SENSEable CITY GUIDE

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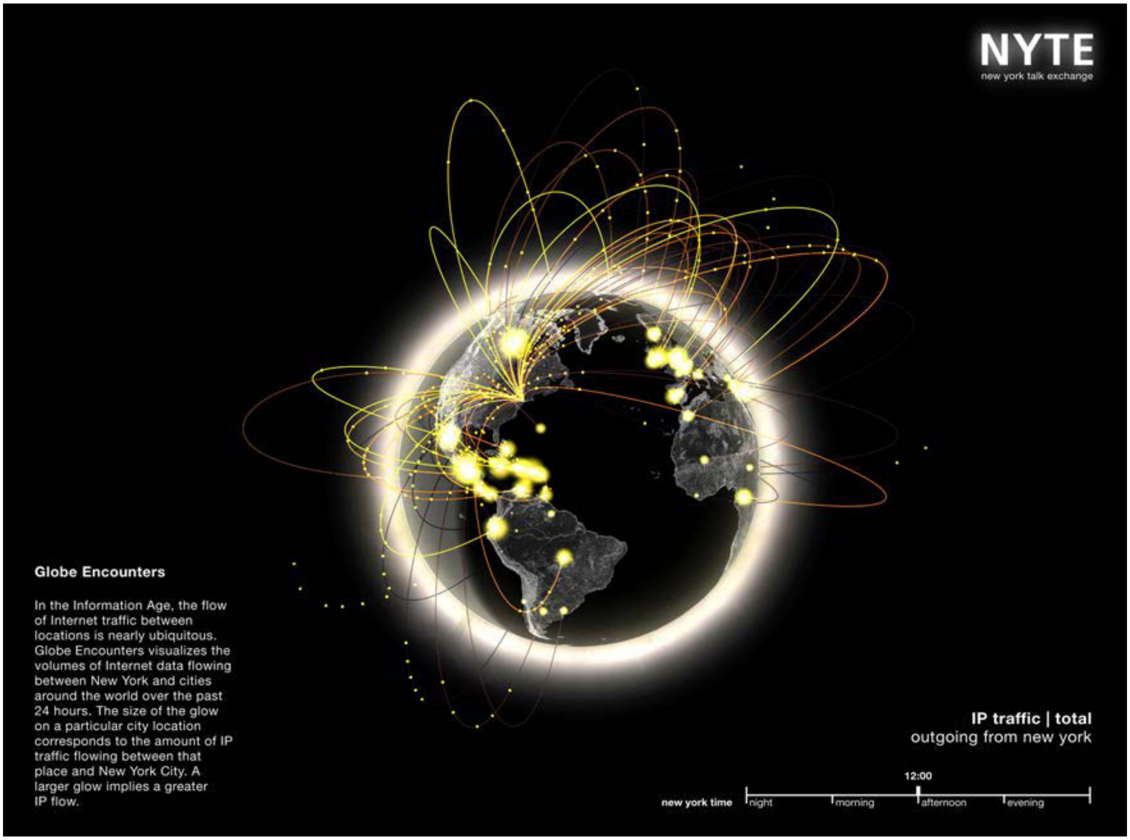
THE SENSEable CITY GUIDE



SENSEable CITY GUIDE
WORLD MAP

The SENSEable City Guide provides an introduction to the work of the SENSEable City Lab, at the Massachusetts Institute of Technology. Showcasing research undertaken by the Lab, it provides a vision of the SENSEable City through an exploration of mechanisms of crowd-sensing, actuation, data analysis and computation. This book contains four essays written by researchers and directors at MIT's SENSEable City Lab. Two of the papers are vision focused: they draw from historical architectural, and academic trends to show the direction that cities are taking, now that computing has become embedded into our urban fabric. The second set of papers document current research, in particular, they reveal our new found ability to understand human action in space through collecting, visualizing and analyzing the digital traces of our everyday lives.

SENSEable CITY LAB - MIT - BOSTON

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THE SENSEABLE **CITY** LABORATORY FACT SHEET

by Assaf Biderman, Nashid Nabian, Prudence Robinson, Christine Outram and Carlo Ratti

Welcome to the SENSEable City Lab – a multidisciplinary research group that studies the interface between cities, people, and technologies. We investigate how the ubiquity of digital devices and the various telecommunication networks that augment our cities are impacting urban living. With an overall goal of anticipating future trends, we bring together researchers from over a dozen academic disciplines to work on groundbreaking ideas and innovative real-world demonstrations. This research is undertaken in partnership with cities, the private sector and other universities; through this collaborative approach we strive to reveal how a new, rapidly expanding network of digital devices is serving to modify the traditional principles of understanding, describing and inhabiting cities.

Quick Facts:

- Founded in 2004 within the Department of Urban Studies and Planning, MIT
- Directed by Carlo Ratti and Assaf Biderman
- 20+ researchers from architecture, urban planning, computer science, mechanical and electrical engineering, sociology, mathematics,graphic and interaction design and data mining.
- 300+ scientific papers published
- 50+ real-world projects
- 25+ exhibitions
- 200+ conferences keynote addresses
- several patents

Over the past few decades, an emerging suite of miniaturized, networked, and pervasive digital technologies has woven itself into our urban environment – our buildings, urban infrastructures, objects, and communication devices. These digital technologies are embedding a new functional layer over our cities, and are creating a digital nervous system with which we interact on a daily basis. Given this, and when considered alongside the unprecedented rate at which cities are being constructed, we are witnessing a paradigmatic shift across all aspects of urban research, including, architecture, governance, infrastructure, services management, transportation and urban planning.

This new condition requires collaboration across multiple disciplines in order to collectively shape our urban future.
The SENSEable City Lab is at the forefront of this anticipatory research working with cities and companies to address these challenges and opportunities. Key to our success in this arena, is our multidisciplinary project-based approach to research, alongside the structure of the SENSEable City Consortium, which brings together visionary cities and companies from around the world.

Research by design and design by research: this is how we do projects. We start with a vision of how new technologies are transforming our interaction with the built environment and in multidisciplinary teams we work to develop new research methods and technologies that provide insight into the transformations we face. These are then developed into an experimental deployment in the city – what we call an 'urban demo' – which engages people (citizens, city managers, and the private sector) in experiencing a possible future scenario of life with technology in the city. Some of the technologies we develop may be out of immediate commercial reach, but we develop the scientific grounding for their realization and the urban demo allows us to gather feedback about our technological interventions and opens a public debate about the implications of empowering our physical environments with technology.

Meanwhile, the SENSEable City Consortium brings together MIT researchers and external partners to jointly share a vision, develop technologies, and deploy projects. Working primarily with cities, non-profits organizations, and companies that are at the forefront of servicing cities with digital technologies and information.

The consortium is a critical component of the process, serving as a platform for creating partnerships, exchanging knowledge, and raising funds. Partner cities in the consortium offer test cases, industry provides technical expertise, and the lab unites public and private sectors behind an umbrella vision of a shared future.

The SENSEable City Lab‘s experience includes 50 completed projects and 300 scientific publications. The group's work has been exhibited in leading venues, including the Architectural League of New York, the Canadian Centre for Architecture, the Design Museum in Barcelona, MoMa, the MIT Museum, Venice Biennale, and Zaragoza's 2008 World Expo. In addition, The SENSEable City Laboratory's work and vision is frequently featured by global media and press outlets including, ABC Radio, Architectural Record, Associated Press, BBC, Boston Globe, CBC, CNN, Discovery Channel, The Economist, Financial Times, International Herald Tribune, Le Monde, Metropolis, National Geographic, New Scientist, Newsweek, NPR, The New York Times, Science, Science Daily, Seed, Time Magazine, Wall Street Journal, and Wired among others.

THE SENSEABLE CITY: THE SENSEABLE CITY LABORATORY VISION FOR A CYBERNETIC MECHANISM OF SENSING, ANALYSIS AND ACTUATION

by Carlo Ratti

In 1995 scholars speculated about the impact of the ongoing digital revolution on the viability of cities. Only 14 years ago, the mainstream view was that, because digital media and the Internet killed distance, they would also kill cities. George Gilder proclaimed that, “cities are leftover baggage from the industrial era” and concluded that “we are headed for the death of cities,” due to the continued growth of personal computing, telecommunications, and distributed production. At the same time, MIT Media Lab’s Nicholas Negroponte wrote in Being Digital that, “the post-information age will remove the limitations of geography. Digital living will include less and less dependence upon being in a specific place at a specific time, and the transmission of place itself will start to become possible.”

In fact, cities have never prospered as much as they have over the past couple of decades. China is currently building more urban fabric than has ever been built by humanity. A historic moment occurred in 2008: for the first time in history more than half the world’s population – 3.3 billion people – lived in urban areas.

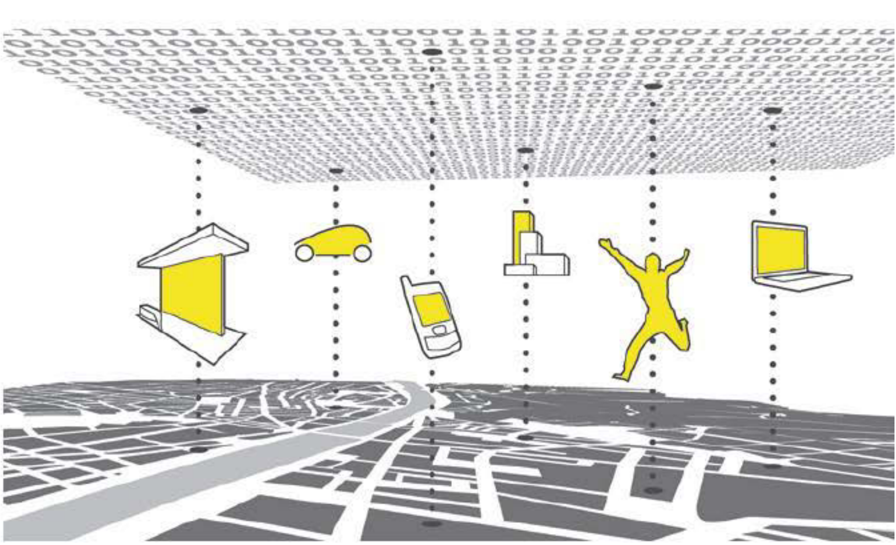
The digital revolution did not end up killing our cities, but neither did it leave them unaffected. A layer of networked digital elements has blanketed our environment, blending bits and atoms together in a seamless way. Cameras, microcontrollers, and sensors are used ever more extensively to manage city infrastructure, optimize transportation, monitor the environment and run security applications. Advances in microelectronics now make it possible to spread “smart dust”—networks of tiny, wireless, microelectro–mechanical system (MEMS) sensors, robots or devices.

