UNDERSTANDING RELATIONAL LOCATIONS AND COMPLEX URBAN SYSTEMS

MAPPING THE RELATIONS BETWEEN COMPUTATION, SPACE AND INFRASTRUCTURE

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I hereby declare that all of the work presented in this thesis is my own.

Carina Lopes, April 2016.

To my dear mother.

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ABSTRACT

This thesis examines how computation has become part of different aspects of urban territories. In particular, this research focuses on the increased softwarisation and datafication of these territories and consequently, on the conditions that have favoured the emergence of new modes of urban spatialities. It proposes that relational locations have emerged as prevailing urban spatialities, brought about by the relations between space, infrastructure and computation.

Beginning with an analysis of the relations between these three areas, it is shown that the crucial impact of computation, through the processes of softwarisation and datafication, mostly takes place within complex urban systems and their tendency towards convergence and concretisation, now accelerated and intensified. Furthermore, it is proposed that this tendency is increasingly sustained by the development of relations of mutual dependency and continuous feedback with practices of standardisation and risk management, which have become specifically location-oriented. From this standpoint, two case studies emphasise the localised implications of the transversal logic of computation. The first case study starts with the analysis of the convergence between the traffic management infrastructure and the air quality monitoring network. It draws attention to the dynamics established, extension of scope and use of indeterminacy as a management tool. The second case study focuses on the intensive gridding that new approaches to the logistics' last-mile are creating. The delivery of 'parcels' continuously divides space and monitors increasingly more elements, turning vehicles into dots.

The main argument of this thesis is that complex urban systems and the relations that support them are central to the understanding of computation throughout urban territories. This thesis aims to show that the impact of the computational logic goes beyond its area of immediate action, increasingly creating contexts of mutual dependency and co-evolvement and translating adjacent elements into computable formats.

CONTENTS

TABLE OF TABLES

TABLE OF FIGURES

1. ENTERING RELATIONAL LOCATIONS

1.1. Experiencing complex urban systems

During the first week of January of 2010, a parcel with 20 kilograms of research books was sent from Lisbon to London. The parcel, sent as a trackable item, was what is defined by the Portuguese postal services as a multi-post bag[1] – a service specially designed for the transportation of non-commercial editorial material, both newspapers and books, as well as pamphlets and catalogues. A few days later, the parcel arrived in London. It had followed the normal procedure of scanning at arrival, as shown by the online tracking system where dates of key events were recorded: date of registration at a local post office (in Lisbon), clearance to proceed from the central mail-sorting warehouse (in Portugal), arrival in the UK and waiting allocation by the local post office (in London).[2]

After crossing around 2,200 kilometres, the parcel became lost within the last few kilometres of its final destination. A process of many weeks followed the parcel's initial arrival in London. Complaints were firstly made to the British Royal Mail through its online customer support service. The parcel was then searched for at the National Return Letter Centre in Belfast, where lost, unclaimed and unclearly addressed parcels are stored for a limited period (Rosenbaum, 2011).[3] Finally, the parcel was declared lost and erased completely from the system. The accountability for such loss was attributed to the system, which at some stage lacked the ability to track down the parcel. The whereabouts of the much-missed multi-post bag containing mostly research books for my PhD project became a mystery. These events took place within a technical system developed precisely to manage millions of trackable post elements, by logging location after location, deciding the next destination and managing the delivery process. Moreover, the responsibility for

[1] For more information on the different categories of international postal delivery please see (in Portuguese): http://www.ctt.pt/solucoes-empresariais/solucoes-sectoriais/correio-editorial/saco-multipostal.html.
[2] Registered mail is a standard service offered across many countries. It is identified through a standardised 13-digit reference number in which the last two letters indicate the country from which it is sent. It allows mail to be tracked online throughout its journey up to its reception by the recipient for whom it is intended.
[3] Stored correspondence is kept for approximately four months, after which it is disposed of (Royal Mail, 2014) or goes for auction. For the tax year of 2010/11 the revenue from such auctions came to nearly £1m (Rosenbaum, 2011). For further information, see: http://www.royalmail.com/personal/help-and-support/what-happens-if-you-cant-deliver-something.

compensation was finally attributed to the Portuguese postal service, having been the departing point of the multi-post bag. In compliance with international postal service agreements, I received a compensation of 128 euros, covering little more than the cost of the original shipment.

