DECODING THE CITY
Urbanism in the Age of Big Data

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Introduction

How to explain the paradox that urbanism, as a profession, has disappeared at the moment when urbanization is everywhere – after decades of constant acceleration – is on its way to establishing a definitive global "triumph" of the urban condition.
Rem Koolhaas (1995)

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In his 1995 essay "Whatever Happened to Urbanism," Rem Koolhaas diagnosed urbanism as a failed discipline. In the light of rampant global urbanization, the profession has failed to give shape or even to influence the physical, social, and economic realities of cities. While during the nineties, the main challenge was dealing with quantity, now, almost twenty years later, the situation presents itself as more ambiguous. Following more than fifty years characterized by suburbanization and the erosion of urban centers, cities in the developed nations have taken two different paths: They either have returned as global economic players of unprecedented power, or have become shrinking cities – hollowed out by deindustrialization and demographic changes (Ryan 2012). Meanwhile, in the emerging economies of the developing world, urbanization is continuing at an undiminished rate. Globally, it is expected that 67 percent of the world population will live in cities by the year 2050 (United Nations 2012, 2).

For the discipline of urbanism, the struggle continues. Both of these trajectories present challenges in terms of infrastructure provision, housing, and socioeconomic development. But planners, policy experts, and economists are no longer the only specialists responding to these challenges. New actors enter the stage and bring new approaches to the field. Perhaps the most significant developments have happened in the domain of data-intense methodologies. The term *big data* refers to the availability of massive amounts of machine-readable information. This information is generated by the sociotechnical systems in which humans are increasingly entangled, by choice or by necessity: cell phone networks, credit card systems, or social media networks. Since the "digital exhaust" generated by these systems is so closely connected to our daily lives, it becomes a valuable resource for observing the processes and interactions of society at almost no cost. However, because of the massive quantity of these data sets, which were not created and structured with research purposes in mind, new methods are required for analyzing them.

Following the increasing availability of such digital data sources during the past ten years, the social sciences have taken a quantitative turn, often labeled *computational social science* (Lazer et al. 2009). In combination with large data sets, new computational methods allow researchers to address topics such as environmental perception, sentiment, or social connection, which were previously limited to qualitative modes of inquiry. Computational social science has brought together sociologists with physicists, mathematicians, and computer scientists, who have recently discovered cities as a topic that provides numerous intriguing research problems to work on. In particular, the emerging field of network science – the study of complex networks – has made a significant contribution to urban research literature (Börner, Sanyal, and Vespignani 2007). Network science stands for a shift from an exclusively spatial perspective on urban data to a topological perspective, focusing on relationships and interactions between people, places, and institutions at any scale. In this sense, network science actualizes ideas that scholars such as Manuel Castells have introduced into the urban studies literature (Castells 1996). By abstracting cities as spatial social networks of interaction, network science helped to uncover structural commonalities shared by almost all urban systems, allowing researchers to describe and predict how cities evolve and will grow over time (Batty 2013). In engineering, the field of urban informatics stands for the instrumentation of cities with sensor networks (Foth 2009). This includes the ubiquitous integration of technologies such as Global Positioning System (GPS) into everyday devices, which have enabled a real-time representation of urban conditions. Smart cities, both an academic and an engineering discipline, is advanced by systems theorists and companies such as IBM, Siemens, or Cisco. The concept of smart cities promises to improve the management of cities by making its infrastructures more adaptive – able to collect information about its own state and to regulate itself based on the state of the whole system. Finally, perhaps most fundamentally, the role of the citizen in the governance of cities has changed in important ways. The rise of social media led to new forms of participation and social activism. Beyond traditional forms of participation in planning projects, citizens voluntarily fulfill increasingly sophisticated roles in monitoring, management, and governance of the city and its infrastructure – a phenomenon that Eric Paulos called the rise of the "expert amateur" (Kuznetsov and Paulos 2010).

In the light of these developments, we believe that it is necessary to reexamine the state of urban planning, and explore, while avoiding the trap of "Big Data Hubris" (Lazer 2014), how these approaches can lead to a new understanding of the city.

While the discussed approaches are relatively recent, they are not without precedents. The history of urban planning has many examples of paradigm shifts initiated by new technology.

