutch houses, with the goal that "people will be able to design their own homes and then print them out."[9] And, as far back as 2014, high hopes were set for the construction of a 3D-printed, plastic canal home in Amsterdam that appears to have never come fully to fruition.[10]

Smart bridges are also not a new concept. Sensors have been applied to bridges in recent years, in an attempt to improve infrastructural safety and security. For example, Brock Hedegaard, Catherine French, and Carol Shield published on thermal gradient effects using bridge data from Interstate 35W in downtown Minneapolis, Minnesota in 2013.[11] Their research likely transpired because the prior I35W bridge collapsed in 2007, killing 13 people and harming 145.[12] Meanwhile, Sandia National Laboratories, a contractor of the U.S. Department of Energy's National Nuclear Security Administration is building a line of sensors for checking and maintaining bridge infrastructure.[13] Given the life-or-death nature of bridge maintenance, it seems reasonable to monitor the infrastructure, especially when experimenting with new forms and materials.

From the beginning, Autodesk not only took the role of a primary sponsor for the MX3D bridge but also provided tools to design the bridge in the virtual environment. The bridge used scanning technologies of Arup so that it could fit the canal in the Red Light District where it was set to be installed. Imperial College London used sensors to test the structural integrity of the printed stainless steel. The Alan Turning Institute committed to creating a digital twin of the bridge that could be used to predict future safety concerns.[14]



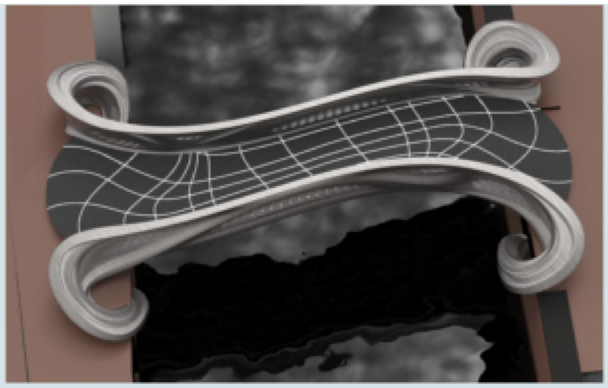
Stress Analysis, by Arup, Joris Laarman Lab

Without sensors, testing, and a digital twin, it would be harder to predict the load maximum for the MX3D bridge or determine how well it will age with time. The bridge's form was optimized digitally and built with a design requiring 3D printing. Because 3D printed stainless steel is a new material that behaves and reacts differently from traditional steel beams, and that the calculations required to estimate bridge behavior at varying loads for such a complex design benefit from computer assistance, the sensors are one with the bridge.[15]

2. Permanence

So far, the MX3D bridge has been addressed as a material object with a hidden dimension. Yet, at the time of writing, the bridge is still in the making. Printing completed in 2018, so the bridge can now be experienced as a material object. Yet, the sensor network was only completed early 2020, the frequency at which the data will consistently be captured is still unset, and processing tools are still in development.

For the time being, one can experience the material object at the University of Twente but only imagine the fully functional bridge in its final neighborhood setting. Still, even once the structure has been placed, it will only be a temporary fixture of the built environment, with an intended two- to three-year tenure in the canal.



Bridge Design Rendering, by Joris Laarman Lab

Even before printing, the conceptual bridge became visible in various computer-generated renderings and the well-documented and publicized production process. While the use of computer-generator renderings in design and architecture has become an established practice, there is a notable difference in this case because the bridge was printed from the final virtual 3D model. This makes the bridge an interesting example of what Vilém Flusser has called a “technical image” that no longer represents what exists but points to the potential of what may come; the computation and manipulation of such images becomes central to designing.[16]

If we consider the sensor-network and the material bridge as a unit, the bridge remains unfinished as long as the sensor-network is incomplete. However, it is hard to determine when, if ever, a sensor-network is complete, especially when data processing tools are constantly developing and different data usages can be imagined. At the same time, it is challenging to determine completion of the structural bridge. In order to transport the structure, the end spires have been removed, re-welded, and removed again; this is likely to happen at least once more before the bridge is placed. At least the material bridge might be “finished” when functional or when the complete model has been printed but neither of these metrics seem to work as well for the sensor system. Hence, one change that IoT-enabled infrastructures may bring is that we have to respect the duplicitous nature of digital/material objects, which makes them less finite than ”merely” material objects.[17]

Thus, the current status of the bridge invites rumination on what it might become. This openness may continue after the sensor installation is complete. The way the data is used may reshape the meaning of the bridge. Meanwhile, the mere possibility of repurposing leaves potential for transformation. The bridge could become an art project, interactive playground, node in an IoT network, tool for urban planning, or instrument of police surveillance.

