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CITY OUT OF CHAOS: SOCIAL PATTERNS AND ORGANIZATION IN URBAN SYSTEMS

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ABSTRACT

This research develops innovative approaches for urban studies, applying the theories of evolutionary physics and ecosystems to urban systems and defining a theoretical interdisciplinary approach. A new social positioning method for monitoring urban mobility, named Mobile Landscapes, studies the space–time behaviour of urban society. This project uses location-based data from cell phones to reveal the locations and intensities of urban activities (people using space) and to analyse mobility patterns in cities. An aim of the Mobile Landscapes project is to investigate human dynamics. Considering a city as a place of interactions between humans and the built environment, maps of social activity reveal how urban–social systems have self-adaptive properties like complex dissipative systems. Focusing on dynamic patterns of urban–social activity, this project highlights the role of time in urban processes and takes an evolutionary approach to urban planning and design. The case study described in this paper is based on data from cell phone antennas in the metropolitan area of Milan, Italy.

Keywords: complex system, dissipative structure, ecosystem, mobile landscapes, mobility pattern, self-organization, social behaviour, urban system.

1 INTRODUCTION

People interact in cities. Despite stationary urban infrastructures and built environments, their changeable relations, intensities and locations generate complex behaviours. Evolving trends, unexpected events and dynamic patterns, fluxes flowing through and within city boundaries, call for new approaches to urban and regional studies.

Increasing mobility of goods and people and other phenomena associated with the global market, communication technologies and the Internet, the demand for information and constant connectivity, all have to be taken into account when investigating urban dynamics. For instance, mobile phones have a significant impact on social behaviour. In the last few years, social life and ways of working and using space have changed due to the advent of these services. The main results have been fewer constraints and higher flexibility and freedom of movement. The dynamics of social systems and interactions with the urban environment have become more complex and new information is required to understand their evolution. Therefore, on one hand, mobile technologies have increased complexity and uncertainty in urban–social dynamics; on the other hand, they are a valuable and accurate source of information.

In particular, positioning information of mobile devices provides an overview of the actual location of urban activities through the location of people (carrying a cell phone) who use space and move throughout the city. It is possible to describe the space–time movement of society better than ever before due to the development of social positioning methods. 'The Social Positioning Method uses the location coordinates of mobile phones and the social identifications of the people carrying them for the purpose of studying the space-time behaviour of society' [1].

According to Ahas and Mark, the social positioning method (SPM) has three important aspects [2]:

- SPM data indicates the position and movements of people;
- the quantity and precision of SPM data is considerably greater than that of earlier studies on space–time movement;
- the SPM makes it possible to work in real time.

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Databases set up with SPM contain more precise information of movement than those obtained from travel diaries and questionnaires. The number of groups of people moving in particular areas can be estimated and it is also possible to observe time changes in urban space use. 'The existence of such data flow would enable us to design a dynamic space, which changes in respect of the number of people […]. Changes are based on a long-term analysis of timelines or on the properties and needs of people moving in real time in a certain area (street, building)' [2].

The SPM may therefore transform the geographical and social sciences. Focusing on urban–social dynamics, evolutionary and stochastic patterns of human life can be decoded and constitute added value in research on human settlements. 'Instead, the manifestation of the powers that configure the city has shifted from the outwardly visible to the invisible – that is, the city is not rendered through composition, gravity, form, or material, as much as it is through demographics and economic performance. […] no longer is the city visualized or composed as much as it is empirically computed' [3].

Computed geographies of urban dynamics in terms of people density and mobility and their applications in the organization and planning of public life are the main issues of recent urban and regional research on social behaviour and human life. 'The database created using the positioning method will make urban planning more human-centred. Until now, analysis based on static databases describing the properties of space has been the prevailing planning method. SPM will supplement this with dynamic data on the movement of people, which will make the focus of the entire planning process more human-centred. Such a change has been predicted and expected for some time – analysis of static space data leaves many questions unanswered and simply cannot keep up with the dynamics of real life' [2].

