

From Digitalization to Capturing “Cityness”

Is it possible to make the essence of good cities measurable with sensors and algorithms?

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ABSTRACT | This paper seeks to uncover whether or not cityness can be made measurable and suggests a possible case study to operationalize cityness. Cityness is a value comprised of city users and the built environment. While it has repeatedly been confirmed that certain characteristics of cities have tangible benefits, it remains challenging to understand how and to what extent these traits can be nurtured by the built environment. Recently, however, the increasing digitalization of public space has brought new opportunities to operationalize physical properties and human interactions that lead to cityness. This article reviews and ethically examines a continuum of experiments using digital tools ranging from GIS to IoT systems to see to what extent they can successfully quantify previously intangible traits of city life. Finally, it introduces the case study of a sensor embedded 3D printed footbridge that was installed in De Wallen, Amsterdam Summer 2021. Ultimately, the bridge provides an opportunity to study how a singular infrastructure relates to cityness over time and in relation to naturally occurring events.

KEYWORDS | Cityness; Built Environment; Big Data; Digitalization

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1 Introduction

Some cities are better to live in than others. “Livability” indexes have been used to help people determine where to reside. These indexes rank outcomes of cities across domains such as stability, healthcare, culture, education, and infrastructure (The EIU 2021), but fail to capture the feeling of a city. To understand what truly makes a city a successful *city*, we must use a different term, “cityness.” This paper seeks to understand whether “cityness” can be made visible and measurable with the growing presence of digital tools in urban life. One such example is the MX3D bridge in Amsterdam, a 20 square meter 3D printed stainless steel structure equipped with a sensor system to monitor its structural integrity.

The central concept of “cityness” will be expanded upon in section three of this paper, but for now it is useful to know that the term was coined by Saskia Sassen as an alternative to Western notions of urbanism as a way to describe how people and infrastructure meld together to create new life worlds (Sassen 2010, pp. 13–18). A street can become a place for children to play baseball or the prime location to generate parking ticket revenue (or both). A corner brings together and connects the life worlds of hotdog vendors and business people. Just as the concept of “humanity” captures what we look for in the best of human beings, “cityness” functions in a similar form for cities. There are two main factors that contribute to cityness. One is the built environment. This conception of the city is mostly devoid of users and cultures, instead, emphasizing how physicality shapes usage. Alternatively, one could focus on users and their flow *through* infrastructure. From this perspective, culture, behavior and interactions define the city and shape its physicality, not the reverse. Such a mindset might suggest that any location could have “cityness” if the right people showed up and unleashed themselves upon the infrastructure. The blurry nature of the relationship between the built environment and city users can frustrate those trying to cultivate cityness.

Despite their economic, geographic, cultural, and infrastructural differences, cities have a thread that connects them – without which it would be impossible to distinguish cities from non-cities. Yet, separating out the thread into stands can be difficult as there are innumerable dependencies. Does one begin with the built environment or first work to facilitate interactions? More importantly, what makes a good city – what specific infrastructures and interactions in and around the built environment are desirable and needed?

While these questions are not new, the data with which life in the city can be studied empirically has increased with the digitalization of public space. Digital feedback mechanisms, such as mobile phones, smart cars, smart street lighting systems, and digital kiosks, are often more vigilant and consistent at recording

than humans, and, therefore, can be used to analyze behavior in spaces previously impossible to study with the same level of scrutiny. Due to the relative nascence of digital infrastructure in public space, the recently increased power to process big data, and the diversity of academic backgrounds connecting digital data to city characteristics, literature is scattered between disciplines and, therefore, inconsistently categorized.

This paper begins with the inherent relationship between cities and data in the current digital age, arguing that data collection has become a fixture of the built environment. Next, we will have a closer look at the value of cityness and why it is useful to understand how the built environment and city users come together to make thriving cities. These two sections provide the context for a brief literature review of projects connecting urban big data to concepts and aspects of cityness. This review ranges from experiments where individuals were likely left unaware of the research and outcomes (passive) to those that actively involve the data generators (active). We will analyze the benefits and shortcomings of both approaches, active and passive. The active/passive-distinction is important because it is possible to use preexisting digital technology to measure cityness and also feasible to create technology specifically with the intention of increasing or measuring cityness. Informed contributions also may have an impact on cityness itself.

This paper concludes by incorporating findings from the review to articulate data processing goals for an IoT footbridge installed in De Wallen Amsterdam in summer 2021. Given that pedestrians and cyclists function as load on the bridge, it is reasonable to expect that general usage trends may be monitored. Naturally, bridge users will actively cultivate cityness as they go about their lives passing across the infrastructure. These moments of interaction may be captured and processed, both passively and actively, to systematically analyze the intersection of built environment, city users and IoT technology over a two-year period.

2 Digitalization of the Built Environment

Data generation and processing has become a part of public space. Not just of self-identified smart cities, but of less technologically enriched locales as well. Generated largely through city users, big data is stored and accessed primarily by corporations and the government, and secondarily by practitioners of the city. From smart phones, to Google Maps, to public online review services, the conversation of cityness can hardly take place without acknowledging data, as increasingly more city artifacts are capable of digitally collecting and sharing information.

This dynamic only intensifies when one considers the volume of corporate and government owned IoT (internet of things), sensor embedded devices capable of communicating and reacting wirelessly, infrastructures increasingly proposed for introduction into public space.

City users are often unaware of the extent to which they contribute to public databases. "Public" here is a tricky term because data is commonly stored and shared in the gray area. Seemingly private data ownership frequently means shared rights between the maker of the data and the institute providing the means to capture and store it (Al-Khouri 2012). This means that the government can often access parts of seemingly private data. "Customers, Users, or Citizens," a 2016 report on Amsterdam, listed individual data collected in the city. The non-exhaustive list was extensive. It included mobile phone records, social media postings, volunteered geographic information, identity and address information, CCTV, license plate number recognition, car GPS, tax records, bank records, travel card information, WIFI data, healthcare data, pensions and benefits, drivers licenses, vehicle information, utility (water, gas, electricity) service records, education records, and criminal records (Taylor et al. 2016).