As differing elements of the bridge expose themselves, the bridge will develop increased aesthetic sensibilities. In order for something to be experienced, it must be made perceptible. It needs to draw the user's attention and be picked up by some combination of senses. In the same vein, all things able to be sensed possess aesthetic qualities. The bridge itself, as a material object, can communicate through its design, materiality, and vibrations as bodies hunker across but the sensor system adds dimensions for the bridge to self-express. This expression capacity increases with awareness, visibility, and communication of data to users. As with the unusual design of the bridge, making the bridge data visible may increase attention to the structure, changing the relationship between user and object.

Postphenomenology has already proven useful in categorizing relationships between citizens and "smart" city initiatives.[18] This framework is based on the scholarship of Don Ihde and Peter-Paul Verbeek, who simplified human-technology-world relations as follows: 1) embodiment, where technology becomes an extension of self, such as the case with eyeglasses; 2) hermeneutic, where technology represents the world, such as maps; 3) alterity, where the technology presents itself as quasi-other and invites interactions, for example, vending machines; and 4) background, where technology becomes one with the world such as air-conditioning systems.[19] Depending on how the digital properties of the bridge take shape, it seems that human-technology-world relations shift as user experience moves from footsteps to data to art, as will be explored in the following sections, where we will move from the material object ("footsteps") to the sensing through and by the bridge ("data") to interactive design, where the users are made aware of the surveillance capabilities of the bridge through the bridge itself ("art").

3. Footsteps

In late October 2018, during Dutch Design Week in Eindhoven, the MX3D bridge stood on concrete blocks that formed awkwardly proportioned stairs up to its curved deck. Visitors to the bridge worked their way up the steps to walk over the bridge that hovered over flat concrete able to more efficiently transport one between either of the bridge's entryways. If one chose to peer under, instead of climbing atop, one would see sensors and wires affixed to the base that connected to more wiring. This wiring traveled under a yellow and black covering that led to a small shipping container, with servers intaking data. Researchers with tablets meandered the vicinity, offering real-time views of the sensor data, in the form of line graphs and numerical metrics.

In the context of the exhibition, people chose to walk over the bridge out of curiosity instead of need. Visitors took photos, sat in its curved spires, leaned against the railing, and ate food truck meals on the concrete blocks leading up to the entryways. Some peered underneath at the wires that, from looks alone, were not as captivating as the bridge itself. The bridge became an interactive, infrastructural spectacle, even though, during the span of the event, it was an impractical object. In fact, the bridge stood out so well that it won the people's choice award out of all the projects exhibited at Dutch Design Week.[20]

MX3D Printed Bridge at DDW, by Tim Geurtjens

Those who managed to get hold of one of the tablets, with real time feedback on load at various points along the bridge, could be found banging their hands against the rails or jumping on the deck to see simple line graphs spike. Depending on the level of engagement with the information available within the shipping container or by the tablet laden experts, one could experience the bridge differently. For some, it was a stunning example of new printing techniques; for others, it was a simple feedback system to experiment with as long as the processed data was in their hands.

Some people engaged with the data; the shipping container had information on the installed sensor network. Maybe some knew about the sensor network beforehand, and that was what brought them to the bridge. Researchers at Autodesk, in Canada, could view the data feedback without visiting the physical bridge. One could imagine that the type of data shown, its accuracy, and what it is processed to represent could have a large difference on experiential relationships with the bridge.

These levels of familiarity with the bridge are outlined in Figure 1.