Most noticeable is the explosion in mobile-phone usage around the globe. More than four billion mobile phones were in use worldwide by early 2009. Mobile phones are ubiquitous, permeating socioeconomic classes and five continents: they allow us not only to communicate with each other in unprecedented ways, but to create a pervasive sensing network that covers the whole globe. One important consequence of this process is that cities can start to work as real-time control systems, regulated by a number of feedback loops. In past decades, real-time control systems have been developed in a variety of engineering applications. In so doing, they have dramatically increased the efficiency of systems through energy savings, regulation of dynamics, increased robustness, and disturbance tolerance. But the question still remains: can a city perform as a real-time control system? The city already contains actuators such as traffic lights, remotely updated street signage, etc. However, more profound actuation presents further challenges: for instance, the size of a street cannot be readily doubled in real time if we detect traffic congestion. However, unlike other real-time control systems, cities have a unique feature: its citizens. By receiving real-time information, appropriately visualized and disseminated, citizens themselves can become distributed intelligent actuators, pursuing their individual interests in co-operation and competition with others, becoming prime actors on the urban scene. Processing urban information captured in real time and making it publicly accessible can enable people to make better decisions about the use of urban resources, mobility and social interaction. This feedback loop of digital sensing and processing can begin to influence various complex and dynamic aspects of the city, improving the economic, social, and environmental sustainability of the places we inhabit.

For example, an automated trip planner that relies on real-time information about bus, train, and taxi locations, as well as congestion and pollution levels, can help people find the fastest, least polluting, travel route. A simple real time feedback mechanism between citizens and emergency-rescue units could also help to prevent mistakes like those that affected New Orleans before and after Hurricane Katrina in 2005. Feedback loops could grow inside each other: buildings could become probes and ambient displays; evolving into real-time, responsive devices in their own right.

The implications for architectural aesthetics are fascinating. For several years now architecture has attempted to mimic in formal terms the rapid flow of digital information. We can think of any number of fluid buildings. Unfortunately, once built, shapes that are designed to look fluid tend to end up frozen in concrete or steel. Professor Antoine Picon, Harvard Graduate School of Design, predicted that as cities incorporate digital technology into their very body, architecture itself will conversely become more restrained. Picon's view is heretical. He compares work by architects such as Zaha Hadid to the Baroque architects of the 17th and 18th centuries who were "obsessed by questions like the trajectory of light inside churches and its spiritual meaning".

Like our contemporaries, says Picon, Baroque architects preferred to imitate movement in their work rather than create buildings that made movement easier. Picon predicts a return to the Neo-Classical approach. We'll see more "compositions that remain voluntarily rigid in order to be functionally more efficient" and a "digital/minimal attitude in which unwanted agitation is suspended". In 1963, the British architect Cedric Price created the idea of a Fun Palace. "Every town should have a space... where the latest discoverings of engineering and science can provide an environment for pleasure and discovery," he said. We need Fun Palaces for the post-digital era, and MIT's Senseable City Lab is paving a way toward this future by focusing on possibilities in terms of sensing, computational data analysis, and actuation.[1]



How can a city perform as an open-source real-time system?
Wiki City Illustration by Kristian Kloeckl, MIT SENSEable City Lab.

[1] Reprinted from Ratti, C. (2009) Grid Unlocked. The information network will free the transportation network. The Digital City. Wired UK. p.4.

THE SENSEABLE **CITY** AND MECHANISMS OF [CROWD-]SENSING

by Francisco C. Pereira, Andrea Vaccari,
Fabien Giardin, Carnaven Chiu, and Carlo Ratti

The mid-sized and large cities of the 21st century lead a "double life," – they exist both in the physical and the digital worlds. Although these worlds do not physically share the same spatial or temporal dimensions, the anonymous citizens constantly projects the physical world onto the digital world by leaving voluntarily or involuntary traces while living their lives on various networks. Websites such as Flickr, Twitter, Facebook and Wikipedia are repositories of what citizens sense in the city and include reports or announcements of events and descriptions of space. What is contained and continuously added to these repositories can be used in enhancing the SENSEable City with different mechanisms of registering, or in other words sensing, its real-time dynamics.

For almost every city across the world, there is a digital version available, spread across different on-line platforms and systems. These digital cities are rich in diversity and content with respect to their physical counterparts. More importantly, the large majority of this content is intensively created and updated by individual local citizens, tourists, and organizations, in many cases at a quasi-real time rate. Such dynamics bring a historically unprecedented intensity of experience to the city: the crowd of urbanites upload pictures of popular events, sends tweets in real time about life in the city, create and updates pages in Wikipedia about the city, and finally offer feedback with opinions and hit on the best content. These acts of communication generate different kinds of data that provide unique views on how people experience the city. Such a tech savvy and networked crowd is therefore the sensor that allows us to understand the rhythms and dynamic patterns that the city and its citizens experience at a quasi real-time rate: a phenomenon referred to as crowdsensing.

Eyes of the World, is an example of making sense of what is being crowd-sensed in the digital counterpart of a given city. Here, the attractiveness of places and events are visualized and measured from the density of user-generated data, particularly Flickr photos, with their tags and geo-references. In what follows, we summarize specific experiments in Barcelona, New York City, and Rome, highlighting the experience of using visualizations to ground and evaluate urban strategies as well as examining spatial dynamics. In a second project, My Architect, this idea is further explored by benchmarking "iconic architecture" from user-generated content. This type of analysis helps evaluate the success of architects in promoting the image of a city.

In terms of collecting and mining information in Eyes of the World and My Architect, Flickr is used to source crowdsensed information. Flickr users share and organize photos, with an additional option of assigning geographical attributes. Each time a photo is anchored to a physical location, Flickr adds a longitude and latitude value together with an accuracy attribute, which is derived from the zoom level of the map used, in order to position the photos. The system also adds metadata embedded by the camera into the image, thereby completing the spatiotemporal information. Once user-generated content is appropriately associated with physical places through geographical information, it can be widely applicable in the study of urban processes. This data set not only allows us to consider mobility and tourism at different scales—from within the city, to between cities, and even countries—it also permits us to identify connections between different areas of the city for example, the demography of visitors to tourist hotspots. Finally, it allows us to begin to comprehend how people individually and collectively interpret a city; which locations are considered more or less important, and what salient characteristics are captured by the eyes of the visitors.

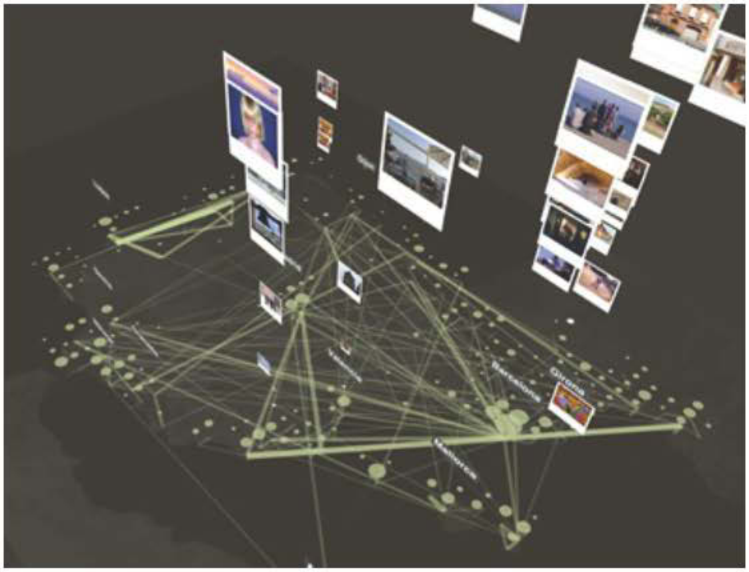
In both the Eyes of the World and My Architect the goal is to visualize what is crowdsensed as it appears online and translate it into meaningful information. To this effect, positioning a photo on a map is not simply about location, rather it is an act of communication which represents a location, time, and experience that individuals consider relevant for themselves and others. Our results clearly show that Flickr users have a tendency to point out the highlights of their city visit while skipping over the lowlights of their trip.

The Eyes of the World a series of dynamic visualizations showcased in Barcelona's Design Museum. It illustrates the photos people visiting Spain leave behind, as evidence of contemporary tourism in the country. They reveal the dynamics of civic landscapes, as viewed and collaboratively reported by their visitors. The attractiveness and popularity of places and events are revealed by visualizing the density of user-generated data, using the photographs tagged with information about their location and time that they were uploaded. User-generated electronic trails based on the sequences of photographs are then used to reveal the presence and movement of visitors in a city. Such data visualizations that geo-localize the content generated by the user's experience of a given urbanity, reveal how cities are interpreted by their occupants. An animation of the photos geo-tagged to different neighborhoods of Barcelona, with descriptive tags that relate to "partying" in the summer of 2007, shows that Barcelona's old town (Ciutat Vella) is where one goes to have fun. Another visualization in the same set looks at how Spain is photographed by tourists over the course of one year. While the photos overlap in certain locations and expose places that attract the photographer's gaze, in other locations, the absence of images is eye-catching, revealing the less documented parts of Spain.[2]

2 MIT SENSEable City Lab: Carlo Ratti-lab director | Assaf Bidermann-associate director | Fabien Girardin-project leader | David Lu-visual designer | Andrea Vaccari-data mining. Universitat Pompeu Fabra: Ernesto Arroyo - interaction designer.
http://senseable.mit.edu/worldseyes/index.html

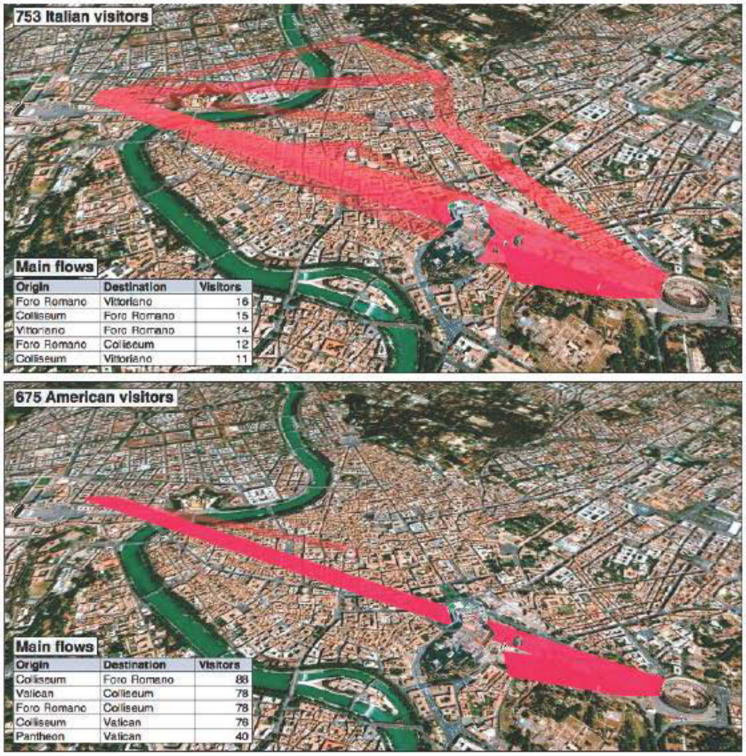
3 Girardin, F., Calabrese, F., Dal Fiore, F., Ratti, C. and Blat, J. (2008) Digital footprinting: Uncovering tourists with user-generated content. IEEE Pervasive Computing, 7 (4), pp.36–43.

In the case study of Rome, Italy[3] the potential of user-generated electronic trails to reveal the presence and movement of visitors in a city is illustrated. Using novel data collection techniques, analytical methods and visualization tools, the city dynamics encoded in collectively generated and geo-tagged content is uncovered. Through mining the tagged photos and cross referencing the locations associated with the photos, with temporal information stored with individual photos, our analysis revealed the most popular locations in the city, such as the main train station next to Piazza della Repubblica. It also served to identify the temporal signature of these populated areas, i.e. which time of day and during which days of the week do these areas witness the most crowding.