When considering future cities, the above examples might be just a taste of what is to come. IoT technologies will likely be applied to a growing subset of infrastructure. Already, smart lightening systems and walk buttons appear in a number of international metropolises such as Hongkong and Amsterdam. Smart environmental monitoring, structural health monitoring, and power grids may soon to follow. While IoT tools might seem to have a simple problem space and clear functionality, the consistency and volume of data they collect can allow for detailed analysis. For example, smart grids could be considered a privacy violation due to the fact home activity can be revealed by energy usage patterns (Tally, Rodrigues, and Wright 2019).

In 2012, Sargasso estimated that the Dutch government operated an estimated 5000 individual databases within which a resident's data could be stored (Door 2012). At the time, most Dutch citizens were only in a dozen or so, but residents with unique characteristics, such as individuals with a criminal history, disability, terminal illness, low academic attainment, social service beneficiaries, asylum seekers, and veterans, could be found in hundreds of databases (Door 2012). Unsurprisingly, not everyone is subject to the same scale and scope of surveillance and scrutiny, which creates disparities and concerns with regard to equal treatment.

While some demographics face increased data collection and scrutiny, others are excluded. Some lack the capability to use online resources and others choose to limit their online presence (Reisdorf and Groselj 2015). Meanwhile, government

can also deprioritize collecting data on certain groups either by surveilling some areas less than others or by using data collection tools that only register certain members of society. For example, individuals who own smart phones, but cannot afford unlimited data may be more likely to log in to public Wi-Fi networks.

This issue mirrors in reverse for public IoT infrastructures. Some people cannot avoid sensors in public space. They may be dependent on being tracked to participate fully in society by using infrastructures such as public transit or living in a heavily surveilled zone. In some cases, such as preventing theft, one might prefer to be part of a larger data set and feel disadvantaged if surveillance cameras were not in their neighborhood. An individual would be disadvantaged if they could not take part in a city that demands data in return for access to basic infrastructure.

Interestingly, in a study on strategies for perceived surveillance in Amsterdam, both a technical researcher and profiled individual expressed that a partial surveillance state might be worse than one with complete information as the former would be more likely to have false positives (Jameson, Richter, and Taylor 2019). This line of thought suggests that fairness and equality would mean collecting *more* data on *all* individuals so that everyone is registered under the same levels of scrutiny. Obviously, such a step would limit individual freedom, although, it seems that public space may already be digitalized to the point that freedom is irrelevant and autonomy to escape the system is restricted. From birth one is registered and captured as various data points. Perhaps the conversation will need to shift to what kind of data collection and governance promotes fairness to all members of society.

Digitalization has evolved with the city. Digital tools shape the way one navigates space: where it is light or dark, what is recommended to attend or visit, what route to take, where one feels secure or alone. All these factors have an influence on city dwellers and, thus, shape the cityness of an area. Given the degree to which cities and citizens depend on data gathering instruments, the lack of tools for users of the built environment to view their data in a form that is usable and accessible is noteworthy. Using data sources to openly measure and improve cityness might help make the data beneficial and visible to those actively contributing to these databases. The next section illustrates the value of cityness, and why, despite possible downfalls, it may be useful to use city data to operationalize the concept.

3 City Users and the Built Environment

It has been shown that certain layouts of urban environments are correlated with, and, therefore, likely to promote certain behaviors, which in turn have negative or positive associations with cityness. For example, bicycle lanes may decrease driving and walking (O'Sullivan 2017) communal spaces encourage community activity (Zhu 2015, pp. 44–53), lights decrease criminal activity and keep people out later into the night (Painter 1996), and indoor walkways between buildings may decrease business on the ground floor (Robertson 2007, p. 366). The factors are limitless, but overly grooming the built environment for cityness does not necessarily guarantee improvement.

In the 1960s American activist, Jane Jacobs, grew frustrated with the increasing presence of cars in American cities. She noted how builders of the city environment prioritized planned construction over spontaneous creation. Jacobs argued that cars and an overly architected built environment would kill the city. This led her to publish *The Death and Life of American Cities*, in which she argued that good cities require mixed land use, short street blocks, diversity of age and function of buildings, and density of people and infrastructure (Jacobs 1961). Jane Jacob's criteria for the good city imply that the wrong type of built environment would limit cityness in the American Cities she wished to protect.

Saskia Sassen expanded upon Jacob's approach, settling on the notion of "cityness" as a rejection of the previously westernized mindset on the ideal urban environments (Sassen 2013). She argues that cities require a level of unfinished-ness (Sassen 2013, p. 209). Leaving a purposeful gap in designing for cityness allows urban initiative to creep through the cracks. Sassen also notes that differing cultures will affect cityness differently in similar built environments (Sassen 2005, p. 1). In China, a locale may not need to be made "public" or given a designed purpose to turn into a community center. Community members are much more likely to pull up chairs and play mahjong at a bus stop in Shanghai than in Los Angeles, CA (Sassen 2005, p. 1).

Cityness reveals itself differently amongst varying cultures. The values that drive the feeling of a good city do not differ wildly, but the forms in which user initiative and the built environment take shape may vary greatly. For example, it is generally accepted that walking promotes health and elongates individual lifespans (De Nadai et al. 2016). Additionally, walking may result in more interactions within the built environment. Walkers may engage with stores, restaurants, parks, markets, or other individuals (Rogers et al. 2011). Yet, "walkability" is not a trait of cityness – rather, it is a value designed for in the built environment. Only the degree to which people *actually* walk and the interactions fostered by their move-

ment can have a bearing on the cityness of a locale.