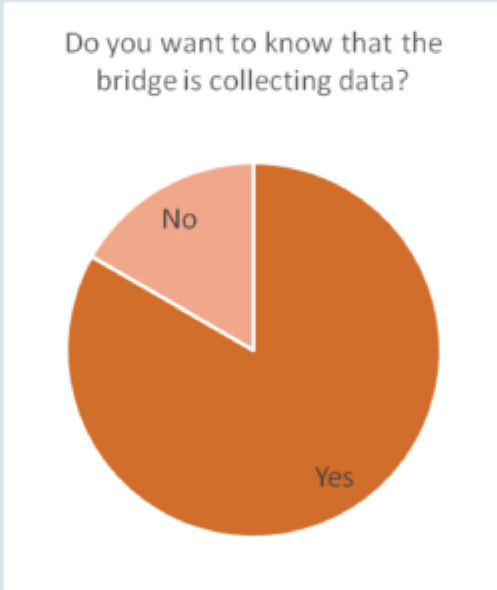
Location, too, seems to play a role on perception and usage. At MX3D, the bridge awaited placement, often unused, without any readily available means to walk across. One could hurdle oneself atop, as there were no stairs to reach the base, but for those who work at MX3D there was no prolonged need or desire to play with a functionless bridge; they already had had their fun. Currently, the bridge sits on University of Twente's campus, with steps on either end, primarily used for sensor installation and research.

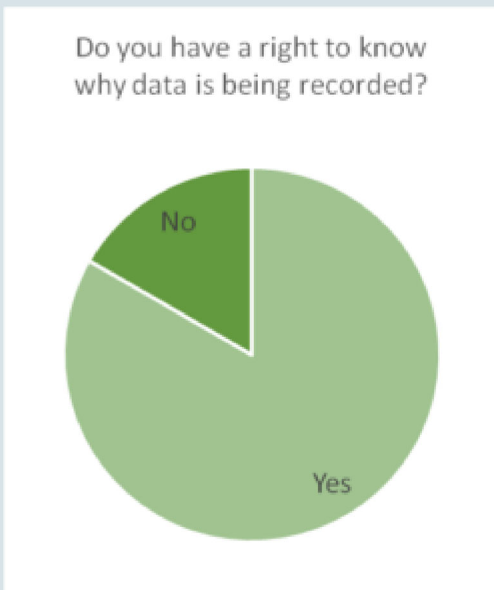
This raises the question of what will happen to the bridge when it reaches its final home in the Oudezijds Achterburgwal canal in De Wallen, Amsterdam's Red-Light District. Will a consistent flow of tourists maintain the bridge's novelty factor or will it become standardized, like the other 1,200 bridges peppering the city? In a community meeting, some residents voiced the concern that the demand to see and visit the innovative bridge may demean the practical use of the bridge (crossing) for residents and commuters.[21] The concern of crowdedness has overshadowed any apprehension of surveillance, even though the participants were informed about the sensor-network on the bridge.[22] Already, the more immediate matter of the envisioned physical bridge had taken precedence over the data for those who live in the area.

4. Data

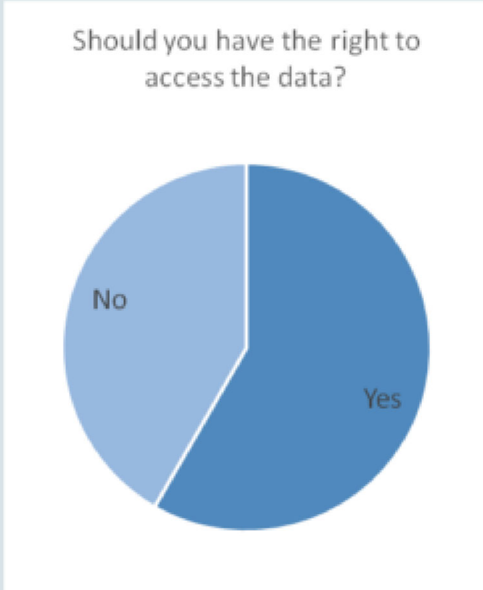
Unlike the De Wallen residents, for participants of the "Data in the City: Ethics" workshop, data collection was at the forefront of their perception of the bridge. None of the participants had experienced the bridge in person, and few were aware of the data gathering capabilities of the infrastructure before the workshop began. The goal of the workshop was to design a system for data awareness on the bridge and to make the data acquisition and processing visible. In order to do this fairly, first the participants had to determine individual rights and interests relating to the bridge's data gathering capacity. The nature of the data awareness system, or lack thereof, would influence aesthetic perceptions and relationships with the bridge.