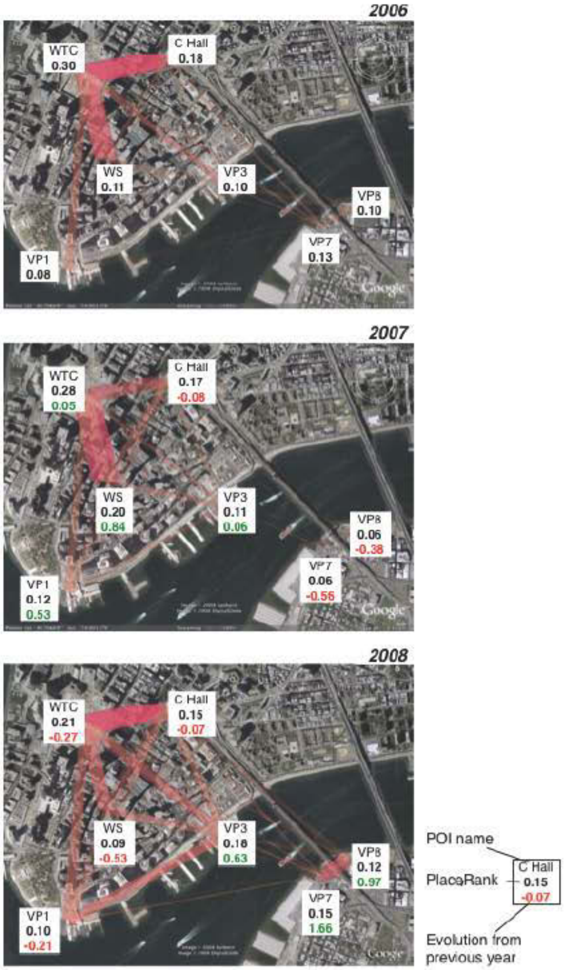
A visualization of how Spain is photographed by tourists over the course of one year. While the photos overlap in certain locations and expose places that attract the photographer's gaze, in other locations, the absence of images is eye-catching, revealing the less well documented parts of Spain.

The study of such digital footprints also enables us to uncover the 'desire lines' embodied by people's paths through the city: by examining spatial clustering of the data, the most active areas of the city in terms of population of geo-tagged user-generated content is revealed. Aggregating the individual popular places permits the generation of desire lines that capture the sequential preferences of visitors. For instance, in the case study of Rome, 753 visiting Italian photographers were active across many areas of the city, while 675 American visitors followed a more narrow desire line between the Vatican, the Forum, and the Coliseum. This does equate to American tourists not exploring Rome, but rather they concentrate on these points of interest to document their visit to the city.



An evolution geovisualization of main paths taken by photographers between points of interest in Rome. Significantly, the 753 visiting Italian photographers are active across many areas of the city, whereas the 675 American visitors stay on a narrow path between the Vatican, Forum, and Coliseum. (Different scales apply to each geovisualization.)

In a follow-up case study that took place in New York City[4] in 2008, we employed the same approach to identify how particular areas within the city are frequented by people. The spatio-temporal character of use served to inform the local authorities about the success of the Waterfalls, a public art project of four man-made waterfalls rising from the New York Harbor in the East River between June 26 and October 13, 2008. The Waterfalls were intended to attract visitors and New Yorkers toward the city's waterfront, with the goal of revitalizing the area and stimulating social activity and new business. Given the large investment to finance the temporary installation, the organizers wished to assess the economic impact of the event. Traditional methods such as head counts and surveys which produce accurate estimates for confined areas, where unable to capture the dynamism of the open space around the waterfront. In contrast, our analysis of geo-referenced photos was able to quantify the influence of the public art exhibition on the attractiveness and popularity of various vantage points in proximity to the event. This was determined through an examination of the presence of photographers during the summer of 2008 compared to prior years, most likely elicited by the Waterfalls.



An evolution of the flows of photographers in proximity to the exhibit based on the analysis of photos generated between June - October, 2006, June - October, 2007, and June - August 15 in 2008. In 2008, when Waterfalls opened, VP3, VP6 and VP7 massively increase their PlaceRank.

[4] Girardin, F., Vaccari, A., Gerber, A., Biderman, A. and Ratti, C. (2009) Quantifying urban attractiveness from the distribution and density of digital footprints. International Journal of Spatial Data Infrastructure Research, 4, pp.175-200.

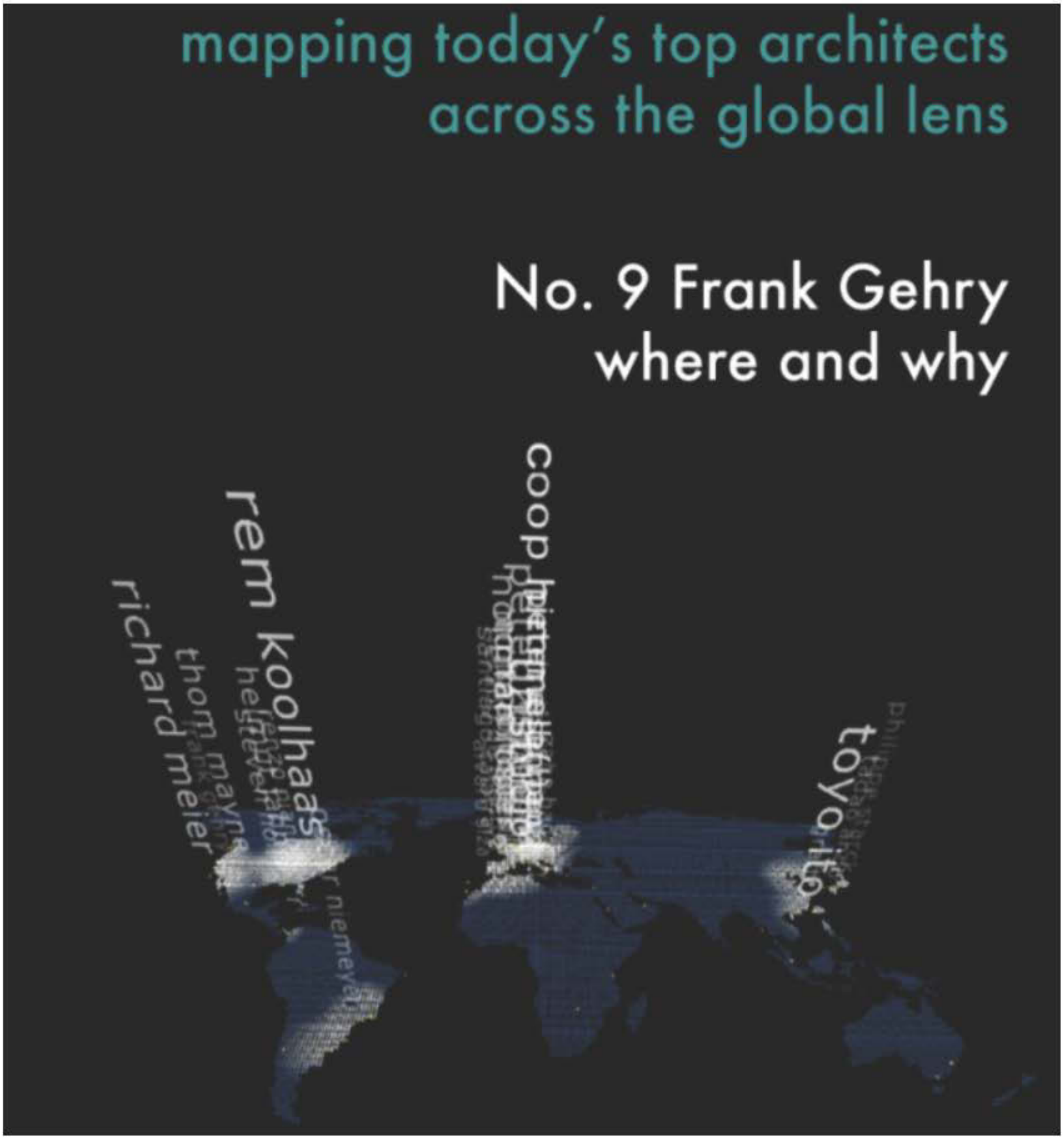
The aggregated spatio-temporal records provide a novel perspective of mobility and travel. For example, mapping this new type of digital footprint shows the capacity of an event to drive people to less explored parts of a city over time. Such information can be highly valuable for urban design and tourism studies alike.

Taking a global view of the presence and work of some of the world's greatest architects today, My Architect is a project that serves as an extension of the Eyes of the World using the same principles and with a very similar set of components.[5] The key difference between the two projects is that My Architect is driven and developed with a very focused subject matter, architecture. This project is intended to refine our image of the profession based on the action of the general public. More importantly, the result is delivered through a process of the un-academic and non-commercial narrative, using photos available online to define a general view. It depicts the formation of iconic architecture and star-chitect culture (the realm of celebrity architects). Through visualizing mined and thematically aggregated Flickr information, the clusters of physical presence of each architect is highlighted, also showcasing the architect's most famous works through photos captured by anonymous photographers around the world. The project also features a ranking of today's architects based on the size of their online photo collection.

The very first step of My Architect was to situate information in the context of architectural subject matters. It began by gathering a list of approximately three hundred living architects from around the world based on various online platforms such as Wikipedia and popular architecture-related blogs and sites. From this initial list, a secondary list of the top 50 architects was created based on the total number of photos available on Flickr for each architect. This information was garnered from the user-generated tags associated with each of the Flickr photos. To ensure that the photos returned from the search were relevant to architecture, we put together a list of the most popular words that Flickr members used to tag architecture-related photos. This criteria included, among others: "architect", "architecture", "building", "contemporary", "design", "designer", "doors", "exterior", "façade", "house", "interior", "modern", "museum", "outdoors", "tower", "skyscraper", and "windows". We used this list to search all available tags retrieved for each photo and refined the selection of photos accordingly. We then ran a filter script to check for matching tags between the collected list of Flickr tags to the list of architect's name. If the script identified matches from the two sets, the photo remained in the collection. If not, the photo was excluded. We then determined the top 50 architects in the world based on the size of the photo collection filtered through this process.

[5] Girardin, F., Calabrese, F., Dal Fiore, F., Ratti, C. and Blat, J. (2008) Digital footprinting: Uncovering tourists with user-generated content. IEEE Pervasive Computing, 7 (4), pp.36–43.