Los Angeles, notorious for its urban sprawl has now become a popular zone for electric scooter rideshares (Fonseca 2019). This is unlikely a coincidence. An infrastructure built to support cars, mixed with tourists, traffic, warm weather, and those who cannot afford automobiles becomes a reasonable space to scoot. Ricky Burdett, Urban Studies scholar at London School of Economics has suggested that it is time to delve deeper into Sassen’s notion of cityness and focus on cities themselves. He points out that one would never mistake “Londoness” with physical essences of New York City, Hongkong, or Mumbai (Burdett 2012, p. 92). Such a framing may be useful when connecting city users to the built environment.

As Burdett argues, the spatial flavor of a city is strongly linked with an area’s sense of identity. This claim can be taken further still. Within each city, different districts have their own life and individuals operate bound by the rules of the subcultures. Cityness exists too in the microsites, that, upon zooming out, form thriving or failing metropolises. Cityness might be best thought of in the lens of Wittgenstein’s family resemblance (Wittgenstein 1953). Certain traits may stand out and link differing individuals together. Some traits might be more dominant than others. Two members of the same family might not even have any overlapping traits even though they overlap with other members of the group. In other words, cities that look and operate quite differently can still have a high degree of “cityness.”

Separating cityness into factors of user initiative and the built environment allows for measurement, division, and comparison in a way otherwise impossible by staring blankly at the macro city and its cityness. While attempts have been made for generations using sporadic manual counts to better understand how the city operates and functions (Shuldiner and Shuldiner 2013), until recently, consistently measuring relationships between city users and the built environment has been challenging due to the fact that cityness is formed by forgotten and often invisible interactions.

As philosopher, Michel de Certeau poetically captured in the 1980s, “The ordinary practitioners of the city live ‘down below,’ below the thresholds at which visibility begins [...] they are walkers [...] whose bodies follow the thick and thins of an urban ‘text’ they write without being able to read it” (De Certeau 1988). This dynamic of the practitioners of the city actualizing cityness in a way impossible to continuously “read” is swiftly changing with the growing presence of data gathering in public space – now more invisible interactions can be revealed at a higher volume and clarity than ever before.

4 Capturing Cityness

Some mixture of urban initiative and built environment design should generate normatively positive outcomes such as beauty, tranquility, safety, sense of belonging, and navigability. These outcomes are positive values ascribed to cityness. With increasing forms of data in the public sphere, it becomes relatively easier to quantify empirically how cityness operates in varying urban locales. While it may be impossible to fully capture the essence of cityness, some underlying values may be more easily quantified. Surveying a range of studies and experiments in this domain makes it easier to determine what works and what does not to identify possibilities for future research.

To study the existing scholarship and literature in this domain, studies were found by first querying the following combinations of search terms in Google Scholar, Springer, and Science Open databases: ["cityness," "urbanism," "city," "built environment"] AND ["IoT," "data," "measure."] Second, filters were utilized to further narrow the papers to English manuscripts, published within the past twenty years that used IoT technology and or big data to capture and operationalize features of cityness. Relevant citations from these articles were also added in addition to incidental finds. Remaining works were further narrowed to those that could convey a diversity of current approaches. While all studies relate to cityness, capturing cityness was not the intent of all the authors listed. Variety was prioritized over representation. Some topics such as "walkability" have a greater body of supporting research while children's perceptions of cities are harder to find.

Finally, the distilled 13 studies were divided between passive and active techniques. Passive techniques operationalize (aspects of) cityness using big data and pre-existing datasets without outside participation from the practitioners of the city. Active techniques, conversely, employ the data sharers into the operationalization process. Admittedly, the distinction between passive and active technologies is not always clear cut. A narrow and strict understanding of "active technologies," would only include data that users of an urban space willingly and knowingly provide input for the measurement. With social media data, e.g., it might not always be clear, what is considered to be active. Clearly, the secondary use of data should be considered as passive. While the users do actively provide input to the social network, they do not intend to participate in research or a study. However, if a specific group consciously allows a researcher or a municipality to monitor their social media data, we may consider the approach to be active.

4.1 Capturing Cityness with Passive Techniques

There are some positive aspects of passive data collection techniques including lowering opt-out bias. In participatory or active systems, typically people can choose whether or not to take part in data collection or the degree to which they are involved. Those with more knowledge or who can afford alternatives might opt out thus making the data less representative. Conversely, if people are not aware that they are being recorded they are much more likely to “act normal” thereby making the data more accurate. It is also worth noting that this may also work in reverse, sometimes the least privileged lack access to “standard” devices like credit cards and cellphones. Therefore, conclusions from general population data would naturally bias the privileged.

Moreover passive techniques for operationalizing cityness with IoT technology often involve the secondary use of data or function creep. “Function creep” refers to when a device originally designed for one intended purpose is used for another (Dahl and Sættnan 2009). One result of function creep is the lack of freedom for participants to choose their research contributions. This is not solely an issue of the initial data collection itself, which was likely already consented to without a clear informative process or access to alternatives, but the lack of awareness of *what* they contributed to and its outcomes. Passive techniques also leave researchers to determine *why* certain data processing outcomes were found instead of allowing the data producers to inform. This could lead to inaccurate conclusions from data analysis and false future predictions if behavior shifts for cultural reasons not captured in the data.

Among passive techniques, call detail records (CDRs) were the most common form of data collected for analysis. Researchers would access anonymized sets of data from telecom companies and use the data for a variety of purposes including determining commuter behavior (Kung et al. 2014) and tracking individual locations to find important places in individual’s lives (Isaacman et al. 2011). Cell phone usage patterns were used to estimate regional poverty rates (Smith-Clarke, Mashhadi, and Capra 2014) and urban behavioral differences across continents (Grauwin et al. 2014). None of these studies made any mention of informing the main data group that their anonymized cell phone data was used or the results of the study. The one exception was a group of primarily friends and colleagues used to train machine learning systems to identify important locations in people’s lives, that machine learning system then was used to make sense of a large anonymous dataset (Isaacman et al. 2011).