Around the same time, on a very cold night in central London, there was a bus that never arrived. After waiting for 90 minutes at the bus stop, I gave up and returned home frustrated. At an LED (light-emitting diode)[4] screen placed at the bus stop, officially known as the 'countdown sign', the information being provided kept jumping from 'imminent arrival' to 'due in 9–10 minutes'. The minutes showing on the screen lasted longer than 60 seconds;[5] the system probably did not account for a bus stuck in traffic or broken down and parked somewhere on its route. Countdown signs were installed as part of a series of changes within the network of buses operating in London, under the project *iBus*.[6] Fully deployed between 2007 and 2009 (Transport for London, 2008), *iBus* provides Transport for London and its users with real-time information on the location of each bus. A second generation of the countdown sign came into use in 2011, adding to the *iBus* ecosystem an "SMS service that sends bus information to phones, improved bus stop signs, and a web app (plus mobile-friendly version)" with updated information on arrival times for all of the "19,000 bus stops" across London (Stephens, 2011). It all started with a shift from analogue radios (that gave an approximate guess on the location of each bus) towards a digital system. This combines "GPS satellite data and GPRS mobile telecommunications technology"[7] with an accuracy of about 100 metres (Kleinschmidt, 2007), being technically enabled by the "Windows-based computer, GPS unit, turn-rate sensor and speedometer" installed in each vehicle (Dodson, 2008), ensuring in this way "state-of-the-art Automatic Vehicle Location" (Transport for London, 2008).[8] In order to increase the accuracy and reliability of

[4] Light-emitting diodes are especially used in electronic equipment, such as digital screens displaying a limited amount of information, e.g. clocks, timetable screens or other screens found throughout motorways. Over recent years, LED lighting has also been replacing traditional public lights as it offers lower maintenance costs, requires less power and provides brighter light.

[5] Although the screen showed 9-10 minutes of waiting time, the minutes on the screen would go down very slowly to then return to a higher waiting time again, misleading the user with the information being provided.

[6] The *iBus* project initially aimed at making the network of buses in London more user-friendly for the visually and hearing impaired population (Transport for London, 2009).

[7] GPS stands for Global Positioning System, while GPRS means General Packet Radio Service.

[8] Installed by Siemens, the system covers Transport For London's fleet of over 8,000 buses and it makes possible for the police and other security agencies to pinpoint the precise location of each vehicle in a case of emergency. Overall, the system is more than a simple tracking system as it is also integrated with the general

the GPS system, it also mixes in a few other "tracking methods" such as "gyroscope, odometer feed, [and] route layout on board" that allow an updated exact location "every 30 seconds" (Stephens, 2011). Data collected by each vehicle is brought together into "a central computer" where an overview of the entire system is made possible (Kleinschmidt, 2007), located at the "CentreComm, London Buses' 24/7 Command and Control Centre" (Transport for London, 2008). Nonetheless, and as with the bus that never arrived, Transport for London states under its terms and conditions for live bus arrival[9] that the service has its own limitations. These were the same limitations that led me to wait for 90 minutes or that would exempt the bus provider from any responsibility in most cases: "the accuracy and the timeliness of the information" can be constrained by "traffic, road works, general maintenance, accidents, bus stop closures" and by reasons directly linked with third-party service providers (Transport for London, n.d.).

In this way, Transport for London seeks to protect itself from liability, resulting mostly from services constrained by multiple variables that might have not been considered when the service was designed or, also possible, resulting from services that genuinely stand outside its area of responsibility and core business. In a similar way, Royal Mail manages to avoid accountability for a parcel that arrives within British territory, is logged into its system and then gets lost within the very last kilometres of its destination. Both events raised my curiosity about the underlying structure of increasingly complex urban systems, which seem to expand physically across space and impact beyond their own geographic locations. The smooth running of urban infrastructure generally means little questioning by its users; it means that everything is working as expected. By remaining in the

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traffic control system, permitting it to "trigger priority at traffic junctions" for the buses approaching these same junctions (Kleinschmidt, 2007).