Girardin, F. Dal Fiore, F., Ratti, C. and Blat, J. (2008) Leveraging explicitly disclosed location information to understand tourist dynamics: A case study. Journal of Location-Based Services, 2 (1), pp.41–54.


mapping today's top architects
across the global lens
No. 9 Frank Gehry
where and why
rem koolhaas
richard meier
coop
toyo ito

The analysis and plotting of this data onto a map provides an insight into the global hotspots of architectural interest, and how this contributes to the intensity of tourist activity. The image of a city and/or a place is portrayed through different architects' work. It shows the dynamic aspect of how people utilize the photographic medium to explore the primary discipline of architecture and architectural experience. To this effect, My Architect offers a collaborative inquiry into the making of the world's architectural scene. As with any kind of dataset, user-generated data that is used in both of the above mentioned projects provides a snapshot of the spatio-temporal dynamics. And yet, their subjective nature allows us to get a sense of how people experience a city, from what people like to report and what matters to them. The collection and analysis of this data permits the development of new urban indicators, which may be useful to evaluate urban strategies. If such information retrieved from pools of user-generated data is aggregated with information retrieved from pervasive sensor networks in urban areas that allow for passive activity sensing, the interplay between top-down systems of command and control versus bottom-up systems for collective action, will gradually reflect more accurately our digitally augmented cities' reality, and become an even more powerful source to understand it.[6]

A visualization that highlights the clusters of physical presence of each architect, also showcasing the architect's most famous works through stunning photos captured by anonymous photographers around the world. This project also features a ranking of today's architects based on the size of their online photo collection.

[6] Partial reprint from Pereira, F. C., Vaccari, A., Girardin, F., Carnaven, C. and Ratti, C. *(Forthcoming)* Crowdsensing in the Web: Analyzing the Citizen Experience in the Urban Space. In: Foth, M., Forlano, L., Satchell, C. and Gibbs, M. (Eds.) (2012) *From Social Butterfly to Engaged Citizen: Urban Informatics, Social Media, Ubiquitous Computing, and Mobile Technology to Support Citizen Engagement. Cambridge*, MA.: MIT Press. Ch. 19

THE SENSEABLE **CITY** AND MECHANISMS OF ACTUATION: NETWORKS AND NEO-CYBORGS

by Nashid Nabian and Carlo Ratti

In his 1969 article "The Architectural Relevance of Cybernetics," Gordon Pask proposed that architectural spaces should be designed as systems capable of responding to emerging conditions, and adapting to the needs of their inhabitants. To this effect, he compared such spaces to cybernetic systems. Following the same line of thought, we may conceive of the digitally enhanced, postmodern city as a cybernetic mechanism that accommodates interaction and actuation in its capacity as a spatial system capable of extracting contextual information, acknowledging the inhabitants' desires and needs, and adopting behavior patterns based on what it learns. Such a cybernetic urban system achieves its monitoring with sensing technology. It is conditioned through computational processes that are based on detected spatio-temporal changes. It is actuated through embedded virtual or physical agents, human or non-human- that provoke changes detectable by the inhabitant, or that enhance the spatial experience of the occupant in an explicit or implicit way. The most promising aspect of a city that is a cybernetic mechanism is the fact that its citizens are hyper-connected leading their lives as always on-line and connected. This allows for the transformation of the urbanites to agents that act as sensors and actuators of the city in their own right, broadcasting and receiving information through various networks that augment the cities that they inhabit

"Total Fluidity on All Scales" was the title of a Zaha Hadid lecture at the Massachusetts Institute of Technology in April 2007. For several hours the audience stood in front of wondrous forms of all scales that suggested the idea of movement – from objects to buildings, and even cities.

The quest for movement in design can be traced back to Baroque times. Baroque master architects like Bernini made static structures appear to be in perpetual motion by representing one moment in which movement is frozen, provoking "the illusion of the eminence of motion."[7] A similar attitude led to the Futurist movement, where visual artists tried to depict movement and change through two techniques: "representing the processes of corporeal movement," and "an interpenetration of the volume that moving entities occupy."[8] A few years later, Le Corbusier offered a theoretical framework for movement in architecture by equating it with a machine for habitation, and speculating how mechanized civilization might find architectural expression with artifacts that actually 'look' like machines.[9] In all of these attempts – and several others that we will not review here – the emphasis was on designs that would look moving and alive, creating life or its illusion with human artifice and the proper technology.
There is, however, another approach to the design of moving, living artifacts, which we believe holds the most promise for the future. Often relegated to niche designers and inventors outside the world of architecture, it focuses not on form, but on process: how movement can actually be implemented, not merely represented.

This idea can be traced back to the 18th-century phenomenon of self-operating machines called automata ("that which acts on its own will" in ancient Greek). Automata were complex, programmable machines that exhibited lifelike movements. From the 17th century onward, they became the center of much intellectual and artistic speculation, and found their way into the curiosity cabinets of the royal courts of Europe. One famous example is the Joueuse de Tympanon, a mechanized doll that played a musical device by striking its strings with hammers, built for Marie Antoinette by David Roentgen and Pierre Kintzing c.1784.

The Enlightenment's ideological shift from a natural to a mechanistic world view, represented by Descartes's interpretation of natural organisms as automata, allowed man to reconsider the origins of life: since any living organism was a mechanism with identifiable rules of operation, and man could create complex mechanical systems, then the ability to create life was no longer the domain of the Almighty. A few decades later, in 1822, Charles Babbage's proposed machines would advance man's quest to create

[7] Silvetti, J. (2007) The Muses Are not Amused: Pandemonium in the House of Architecture. In Saunders, W. S. (Eds.) (2007) *The New Architectural Pragmatism: a Harvard Design Magazine Reader*. Minneapolis: University of Minnesota Press. pp. 176-198.

[8] Giedion, S. (2008) Space-Time In Art, Architecture and Construction. *Space, Time* and *Architecture*. Cambridge, MA; London: Harvard University Press. pp. 429-477.

[9] Le Corbusier (1970) *Towards a New Architecture*. London: Architectural Press.

life towards the automated actuation of the physical world. His mechanical control systems could be considered the precursors of today's computers – and one could perhaps claim that Babbage's Difference Engine was the first cybernetic mechanism, although the feedback between the system's output and input was mediated mechanically rather than electronically. Cybernetics officially emerged with Norbert Wiener and his principle of expanding human control over the environment using electronic interfaces. As such, computer technology would become a means of extending human capabilities based on what Wiener defined as the feedback principle, i.e. when a system changes its course of action and mode of operation in response to its current context, including the desire of a controlling human agent.

Cybernetics soon moved into the realm of architecture. Cedric Price's proposal for the Fun Palace was perhaps one of the first examples of an architectural cybernetic system that incorporated Wiener's feedback principle. It centered on new technology that made Fun Palace responsive to visitors' needs by dynamically adapting its spatial configuration. The proposed building was a kit of pre-fabricated modules that would constitute a variable structure, which Price claimed "[could] be assembled, moved, re-arranged and scrapped continuously."

The vision of architectures capable of soliciting their inhabitants' control over the production and consumption of space also prevailed in Yona Friedman's 1958 manifesto for Mobile Architecture. In it, he described the "dwelling decided on by the occupant" by way of "[loose] infrastructures that are neither determined nor determining," but in constant redefinition by members of a "mobile society."[10] Friedman's concept glorified the role of the users of architectural space. He tried to offer simple manuals for visions of cities where dwellers would shape their environments, such as a mobile city where buildings would only minimally touch the ground, allowing them to be dismantled and moved by their occupants. In this utopian mobile city, space effectively becomes an interface through which the inhabitants realize their desires and regulate their needs.

It could be said that all of the above work, dating from the mid-20th century, already contained most of the principles necessary to design responsive, living environments. However, at the time it still lacked the effective communication infrastructure necessary in order to acquire global relevance. This has now emerged in the digital net.

Here we need to clarify the concept of network in architecture: "net talk" is not "new talk." In his 2001 article "Network Fever," Mark Wigley expresses his doubts about the networked condition as a completely new intellectual and socio-technical phenomenon, building his hypothesis on precedents from the 1950s and 1960s that signaled a "radical confusion of architecture and network."[11] He cites Team 10, who, in the late fifties, created urban projects where complex vehicular, pedestrian, and courtyard circulation systems were embedded in a dense infrastructural "mat" of woven, built forms. Additionally, he reminds the readers that the Metabolists wrote about architecture as biological circuitry capable of perpetual self-adaptation to the "metropolitan flux" of the sixties. This fascination with constructed landscapes as networks, Wigley reminds us, is apparent in Stefan Wewerka's 1953 Experimental Structural Web description of cities "as compact bundles of overlaid net-structures," whose infrastructural network of communication and conveyance of material entities became indistinguishable from the cities themselves, to the extent that in Denis Crompton's (Archigram) 1964 proposal, Computer City, "The Network [took] Over!"[12] In its extreme, the city was envisioned as a computer where everything was hardwired to everything else.

[10] Friedman, Y. (2006) *Pro domo*. Barcelona: Actar.

[11] Wigley, M. (2001) Network Fever. *Grey Room* 4, pp. 82-122.

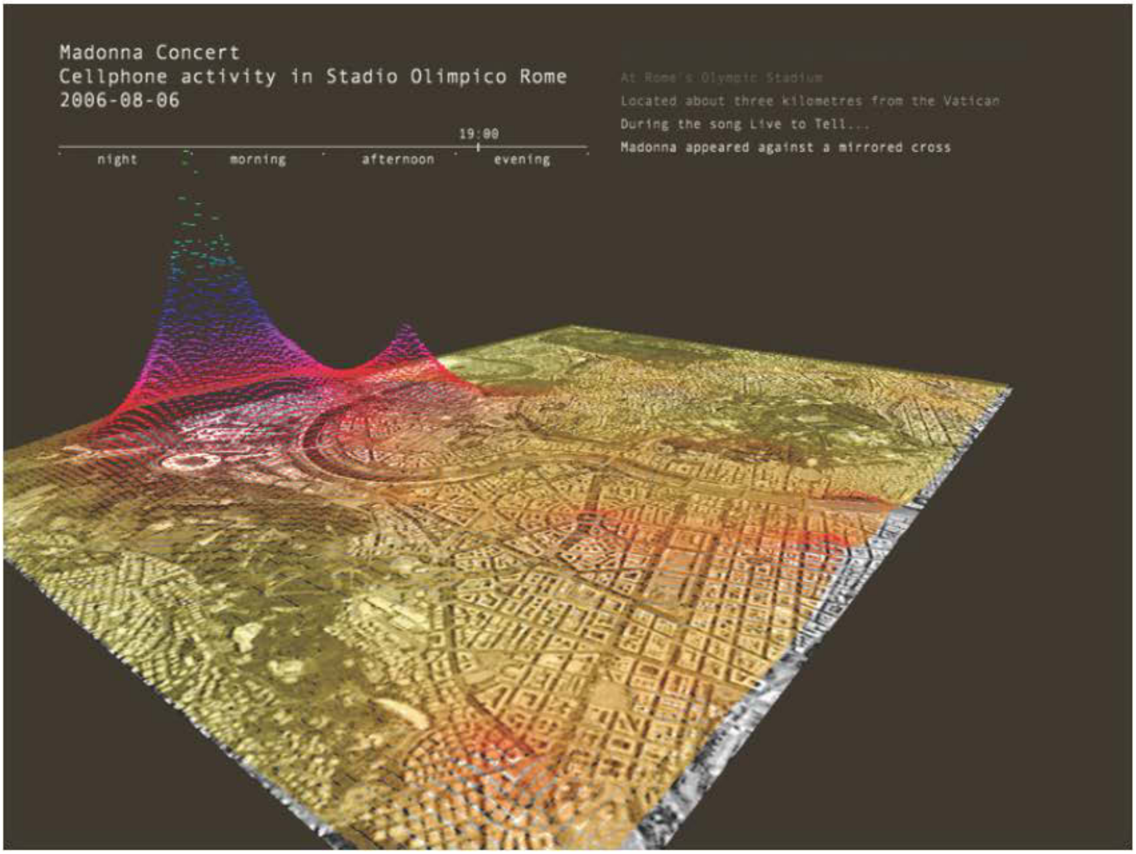
[12] ibid.