Digital collaborative platforms such as Foursquare, Fliqr and Twitter were also well utilized. Foursquare was used to help determine “mixed use” areas in an

Italian study to verify Jane Jacob's criteria for good cities (De Nadai et al. 2016). Foursquare and Fliqr were used to operationalize two theories relating city user initiative and the built environment to street safety (Quercia et al. 2015). Foursquare and Twitter data were used to connect built environment attributes and social network updates to crime rates throughout New York City (Yang et al. 2018). These researchers found that categories "Argentinian Restaurant' and 'Mexican Restaurant' [...] will probably lead to a prediction of crime incidents. On the other hand, [...] 'College Auditorium' and 'College & University', [...] will reduce the probability of crime incidents" (Yang et al. 2018). This finding is interesting when US college campuses are notorious for crimes like underage drinking, sexual assault, and drug use. This outcome suggests that the pre-existing dataset used to train the crime predictions may have been already biased. Likely, a combination of the types of crime the researchers chose to target and the reality of which groups are more heavily policed led to these correlations.

In order to make the sensor data useful, nearly all studies had to corroborated by pre-existing data. This took the form of census records (De Nadai et al. 2016; Grauwin et al. 2014; Isaacman et al. 2011; Smith-Clarke, Mashhadi, and Capra 2014), land use data (Grauwin et al. 2014), mapping data (Isaacman et al. 2011), poverty rate estimates (Smith-Clarke, Mashhadi, and Capra 2014), and open crime data (Yang et al. 2018; Quercia et al. 2015). Essentially, validation of the new big data systems was frequently performed by correlating findings with older and or less precise, non-digitally sourced systems. On one hand, there is a desire for quicker and more accurate data systems, on the other, these systems require validation and calibration from pre-existing non-digitally sensing sources.

As much as big data combined with machine learning has the potential to be more precise than prior systems, building it often involves training correlations on earlier, possibly more biased data. Due to this, it could be possible that real world improvements may not be captured in machine learning systems based off historic trends – especially when "the sensed" are not actively involved in adjusting the system. See Table 1 for a full overview of experiments referenced, including data used, techniques, and purpose in association with the corresponding city.

Table 1: Passive Experiments Operationalizing Cityness

	CITIES	“CITYNESS”	DATA	TECHNIQUE
(Grauwin et al. 2014)	London, New York, Hong Kong	Universality in cross cultural mobile activity	Aggregate 3G mobile traffic data (# of calls, SMS, requests, amount of data downloaded) and census and land use data	Used K-means clustering of pixelized mobile activity. Distinguished moving and call patterns between regions within cities and then between all cities.
(Isaacman et al. 2011)	Los Angeles, New York, New Jersey Counties	Favorite locations across cities	Call detail records (CDRs), US census for validation	Used clustering and regression of CDR tower start and end locations to predict where people frequent across days.
(Kung et al. 2014)	Ivory Coast, Portugal, Boston, Saudi Arabi, Milan	Universality in commute patterns	Call detail records (CDRs), GPS car data for Milan	Determined location for home and office from CDR using time of day and call frequency. Commute time = time between locations for those who call every hour average.
(De Nadai et al. 2016)	Bologna, Florence, Milan, Palermo, Rome, and Turin	Mixed use, small blocks, building (age/form), density	Mobile phones, Italian census records (ISTAT), Open Street Map, Urban Atlas, Foursquare	Built regression models for each criteria using various combinations of datasets.

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Table 1: Passive Experiments Operationalizing Cityness

	CITIES	“CITYNESS”	DATA	TECHNIQUE
(Quercia et al. 2015)	London	Jane Jacob’s safety criteria: “eyes on the street” and Jeff Speck’s walking criteria: useful, safe, interesting, comfortable	Mapping data, Foursquare, Flickr, Walkonomics (app derived by one of the authors that combines user input and government data – including crime rates – to rate street walkability)	Analyzed data in correlation with research questions – can walkability be found from user photo tags or presence of specific types of places? Can safety be determined from night activity, activity segmented by gender/age, or the presence of types of places?
(Smith-Clarke, Mashhadi, and Capra 2014)	Cote d’Ivoire, Anonymous Region ‘B’	Regional poverty	Poverty rate estimates from International Monetary Fund, census data, call detail records (CDRs)	Linked and correlated CDR mobile activity levels to poverty levels.
(Yang et al. 2018)	New York City	Safety, regional aesthetics	Twitter, Foursquare, Open Crime Data	Used historical crime data, features extracted from Twitter and the built environment (Foursquare), and linked them to see which combination worked best under a variety of statistical analysis techniques, including neural networks and logistic regression.

4.2 Capturing Cityness with Active Techniques

Active techniques also come with their own positive and negative consequences. Actively receiving input from individuals often forces subjective outcomes even when the data is meant to be quantitative. For example, individuals can choose whether or not to take part in the data gathering process, thereby making all results only reflective of interested parties. Processing and formatting qualitative

data (as opposed to quantitative) can be more difficult because there is no "standard" human, unlike sensing devices that are built to operate equivalently. Feedback on metrics such as beauty or safety may differ greatly on an individual level. Two people could describe and interact with the same built environment differently.

Gathering feedback in the form of questionnaires and surveys, even when quantitative, can be time intensive and may also require overcoming possible language barriers. In addition, transforming qualitative data into a quantitative format can be challenging. For example, different standardization methods may lead to opposing results. It is also harder to maintain the constant active feedback systems that might be inherent to more passive, sensor laden, techniques. Also, since qualitative work often involves eliciting the opinions and permission of individuals, anonymity is harder to achieve. The calculations become groupings of individual's *thoughts* as opposed to group *behavioral* trends.