By the 1960s, cybernetics, the science of dynamic feedback systems, had started to leave a mark in the domain of urbanism, with both good and bad results. On the positive side, cybernetic models brought a fresh perspective for investigating urban systems. With its focus on dynamic states, feedback, and systemic processes, cybernetics brought new attention to the temporal and ephemeral, and was in many ways conflicting with high-modernist planning theory with its strict compartmentalization of functions. But cybernetic models have also led to some catastrophic failures, as in the case of the 1970s redesign of New York's fire system by the RAND corporation, which left poor neighborhoods underserviced, resulting in rampant fires and social unrest (Flood 2010). The mismatch between complexity of the problem and the inadequacy of the means is self-evident in the perhaps most ambitious cybernetic experiment: project Cybersyn, designed to control Chile's national economy under the Allende presidency (Pickering 2010, 258).

Apart from the obvious failure to capture the sociopolitical dimension of urban systems, cybernetics can also be challenged from another perspective: it simply does not lend itself to good design theory. It is apt for simulating adaptive, complex dynamic systems, but it provides little guidance for future alternatives. As Andrew Pickering suggests, cybernetics is performative rather than representational: it operates in a black box that adapts to current states, but it does not provide an abstract image of the world in its current or desired state (2010, 19). Nevertheless, the idea that data opens up new territories for urban planning and design has a long tradition that can be traced back to the meticulous mapping efforts by Giambattista Nolli in eighteenth-century Rome or Ildefons Cerdà in Barcelona. In *The Sciences of the Artificial,* Herbert Simon calls for a rigorous design science, a "body of intellectually tough, analytic, partly formalizable, partly empirical, teachable doctrine about the design process" (Simon 1996, 113). Such a design science would serve two functions: first to evaluate the performance of a given design, and second, to guide the identification of alternative scenarios. The role of design is the reconciliation between the "inner" world of physical objects and an "outer" world of its goals and functions. "The natural sciences are concerned with how things are. [...] Design, on the other hand, is concerned with how things ought to be." (Simon 1996, 114)

About This Book

This is a book about models for capturing these phenomena for understanding and improving cities. While big data can improve our understanding of urban systems, little attempt has been made so far to think about the consequences for design. This book represents a cross-sectional view of the research agenda practiced at the SENSEable City Lab at the Massachusetts Institute of Technology. Situated in the Department of Urban Studies and Planning, the Lab is an interdisciplinary institution exploring how real-time technologies can help us to better understand our cities, as well as conceiving possibilities how these technologies can improve our cities. The authors of the individual contributions are current and past researchers at the MIT SENSEable City Lab, as well as frequent collaborators. They come from a range of different backgrounds, including architecture and urban planning, sociology, political science, mathematics, computer science, physics, and visual design.

The contributions in this book address the generation of urban data, their representation and analysis, and finally their relevance for urban planning and design. To that effect, this volume is structured into three parts. The first part focuses on case studies discussing the origin of urban data, their collection and generation, including their inherent gaps and biases. The second part focuses on questions of representation, either as visual or mathematical models. The third part finally focuses on the implications for urban design.

In his opening contribution, Fabien Girardin explains the notion of digital footprints, data left by humans using digital services. Girardin distinguishes between passive footprints, generated without the user's awareness, and active footprints, deliberately created and shared by the users. He illustrates how user-generated data from photo-sharing websites can be used to investigate the travel behavior of tourists. Since an increasing number of photos voluntarily uploaded to such sites contain explicit geographic and temporal information (Geotags), photo-sharing sites allow insights into how different groups of people travel and which interests and values guide them. Michael Szell and Benedikt Groß focus on the possibilities of public data sets collected for accountability purposes. They work with a data set of 170 million taxi trips in New York City over one year, and acquired from the city government through a Freedom of Information Act request. Identifying vast redundancies in the system, the authors explore the possibility of an alternative, sharable urban taxi system. In the third contribution, Tony Vanky investigates the sometimes-ambiguous relationships of trust of people toward urban data. Currently, there are few attempts to measure the relevance of urban real-time data: how they affect the interaction with urban infrastructure. Using Singapore as an example, Vanky describes such measures: whether there is use and appreciation of real-time urban data, and how the information affects the spatial decisions of citizens at an individual level.

David Lee discusses the data collection methodology of participatory sensing (Burke et al. 2006), a way to actively involve volunteers in targeted data collection using location-based technologies. Using the example of the Trash Track project, Lee explores how the experience of participating in such a project in return changes the behavior and perceptions of the participants themselves, for example, whether the helping to investigate the fate of trash might change their attitudes toward waste management and recycling. Finally, Francisca M. Rojas maps the cultural geography of New York City through aggregated cell phone data, contrasting the data set with the official census information in terms of validity and quality. In her analysis of the telecom data, she maps out not only the global activities of New York's economic centers; but also the realities of immigrants and migrant workers who remain in constant connection with their home countries.