Yet, the network concept has recently undergone a revolutionary process that has led it to reaches well beyond its twentieth century embodiment. 1950s' architectural readings of networks looked at a top-down infrastructure where functions were plugged in, and through which commodities––material and virtual–– were distributed from their sources to consumers. Twenty-first century versions of networks are distributed, bottom-up structures that for the first time allow humankind to gain constant, seamless access to real-time information.

Embedded technologies for acquiring information, (such as networks of monitoring devices), and delivering information (such as networks of actuating devices), allow for a world wherein every object is connected to all other objects, and has embedded computing and communication powers. Additionally, humans have become part of the network. Mobile technologies digitally extend each individual by providing them with a mini-terminal equipped with embedded sensors and a portal for the delivery of information – be it an iPhone, smart phone, or any hand-held, personal computing device. Such devices are capable of establishing data connections both to the infrastructural mobile networks, and to the more localized, ad hoc networks mediated through Wi-Fi and Bluetooth technologies.

Under these circumstances, Wiener's cybernetics can become a global reality. Once spaces become dynamic, their inhabitants can be incorporated as entities with transient preferences and needs. Instead of generic "occupants" they become hyper-individualized "users." They interface with a world embedded with networked microprocessors, where the digital and the physical merge in the Ubiquitous Computing paradigm first recognized by Mark Weiser. [13] People play key roles in this system as agents of sensing, regulation, and actuation. In terms of sensing, they voluntarily and involuntarily leave digital traces on various networks deployed over space. The network records every time a credit card is used, a text message or an email is sent, a Google query is submitted, a phone call is made, a Facebook profile is updated, a photo is tagged on Flickr, or a purchase is made in an online store. Once the datasets are attached to physical space, landscapes are transformed into new info-scapes. In turn, these info-scapes provide citizens with a better knowledge of their environment, and allow them to make more informed decisions. Indeed, this seems to be the most promising characteristic of the city of the future, which becomes "smart" through the collaborative activity of the sentient, self-reporting agents who are its citizens. It will be a desirable place to live and work, since it offers a platform for reinforcing identity and culture through collaboration.

[13] Weiser, M. (1991) The Computer for the Twenty-First Century. *Scientific American*. pp. 94-100.



An example of info-scape: Real-time Rome. Aggregate picture of data transferred through the Telecom Italia cellphone network during a Madonna Concert.

The Real-time Rome project looks at how positions and activities of mobile phones can be used to "sense" people's presences. When aggregated at the highest possible level, mobile location data does not impinge upon the privacy of individuals, but can return important information on the concentration and relative weights of human activities in the urban environment, as well as flows and patterns of city use. Visualizations and analyses of such data can be obtained in as close as real-time as possible. Such visualizations allow for answering various questions regarding the dynamics of a city: How many people are there in a given area? Where is traffic piling up? What percentage of people have left the critical area? What is the current demand for public transportation? How many people will look at that billboard? What is the pattern of inflow and outflow of people from the city? What's the hottest spot in town right now? Copyright MIT SENSEable City Lab, for full credits see http://senseable.mit.edu/wikicity/rome/

An example of an info-scape: sample visualization from the Trash Track project tracking a tagged aluminum can as it travels through the garbage collection network of the city.
Trash Track consists of digitally enhanced tags that were attached to objects and could report their location to an Internet backbone infrastructure via cellular network. Trash Track made use of these location-reporting tags to track urban disposal and study the efficiency of the urban waste-removal chain. The platform allowed designers and planners to analyze the acquired data, and make well-informed, high-level decisions about how the given constructed landscape is managed. Therefore, a multiplicity of questions about the dynamics of the urban removal chain could be addressed empirically: is our removal chain efficient? Is hazardous waste managed properly, or are there loopholes in our system that need to be taken care of? Is the recycled waste really recycled, or does it end up in dumps? The Trash Track system can have a great impact on the nature of the perceptual relationship that a city or region develops with its waste disposal habits. Copyright MIT SENSEable City Lab, for full credits see http://senseable.mit.edu/trashtrack/

The sensor-actuator citizen is a new subject emerging from the hybrid of technology and biology: a neo-cyborg. Traditional cyborg theory proposes either the gradual disembodiment of each subject, who leaves behind physical existence to move towards a new digital status, or a disconcerting integration of machine and human that results in android monstrosities.[14] However, the neo-cyborg has a much more positive characterization: it is a proper body that uses various networks to extend its physical boundaries.[15]

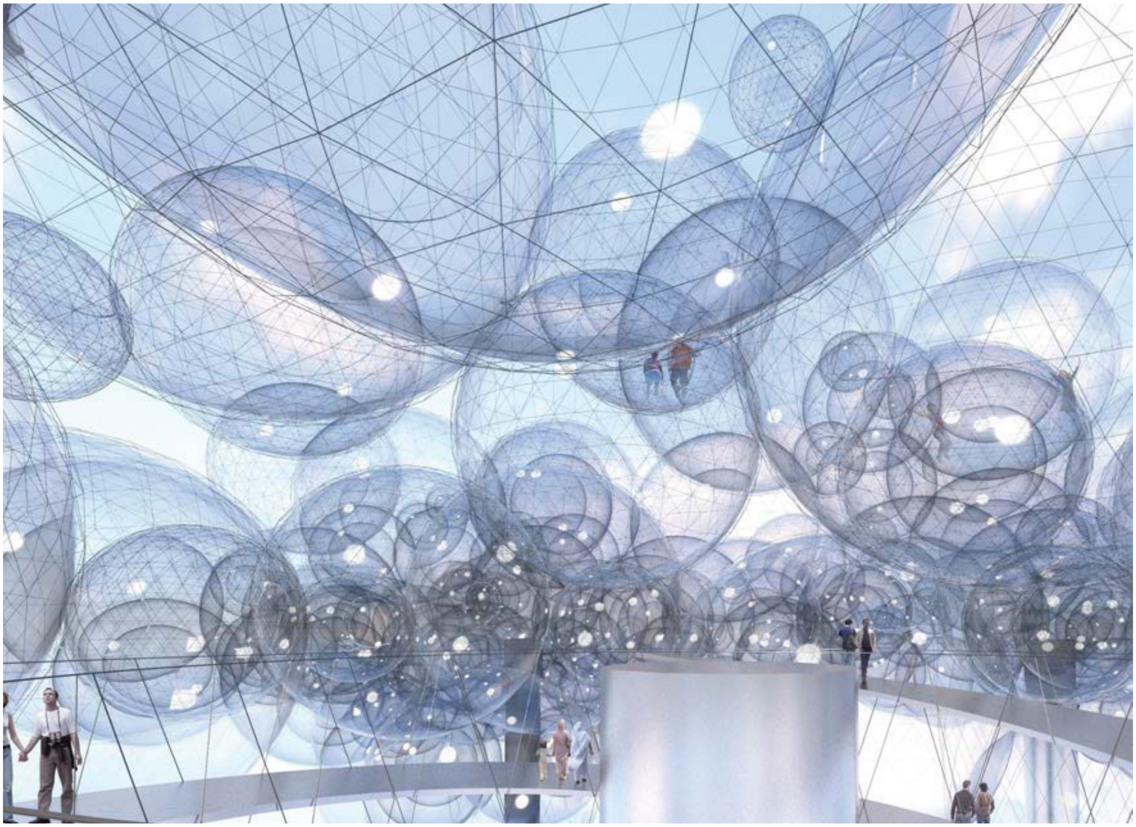
Instead of merging humanity with machines, the neo-cyborg merges humanity with real-time information. What type of society could result from this? The answer, we believe, is a peer-to-peer collectivity or "multitude." In both Empire and Multitude, Hardt and Negri introduce the "multitude" as a postmodern form of collectivity. It differs from other forms of collectivity that reduce diversity to a single unity, in that subjects in a multitude retain specific differences, becoming hyper-individuals. The multitude is an "open and inclusive concept," [16] meaning that subjectivities are not excluded or included based on their singularities. Hardt and Negri equate the multitude to a distributed network where separate nodes are all connected and "the external boundaries of the network are open such that new nodes and new relationships can always be added." Thus, subjects in a multitude are "becomings" instead of beings–—capable of establishing new connections and perpetually in a state of flux. In the multitude of a peer-to-peer network, the central authority is replaced by collaborative relations. Terms such as "Flashmobers," "Generation Text," "Thumb Generation," "Collective Intelligence," "Smartmobs," and "Me++" are manifestations of this phenomenon: they describe the denizens of a looming new generation of living, responsive architectures.

[14] For more information on cyborgs and post human discourse: Hayles, N. K. (1999) *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics*. Chicago: University of Chicago Press., and Clark, A. (1997) *Being There: Putting Brain, Body, and World together again*. Cambridge, MA: MIT Press., and Kapper, M. C. (2004) *Affect as Epistemic Source in a Posthuman Age*. Ph.D. dissertation, Purdue University.

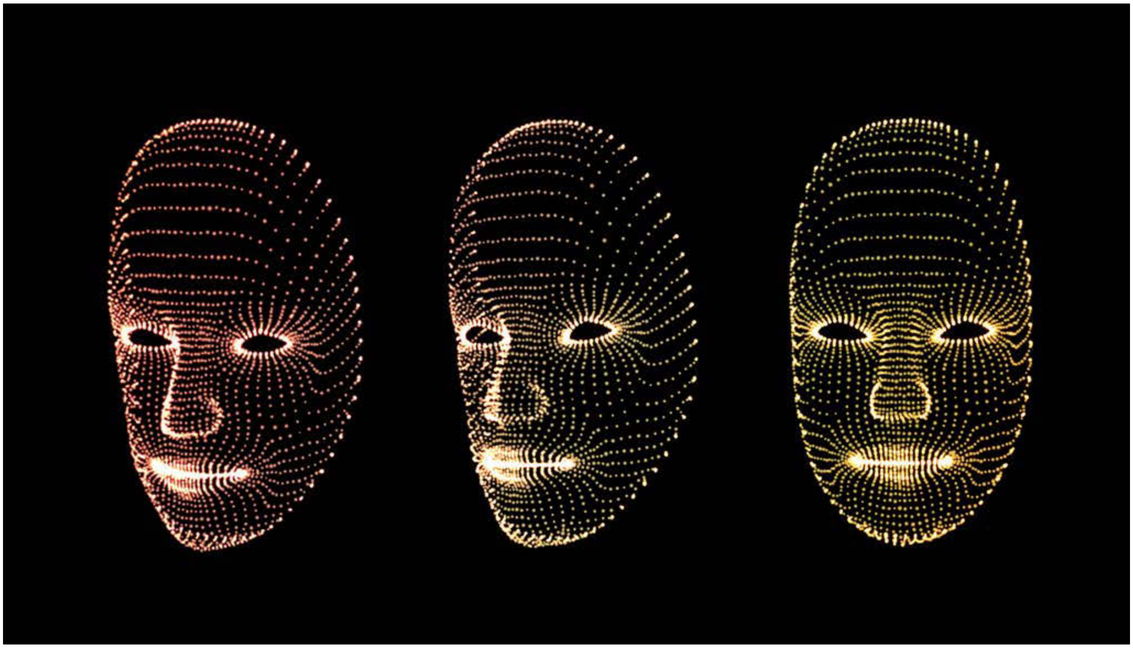
[15] Reprint from Nabian, N. and Ratti, C. (Forthcoming) Living Architectures. *Net Works: An Atlas of Connective and Distributive Intelligence in Architecture*. London: AA Books. (*Introduction*)

[16] Hardt, M. and Negri, A. (2000) *Empire*. Cambridge, MA: Harvard University Press., and Hardt, M. and Negri, A. (2004) *Multitude: War and Democracy in the Age of Empire*. Cambridge, MA: Penguin.