Still, there are some clear positives to active cityness and IoT research. First, opinions are inherent to understanding perceptions of the city. Behavior might take up one aspect of urbanism, but to fully understand how the city works it is useful to know why people are compelled to perceive the city in a certain way. Instead of collecting and processing data to find patterns and then later hypothesizing about why certain behaviors occurred, active research seems to better answer the question of why and then find the behaviors associated with that perception.

There were differing forms of active techniques used to operationalize the concept of cityness using big data with many of the digital tools made to receive input or be viewed or interacted with by individuals. Google Street View was commonly utilized as it allowed participants to virtually interact with and therefore provide feedback on the built environment. Two experiments had platforms for online participants to use Google Street View to rank images for values such as "tranquility," "beauty," "happiness," "safety," and "wealth" (Dubey et al. 2016; Quercia, O'Hare, and Cramer 2014). The results of these surveys were used to train machine learning systems that could predictively score a street image according to value driven criteria. These examples are considered active because the machine learning algorithms developed relied on informed participation.

Geographic information systems (GIS) were also employed because they can layer data on top three-dimensional maps, embedding greater significance into the projection. GIS was used to determine walkability based on macro and micro elements of the built environment (Zandieh et al. 2018). The GIS system contained the environmental attributes that might not be captured on a regular map that could impact walking patterns. This experiment also surveyed older adults to see their thoughts on what areas they considered walkable and why. A study on

children's perceptions of the city used GIS to mark areas that the children found "comfortable," "a sense of belonging," and other criteria (Alarasi, Martinez, and Amer 2016). Generally, human feedback combined with location data was popular in active research; in one study, Twitter data was combined with surveys to see if tweets could predict regional quality of life (Zivanovic, Martinez, and Verplanke 2020).

Perhaps the most interesting case is SmartSantander and the Pace of the City mobile phone applications. In this instance, users of the applications agreed to share sensor data from their mobile phones and also usage behavior within the application in exchange for city data and aggregated data from other users (Gutiérrez et al. 2013). Monitoring usage behavior allowed researchers to understand trends in how the application was utilized. The concept was that instead of a top down corporate or government enforced smart city, city practitioners were the producers and consumers of the smart city and its data. Nonetheless, having one entity that processes, organizes, and also studies how city users produce and consume data may be too structured and diminish "unfinished-ness" and therefore, according to Sassen's line of reasoning, may also reduce *cityness*.

Active approaches to measuring cityness generally avoided the need to corroborate or calibrate data with older data sets like census records. There was one exception in this short overview. In the study to measure walkability, transportation data was utilized along with questionnaires (Zandieh et al. 2018). Still, it is unclear if active feedback is necessarily better or worse than larger, pre-existing datasets due to issues like opt in bias, but at least they may give a more detailed and up to date reasoning than solely quantitative data points. For an overview of the studies presented, see Table 2, where the city, value of cityness, data, and operationalization techniques are highlighted.

Table 2: Active Experiments Operationalizing Cityness

	CITIES	“CITYNESS”	DATA	TECHNIQUE
(Alarasi, Martinez, and Amer 2016)	Enschede	Social integration, Community space, belonging, comfort, variety of activity, interest	Participatory mapping, focus group discussions, guided tours, interviews, GPS, photo/voice recordings, Google Earth, Google Street View, Geographic Information Systems (GIS)	Children mapped their perceptions of the city, toured the city, stopped to take photos and tell narratives in certain areas, and had lengthier interviews on their perceptions of the city. All steps were combined into a GIS tool.
(Dubey et al. 2016)	(56 major cities from 28 countries)	Safe, lively, boring, wealthy, depressing, beautiful, universality	Google Street View images, crowdsourcing results	Crowdsourcing ranking game for humans to rate images as more or less (safe, lively, etc.) and neural networks for computer to predict rating of new images.
(Gutiérrez et al. 2013)	Santander	Citizen participation (data sharing and engagement)	Public government data, phone sensor data (GPS, acceleration, temperature, humidity, etc.)	Crowdsourced mobile phone sensors aggregated information which then was shared back to the users of the Pace of the City application. Additionally, people could upload information such as events. SmartSantander, another application, took available city data and along with user data and shared it using maps and augmented reality.
(Quercia, O'Hare, and Cramer 2014)	London	Tranquility, beauty, happiness	Google Street View, Geograph (broke up into colors, textures and words), crowdsourcing results	Crowdsourcing ranking game for humans to rate images as more or less (tranquil, beautiful, safe) and three computer vision techniques (color, texture, object) to predict rankings of new images.

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Table 2: Active Experiments Operationalizing Cityness

	CITIES	“CITYNESS”	DATA	TECHNIQUE
(Zandieh et al. 2018)	Birmingham	Walkability based on macro and micro environmental attributes	Geographic Information Systems (GIS), transportation data, questionnaires	Elderly population surveys were done to gather information on the micro environment. This was combined with macro GIS data on the built environment and both were compared to transportation data to see the correlation between built environment attributes and walking.
(Zivanovic, Martinez, and Verplanke 2020)	Bristol	Quality of life	Twitter, quality of life surveys	Automated sentiment analysis of tweets, rating positive and negative in a five point scale. This data was compared to quality of life surveys.

5 IoT Smart Bridge and Cityness

Before moving forward, it may be helpful to review whether any of these studies were successful in measuring cityness. Returning to Wittgenstein’s family resemblance, no singular trait can individually be said to capture cityness. Choosing to focus on a subset of characteristics may also overlook equally important cityness factors that may occur to a greater magnitude in a different location. There is a possibility that in the process to operationalize cityness we shift to a world where cityness becomes defined by quantitative characteristics instead of a qualitative sense of place. This blurring may intensify as machine learning tools adapt to make more features able to be sensed. As more qualitative features become measurable, cityness may come to be understood by the less subjective machine as opposed to the masses of city practitioners. Such a formulation for cityness may lack the very nuance that we seek by using the term over others such as “livability.” Conversely, there may eventually be a plethora of algorithms in disagreement over what constitutes cityness. This scenario however does seem to fit the trend of technology aligning to standardized forms of measurement.