2 THE ECODYNAMIC VIEWPOINT

There is a fascinating theory that looks at the city as a place where many interacting agents coexist in an apparent herd of disconnected signals, textures and settings. These engaging landscapes have changed the perception of cities. The city is assumed to be an open system with the dynamics of a living ecosystem, an evolutionary organism or even a dissipative structure. According to Scandurra, 'A town is like an artificial ecosystem where there is a continuous exchange between living organisms and the physical man-made environment in which they live' [4]. The stationary structure of buildings, streets, infrastructures and other settings is therefore just a stage for a multiplicity of activities, dynamic phenomena and coevolutionary processes. The city is no longer conceived as the lifeless inert structure that supports life, as does the sum of buildings, technologies and distinct isolated elements; on the contrary, it is an evolutionary organism that constantly interacts with people; it is customized by people and customizes human behaviour. An evolutionary approach is therefore required, referring to Eugene Odum's definition of an ecosystem as a unit of biological organization consisting of all the organisms in a given area interacting with the physical environment [5].

These assertions suggest a shift from reductionism and determinism to a new science of complexity applied to urban and social studies. Brief definitions can be provided to classify different approaches [6]. Through *reductionism*, new properties of a system and the whole are explained in terms of old properties and the system's parts. A system is seen as the agglomeration of its parts; its structure and behaviour in time and space are explained by reference to processes of the single parts. *Determinism* can be defined as a rigid mechanistic epistemological approach purporting that an event or a sum of events necessarily results in a certain way and a certain output.

In opposition to these theories, an emerging epistemology argues that the new and the whole are more than the old and the parts. 'The qualities that result from temporal and spatial differentiation of a system are not reduced to the properties of its components; it is maintained that the interactions between the components result in new properties of the system that cannot be fully predicted and cannot be found in the qualities of the components' [6]. In some disciplines, this theory is known as *emergentism*, which is regarded as the philosophical level of the new sciences of complexity [7].

Hence there is a call for systemic approaches that investigate the world, focusing on relations between components and the emergence of collective properties. The life of human systems is therefore the focus of this research project. With regard to evolution and design, Erich Jantsch writes: 'Human life is movement. It is movement not by and for itself, but within a dynamic world, within movements of higher order. […] these higher-order movements constitute the life of human systems' [8]. With regard to these higher-order dynamics, the organization of human life is studied as a whole with new emerging collective properties and not merely as a sum of individual behaviours. The formation of mobility patterns in urban areas, their evolution in time and their relations with the built environment require a holistic approach based on general systems theory in an evolutionary framework. In practical terms, people's movements are studied by collecting data on a microscale (location data from personal mobile devices) while observations are made on a macroscale. In other words, the interactions between society and the built environment change and take various forms that can be observed on different space–time scales. Organizational and developmental properties in cities and ecosystems are considered as wholes and their structural and dynamic properties are studied in order to describe and explain the formation of macrolevel patterns in systems, such as society, composed of many interacting microlevel components (individuals) [9].

A few concepts from evolutionary physics promote understanding of urban systems and the pattern generation of urban mobility can be explained in terms of organization processes in complex self-adaptive systems. Non-equilibrium thermodynamics represents an authentic path change in the study of natural and man-made systems and their dynamics in an evolutionary framework. These theories deal with living systems and involve disciplines concerned with social behaviours, human settlement and dynamic phenomena. The novelty is that 'physics leaves its ivory tower of useless purity and comes to grips with nature, society, the bios and the oikos' [10]. Signs of complexity in urban–social systems can be recognized and attention is drawn to the network of relations between man and the environment, living and non-living entities, society and the city, laying the foundations of an ecodynamic viewpoint for urban studies.

The observation of evolutionary and narrative elements is a starting point, as Prigogine underlines: 'at all levels of nature we see the emergence of "narrative elements". […] At all levels we observe events associated with emergence of novelties, which we may associate with the creative power of nature. These narrative historical aspects are part of complexity' [11]. This new vision has changed the perception of cities, focusing on general behaviours and ordering principles in a holistic framework. The idea that a city can be conceived as a complex self-adapting system, or even a living ecosystem, is a key point for urban research.

In a city or social system, the configuration of interactions between parts, such as individuals, and between the parts and the whole, is an expression of the system's organization, achieved by processes of adaptation and selection. Single parts of the system interact with each other and organize themselves by exchanging information. This general organization extends to the whole system. 'Organization emerges on a macroscopic space–time scale, that is many times bigger than microscopic interactions between the elements' [12]. The organization of a system emerges spontaneously as additional information that is not available by observing single parts. 'Organisms continuously adapt to each other by co-evolution and constitute an ecosystem. These are examples of groups of agents, which in seeking their own consistency and mutual adaptations transcend themselves and acquire collective properties, like life and thought, that do not exist individually' [13]. It is obvious that 'the whole is greater than the sum of its parts' [14]. Societies and towns, as well, result from the aggregation of groups of individuals and show emerging collective properties that single elements do not have.