[9] See https://tfl.gov.uk/corporate/terms-and-conditions/live-bus-departure-information. The section of 'Terms and Conditions' that often operates in the background of many infrastructural systems and their online platforms and mobile media applications is an area that has received limited academic attention. Laura Stein (2011) looked at this particular aspect within social and participatory media platforms, explaining that terms and conditions are a socio-technical construction, becoming the expression of the interaction between "software and hardware design, social and cultural practices including knowledge, forms and formats; user content and communication; other social and institutional arrangements related to law, regulation or corporate practice". As the expression of the interaction between material and non-material elements, terms and conditions offer a slight insight into the systems they serve. A company or a service provider, as an element of complex urban systems, encounters within its 'terms and conditions' a protection or buffer against external uncertainties, bringing to its realm all possible players, while intending to prepare for those situations not yet expected or foreseen. Terms and conditions pre-define the working context of the system and also manage potential liabilities and risks. They provide a way out for the company delivering the service. These issues are discussed in more detail in Chapter 3 under reflections on practices of standardisation and risk management.

background, infrastructural systems and their technical assemblages, working throughout urban territories (and here referred to as complex urban systems), demonstrate normality and an integrated running of the different technical elements (Star, 1999). Complex urban systems, at the centre of this thesis, imply for this reason infrastructural systems that have been already embedded and transformed by computational processes, expressing a high degree of complexity and the ability to converge with other systems, while being able to work at local and international level without much differentiation and through a process of continuous expansion.

Parallel to both of these events and around the same time of my move to London, a news story making headlines in Spain raised my attention. It was about the manipulation of air quality data in Madrid through the physical relocation of the city's air quality monitoring stations. Previous to my arrival in London, I had been working in Barcelona for three months, which together with Madrid has ongoing air quality problems. In both cases, this is largely exacerbated by their geographic location and unique climate conditions. In the last few weeks of 2009, Madrid's network of air quality monitoring stations underwent a series of changes. Some stations were completely eliminated while others were moved further out from the centre and closer to greener areas. The number of stations was reduced from 27 to 24 active stations, and contrary to their previous organisation, they were divided into three groups according to the type of contaminants collected and areas of location (Sevillano, 2011).[10] This meant a break with all data collected previously throughout the metropolitan area, curiously, in the same year that strict European air quality regulation came into force. Two of the most problematic stations disappeared – *Luca de Pena* and *Plaza del doctor Marañón* – while the data collected on nitrogen dioxide (NO_2) suddenly showed a 30% reduction in relation to the previous year (Sevillano, 2011). The changes implemented across the network in 2010 can be understood as a direct consequence of the European regulation that specifies new limits for air pollution levels (European Parliament, 2008) or as a radical action taken by the City Council of Madrid to avoid hefty fines from the European

[10] The new arrangement of the stations based on type of location and pollution source was defined by the new European legislation that came into application then (European Parliament, 2008). These and other issues surrounding the processes of air quality monitoring and data collection are discussed in Chapter 4 and are central to the first case study.

Commission, designed and implemented according to the constraints and ambiguities offered by the new legislation.

These three events and their infrastructural contexts represent complex urban systems that rely on a range of networked technical and non-technical elements that are not necessarily perceived or visible to their users. These systems are composed of warehouses, tracking devices, sensors, databases, servers, management software and LED screens. The three complex urban systems collect and exchange information throughout their networks, directly constraining how spaces are used and experienced, while simultaneously embodying the impact of regulation being developed at multiple locations. Royal Mail, Transport for London and Madrid City Council are just three examples of bodies governing numerous complex urban systems, which cohabit metropolitan areas. Responsibility is shared and passed over to third parties and external providers. The understanding of how these systems work is diffused and scattered, making it harder to untangle their dynamics or press for more accountability from their governing bodies.

If the multi-post bag, the bus stop and one of the air quality monitoring stations were individually taken into consideration, it would be found that, in each case, the object of concern is always relatively small in comparison to the wider operational systems of which they form a part. The multi-post bag's barcode, the LED screen and the sensor, even with their small-scale materiality, are able to embody and simultaneously express the dynamics of large data systems, software assemblages and operational structures. The first event, the lost multi-post bag, exposed technical and material layers of contemporary transnational postal services – databases, recording and tracking systems, organisational hierarchies, material flows to off-site cheaper locations and international commercial agreements. The second, the bus that never arrived, highlighted the intrinsic capacity of these systems for error, to miss out or encounter unforeseen obstacles. It showed that computational management systems are never all-encompassing, but that supported by their risk management strategies, they create a degree of protection against the unplanned and unforeseen. The bus that circulates through the urban cacophony is exposed to weather conditions, traffic and an overworked mechanical system. The last event, with its air quality monitoring stations, reminds us that air is also an element of urban management constrained by regulation, scientific disputes over data collection and complex systems of classification and standardisation. It is one of the many systems being managed and run by cities; it is part of a broader set of interests, policies, internal and external pressures and expectations. Overall, there seems to be a recurrent difficulty in opening up the events taking place within all of these systems. Nonetheless, the position of the bag's barcode, the LED screen and the sensor can be made relevant if they are considered as entry-points to complex urban systems. They offer a path for a contextual inquiry about the systems they belong to. The three events came then to shape the development and structuring of this research project and their repercussions can be felt throughout this body of work, and more precisely, in each of the case studies, inspired by and originating from these same events. More importantly, these events radically challenged the early stages of this research project, taking it into unplanned or unforeseen directions.