Another less dramatic conclusion that may be more likely in the near future is that as digital technology becomes further infused with the built environment, these technologies themselves will have an effect on cityness and be able to communicate their role back to us (Cammers-Goodwin and Nagenborg 2020). When looking towards future cities, the capabilities to gather both quantitative and qual-

itative data digitally is expanding. Smart lamp posts already exist, but there is room to go further, the city of Den Haag, the Netherlands sponsored research on citizen reactions to a lamp post that could parse conversations and talk to passerby (Leeuwen et al. 2018). These tools will be embedded in the built environment and how they are used will be shaped by city user initiative. At the same time, IoT infrastructure will have a large impact on cityness and offer unique data to study it. The question is how to determine what is useful and what is necessary. In order to begin to answer some of these questions the BRIDE project is beginning empirical work on the sensor embedded MX3D bridge.

The 20 square meter surface area of MX3D's 3D printed stainless steel bridge has the potential to act as a nervous system for the region it creates. The structure itself physically adds usable area to the built environment, but through an artistic form, and unlike most current infrastructures has the ability to “feel” what is happening to it. Embedded into its body is a sensor system that can measure acceleration, incline, strain, and temperature, among other criteria. Pending city approval, on each side, a camera will be stationed that skeletonizes human movement, transforming the image into a JSON file of stick figure coordinates. Actual video footage will not be accessible to most researchers and will be deleted within six months. The sensors will primarily be used to ensure and test the structural integrity of the bridge. This is useful because 3D printed stainless steel is a relatively new material and the bridge was designed with optimization software in a virtual replica of the canal in which it is to be placed. The sensors embedded on the bridge will offer security in the space of uncertainty inherent with new forms of construction.

The bridge, which is installed in Amsterdam's centrally located Red Light District has the secondary possibility to operationalize local cityness. With the sensor data one can measure how usage of infrastructure changes for city users based on local temporal changes such as time of day, day of the week, season, and events. Ongoing qualitative research has informed what aspects of data most interest individuals ranging from tourists to commuters to residents.

People are most interested in data that they can understand such as load and temperature as opposed to acceleration, for example. Data visualizations are currently provided to the public through the bridge website thus creating a feedback loop

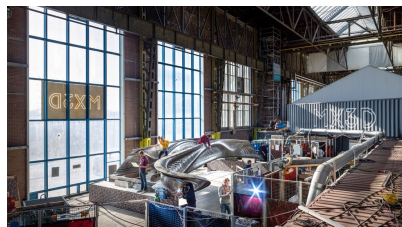


Figure 1: MX3D Printed Bridge 2018, photo by Thijs Wolzak.

connecting city practitioners, sensors, and the built environment.¹

Operationalization is planned to work by using partially active participation to recognize general bridge behaviors which can be translated into machine learning algorithms that connect sensor feedback to bridge activities with varying levels of certainty. At the base of the bridge are small plaques that show that the bridge is smart and also link to a site with additional information. The external site informs 1) that the bridge is collecting data 2) what data is collected 3) who is collecting the data, and 4) what are the research purposes. Theoretically, a user of the bridge could know that the bridge is collecting data, especially those that live and commute in the area. However, it is also probable that for most inebriated tourists, children, those with visual impairments, and the average pedestrians whose eyes are not searching for signs, their contributions will be passive. The long-term goal is that anonymous data from the bridge can be transformed into useful feedback to the public. It should be noted that goals like these easily become justifications for public data collection whose primary interests will not enhance the lives of those who contribute to research (Cammers-Goodwin and Stralen 2021). Admittedly, operationalizing cityness accounts for a fraction of the research utilizing the bridge data, which mainly centers on civil engineering interests.

Of course, a singular bridge in an iconic area cannot be used to make city-wide generalizations on cityness. The area is too small and both the region and the bridge are too specific. Nonetheless, understanding how the region functions might help inform improvements for all user groups. Residents of the area are notoriously concerned about crowdedness, understanding factors that generate more crowds, or, better yet, *less* crowds, may make the area more pleasant and safe for all involved, especially if the measures taken do not diminish the cityness of the area. In fact, concern over crowdedness is so strong that, pre-placement, surveillance was not a primary interest for bridge users or current residents of the De Wallen area, whose main apprehension is the bridge generating more visitors.

A prototype of how the bridge may inspire and help operationalize cityness occurred in October 2018 during Dutch Design week, where the bridge took home the People's Choice Award. Most passerby were taken with the physical structure of the bridge despite technologists walking around with tablets displaying live feedback from load sensors and accelerometers adhered to the underside of the deck. Even though the bridge hovered over flat ground at the event, people gathered and leisured on the structure, banging on the walls, jumping on the deck, and taking photos. Compared to the studies examined in the prior section, the bridge being an infrastructure that happens to be "smart" has a closer relationship to cityness

¹ See: <https://www.smartbridgeamsterdam.com/>.

The bridge effectively generated activity that would not have occurred without the presence of the structure. The bridge, *the built environment*, inspired cityness.