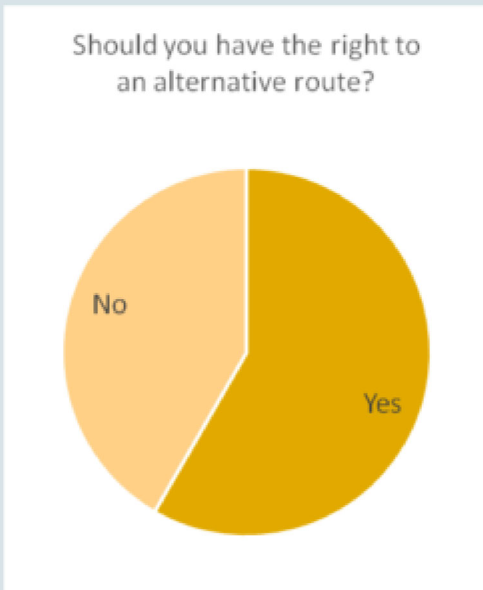
When individuals were informed about the possible desire to understand human behavior on the bridge, ten out of twelve expressed "wanting to know that the bridge is collecting data." One of the two who did not care wrote, "I don't care if it records my data because it is anonymous," while the other simply said, "No." Out of those that responded to the question asking if they had a right to know that the bridge was recording data, ten out of eleven responded that they did have a right to know. Some responses included, “Yes, it is my data” and “Yes, depending on the type of data (anonymization also matters).”





When it came to the right to know why their data was being recorded, ten out of twelve participants felt that they did have a right to know why the bridge was recording data. Moreover, three individuals specified that the why made a difference in terms of whether or not they were okay with the recording. One wrote, “Yes, definitely [...] (I’m okay if it’s used by policy makers but [...] less if advertisers use it).” Another stated, “Yes. It cannot be used for purposes without consent.” Someone felt that “multiple uses [are] not fair” and that “maybe [they] don’t want that.” One person wanted to know “just out of curiosity.”





Respondents were more divided on whether they felt that they should have a right to access the data produced from the bridge and whether it should be in raw or processed form. Five out of twelve participants felt that they did not have the right to access. One of the main concerns from both sides seemed to be that if they had the ability to access the data, everyone would also be able to access it. People also felt that they would not be able to make sense of the raw data. Generally, the responses to this question were less certain, with one respondent answering, "don't know," and another writing, "I think no." The yes responses were also more factor dependent: "Raw and processed, only data about yourself," "Yes, but anonymized, aggregated," "If there was mutual consent between both parties," "Yes, [but] not the raw one, maybe I don't know how to use it. But, processed, yes." Only one respondent was certain: "Yes, because it is my data."

People were conflicted over whether individuals had a right to an alternative route without recording mechanisms. Seven out of twelve participants strongly felt that alternate routes were necessary while the remaining five felt that, in some circumstances, they did not have this right. Some issues that were raised by this group were the type of data, how sensitive it is, how quickly it is processed and deleted, and if data collection would benefit their personal safety.

Equipped with a sense of personal rights for data awareness, groups attempted to make a system to inform bridge users that the bridge collects data. Understandably, groups could not come up with a design for the data awareness on the bridge without flaws. The favored bridge design was described to the larger group as follows:

Our idea was basically to put an interactive screen at the start of the bridge, at each end, so like a touch screen. And we would want to put a visual representation of the bridge on it.

And you can touch on the sensors and then see what each sensor is recording, why is it recording, and also who is it recorded for and who is going to use the data. What we think is the most important part is to know what is being recorded and why it is being recorded.

And in that way people can decide not to walk on the bridge if they really do not want to since the screen is at the start and if they want to, they know what is being used for. And the interactive part is just to make it interesting for people to touch the screen, [be]cause interactive things attract people, we guess.

Favored Group Depiction of Data Awareness Solution

Someone from a differing team pointed out that the tool, as described, would not work very well for blind people, which led them to update the design to have floor grooves leading people to the screens and audio, in addition to text on the interactive screen. The second most popular design included a projected visual that would alert someone to the fact that the bridge is recording data and lead them to a physical sign. The last group got so stumped trying to think of an idea to ensure no one would cross the bridge without first consenting, that they eventually envisioned a system where individuals would have to turn in a consent form to the government to pass over the bridge. Others pointed out that might be more problematic than the sensors themselves.

For the participants of the data awareness workshop, the bridge was not an element of the background but an instrument with unknown outcomes. It developed a sort of alterity relation, drawing attention away from the world, assisting a one-sided transaction. It is interesting that it was essential to each group to make the data awareness tool as noticeable as possible. This could be challenging, though, for those who do not want to know or care to know about the bridge data collection and would prefer for the bridge to not slow down traffic or distract from their day and just act like a regular bridge.