Ilya Prigogine says: ‘obviously in a town, in a living system, we have a different type of functional order. To obtain a thermodynamic theory for this type of structure we have to show that non-equilibrium may be a source of order. Irreversible processes may lead to a new type of dynamic states of matter which I have called “dissipative structures”. [...] These structures are today of special interest in chemistry and biology. They manifest a coherent supermolecular character which leads to new quite spectacular manifestations. [...] How do such coherent structures appear as the result of reactive collisions?’ [15].

With regard to the self-organization of complex systems, Prigogine gives an easy example to intuitively explain how order comes out of chaos and structures emerge [16]. According to Prigogine, construction of a termitarium is a coherent activity that suggests the existence of a ‘collective mind’ in the community of termites. Curiously, termites need little information to build such a huge complex structure. Termites interact with each other as the particles of a gas collide and react with each other in a box. Very few choices can direct a system in an unstable condition towards a certain configuration. To our knowledge, termites do not follow any prescription or general information; only specific interactions between individuals suggest or constrain (select) different kinds of behaviour. There is no commander, architect or mastermind behind the termitarium. Is there any consciousness of the system as a whole?

This description and the question introduce the problem of stability and bifurcations. What events and innovations will regress? Which will develop and affect the whole system? On one hand, conditions of non-linearity may create order, bringing it out of the chaos of elementary processes; on the other hand, conditions of non-linearity may destroy this order but allow new coherence to emerge beyond another bifurcation. An organization or system functioning without any apparent general law is based on natural macroscopic processes generated by a multiplicity of unordered microscopic processes that, under certain conditions, depend on fluctuations.

Organization and self-organizing processes in complex dissipative systems therefore depend on both micro- and macrodimensions. On one hand, interactions between the constituents allow them to adapt to each other, and a microscopic fluctuation caused by a local perturbation may be amplified until it pervades the whole system, creating an ordered structure. In a complex system, non-linearity can reinforce a local action to generate a chain of effects throughout the system. On the other hand, self-organization is a sort of unconscious forecast. The system explores many kinds of possible organization and the one that emerges depends on feedback from the environment. It is a sort of selection; the organization adopted by a system is the one that coordinates interactions between constituents according to suggestions coming from the environment. That is why selection works on a macroscopic level. In conclusion, non-linearity not only amplifies from local to global levels but also from global to local levels. The direction of information is from the top down and from the bottom up, which means from the global to the local level and from the local to the global level.

Fluctuations with an external or internal origin, can generate new structures. The activity of the system is adaptive. If the evolutionary trend of a system is described by a diagram of bifurcations with many branches, the choice of a branch at a bifurcation point depends on small local fluctuations that constantly occur. For instance, what happens when uncontrolled events (mutations, technical innovations) introduce new constituents that are involved in the processes of the system? New constituents, even in infinitesimal quantities, activate a new series of transformations among the constituents of the system, setting up competition with the modes of functioning of the branch. If this structural fluctuation successfully prevails, the whole system will adopt new modes of functioning (the new branch) and its activity will have a new syntax.

However, fluctuations are consequences of the law of *least resistance*: elements always modify their interactions with other elements, looking for the most advantageous. Amplification of fluctuations is caused by non-linearity and allows macroscopic and ordered structures to emerge and grow. These processes of adaptation and selection belong to non-equilibrium systems, the dissipative dynamics of which feed on information exchanges and energy flows. According to Prigogine, living dissipative structures actually behave like open systems in a steady state (dynamicity, diversity, life) that maintain themselves in life (at high levels of order and complexity) by self-organizing due to material and energy fluxes received from outside and from systems with different conditions of temperature and energy. The arising of space configurations and time rhythms in dissipative structures is a phenomenon known as 'order by fluctuations' [16]. 'We can imagine dissipative structures as *giant fluctuations* maintained by flows of energy and matter' [16]. These structures are the result of fluctuations maintained in a steady state; once established, steady states can be maintained with respect to a huge class of perturbations.