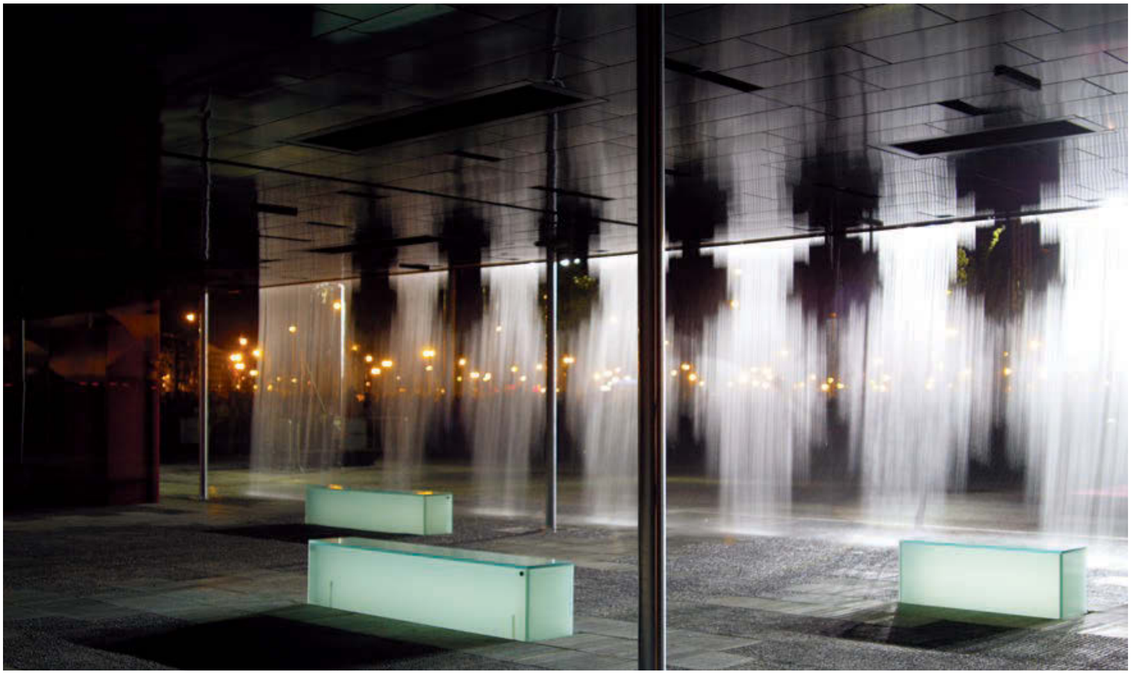
An example of Sensor-Actuator Citizen Principals at Work: Photographs of Copenhagen Wheel Prototype.
The Copenhagen Wheel quickly transforms ordinary bicycles into hybrid e-bikes that also function as mobile sensing units. It captures the energy dissipated while cycling and braking, and saves it for when the biker needs a bit of a boost. It also maps pollution levels, traffic congestion, and road conditions in real-time. Controlled through the cyclist's smart phone, the Copenhagen Wheel becomes a natural extension of the cyclist's everyday life. The phone can be used to unlock and lock the bike, change gears, and select how much the motor assists the biker. As one cycles, the wheel's sensing unit also captures one's effort level and information about surroundings, including road conditions, carbon monoxide, NOx, noise, ambient temperature, and relative humidity. People can access this data through their phones or the Web, and use it to plan healthier bike routes, to achieve exercise goals, or to meet up with friends on the go. The bikers can also share their collected data with friends, or with city—anonymously if they wish–thereby contributing to a fine-grained database of environmental information from which all city inhabitants can benefit.



An Example of an Urban-Scale Digital Display Technology and Interactive Structure: the Cloud
The Cloud provides two resources–energy and data–harvesting both from the natural ecosystem and humanity's complementary cybersphere, and fusing the two. Rainwater trickling over its surfaces and displays is collected and redistributed. Wind energy, amplified at elevation, is harnessed. Photovoltaic inflatables at the fringes can be unreeled during the day and docked at night, or in high winds. Furthermore, In the Cloud display system, the patterns of its animated, spherical skins offer a civic-scale interface for the delivery of real-time information to the inhabitants and visitors of the city.



An example of Innovative Digital Display Technology: Flyfire
Flyfire explores how display technologies can actuate the space of the city. It uses a large number of self-organizing micro-helicopters that contain small LED's and act as smart pixels. The helicopters are controlled to create synchronized motions and form elastic display surfaces. This allows any ordinary space to transform into a highly immersive and interactive display environment. The proposed mechanism explores the possibility of a free-form spatial display that consists of a swarm of pixels that self-organize in real-time to adapt to the display requirements of any given scenario. Rendered views illustrate how Flyfire technology can be deployed for displaying raster information as two-dimensional re-created graphics, and vector information as three-dimensional re-created volumetric compositions.



An Example of Interactive Architectures Functioning as Digital Information Portals: the Digital Water Pavilion.
The Digital Water Pavilion is a singular and innovative project of Milla Digital, implemented by Expoagua Zaragoza 2008 on behalf of the City of Zaragoza. Located in the connection node of the Expo site with the Milla Digital area, this Pavilion of minimalist expression and small dimensions is simultaneously: a sophisticated machine of high mechanical precision; a building appearing and disappearing thanks to a 12 hydraulic pistons system; and a place where spaces are flexible, changing, and responsive due to the action of 120 meters of water walls digitally controlled by almost 3,000 electromagnetic valves. The digital water curtain had the potential of functioning as an architecturally embedded screen for delivering information, materialized as droplets of water. Photographs of the interactive water wall, illustrates how the wall ! is animated and digitally controlled by almost 3,000 electromagnetic valves.

THE SENSEABLE CITY AND MECHANISMS OF DATA ANALYSIS AND COMPUTATION: CASE OF EIGENPLACES WHERE CITIES ARE ANALYZED USING SPACE-TIME STRUCTURE OF MOBILE PHONE NETWORKS.

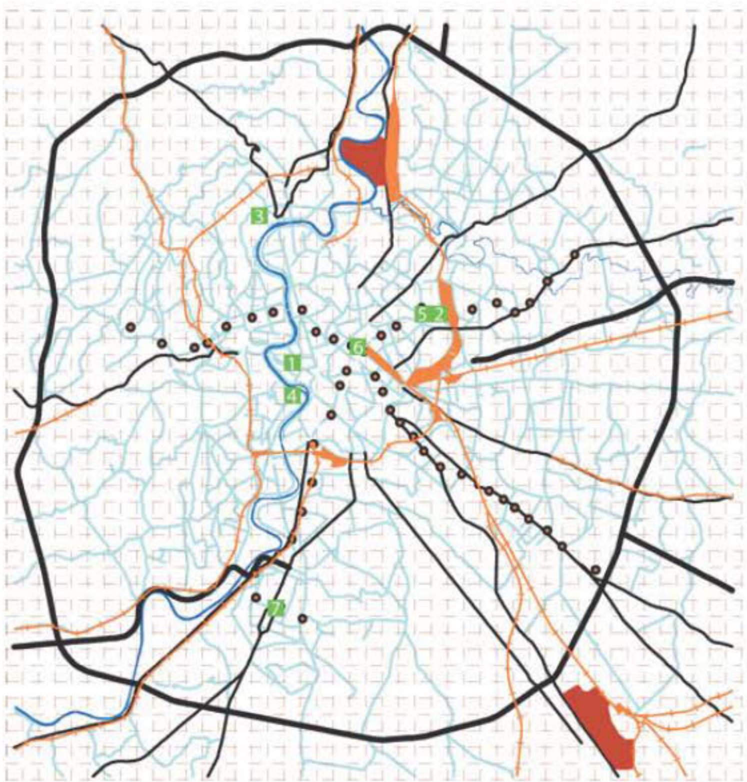
by Jonathan Reades, Francesco Calabrese, and Carlo Ratti

Several attempts have already been made to use telecommunications networks for urban research, but the datasets employed have typically been neither dynamic nor fine grained. Against this research backdrop, the mobile phone network offers a compelling compromise between these extremes: it is both highly mobile and yet still localisable in space. Moreover, the mobile phone's enormous and enthusiastic adoption across most socioeconomic strata makes it a uniquely useful tool for conducting large-scale, representative behavioural research. In Eigenplaces, we attempt to connect telecoms usage data from Telecom Italia Mobile (TIM) to the geography of human activity derived from data on commercial premises advertised through Pagine Gialle, the Italian `Yellow Pages'. We then employ eigendecomposition - a process similar to factoring but suitable for this complex dataset – to identify and extract recurring patterns of mobile phone usage. The resulting eigenplaces support the computational and comparative analysis of space through the lens of telecommuniations usage and enhance our understanding of the city as a `space of flows'.

Our analysis builds on aggregate mobile phone data supplied by TIM between July and September, 2006. Data collected at fifteen-minute intervals at the trans- ceiver level across a 47 km2 region were transferred via secure-FTP (file transfer protocol) to servers at MIT. Three months' worth of data represents the cumulative daily phone usage - voice, text, and data - of more than one million TIM subscribers and visitors to Rome. In all, the dataset contains more than 3.5 million observations. Network data were supplied in Erlang, an aggregate measure of bandwidth usage that is often used in network capacity planning on GSM(2) networks and which can be easily collected by the operator.

The Erlang is also completely anonymous, since it is defined as one person-hour of phone usage: consequently one Erlang could be the result of a single person talking for an hour, two people talking for a half-hour each, thirty people speaking for two minutes each, and so on. In effect, Erlang data provides a view of urban space as seen through network bandwidth consumption and, indirectly provides an insight into the spatial and temporal dynamics of urban life.