1.1.1. The context

As already indicated and implicit in the description of the three events, this research project started in early 2010. It began as a project on locative media. From its outset, it was concerned with the spatial and empowering possibilities of mobile devices, in comparison with the desktop Internet, and the impact of portable, networked and location-aware devices on existing modes of space. It also aimed to consider how locative media enabled and reinforced a 'return' to the outside, in terms of reformulation of location, outdoors sociability and possibilities for multiple narratives on urban spatialities. However, and as a consequence of the events that took place during the winter of 2010, I became interested in complex urban systems, which necessarily included locative media. These urban systems, brought to my attention in moments of partial failure, allowed a degree of interaction with their assemblages through relatively small material interfaces. They were shown to be supported by much wider infrastructural systems, while simultaneously tied to specific locations and restricted by their relations with other systems. As my research on locative media moved forward, constrained by the described events and the infrastructural systems that I had become aware of, the focus of this thesis slowly shifted into these types of systems, populating, enabling and underlying so many aspects of contemporary urban life.

The transition from locative media to urban computational systems resulted in a change of perspective and scale as I later discuss in this introduction, as well as a change of the subject of concern. The emphasis became the technical system in opposition to the subject that uses and experiences locative media or complex urban systems. Although often haunting this research project in a tension that is never fully solved, the citizen, user or urban dweller, the element that makes the described urban systems accountable, is mostly left as the unspoken element. Their presence is nonetheless felt in many instantiations of this thesis, from the three events just described to different aspects of the two case studies. This is done as a way to privilege the internal dynamics evolving among technical systems, but without the desire to disregard the wider existing dynamics and the ways that the discussed technical systems are often encountered or made visible. If the described and discussed technical systems throughout the following chapters are often encountered from an on-the-ground perspective, the need to narrow the focus of this research has meant that the emphasis has been put on what has a technical and infrastructural character.

In parallel to the changes to the research project and not too long after the three described events, I suddenly found myself placed in a triangular setting of three distinct urban territories – Barcelona, Lisbon and London. All of these three urban territories have contributed, in one way or another, to the conceptual formalisations that are explored and developed throughout this thesis. Between the starting out of this research project and its conclusion in 2016, I also spent three years working closely with many local governments, which responsibility is to oversee and manage urban territories of different scales and complexities within Europe and North America. The time I spent with these teams, in their majority working at the Mayor’s Office or within the areas of innovation and economic development, necessarily had an impact on my understanding of the challenges they faced. These challenges ranged from the implementation of innovation strategies, to the deployment of digital systems or even how to make compatible alignments between systems that no one had touched for decades and that were in need of urgent upgrades. During the three years I was often faced with the question of how to read these systems, beyond their own technical elements or perceived impacts. The same difficulty applied to the attempt of making sense of their complexity.

It is within this background of events that the research presented throughout this thesis took form as a mapping process of the relations and engagements developed between computation, space and infrastructure. The objective that drove this process was the search to understand the impact of the extension of computation into urban contexts at the level of infrastructure and the resulting modes of spatiality. In this way, the chapters that follow this introduction aim to contribute to our understanding of the internal dynamics of technical urban systems in order to articulate the impact of the extension of computational processes. From a perspective that assumes the difficulty to trace computational processes, which action is at the forefront of urban life while the supporting systems tend to sit in its background, this thesis looks at the dynamics unravelling within technical systems and what these mean for urban contexts and its modes of spatialities. Sitting at the confluence of software studies, human geography, science and technology studies and cultural studies, this thesis aims to bring a contribution to already existing discussions, as it is presented in the following chapters, that contemplates the internal dynamics of technical systems and the relations established and developed with their context of action. More precisely, this thesis aims to answer three questions:

- What are the consequences of the extension of computation to space and urban infrastructure?