In line with this analysis of the general behaviour of complex systems, we turn to human systems, the dynamics of which reveal self-adaptive properties. The question is: 'how do humans interacting with their biophysical environment generate emergent collective behaviours [...] in urbanizing landscapes?' Theories about complex adaptive systems provide tools with which to analyse how landscape-scale organization of structures and processes arises in urbanizing regions; how it is maintained; and how it evolves by local interactions of processes that occur at smaller scales among social, economic, ecological, and physical agents [17].

Patterns of urban mobility can be studied according to the theory of dissipative structures. Induced perturbations, order by fluctuations and pattern formation can be observed at different levels in urban and social systems. 'In a town, the natural cycles are almost completely replaced by artificial cycles. The results let us consider the concept of ecosystem in more abstract terms. The ecosystem may be a set of interactive conditions rather than a physical system' [18]. People using urban spaces, moving through buildings and infrastructures, and exchanging information through communication technologies are a practical aspect of urban complex systems. A scientifically rigorous approach is a must to handle these dynamic factors in order to understand social behaviours and their evolutionary trends with respect to their environmental context. 'Knowledge of nature must come from a global, systemic view of events and from study of the network of information joining the various forms of matter, energy and life in time and space' [19].

3 DYNAMIC PATTERNS OF URBAN MOBILITY: THE MOBILE LANDSCAPES PROJECT

A joint research project, named Mobile Landscapes, was recently conducted at the MIT SENSEable City Laboratory in Cambridge, MA, in collaboration with the Department of Chemical and Biosystems Sciences of the University of Siena, Italy, and in partnership with a European telecommunications company.

This and a few other experiences show that the patterns of urban–social dynamics can be decoded and their geographies revealed. The collective behaviour of people using urban spaces and the interactions between men and the built environment can be analysed and signs of complexity in urban ecosystems can be shown. Mobile geographies of urban–social activity (people using space) are therefore useful for analysing urban dynamics (space–time behaviour of society throughout the city) through visualization in the form of maps and temporal sequences of maps.

The Amsterdam Real Time project was one of the most significant experiences in terms of urban analysis (Fig. 1). It aimed to construct a dynamic map of Amsterdam based solely on the movement of people carrying GPS devices, tracked in real time. The underlying idea, developed for an exhibition, was that 'every inhabitant of Amsterdam has an invisible map of the city in his head. The way

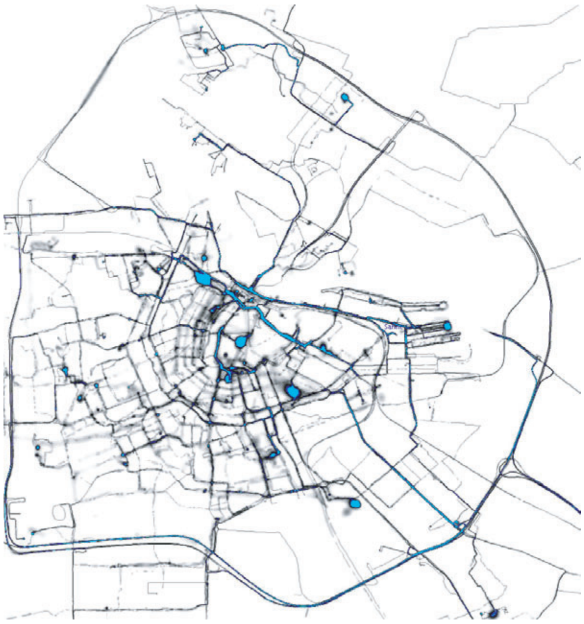

Figure 1: The Amsterdam Real Time project [20].

he moves about the city and the choices made in this process are determined by this mental map. Amsterdam Real Time attempted to visualize these mental maps through the mobile behaviour of the city's users' [20].

The Mobile Landscapes project uses technology that determines the geographic locations of cell phones in order to analyse mobility patterns in towns. Location-based data from mobile devices were collected and processed in an anonymous and aggregate form and plotted on a sequence of maps. An immediate overview of mobile phone density in the urban context was obtained. The project is briefly described in this paper. An extended description with detailed information about existing applications of location-based services, cell phone positioning methods and other technical aspects has already been published [21].

Traffic data are related to the various antennas that record the users connected to them for phone calls or text messages. This data is normally recorded by cell phone operators in the running of base station infrastructure and is readily available. It is expressed in *earlangs*, a standard unit of traffic intensity in telecommunications systems (this unit combines the number of calls with the duration of the calls; e.g. one earlang is the equivalent of a call one hour long, two calls half an hour long or 60 calls one minute long, and so on). Each traffic value is related to a cell, that is a circular area, around a base station, covered by the GSM signal. The location is given by the coordinates of the antenna. In other words, traffic data are collected dynamically by the hour for each antenna and its location is fixed, namely the position of each base station.