The second section of the volume, dedicated to visualization and modeling, is opened by Kristian Kloeckl, who documents an initiative that explores the development of an urban real-time data platform for Singapore, facilitating the collection, combination, and distribution of multiple data streams from urban networks. These "urban demos" provide concrete examples of how meaningful visual representations of data open up possibilities for stakeholders from different domains, facilitating a crosscutting discourse about urban issues. The visualization experts Pedro Cruz and Penousal Machado reflect in their article on the use of metaphors and figurative approaches in urban data visualization. They focus on a dilemma that makes geospatial visualization a difficult problem – the dilemma between the spatial nature of urban systems and abstract nature of data to be represented. The authors explore the relationship between the properties of the underlying data and the representational strategy; distinguish between visualization as a "photograph" or a "caricature" of information. The network scientists Philipp Hövel, Filippo Simini, Chaoming Song, and Albert-László Barabási are concerned with the observation, formalization and prediction of human mobility behavior based on telecom data sets. These data sets from cell phone network providers include implicit information about the spatial movement of cell phone subscribers, making it possible to answer questions such as: how predictable are we in our daily routines? In their mathematical analysis, the authors discover a surprising regularity in the way people travel, and provide a mathematical model for describing human mobility behavior. Kael Greco explores representational strategies for urban data based on a mobility research case study in the city of Riyadh, Saudi Arabia. The text approaches the complexity and nuance of urban data from two related, but antithetical perspectives: first, using spatial data to develop new modalities of seeing the city, and second, using the structure and composition of the city to provide new ways of seeing and understanding social data.

The third part opens with a contribution by the urban planner Andres Sevtsuk, who contrasts the plan as the traditional representational tool of urban design with the representation of the city as a network. Sevtsuk, a researcher in the emerging discipline of configurational studies, shows how structural measures of urban path networks, such as "betweenness" or "reach" offer powerful approaches for explaining attractiveness and locational quality within an urban system. Markus Schläpfer's work also situated in the domain of scaling studies addresses the issue of polycentricism of urban structure in relation to the travel behavior of tourists and city dwellers. Using telecom data sets, Schläpfer investigated the destinations and temporal rhythms of hundreds of thousand people in Singapore, Lisbon and Boston. The physicist and pioneer of the emerging research area of scaling studies, Luís M. A. Bettencourt explains the many ways in which the overall scale of an urban system determines a range of urban qualities and measures, such as the average number of personal contacts, the per-capita economic output and innovation, but also the prevalence of crime. His mathematical theory describes how cities change as they grow, and how these changes affect the lives of their citizens. Stanislav Sobolevsky's contribution focuses on the ramifications of human communication for how regions and their boundaries are defined. Using examples of countries such as Great Britain, France, and Belgium, the author shows how Manuel Castell's concept of the space of flows (Castells 1996) can be charted in geographic space using cell phone data.

How can these methods lead to a new design practice for cities? Koolhaas concludes: "If there is to be a 'new urbanism' it will not be based on the twin fantasies of order and omnipotence; it will be the staging of uncertainty; it will no longer be concerned with the arrangement of more or less permanent objects but with the irrigation of territories with potential [...] it will no longer be obsessed with the city but with the manipulation of infrastructure for endless intensifications and diversifications, shortcuts and redistributions – the reinvention of psychological space." (Koolhaas 1995, 31)

Computational models driven by data are a powerful way to incorporate uncertainty, irrigate potentials, and capture subjective and invisible qualities generally associated with psychological space. Data allows us to model the highly dynamic nature of cities, their social life, and their infrastructure networks at an unprecedented level of detail.

Privacy and Surveillance

You imagine, as does everybody else for that matter, that our organization has for many years been preparing the greatest document center ever conceived, an archive that will bring together and catalogue everything that is known about every person, animal and thing.
Italo Calvino (1995)

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Privacy and digital surveillance remain central concerns that are tightly connected to the technical nature of digital systems. Often, privacy issues arise as unintended consequences of these technical properties. In 2010 it was revealed that the two major mobile operating systems provided by Apple and Google store and collect the location information of its users. The immediate purpose was not surveillance or targeted marketing: both operating systems relied heavily on information about known Wi-Fi spots and cell towers for establishing the user's location. Since the location of private Wi-Fi spots is hard to come by and changes frequently, both systems relied on users' phones to collect this information through an invisible service, by automatically mapping every hotspot users encountered. Privacy concerns arise not from this original purpose, but from its consequence – the existence of a vast, dynamic database containing detailed information about each user's behavior.