- What happens within the internal dynamics of technical systems that can support or not these same processes?

- What is unique to the interaction between space, infrastructure and computation that not only transforms the way space unravels as well as transforms the existing relations within urban contexts?

Complex urban systems are key to the understanding of this transformation, which has favoured the emergence of new modes of urban spatialities – called, in the context of this research, relational locations. This mode of spatiality, formed by stable and non-stable geographic points, sustaining spatial and technical processes that can easily go unnoticed, is the outcome of evolving relations between computation, space and infrastructure. Geographic points refer to the role that locality and geographic enhancement play within complex urban systems. When it comes to relational locations, these can be said to be the spatial outcome and expression of the assemblages formed by complex urban systems, in a direct reference to here and there, local and global. Relational locations are in this way at the core of this research, which argues that these modes of spatialities are increasingly more common. By navigating through relational locations and their contextual assemblages and dynamics, the impact of computational practices in the arrangement and structuring of urban and spatial relations will be shown. More precisely, it will become visible how computation has transformed dynamics between the technical elements forming complex urban systems, feeding into their tendency towards concretisation, while accelerating and intensifying these same processes. It is proposed that this tendency is increasingly sustained by the development of relations of mutual dependency and continuous feedback with practices of standardisation and risk management, which are highly location-oriented. Overall, it will be demonstrated that the impact of the computational logic goes beyond its area of direct action, increasingly pervading adjacent areas.

As a departure point, the importance and influence of locative media can be, nonetheless, felt throughout the research. It provides, both to this chapter and overall thesis, a framing structure to the contextualisation of the analysed systems and dynamics. The move from locative media towards complex urban systems, as a consequence of the three events, felt like a natural development – it was a move away from small handheld devices towards wider infrastructural systems, in which locative media were only a small functioning element.[11] Furthermore, the context of critical analysis of locative media shared many of its concerns with complex urban systems: the military origin and control logic underlying many of the technical developments enabling locative media, the transposition to the urban territory of its early logic of creation, and the commodification process of the different constituting elements through computational practices. Locative media should then, in this context, be taken as an enabler to further consider complex urban systems; locative devices are, within the context of this introduction, like small entry-points to more complex and larger urban infrastructural systems.

[11] Work published recently (Frith, 2015; Wilken & Goggin, 2015) supports this approach by also showing the value of using locative media as elements to enter more complex urban and technological contexts.

The aim of this extended introduction is to establish some of the recurrent issues that are dealt with throughout this thesis. The elements highlighted through the analysis of locative media together with the three discussed events of the winter of 2010 point towards a possible methodology for the case studies, as well as a wider study of relational locations and the context of their complex urban systems. By starting with a brief analysis of locative media, its early development stages and history, a few points start to emerge: the building of the momentum within an assemblage as a sign of major transition and, in most cases, of convergence between two previously separate systems; how the increased presence of computational practices has led to the intensification and relevance of locality within both complex urban systems and their territories; and how the process of transition into commercial settings of a given technical assemblage also leads to the growth of its grey boundaries (areas where the conceptualisation of participation, belonging and engagement are reworked). Concluding, the analysis of locative media brings forward internal tensions and how these are toned down or resolved.

1.2. Locative media

To talk about locative media is to imply the conceptualisation of location. This spatial dimension and evocation of locative media is transversal to the way these types of media have been used and thought about. The word *locative* implies calling upon a place, as in the locative prepositions: *in*, *on*, *at* and *by*. Location gains a new dimension in the context of locative media, which goes beyond a specific physical territory or a geographic point. It implies a degree of movement – by calling upon – through which a transition from a location towards another location takes place; there is something being called upon a specific location, but always in relation to other geographic points – those that have preceded and those that will follow.[12] Location can be said then to become relational, always in formation and relation to other locations. Furthermore, location demonstrates to be, in this context, a

[12] In “Locative Media – Definitions, Histories, Theories”, covering the history of locative media, Rowan Wilken and Gerard Goggin (2015, p.2) add to the contextualisation of the meaning of locative two further connotations: its “legal use” in direct reference to property ownership and the act of “letting to hire”, and in relation to “land settlement practices” and “processes of emplacement”. Although these connotations are important for the authors’ argument on the reinforcement of location, they seem less central to the context of this research project. The emphasis is mostly on the conceptualisation of space in formation and of locations being defined by their evolving relations.

connecting and folding point "between space and practice, between the place and the meaning of the place, and between a location and the embodied production of that location" (Farman, 2014, p.45). Location becomes always more than simply a geographic reference.