Another fascination is the degree to which why mattered for people crossing the bridge. According to the participants, it is a completely different experience feeling that one is being monitored by the government for safety reasons, a company for advertising purposes, or a random creep to please their whimsy. A final curiosity is that it mattered to people that they be informed of data gathering capabilities, even though they were less concerned about having access to the data or alternative routes. It appears that individuals have come to terms with being watched in public space but want to know that it is happening.

The findings suggest that users might still feel empowered to change their behavior within their surroundings, with accurate knowledge of their context. This concept of privacy persists in the non-IoT world, too. In public space, one can look around to see if they are being watched and then adjust their behavior. People rarely feel deserving of an alternate route through public space separate from any other sensing capable individual. Watching elevates to creeping, however, when people are covertly followed without their awareness and for unforeseen purposes. The knowledge of being watched changes one’s experience moving through space but also offers increased privacy because one can adjust one’s behavior and what is outwardly shared and captured.[23]

5. Art

Aside from bigger-picture research goals, how exactly the bridge's sensors will be used in the long term is under development, as the technology to process the data is still being formed. Nonetheless, ideas have already floated around in the media. Lidar magazine writes, "Data obtained from the sensors visualize intelligence about bridge traffic, structural integrity, and the surrounding neighborhood and environment. […] The work on this 3D printed bridge will contribute to the future of safe, efficient and data-driven engineering by monitoring the structure as thousands of people and bicycles traverse the bridge hourly once in place."[24] While the sponsors of the MX3D bridge have their own graphical representations of data in mind, users of the MX3D bridge may have no say on how the data is used or shown to them.[25]

Twenty individuals familiar with Enschede were asked a series of questions to elicit what aspect of cities they found most important and how to use bridge data to strengthen those qualities. Framing the bridge as a useful entity was important to invite a new relation with the infrastructure. For the purpose of the workshop, it was assumed that the bridge would be placed in Enschede.

People generally preferred their cities to be green, sustainable, with parks, culture, bars, cafes, art, food, events, and without excessive noise, like fireworks. These traits were coupled with strong infrastructure and a good train system. Responses were varied when it came to brainstorming the sorts of information that could be obtained from a smart bridge, not necessarily the MX3D bridge, in particular. One person imagined a bridge being able to "detect sexual assaults/sexist behavior (or other kinds of discrimination)." Others imagined being able to identify people via "behavioral ID" and perhaps being able to identify criminal behavior. One group focused on how a bridge might know more about the user's mental state from gait, facial recognition, and obstacle avoidance. One individual looked beyond humans as the primary users and thought about a bridge able to "recognize different types of birds + insects." Then there were ideas about tracking words from conversations, smart phone usage, and means of transportation used. People were also curious about tracking pollution; bridge usage, generally; and traffic flow.

When given the prompt "if a bridge could talk, what would you want it to say?" most took the question quite literally: "Look out & step aside for other people, dude!" "Hello, you are the nth passenger. I don't want it to talk," "Given that you've been in this and that neighborhood, I would suggest you check out…", "I am safe to use," "Don't jump," "Get off, you are too heavy," "Keep walking." Others suggested information people would want the bridge to share, including seismography (earthquake and structural risk), pollution level, weather, nearby criminal activity, nearby public transportation options, and positive affirmations (such as compliments).

When asked what other infrastructures they could imagine the bridge communicating with, ideas once again narrowed. Some were nervous about combining data sources. One wrote "definitely no communication with commercial industries." Another shared that they would not want it to communicate with other infrastructures "other than maybe lights." For those that contributed ideas in addition to or in absence of concerns, candidates for data communication were weather stations, pollution research centers, public transportation, traffic lights, other bridges, police, and emergency units.

Bridge of Requirement Lego Build from Participants, photograph by author

In six groups of five or less, city users attempted to design a bridge application that would work using smart bridge data. (See Table 1.) The "Bridge of Requirement," "Creativity Bridge," and "Crowd Control" were the best received by the participants but that could also be because of the presenters' ability to communicate and bring life to their design concept. The design workshop outcomes suggest that when people are given the power to think of applications that they are interested in, they may become more open to the collection process. Those at the workshop wanted access to useful data and for their city to fulfill their needs, offer peace and security, and give them flexibility in how they use their infrastructure. This contrasted to the first workshop where respondents were not invited to imagine how data usage might be useful to them as individuals.