In the early days of digital media, privacy was mainly discussed in terms of data generation – who is allowed to collect data, and who should have access? In the recent decade, this discussion has shifted toward a discussion of control. This means that the user should own and be able to control any data that concern her life, including being able to trade that data in exchange for money or services. In the simplest form, this control can be implemented via opt-in and opt-out mechanisms. Research on digital traces also leads to insights about how privacy can be protected in the age of big data – what works, what doesn't work, and how mechanisms for privacy protection can be improved.

The question of personal privacy is intimately linked to questions of government transparency. Protection of privacy requires mechanisms for controlling that those rules are actually followed by companies and governments, which can be addressed by a rigorous opening of government data sources. Full transparency for the government, full privacy for the citizen is a frequent demand. In reality, however, those two realms cannot be neatly separated, as private citizens and governments interact in many different ways.

However, none of the approaches sketched above are effective against the "deep state," the domain of government secrecy. The two faces of big data, the civic and the threatening, are palpable in current US legislation. The country has both one of the oldest and most highly developed implementations of a Freedom of Information law, which provides mechanisms for the mandatory public access to government documents. At the same time, the government circumvents this law by entertaining a vast network of agencies operating under strict secrecy outside of public accountability mechanisms. Bringing these issues under democratic control through formal and informal measures requires a public discourse that is informed by a high level of data literacy, a differentiated knowledge of technology and digital data. We understand this book as a contribution to developing data literacy by giving insights into the nature and methods of data-driven technologies. Finally, there is also a historical and cultural dimension of personal privacy. Plain text is perhaps the most persistent and explicit digital expression of human speech and thought, requiring only minimal digital storage space. Without a natural expiry date, the question of data life cycles arises – should personal data, including embarrassing messages from one's youth, be deleted at some point, or made inaccessible? On a larger scale, how much culturally relevant information would be lost in such a case about our mostly digitally documented world?

As Calvino's story about the attempt to preserve the world's memory illustrates, the "total archive" would be an insurmountable restraint for all human agency, which in his story ultimately leads to death.

Nevertheless, on closer inspection, the totalizing idea of big data turns out to be a myth. The data distribution is highly unequal; data is least available precisely where we need it most, for example in the hinterlands beyond the digital divide. The contributions in this volume illustrate the immense value contained in the traces generated by our digital lives for better understanding our cities, our cultures, and our society. We consider the variety of public data sets available from governments, research institutions, infrastructures, and voluntary data provided by citizens a basis for civic discourse and ultimately an integral part of public space.

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Data – Source and Collection

Fabien Girardin

Catching the World’s Eyes

Introduction

Visitors to a city have many ways of leaving voluntary or involuntary electronic trails: prior to their visits tourists generate server log entries when they consult digital maps or travel websites; during their visit they leave traces on wireless networks whenever they use their mobile phones; and after their visit they may add online reviews and photos. Broadly speaking, we propose two types of footprint: active and passive, also referred to in the literature as *volunteered* and *contributed* locational information (Harvey 2013). Passive tracks are left through interaction with infrastructure, such as the mobile phone network, which produces entries in locational logs, while active prints come from the users themselves when they share locational data in photos, messages, and sensor measurements.

The World’s Eyes project (figure 1) investigated the active prints that reveal how people travel and experience a city. Particularly, we used the Application Programming Interface (API) of the photo-sharing platform Flickr to access publically available photos. In February 2009 Flickr broke the hundred-million-georeferenced-photos count (over a total of 3 billion photos in the repository).

Fig. 1.
Screenshot of the World's Eyes project exhibited at the Design Museum in Barcelona in 2008. The visualization uncovers the evolutions of the presence and flows of tourists. As photos pile up to reflect the intensity of tourist activity, they uncover where tourists are, where they come from, and what they are interested in capturing and sharing from their visit.

This represents an unprecedented amount of publicly accessible data produced through people's interactions involving the Web and mobile devices. We caught these "eyes of the world" to investigate visitors' mobility in diverse locations such as the Province of Florence (Girardin et al. 2008a) and Rome (Girardin et al. 2008b) in Italy as well as New York (Girardin et al. 2009).