Some preliminary results from the case study in Milan are presented. The study area was approximately $20 \times 20\,\text{km}^2$, including the city and some inner suburbs. Traffic values are given for each base station and show the relative intensity of cell phone use at a given position in space for one whole day. The results are like thermography maps, highlighting the intensity of urban–social activity and

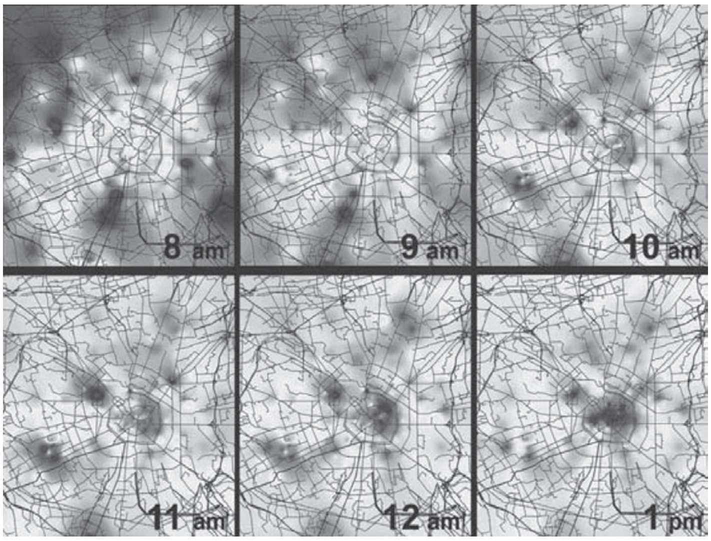

Figure 2: The Mobile Landscapes project: applied to Milan metropolitan area from 8 am to 1 pm ($20 \times 20\,\mathrm{km}^2$ area).

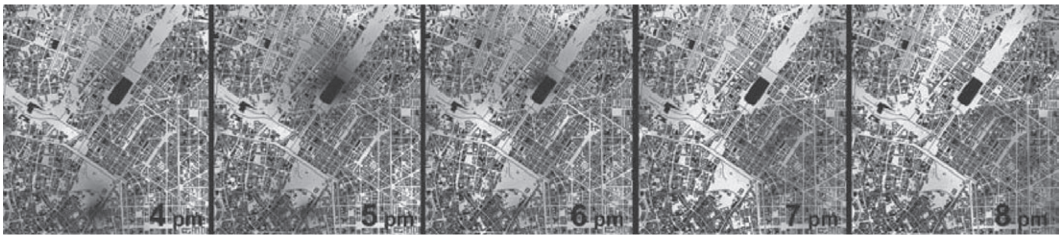

Figure 3: The Mobile Landscapes project: applied to Milan metropolitan area from 4 to 8 pm – zoomed onto the area of Milan Central Station.

its evolution in space and time. Different time bands can be analysed from the 24 hours of the day to long periods like seasons and years.

Figure 2 shows a series of images over the study area between 8 am and 1 pm on Monday, 19 April 2004. It shows that the relative intensity of calls is maximum in the suburbs (mostly residential areas) early in the morning. From 9 am to 12 noon, many people are in the city centre, where areas with mostly services and offices are located; around 1 pm, the highest intensity is detected in the core central district (with shops, restaurants, fast food, services) where, for instance, many workers and students usually go after work and school for lunch, shopping or meeting.

Finer grain dynamics can be highlighted. Figure 3 shows a zoom onto the area around Milan's 'Stazione Centrale', a key railway commuting node. Here it is possible to clearly identify rush hours: in the afternoon there is a certain level of activity in the whole area; from 5 to 6 pm a high density is shown around the station and the last image of the sequence shows low levels of activity in the whole area, once daily commuters have departed.

Furthermore, when the data was processed in terms of relative activity of cell phone antennas (normalized with respect to the daily average and to the average for the whole study area), the patterns of cell phone intensity show a correlation with the intensity of urban–social activity. How people move through urban infrastructures? How do they use public and private spaces? Answers are provided here. Since almost everyone in Italy carries a cell phone, these outcomes, in the form of mobile geographies, are powerful information sources about the intensity of cell phone use that is a likely indicator of people density.