Taking part in the development process changed the relationship between the potential users and the potential bridge. It became a tool to experience and better understand the world, as opposed to a background object or a one-way collection entity. The bridge designs ranged in levels of agency. Some, such as the "Bridge of Creativity," turned the bridge into a manipulatable object by individuals to fulfill their creative needs. Others, like the "Bridge of Requirement" and "Crowd Control," made sense of the world and communicated it back to users, creating a hermeneutic relationship between users and their bridge. The most active designs did not stop with the bridge making sense of the world but also reacting, without necessarily communicating what it "understood" or why it is reacting in a certain way. The designs, such as "Traffic Control" and "Refuel Bridge," might influence people without their direct knowledge or awareness and give individual users uniquely tailored experiences.

6. Discussion

The MX3D Bridge raises the question what it actually means to be a bridge. It is always in a state of flux, ranging from its physical system that can relatively easily be added to and subtracted from because of 3D printing, to the sensor network and its software that might be put to use for differing purposes. Is the real bridge the computer-generated model and the physical manifestation just a printed-out copy? Or is "realness" reserved for the non-digital? Given that the metaphysics of the bridge is so opaque, it seems understandable that further exposure to the digital elements of the bridge shifts relationships with the object, changing perception and therefore aesthetic experience.

Shifts in perceptions of the bridge start at the most basic level, the footsteps. Walking across the bridge creates one notion of the object, perhaps as a background feature in the built environment. But as information access grows, so might the experience of using the object. Awareness of the data gathering, including the methodology, may also change the aesthetic experience of navigating or even defining the bridge. Government safety might make certain users feel more secure while commercial involvement might make people feel indignant and objectified. Regardless, it is likely that knowledge of "by who" and "for what" may also rightfully change user behavior, allowing them to maintain a sense of agency.

Another seismic rethinking of the bridge occurs when the data becomes art, processed, visualizable, and perhaps even actionable. When the data is processed, the bridge's purpose is redefined. It is no longer just a bridge or a bridge with sensors but a communicative infrastructure. While most of the design ideas generated from the "Data in the City: Design" workshop are outside of the scope of the project, it is evident that there are use cases that citizens can imagine for the infrastructure and may even be willing to be monitored to access. Most designs involved some aspect of the bridge becoming another lens through which users understand and interact with the built environment.

The hypothesis explored in this paper might be useful to other “smart” city projects. Smart objects not only have the capability to sense more about their world but also can share that information and morph aesthetic experiences for those who use them. In order to be fair to the practitioners of public space, it is important to allow them to have honest relationships with the objects around them that increase their freedom, privacy, and awareness. Additionally, it is important to think ahead of secondary and tertiary uses of smart technology early in the process.

It is likely that if the bridge had been presented to the “Data in the City: Ethics” participants only as an anonymous structural safety device or a tool to measure pollutants and noise levels, there would have been less concern about data awareness. The irony is that it is the same sensor system that can be used for varying research goals. Load and strain are measurable forces a bridge faces, and the actors causing these on a pedestrian bridge are people. Transitioning from bridge material patterns to people patterns is not a stretch. An appropriate notification scheme could be made for one use case but later rendered insufficient for a new purpose.

There is still research to be done to see if these relational changes persist in other workshops and once the bridge is actually placed. Nonetheless, this paper marks a starting point to envision human technology relations for a singular “smart” object in public space from footsteps to data to art.

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End Notes

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[1] Luciando Floridi, "Things," *Philosophy & Technology* 26-4 (2013): 349.

[2] Kevin Ashton, "That 'Internet of Things' Thing," *RFID Journal* 22-7 (2009): 97-114.

[3] Robert Rosenberger and Peter-Paul Verbeek, "A field guide to postphenomenology," in *Postphenomenological Investigations: Essays on Human-Technology Relations*, ed. Robert Rosenberger and Peter-Paul Verbeek (Minneapolis, Lexington Books), 9-41. (For readers unfamiliar with postphenomenology, we offer a brief summary of the account in section 4.) The emphasis here is on "everyday use." For others, for example, tourists and visitors, the bridge is more likely to become an extraordinary object, something to be actively sought and experienced.

[4] As argued elsewhere, the current trend of using social media, especially Twitter data, for urban planning purposes needs scrutiny not only due to privacy implications but because data-driven urban planning may bias towards those better represented in social media. The same applies for WIFI trackers that track devices and *not* people. See: Michael Nagenborg, "Zukunft mit Daten gestalten," *Communicatio Socialis* 50-4 (2017): 450-459.