Each time a user anchors a photo to a physical location, Flickr assigns longitude and latitude values together with an accuracy attribute derived from the zoom level on a map. Unlike passive prints, we consider that user-generated content provides unique perspectives on mobility. Indeed, the effort of an individual to take a photo, select it, upload it onto a Web-sharing platform and geo-reference it can be more powerful than any survey or GPS log that researchers interested in human space-time activity could access in the past. There is a very real richness to the “intentional weight” that people attach to disclosing their photos, and the results clearly show that Flickr users have a tendency to point out the highlights of their visit to the city while skipping over the lowlights of their trip. This “I was here” brings a notion of subjectivity to the relation of people with space and place (Dourish 2006).

Our work suggests that exploiting this data set to know who visits different parts of the city at different times can lead to the provision of customized services (or advertising), the rescheduling of monuments’ opening times, the reallocation of existing service infrastructure, or the evaluation of specific urban strategies. From a quite different perspective, tourists themselves could be aware of the current ways in which they populate the city, and adopt different strategies as a result.

From the Vision of Dynamic Maps of Human Processes to the Reality

The low cost and high availability of user-generated content now challenges any field that benefits from an in-depth understanding of large-group behavior. Indeed, only a few years ago, the possibility to produce fully dynamic time-space diagrams from the fusion of human activities data and novel forms of analysis was only discussed in the conditional. For instance, Zook et al. envisioned in 2004: “When many individual diagrams are aggregated to the level of cities and regions, these visualizations may provide geographers, for the first time, with truly dynamic maps of dynamic human processes. One might imagine them as twenty-first-century ‘weather maps’ of social processes.”

The presence of active prints suggests that we are at the end of the ephemeral; in some ways we have new means to replay the city and its processes. This potential to replay the city echoes very well with the recent interest of local authorities and urban planners in big data. For instance, tourism is hardly quantifiable, because tourists leave minimal tangible traces of their stay. In the World’s Eyes project, the analysis and mapping of this user-generated content allowed the measurement of the attractiveness of leisure cities and their points of interest. In contrast it also reveals the unphotographed regions still free from the tourist buzz. As photos pile up to reflect the intensity of the tourist activity, they uncover where tourists are, where they come from, and what they are interested in capturing and sharing from their visit.

In order to explore that domain, we followed several steps that start from the collection of digital footprints. We used the Flickr API to retrieve the coordinates of photos and their accuracy, the time at which they were taken, and we also obfuscated the identifiers of their owners. Since we were particularly interested in the behavior of tourists, our analysis platform separated the photographers into two groups, locals and visitors, based on their disclosed presence in the city over time. For the study of Rome over a 3-year period, we collected a data set of 144,501 georeferenced photos that had been uploaded by 6,019 different users. With the accumulation of these data we extracted spatiotemporal characteristics such as seasonality, usage patterns, and spatial distribution, main flows of visitors (i.e., desire lines) and the main points of interest of the city.

Presence in Space and Time

To map the spatial distribution of users, data is stored in a matrix covering the entire study area. Each cell in the matrix includes data about the number of photos taken, the number of photographers present. In Rome, the analysis of visiting quickly uncovers the area's major visitor attractions such as the Coliseum and the main train station next to the Piazza della Repubblica (Girardin et al. 2008b). In addition, temporal signatures provide further evidence to the different types of presence that occur at tourist points of interest. In Rome, it can be further hypothesized that the Coliseum attracts sightseeing activities (i.e., photographers) over the weekend and that the neighborhood of the train station provides facilities for visitors on the move (e.g., people on business trips) during the weekdays.

Desire Lines

The study of digital footprints also enables us to uncover the digital desire lines embodied in people's paths through their visit of a city or a region. Based on the time stamp and location of photos, our analysis platform organized the images chronologically in order to reconstruct the movement of the photographers. More precisely, we start by revealing the most active areas obtained by spatial clustering of the data. Next, we aggregate these individual paths to generate desire lines that capture the sequential preferences of visitors. The location of each user activity (i.e., photo) is checked to see if it is contained in a cluster, and in the case of a match, the point is added to the trace generated by the owner of the photo. This produces multiple directed graphs that support better quantitative analysis, enabling us to obtain the number of sites visited by season, the most visited and photographed points of interests, as well as where photographers started and ended their journeys.