6 Conclusion

The complex multivariable system that gives identity and flavor to the city can be distilled into cityness and further understood as the symbiotic relationship between urbanism and the built environment. Understanding cityness has long term value to the practitioners of the city. With the increasing presence of pre-existing data, data gathering instruments within cities, and tools to elicit qualitative data from city practitioners, operationalizing the factors that generate positive city values is more feasible than ever. In fact, attempts to connect city values to big data sources have already been attempted with call detail records, social media, satellite, Google Street View, phone sensors, online surveys, geographic information systems and other digital tools. The possibility to have a detailed understanding of infrastructure and city user behavior with sensor embedded IoT, however, has yet to reach its full potential. Furthermore, the consequences of such work and appropriate measures for future research have yet to be outlined. The MX3D 3D printed bridge provides an opportunity to explore these unknowns by creating a living laboratory of city practitioner engagement. Users of the bridge can be informed that the bridge is collecting data, and be able to learn from who and for what purpose. The bridge can also serve as a case study to determine if the positive aspects of understanding and cultivating cityness outweigh some of the ethical concerns raised in this paper. This will depend on how the research is conducted and to what extent the research is successful. Hopefully, through qualitative research, not only can behavior be studied, but also *why* groups engage in certain behaviors. Practical data findings can be returned to city users so that the data they generate may be of benefit to them.

Finally the bridge is an opportunity to study local cityness in De Wallen, Amsterdam and understand regional urbanism in relation to times of day, days of week, seasons, and events. There are bound to be complications along the way and questions to be answered about privacy, security, data accuracy, and processing. The issues that occur in this transparent process will hopefully inform future smart city research. Essentially, the MX3D bridge is a case study for what could become the new normal. It is an opportunity to research how smart cities should (and should not) operate to maintain cityness.

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References

- Alarasi, Haifa, Javier Martinez, and Sherif Amer. 2016. "Children's perception of their city centre: a qualitative GIS methodological investigation in a Dutch city." *Children's Geographies* 14 (4): 437–452. <https://doi.org/10.1080/14733285.2015.1103836>.
- Burdett, Ricky. 2012. "Mapping Scales of Urban Identity." *Architectural Design* 82 (6): 92–97. <https://doi.org/10.1002/ad.1501>.
- Cammers-Goodwin, Sage, and Michael Nagenborg. 2020. "From Footsteps to Data to Art: Seeing (through) a Bridge." *Contemporary Aesthetics* 8 (Special Issue). <https://contempaesthetics.org/2020/07/16/from-footsteps-to-data-to-art-seeing-through-a-bridge/>.
- Cammers-Goodwin, Sage, and Naomi van Stralen. 2021. "Making Data Visible in Public Space." *McGill GLSA Research Series* 1 (1): 1–32. <https://doi.org/10.26443/glsars.v1i1.120>.
- Dahl, Johanne Yttri, and Ann Rudinow Sætnan. 2009. "'It all happened so slowly' – On controlling function creep in forensic DNA databases." *International Journal of Law, Crime and Justice* 37 (3): 83–103.
- De Certeau, Michel. 1988. "Walking the City." In *The Practice of Everyday Life*, translated by Steven Rendall, 91–110. London: University of California Press.
- De Nadai, Marco, Jacopo Staiano, Roberto Larcher, Nicu Sebe, Daniele Quercia, and Bruno Lepri. 2016. "The Death and Life of Great Italian Cities: A Mobile Phone Data Perspective." In *Proceedings of the 25th international conference on world wide web*, 413–423. <https://doi.org/10.1145/2872427.2883084>.

- Door, Steeph. 2012. "Meer dan 5000 databases met persoonsgegevens bij overheid." *Sargasso* 10. <http://sargasso.nl/meer-dan-5000-databases-met-persoonsgegevens-bij-overheid/>.
- Dubey, Abhimanyu, Nikhil Naik, Devi Parikh, Ramesh Raskar, and César A. Hidalgo. 2016. "Deep learning the city: Quantifying urban perception at a global scale." In *Computer Vision - ECCV 2016*, 196–212. Lecture Notes in Computer Science. https://doi.org/10.1007/978-3-319-46448-0_12.
- Fonseca, Ryan. 2019. "Scooters, Scooters Everywhere. Here's How LA's Grand Experiment Is Going." *LAist*. <https://laist.com/news/las-big-scooter-experiment>.
- Grauwin, Sébastien, Stanislav Sobolevsky, Simon Moritz, István Gódor, and Carlo Ratti. 2014. "Towards a Comparative Science of Cities: Using Mobile Traffic Records in New York, London, and Hong Kong." In *Computational approaches for urban environments*, edited by Marco Helbich, Jamal Jokar Arsanjani, and Michael Leitner, 363–387. https://doi.org/10.1007/978-3-319-11469-9_15.
- Gutiérrez, Verónica, Jose A Galache, Luis Sánchez, Luis Muñoz, José M. Hernández-Muñoz, Joao Fernandes, and Mirko Presser. 2013. "SmartSantander: Internet of Things Research and Innovation through Citizen Participation." In *The Future Internet*, edited by Alex Galis and Anastasius Gavras, 173–186. Future Internet Assembly. Berlin: Springer. https://doi.org/10.1007/978-3-642-38082-2_15.
- Isaacman, Sibren, Richard Becker, Ramón Cáceres, Stephen Kobourov, Margaret Martonosi, James Rowland, and Alexander Varshavsky. 2011. "Identifying important places in people's lives from cellular network data." In *Pervasive Computing*, edited by Lyons Kent, Jeffery Hightower, and Elaine Huang, 669:133–151. Lecture Notes in Computer Science. https://doi.org/10.1007/978-3-642-21726-5_9.
- Jacobs, Jane. 1961. *The Death and Life of Great American Cities*. New York: Random House Inc.
- Jameson, Shazade, Christine Richter, and Linnet Taylor. 2019. "People's strategies for perceived surveillance in Amsterdam Smart City." *Urban Geography* 40 (10): 1467–1484. <https://doi.org/10.1080/02723638.2019.1614369>.
- Al-Khouri, Ali. 2012. "Data Ownership: Who Owns 'My Data'?" *International Journal of Management & Information Technology* 2 (1): 1–8. <https://doi.org/10.24297/ijmit.v2i1.1406>.