[5] Faculty ethics review board approval was obtained for both workshops. All quoted participants were informed on the nature of the research and signed consent forms to anonymously contribute to "smart" city research. In exchange, participants were informed on topics of data in cities, IoT technology, and design, in addition to being eligible to win prizes. Recruitment

was through email, word of mouth, two Facebook event pages, and the Tankstation website.

[6] For the workshop, the bridge was assumed to be installed in Enschede.

[7] “MX3D Bridge,” Joris Laarman Lab, https://www.jorislaarman.com/work/bridge-update/, accessed May 13, 2020.

[8] Agence France-Presse, “World’s First 3D-Printed Bridge Opens to Cyclists in Netherlands,” *The Guardian*, October 18, 2017, https://www.theguardian.com/technology/2017/oct/18/world-first-3d-printed-bridge-cyclists-netherlands.

[9] Daniel Boffey, “Netherlands to Build World’s First Habitable 3D Printed Houses,” *The Guardian*, June 6, 2018, www.theguardian.com/artanddesign/2018/jun/06/netherlands-to-build-worlds-first-habitable-3d-printed-houses.

[10] Sarah Zhang, “Visit This House Being 3D Printed in Amsterdam Right Now,” *Gizmodo*, March 14, 2014, www.gizmodo.com/visit-this-house-being-3d-printed-in-amsterdam-right-no-1543503640.

[11] Brock Hedegaard, Catherine E. W. French, and Carol K. Shield, “Investigation of Thermal Gradient Effects in the I-35W St. Anthony Falls Bridge,” *Journal of Bridge Engineering* 18-9 (2013).

[12] Sike Schmidt, “Making Sense of Bridges Loaded with Sensors,” *University of Wisconsin-Madison*, October 18, 2017, www.news.wisc.edu/making-sense-of-bridges-loaded-with-sensors/.

[13] Mollie Rappe, “Smarter, Safer Bridges with Sandia Sensors,” *Sandia Labs*, July 5, 2018, www.sandia.gov/news/publications/labnews/articles/2018/06-07/smart_bridges.html.

[14] Faro, “Project Update: World’s First 3D Printed Steel Bridge,” *LIDAR Magazine*, October 23, 2018, www.lidarmag.com/2018/10/23/project-update-worlds-first-3d-printed-steel-bridge, accessed February 4, 2019.

[15] Craig Buchanan and Leroy Gardner, “Metal 3D printing in construction: A review of methods, research, applications, opportunities and challenges,” *Engineering Structures*,

180 (2019):332-348, https://doi.org/10.1016/j.engstruct.2018.11.045.

[16] Vilém Flusser, *Into the Universe of Technical Images* (Minneapolis: University of Minnesota Press, 2012).

[17] From a postphenomenological perspective, material artifacts need to be considered as multi-stable, meaning that they only acquire a specific meaning when in use within a particular context. However, we argue here, that IoT objects further complicate the situation because of the flexibility of the digital side of the object.

[18] Hans Voordijk and Steven Dorrestijn, "Smart city technologies and figures of technical mediation," *Urban Research & Practice (2019)* DOI: 10.1080/17535069.2019.1634141

[19] Robert Rosenberger and Peter-Paul Verbeek, "A field guide to postphenomenology," in *Postphenomenological Investigations: Essays on Human-Technology Relations,* ed. Robert Rosenberger and Peter-Paul Verbeek (Minneapolis, Lexington Books), 9-41.

[20] "Bridge Finished & Winner Audience Award DDW," *Joris Laarman Lab*, www.jorislaarman.com/work/bridge-update-winner-audience-award-ddw/, accessed February 4, 2019.

[21] The meeting was part of the permit approval process to gauge resident interest and concerns about bridge installation.

[22] This could be due to the fact that De Wallen is already under twenty-four-hour camera surveillance in most areas. Interestingly, many of the residents have not experienced the bridge in person. The issue most pressing for them, crowdedness, might have had an additional impact on the focus of the material properties of the bridge.

[23] James Rachels, "Why Privacy is Important," *Philosophy & Public Affairs* 4-4 (1975): 323-333. Retrieved from http://www.jstor.org/stable/2265077.

[24] Faro, "Project Update: World's First 3D Printed Steel Bridge," *LIDAR Magazine*, October 23, 2018, www.lidarmag.com/2018/10/23/project-update-worlds-first-3d-printed-steel-bridge/.

[25] However, part of our research is dedicated to take a more participatory approach.

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