Computed maps of urban mobility therefore make it possible to visualize the behaviour of people in urban areas with regard to the use of infrastructures, buildings, services and other settings. Temporal modality of space uses can be appraised and revealed. This information is much more useful than any conventional description of land use. The Mobile Landscapes project therefore opens the way to a new series of applications for urban studies. Evolutionary and stochastic patterns in human systems are revealed as added value for comprehensive methods of managing urban complexity. 'The contemporary embodiment of general system theory is complexity theory. But there has been a sea change. Dynamics has become significantly more important than structures in providing the essential drivers [...]. The idea that systems can be "explained" in static terms now seems nonsensical' [22]. This method, conceived in an evolutionary framework, belongs to a new urban paradigm.

Pattern formation by social activities, the dynamics of which affect urban texture, is the object of this research. By processing information through spatial (location) and temporal parameters (dynamics), pattern formation and changing geographies may be revealed in the urban context. The subject of study is the life of human systems, which is why mobile geographies work at the scale of huge urban areas and focus on the evolution of the whole social system with its emerging collective properties. The behaviour of the system, consisting of many interactions between single elements, is studied as a whole; the configuration is a network of relations that can change with respect to a series of local perturbations; it reacts and self-organizes in response to local perturbations and external effects. A full real-time monitoring of urban mobility was possible for the first time. Critical points in the use of the urban infrastructure, can be highlighted as well as flows in and out of the city, patterns of daily commuting, weekday trends, weekend activities, and holiday movements. Disasters, concerts, soccer matches, streets closed for roadwork, the opening of a new building with a certain urban function, expansion of the wireless network, a new public transport line and many other events are examples of perturbations that make the system react and self-organize in a new pattern. Real-time services can also make a significant contribution to public safety in the case of emergencies.

4 CONCLUSIONS

'Does the flap of a butterfly's wings in Brazil set off a tornado in Texas?' [23]. The effects of a perturbation, according to the chaos theory, cannot be completely determined or predicted. The organization of complex systems depends on a multiplicity of agents; it is concerned with macroscopic processes generated by a multiplicity of unordered microscopic processes that, under certain conditions, depend on fluctuations. Fluctuations with external or internal origins, can generate new structures that may cause the whole system to adopt new functioning modes with a new syntax.

Non-equilibrium thermodynamics provides general laws about the behaviour of living systems and suggests that an ecodynamic viewpoint is appropriate for urban studies. A city can be conceived as a dissipative structure, the organization of which is the result of fluctuations maintained in a steady state by flows of energy and matter. Even in towns, functional order comes out of chaos! Non-equilibrium may be a source of order.

The aim of the analysis of dynamic patterns of urban mobility is to demonstrate that cities behave like complex self-adapting systems. The Mobile Landscapes project can be applied to urban regions in order to reveal urban dynamics in the form of mobile geographies. Besides potential applications for the management of practical problems and for urban planning, this method enables collective behaviours, perturbations and effects of fluctuations to be studied in complex urban systems with respect to our theoretical framework. Location-based data from mobile phones plotted on sequences of maps open promising perspectives in geographical and social sciences and a new paradigm in urban studies.

In conclusion, the technical aspects of the Mobile Landscapes project introduced in this paper have already been extensively described [21]. A theoretical interpretation of the first results and a new approach to urban studies are discussed here in order to investigate human systems in an evolutionary framework instead of under static, reductive, traditional, urban planning practices. According to this viewpoint, methods for urban analysis address emerging aspects of contemporary cities including practical problems.

As a research effort, the Mobile Landscapes project seems to be topical. The pervasive deployment of new technology is transforming urban–social patterns, making them more complex and fluid. Greater mobility and freedom are changing lifestyles and the use of public and private spaces. As stated by Batty [24]: 'The city has become more complicated thanks to these new innovations, rather than less, and our ability to make sense of these changes in theoretical and scientific terms have not kept up… .' The Mobile Landscapes project shows how to take advantage of the very tools that have made urban life complex and make them work to increase our understanding. It offers an opportunity to understand the mutating complexity of the contemporary cities. Its focus on temporal, rather than spatial patterns, suggests a possible new paradigm for urban analysis: 'Dynamics of course represent the key to all of this. As architects and planners and urban theorists, we delight in approaching the city in terms of its morphology but morphology is not enough. It must be unpacked and the only way to unpack it is through dynamics' [22].

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