Places of Interest

Previous work has demonstrated that spatially and temporally annotated material available on the Web can be used to detect place- and event-related semantic information (Rattenbury et al. 2007). In a similar vein, analysis of the tags associated with the user-originating photos revealed clues about people's perceptions of their environment and the semantics of their perspective of urban space. For instance, the word *ruins* is one of the most-used tags to describe photos in Rome. Mapping the distribution of this tag for 2,866 photos uncovers the most ancient and "decayed" part of the city of Rome: the Coliseum and the Forum. We used this semantic information to define the main areas of photographic activities as part of an economic impact study of *The New York City Waterfalls* in 2008.

Case Study: Measuring the Impact of an Event

In a case study that took place in summer 2008 around *The New York City Waterfalls* public art project, we further explored the characteristics of explicit digital footprints to define indicators that measure the evolution of urban attractiveness. The objective for the local authorities was to compare the evolution of the attractiveness and popularity of urban places at the different vantage points of the project. Therefore, we measured the spatial distribution of locals and visitors and compared the evolution of the presence of digital footprints as evidence of the positive impact of *The New York City Waterfalls* on the attractiveness of the waterfront. Eventually, two main results enhanced the City's report on the event: the evolution of attractiveness based on the presence of photographers and the evolution of popularity based on centrality.

Evolution of Attractiveness Based on the Presence of Photographers
According to the relative presence of photographers, our investigation analyzed the variations of attractiveness indicator based on the presence of photographers during the summers of 2006, 2007, and 2008 (the year of the *Waterfalls*). It reveals a positive growth in the waterfront's attractiveness of 8.2 percent in summer 2007 and 20.7 percent in summer 2008 with respect to that of other areas of interest in New York City, such as Time Square and Central Park, providing an indication of the potential impact of the presence of the *Waterfalls* exhibition.

Evolution of Popularity Based on Centrality
The centrality of an area of interest determines its level of integration into the popular flows of photographers. Our PlaceRank indicator revealed that between 2006 and 2007 the vantage points lost their centrality by 15 percent while the other areas of interest increased their centrality by 10 percent. However, between 2007 and 2008 the vantage points gained 56 percent while the other areas of interest lost 30 percent. In 2008 the vantage points appear as central as other areas of interest, meaning that they are on the tourist path as much as other areas of interest in that section of the city.

This case study provided indications that the emergence of digital footprints creates an opportunity to evaluate in detail the use of space, the impact of events, and the evolution of the built environment. This approach could not only better inform urban design decisions and city management, but also enable local authorities to provide timely evidence to the public about the use of space and about the impact of interventions within the urban fabric. Indeed, the integration of our results in the official study of the economic impact of *The New York City Waterfalls* public art project shows that the indicators proposed by our analysis offered useful measures to complement traditional methods.

Discussion
The ubiquitous technologies that afford us new flexibility in conducting our daily activities are simultaneously providing the means to study our activities in time and space. The exploitation of

user-generated content to better understand mobility in the urban environment led to several implications we would like to highlight.

Technical Implications

Besides our work on urban-attractiveness indicators, other research groups have been using a reality mining approach to derive specific characteristics of urban dynamics (Kostakos et al. 2008; Ratti et al. 2006). A major challenge in this type of approach is to draw a clear understanding of the boundaries and biases of the data. For instance not to confuse behaviors with endorsement, which can be considered as a limitation of *The New York City Waterfalls* case study, as it used the density of digital footprints as indicators of urban attractiveness. Therefore, future studies will need to rely on calibrations with ground truth information produced with proven techniques.

Additionally, some analyses suggest distinct profiles of georeferencing and geotagging photos. These profiles might be based on culture or nationality, the type of tourist in terms of their length of stay or familiarity with the city, their level of technical expertise or spatial orientation ability, and the type of task or type of environment visited. Other questions that should be considered relate to the types of situations during which users are more or less likely to use their mobile devices for data generation. Answers to these types of questions should allow us to define better the meaning of the data and to explore further their potential usage in social sciences and urban studies.

Methodological Implications

The ability to replay the city shows that there are opportunities for researchers to propose novel ways to describe the urban environment. However, there is a big assumption in seeing the world as consisting of bits of data that can be processed into information that then will naturally yield some value to people. It would lead to what we would call data-driven urbanism, as if urbanism could be driven by data. Indeed, the understanding of a city goes beyond logging machine states and events. In consequence, let us not confuse the development of novel maps from previously uncollectable and inaccessible data with the possibility of producing "intelligent maps." Our work precisely draws some critical considerations