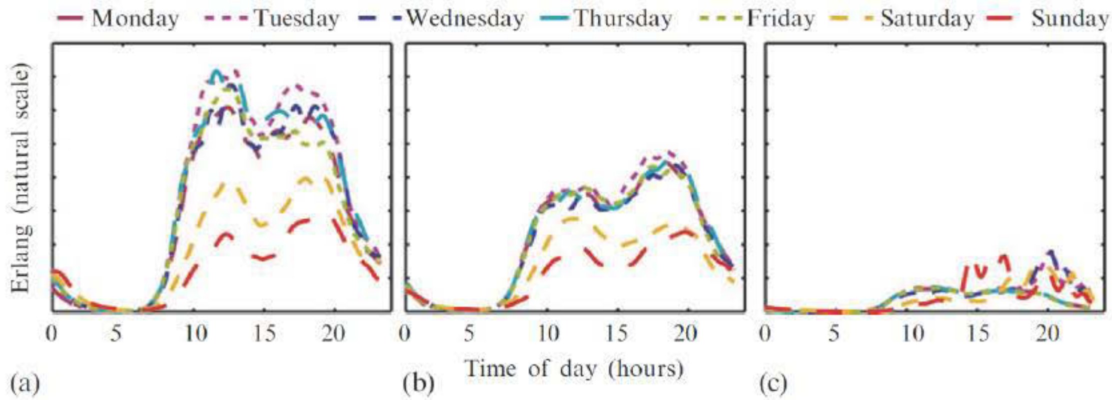
The coverage areas of cellular transceivers overlap to ensure quality of service, often with multiple transceivers on a single mast. Since we lacked the orientation data to untangle their relationships to one another, we used an exponential decay algorithm to divide Rome into 2115 'pixels', each measuring 500 m by 500 m, instead of the more usual Voronoi polygon plot. The rasterizing function enables us to derive an Erlang value for each pixel, which is a composite calculated from the surrounding antennas. Actual Erlang values were also modified by a scaling factor applied by TIM to preserve commercial confidentiality. In a move from Erlang data to 'signatures', we selected seven locations that we expected to have distinct patterns of behavior and, consequently, mobile phone usage for in-depth study: (1) the Pantheon, a key tourist attraction and popular meeting point; (2) Tiburtina, a secondary interchange used by regional trains and buses as well as late-night intercity trains; (3) Olimpico, Rome's main concert and football venue; (4) Trastevere, a popular night time destination; (5) Piazza Bologna, a predominantly residential area; (6) Termini, Rome's main rail station; and (7) EUR, a purpose-built office area southwest of the downtown area.



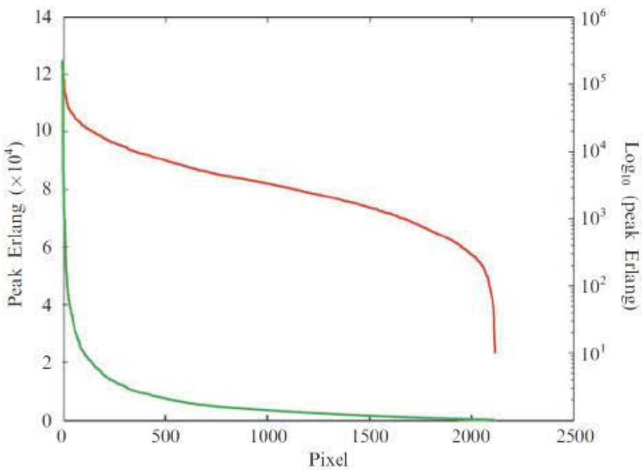
Map of Rome and selected areas of special interest: Black|Major road, Light Blue|Secondary roads, Dark Blue|Rivers, Orange|Rail infrastructure, Red|Airport infrastructure, Green|Selected pixels

Projecting Erlang changes over time for some of the sites mentioned above yields the unique `signature' of phone activity: the area around the Olimpico stadium, a venue for sporting events and concerts, clearly shows a pattern of afternoon and evening activity not seen in other parts of the city. Comparing the tourism-driven area near the Pantheon with a more locally oriented site at Tiburtina, suggests variable and distinct relationships between space, time, and aggregate phone usage. In particular the variability during weekdays, and the contrasting drops in usage over weekends.

While such an analytical approach is helpful in revealing the coarser differences between areas of Rome, it is time consuming to perform this type of intense analysis operation for each cell. To explore the system as a whole we need to first understand the overall distribution of Erlang within the city. To this effect we visualized the distribution of peak Erlang, irrespective of time of day or day of week, for each of the pixels in Rome. The `raw' values shown on the light green line in Figure 9, follows an exponential distribution with its characteristic `long tail'. Plotting the peaks on a logarithmic scale - the darker red line - emphasizes this distribution. We settled on log10 to generate the logarithmic distribution shown below, which we believe constitutes an appropriate transformation under the circumstances, and which also resolves the scaling issue identified above.



Sample Erlang signatures from Rome: (Left) Pantheon (tourist monument); (Center) Tiburtina (rail/metro station); (Right) Olimpico (sports and concerts). These three locations are identified by numbers 1 - 3, respectively in the Map of Rome and selected areas of special interest.

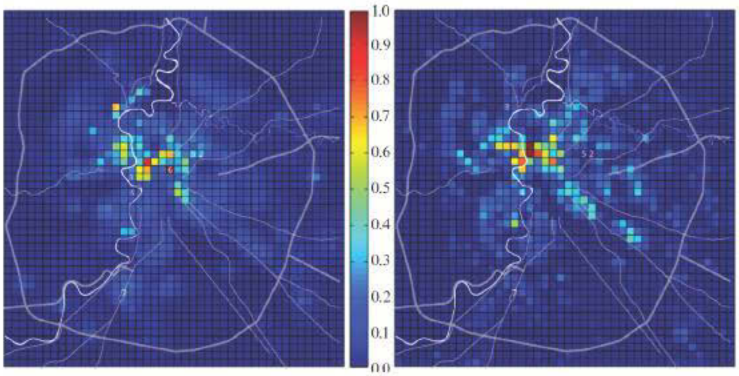


Peak Erlang distribution: The green line denotes raw values; the red line denotes log10 values.

The use of a logarithmic scale also has important analytical benefits: the magnitude of the difference between the largest and smallest peak Erlang values is so great that it would easily mask more subtle features shared between cells with widely differing levels of telecom usage. By taking the log of the dataset we are able to retain fewer features of the signatures.

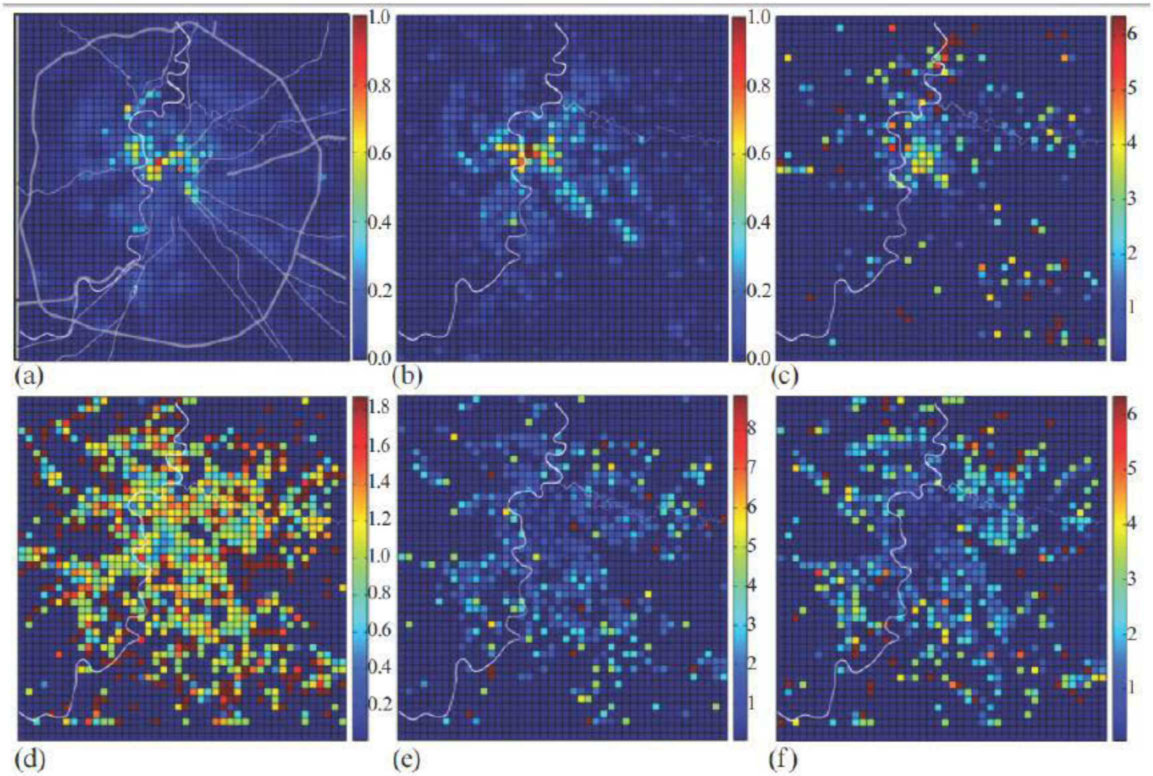
The two illustrated projections suggest a strong connection between these datasets. The highest levels of Erlang on the map are linked to flows of people at the Termini Station and a location near the Spanish Steps. However this second site also points to one of the challenges in using mobile data for urban analysis: it is a geographical high point and hosts a major telecommunications array that is readily `visible' to phones at some distance from the area. Other points of interest include the Piazza Navona, the Olimpico Stadium, and the Vatican. There is also the suggestion of a link to higher phone usage along Rome's major radial access roads and near their intersection with the circular. While this simple projection indicates a relationship between phone usage and socioeconomic geography, it is nonetheless important to quantify this connection.

Further analysis of the maps at a more fine grained scale, was enabled through Seat Pagine Gialle who allowed access to their directory of 50,000 businesses in Rome. The database contains the name and address of each listed business, alongside their geographical location (latitude and longitude), and their advertising category. This latter category was diverse and extensive in the range of advertising groups it included, from the obvious (articles for smokers), to the amusing (ornamental aquariums and accessories), and the rather specialized (eggs). Coordinates were specified to four decimal places, representing an accuracy of approximately 10m. Using this locational data we assigned each business to a pixel and organized the raw categories thematically into use-oriented groups. Our aim was to demonstrate a measurable link between mobile phone usage and business activity, consequently establishing the use of aggregate mobile data as a more empirically robust research tool. The initial step examined the total number of businesses in each grid cell and compared it to peak Erlang values. The correlation yielded a standard deviation of 0.18, with a fairly high incidence of pixels that departed radically from the mean. Similarly, plotting peak Erlang against the number of businesses indicated that there was no single regression that could account for the entirety of telecommunications activity in Rome. The absence of a simple correlation was to be expected, since mobile phone use is not structured solely around the location of businesses advertising in the Yellow Pages.



(Left) Peak normalized Erlang density map; (Right) normalized business density maps.

The enormous number of categories in the raw Pagine Gialle dataset, in tandem with the widely variable number of businesses in each group, led us to select a smaller number of `themes' from within the dataset for further study: (1) accommodation; (2) daily retail; (3) dining out; and (4) food retail. These groups were selected so that there would be enough businesses across the city as a whole for a geographical projection to be meaningful, and so that they would be distributed evenly enough that their relative density provided insight into the city's overall makeup: as seen in the figures, `accommodation' is centrally located, near the areas frequented by tourists, but it also demonstrates significant peripheral clusters that may indicate transport connections (they are near to both of the airports and the orbital). The `dining out' category may be indicative of the Italian passion for food - such establishments are quite literally everywhere, up to the edges of Rome's developed areas, and even beyond in places overlooking the city. Finally, `daily retail' and `food retailers' are relatively scarce in the business core, but are more common towards the edges, which suggests that these are more residential areas.