The digital annotation of locative media can leave a degree of residue, like what is left by the tracking of an object or person as it moves through space, the tagging of specific information to a location by someone that has never been there physically, or the definition of a territory through the often blurred and unstable coverage provided by mobile phone service antennas. The uniqueness of a locative device, as its name already confirms, resides within its ability to localise or be localised, while transitioning from location to location. Like in the case of complex urban systems, this technical ability to call upon a geographic point, always in relation to a series of other geographic points, transforms the dynamics in place within that same location, making location more plastic and sensitive to change, as a specific location becomes the outcome of other elements and their degrees of change placed in different points of complex urban systems. The exponent of this can be the smartphone, where multiple fields of relational locations converge at any given moment (Bratton, 2009; Lapenta, 2011); the smartphone is always in connection, reformulating its locational and relational engagement, both in a passive and active way.

These qualities of location are of major relevance to the understanding of contemporary urban spatialities. As Ben Russell (2004b) explains, location is not "a thing or a service in itself"; it is instead "an enabling attribute". Location goes beyond the context or the geographic point where an event takes place.[13] It is more than a tool to tie down events to a spatial field. The spatial geographic reference of location becomes entangled with a malleable and topological locative condition that can change over time and be influenced by events and changes happening elsewhere. In this way, a specific geographic point connects and is simultaneously connected to other geographic points, leading to the creation of relational locations. The locations being called upon and through locative media are relational locations,

[13] Technically, as Adrian Mackenzie (2010, p.122) explains in relation to wireless technologies, "location cannot be reduced to grid references and map coordinates, especially in cities where signals meet many obstacles", making location more like a floating attribute that can be more or less visible and tangible. Like in the case of wireless experience, location can at times become hard to tag or to define through its geographic point.

but more importantly, they are deeply computational and enabled by the action of pieces of software and diverse methods of data collection. The supporting infrastructure, even when unnoticed or in a process of continuous receding into the background, is what enables and brings into being the described plasticity and sensitivity of location. Relational locations are, for this reason, infrastructural events with topological behaviours. These locations are locative media locations, but also modes of spatiality brought into existence by the action of complex urban systems. As Jason Farman (2014, p.52) writes, in the context of locative media "there are a whole host of communicative objects that are connecting and serve as the 'audience' of locative media", distributed through a locational context and beyond, positioning locative media as part of much more complex material and non-material relations. From a locational perspective, both locative media and complex urban systems are part of the same material spatial arrangement. They cannot be separated.

1.2.1. An account of locative media's history

The history of locative media is a good example of the increased centrality of location within the dynamics encountered throughout defined urban territories and beyond these. As will be shown, during the last decades there has been a shift towards the geographic enhancement of urban territories (with emphasis on location), largely enabled by location-aware and location-oriented technologies. Satellites developed within a military context have been at the centre of these developments.[14] The geographic enhancement fed by the working satellites is the foundation for the ability to tailor and customise that locative media and other location-aware systems have. In this way, technologies that had been initially designed and envisioned within a military context became slowly extrapolated, adapted and coordinated with other urban systems.[15] This made possible the

[14] This refers to the creation of GPS, which was originally developed "in the 1970s under the name of NAVSTAR-GPS" and formed by "24 satellites" under the supervision of "the US Department of Defence" (Frith, 2015). The expansion of the technical developments brought by satellites to other areas was a slow process.

[15] The period "between 1945 and 1960" saw a quick and exponential development of computers and computational systems as part of the "Cold War technopolitical strategies", finally making possible a sophisticated model of "centralized command and control". The global power of America was expressed within its own territory, but also throughout the globe through "computers, radar, and satellites" aimed at "centralized, real-time surveillance and control" (Edwards, 2010, p.189). This global objective required military knowledge and also other sources of knowledge coming from specific "geophysical sciences" such as meteorology, so the

celebration of the outside, a further engagement with neighbours or the early stages of the sharing economy[16] and collaborative consumption like what Ben Russell (1999) had predicted in his manifesto, *Headmap*. The beginning of locative media as a field of action started as a movement, led by media and software artists, responding to the military usage of satellite technologies, restricted to civilian use until the 2000s (Frith, 2015). Up to then, the crucial function "Selective Availability" meant that non-military use of satellite navigation systems was made with induced error (Frith, 2015), limiting the reliability of these technologies for civil use. It was during the Gulf War in 1991 that President Bill Clinton ordered the temporary switching-off of this feature, so the army on the ground could use "civilian receivers" due to the reduced number of available "military receivers", and finally signed its last switch-off on the 1st of May 2000 (Frith, 2015).