- Kung, Kevin S., Kael Greco, Stanislav Sobolevsky, and Carlo Ratti. 2014. "Exploring universal patterns in human home-work commuting from mobile phone data." *PloS One* 9 (6): e96180. <https://doi.org/10.1371/journal.pone.0096180>.
- Leeuwen, Jos P. van, Arn van der Pluijm, Adriaan Doove, Daniël Steginga, Antti Jylhä, Dirk van Brederode, Arnold Jan Quanjer, Gerrit Jan van't Veen, Maarten Duindam, and Bram van Hasselt. 2018. "Kunstmatige intelligentie in de publieke ruimte van Scheveningen." (The Hague), <https://www.persistent-identifier.nl/urn:nbn:nl:hs:17-f8b1efdb-od94-4afo-8d29-d028b26c842f>.
- O'Sullivan, Feargus. 2017. "Breaking Down the Many Ways Europe's City-Dwellers Get to Work." *City Lab* 18. <https://www.citylab.com/transportation/2017/10/riding-bikes-buses-trains-in-european-cities/543141/>.
- Painter, Kate. 1996. "The influence of street lighting improvements on crime, fear and pedestrian street use, after dark." *Landscape and Urban Planning* 35 (2-3): 193-201. [https://doi.org/10.1016/0169-2046\(96\)00311-8](https://doi.org/10.1016/0169-2046(96)00311-8).
- Quercia, Daniele, Luca Maria Aiello, Rossano Schifanella, and Adam Davies. 2015. "The digital life of walkable streets." In *Proceedings of the 24th International Conference on World Wide Web*, 875-884.
- Quercia, Daniele, Neil Keith O'Hare, and Henriette Cramer. 2014. "Aesthetic capital: what makes London look beautiful, quiet, and happy?" In *Proceedings of the 17th ACM conference on Computer supported cooperative work & social computing*, 945-955. <https://doi.org/10.1145/2531602.2531613>.
- Reisdorf, Bianca C, and Darja Groselj. 2015. "Internet (non-) use types and motivational access: Implications for digital inequalities research." *New Media & Society* 19 (8): 1157-1176. <https://doi.org/10.1177/1461444815621539>.
- Robertson, Kent A. 2007. "Pedestrianization strategies for downtown planners: Skywalks versus pedestrian malls." *Journal of the American Planning Association* 59 (3): 361-370. <https://doi.org/10.1080/01944369308975887>.
- Rogers, Shannon H, John M Halstead, Kevin H Gardner, and Cynthia H Carlson. 2011. "Examining Walkability and Social Capital as Indicators of Quality of Life at the Municipal and Neighborhood Scales." *Applied Research in Quality of Life* 6 (2): 201-213. <https://doi.org/10.1007/s11482-010-9132-4>.
- Sassen, Saskia. 2005. "Cityness in the Urban Age." *Urban Age Bulletin* 2:1-3.

- . 2010. "Cityness. Roaming thoughts about making and experiencing cityness." Edited by Richard de Satgé and Vanessa Watson. *Ex æquo* 22 (22): 13–18.
- . 2013. "Does the City Have Speech?" *Public Culture* 25 (2): 209–222. <https://doi.org/10.1215/08992363-2020557>.
- Shuldiner, Alec, and Paul Shuldiner. 2013. "The measure of all things: reflections on changing conceptions of the individual in travel demand modeling." *Transportation* 40 (6): 1117–1131. <https://doi.org/10.1007/s11116-013-9490-5>.
- Smith-Clarke, Christopher, Afra Mashhadi, and Licia Capra. 2014. "Poverty on the cheap: Estimating poverty maps using aggregated mobile communication networks." In *Proceedings of the SIGCHI conference on human factors in computing systems*, 511–520. <https://doi.org/10.1145/2556288.2557358>.
- Tally, Hatzakis, Rowena Rodrigues, and David Wright. 2019. "Smart Grids and Ethics: A Case Study." *The ORBIT Journal* 2 (2): 1–28. <https://doi.org/10.29297/orbit.v2i2.108>.
- Taylor, L, C Richter, S Jameson, and C Perez del Pulgar. 2016. "Customers, users or citizens? Inclusion, spatial data and governance in the smart city: Map4Society final project report," <https://doi.org/10.2139/ssrn.2792565>.
- The EIU. 2021. "The Global Livability Index: How the Covid 19 pandemic affected liveability worldwide." *The Economist*. <https://www.eiu.com/n/campaigns/global-liveability-index-2021/>.
- Wittgenstein, Ludwig. 1953. *Philosophical Investigations*. Translated by G.E.M. Anscombe. Oxford: Basil Blackwell.
- Yang, Dingqi, Terence Heaney, Alberto Tonon, Leye Wang, and Philippe Cudré-Mauroux. 2018. "CrimeTelescope: Crime Hotspot Prediction Based on Urban and Social Media Data Fusion." *World Wide Web* 21 (5): 1323–1347. <https://doi.org/10.1007/s11280-017-0515-4>.
- Zandieh, Razieh, Johannes Flacke, Javier Martinez, and Martin van Maarseveen. 2018. "Relationships between Outdoor Walking Levels and Neighbourhood Built-Environment Attributes: The Case of Older Adults in Birmingham, UK." In *GIS in Sustainable Urban Planning and Management*, edited by Martin van Maarseveen, Javier Martinez, and Johannes Flacke, 63–81. <https://doi.org/10.1201/9781315146638>.

- Zhu, Yushu. 2015. "Toward community engagement: Can the built environment help? Grassroots participation and communal space in Chinese urban communities." *Habitat International* 46:44–53. <https://doi.org/10.1016/j.habitatint.2014.10.013>.
- Zivanovic, Slavica, Javier Martinez, and Jeroen Verplanke. 2020. "Capturing and mapping quality of life using Twitter data." *GeoJournal* 237–255 (1): 237–255. <https://doi.org/10.1007/s10708-018-9960-6>.