Spatial distribution of businesses: (a) normalized peak Erlang, (b) normalized business density; (c) accommodation; (d) dining out; (e) daily retail; (f) food retailers.

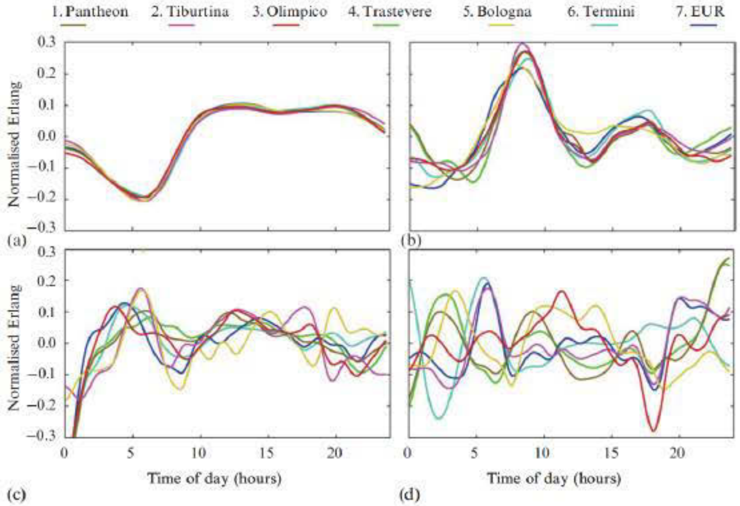
The next step sought to improve our understanding of the relationship between business and residential areas, and their cumulative impact on mobile phone infrastructure, using an eigendecomposition technique to extract patterns from the large datasets that we had. This method decomposes the electromagnetic signature of a pixel into an arbitrary number of components, enabling us to extract the basic dimensions of the relationship between mobile bandwidth usage and urban activity. The number of eigenvectors required to reconstitute the source with an acceptable margin of error depends on the complexity of the raw input data. Quite simply, the more random the original signal, the more information we need to rebuild it. Multiplying each component vector by its coefficient and summing the result enables us to reconstruct the source dataset. Thus, if S is the observed signature for a randomly selected pixel, C is a coefficient, and V is an eigenvector, then: $S=C_1V_1+C_2V_2+...+C_nV_n$.

In our case, data for one day from one pixel can be expressed as a vector with one row and ninety-six columns - one column for each of the Erlang values recorded at fifteen-minute intervals. Lining up the ninety days' worth of data that we collected between 1 September and 30 November yields a matrix of ninety rows and ninety-six elements, thereby allowing us to calculate a covariance matrix and then decompose it into a set of vectors, each modified by the appropriate coefficient. The original signal can be approximated using only the first four eigenvectors from the covariance matrix.

We termed the output of this process an `eigenplace', since it connects the spatio-temporal patterns of mobile phone usage to human activity spaces. By extracting the principal components of each pixel separately, we are able to abstract the daily and weekly routines embodied in an individual place. In effect, the more `routinized' activity becomes in a pixel, the larger the principle eigenvector's coefficient becomes. Conversely, spaces with more heterogeneous types of usage will attach greater importance to the lesser vectors.

Consequently we analyzed the eigenvectors for the seven selected pixels in order to develop our understanding of how these areas behave over time. The first eigenvector clearly suggests a single, underlying, characteristic of mobile phone usage that varies little across space and is driven primarily by the time of day. Consequently, it seems reasonable to connect the first eigenvector to the diurnal cycle of Rome – people waking up, going to work, breaking for lunch, and then heading home in the evening.

Conversely, the high rate of change in the fourth eigenvector suggests that it is largely composed of `noise'. If the first vector is of little use for distinguishing between locations, and the fourth describes only minor aspects of the original signal, this leaves the second and third eigenvectors to account for the majority of the difference seen between the pixels. Here we find some intriguing features: in the second eigenvector the higher values during late night and early hours of the morning in Trastevere and the

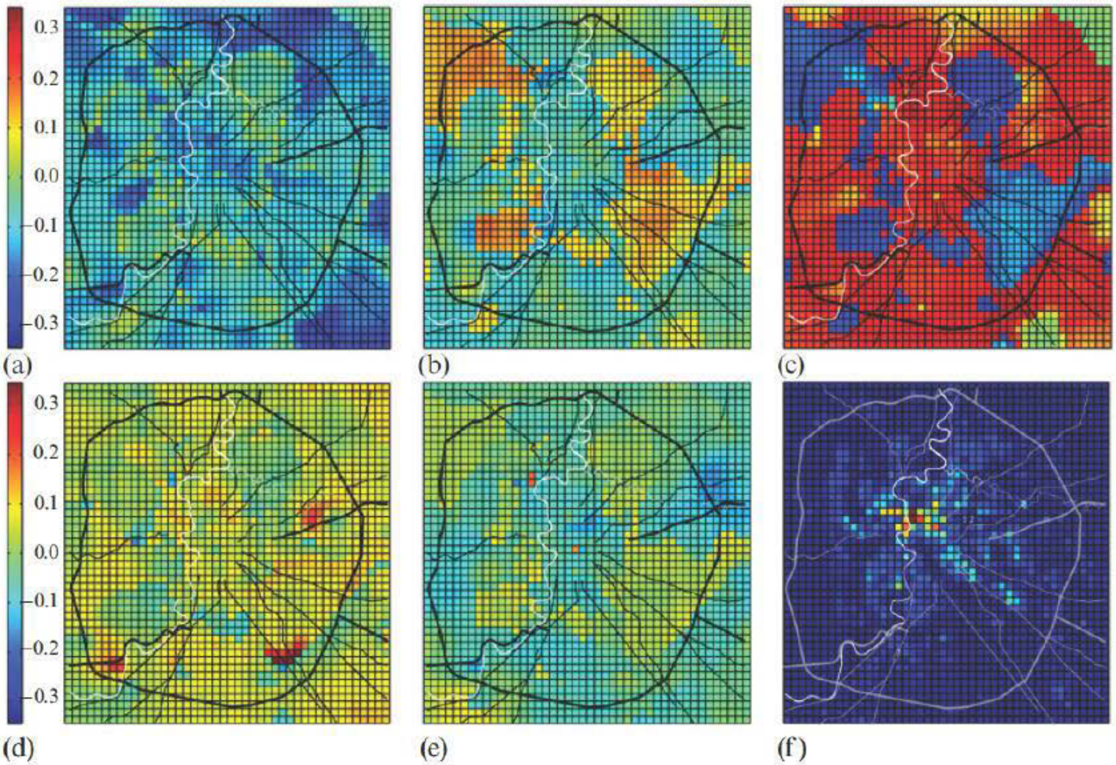


Eigenvectors for selected pixels: (a) first eigenvector, (b) second eigenvector, (c) third eigenvector, (d) fourth eigenvector. The numbers 1 - 7 refer to the seven selected locations in the study.

Pantheon strongly imply nighttime activity. The much smaller drop in phone usage around midday at Piazza Bologna suggests an area with a different usage profile from the other six pixels, and it is the only site connected to a known residential space and, hence to family. The third eigenvector is much more difficult to interpret on the basis of anecdotal evidence, and it should be noted that the coefficients associated with this vector are not of the same magnitude as the first and second; but it is interesting to note that usage at the adjacent Piazza Bologna and Tiburtina falls in parallel during the morning as mobile users flow into central Rome, but follows a markedly different trajectory in the evening as people head home. In contrast, trends in phone usage at the comparatively more distant Trastevere and Pantheon seem to fall more naturally in sync.

Consequently, we returned to the idea behind the normalized peak Erlang plot. Now, however, we are able to focus on the difference that is not explained by the daily rhythm of urban life. Using the same geo-spatial model, we then mapped the normalized peak Erlang based on time and spatial distribution. Several distinct groups of pixels show up in the resulting illustrations. Three pixels, two adjacent to Olimpico and one in the very centre of Rome at Termini Station, stand out for the relatively high levels of usage at 9 pm in the evening. In contrast, the map for 9 am shows comparatively high levels of usage across almost all of Rome except for three specific areas - between Strada dei Parchi and Via Toscolano, to the east of Urbe airport, and to the northwest of Via del Foro Italico. It is intriguing that these same areas also have higher levels of use in the evenings, which would be consistent with residential use.

It is also interesting to examine the map from 1am, from which we can attempt to deduce some areas popular for late night activity: to the west of the Tiber is Trastevere and to the south of central Rome are Ostiense and Testaccio, all of which are areas known for their clubs and bars. Perhaps the most interesting plot, however, is that for 5 pm: three areas are particularly prominent, and they all lie along major radial routes out of the CBD. Since these active areas are located just before motorists would reach the orbital highway, the most likely explanation for the activity at this time is that these places are popular calling points for commuters leaving the city.



Eigenvector map: (a) 1am; (b) 5 am; (c) 9 am; (d) 5 pm; (e) 9 pm; (f) normalized business density

Through this analytical approach to geo-spatial and temporal data of mobile networks usage and through cross referencing it with land-use data, we have shown that there is a clear, identifiable relationship between human activity and Erlang, but that the nature of this relationship is neither simple nor linear. A straightforward regression therefore appears insufficient to account for the way that bandwidth usage changes in areas of intensive activity, such as the CBD. Nonetheless, we have provided modest empirical support for our experiential knowledge of the city's terrain - although indirect, the distribution of businesses provides important evidence that phone usage is connected to local land use in very real ways.

In this eigen decomposition the primary eigenvector clearly indicates a common underlying pattern in the mobile phone usage in Rome, while the secondary and tertiary vectors indicate a spatial variation that is very suggestive of temporally-related and activity-related influences. One powerful effect of this process is that it essentially allows us to factor out the diurnal signal, leaving the key points of difference between each pixel or set of pixels. Thus we have early evidence that the concept of the eigen-place provides a new tool with which to distinguish between areas on the basis of their telecommunications signature.

This surprisingly fine-grained computational approach appears quite sensitive to spatio-temporal influences, and so this new type of data clearly has the potential to significantly expand our understanding of urban dynamics. As a result, we may be able to develop new methods for improving the delivery of public services to all inhabitants - rather than viewing the city in terms of static infrastructures, we can visualize it as an interconnected set of flows (and immobilities), and can try to reach out in ways optimized to the nature of the problem from the human, and not the purely physical or mechanistic, standpoint.

The intimately personal nature of the mobile phone and our growing ability to track it across the urban landscape begins to raise new questions regarding personal privacy at the same time as it opens an unprecedented window into how millions of people, each pursuing their individual interests and responsibilities, use the city. Although the cellular network cannot offer the locational specificity of GPS, its scalability means that it nonetheless remains very attractive for research at scales where higher resolution is unnecessary. In particular, this class of data would seem to be particularly relevant at the city-region level, for which the system is much too large to explore using traditional analytical methods.[21]

[21] Reprint from Reades, J., Calabrese, F. and Ratti, C. (2009) Eigenplaces: analyzing cities using the space-time structure of the mobile phone network. Environment and Planning B: Planning and Design. 36, pp.824-836.