This significant technical change is also aligned with the initial period of development of locative media, which goes from 1999 up to 2005, followed up by a second period that spans from 2005 onwards (Wilken, 2012, p.245). As will be briefly shown, the period of 1999–2005 is mostly distinguished by developments and events related to media art and architecture (Wilken & Goggin, 2015, p.4). Projects developed at the time tried various models of geo-mapping, played with the notion of mixed-reality,[17] brought performance to an outdoors context and expanded the concepts of tracking and tagging, as the examples below describe. The post-2005 period came to be defined by a massive commercial expansion of geo-media and location-aware technologies. This was partly a consequence of the launch of Google Maps and its application programming interface (API), which improved accessibility to geo-related data, and the arrival of mass-produced smartphones, especially the iPhone and its applications store (Wilken, 2012, p.244).[18] As the field's maturity increased, practices concerned with location-awareness also "acquired an

"global panopticon" could be achieved (Edwards, 2010, p.189). The technical expansion in different scientific areas was often the outcome of military and geopolitical objectives, ensuring a privileged position in the decision-making process, but also a dependency on the systems developed and conceptualised within a strategic framework of dominance.

[16] By relying on the capabilities of digital technologies, the concept of the sharing economy or collaborative consumption refers to "an economic model based on sharing underutilised assets from spaces to skills to stuff for monetary and non-monetary benefits" (Botsman, 2013).

[17] Mixed-reality refers to experiences, projects and events that can take place simultaneously online and offline, with the user often being able to move between online and offline without too much disruption. The usage of locative media and mobile phones throughout the urban cacophony has also led to descriptions of these contexts as "scripted" (Andersen & Pold, 2011), "hybrid" spaces (Souza e Silva, 2006), and defined by the "persistent location[s]" of location-bounded marketing (Barreneche, 2012).

[18] This model was soon followed by other smartphone application systems providers such as Google.

increasingly finer granularity from satellites, to cell phones towers, to Wi-Fi triangulation to barcodes and RFID" (Tuters, 2012, p.271). This was a consequence of the improvement of infrastructure, overlapping methods of location-awareness and the entrance of more commercial players to the field, looking for new opportunities provided by new technical developments.[19]

The beginning of locative media is hard to establish. Its emergence is generally pinned down to a series of events that took place between 2002 and 2003, in Amsterdam, Riga and London, even if there were already broad discussions going on at an earlier stage related to location-aware technologies, geo-mapping practices and ubiquitous computing. Karlis Kalnins is often indicated as the person who first proposed the concept of *locative* during online discussions going on around the same time (Hemment, 2006; Tuters, 2012; Wilken, 2012; Wilken & Goggin, 2015; Zeffiro, 2012). Previous to that, in 1999, Ben Russell (1999, p.1) had already positioned *Headmap* as a piece of work "dealing with the social and cultural implications of location aware devices". The first locative media project is considered by some to be the *Amsterdam RealTime* mapping project, which took place in 2002. It was developed as a collaboration between the Waag Society with the artists Esther Polak and Jeroen Kee and with the involvement and support of local residents (Farman, 2015, p.91). The project invited residents to register their "movement through the city" by carrying a "GPS tracer", information that was then used to build "a map of Amsterdam that was based on the movements of people rather than streets and blocks of houses" (Greenfield & Shepard, 2007, p.14). The static map of streets and buildings was overlaid with a map of common routes expressing the relation between the local residents and their living space, varying according to the resident.

There are other key projects and events relevant to highlight as they testify the momentum being built. Back then, Blast Theory was already a group of artists

[19] Marc Davis, a professor, started around the same time the Yahoo Lab at Berkeley University of California. Here, between 2005 and 2006, he worked on projects related to the transition from users to producers of media through mobile phones, more precisely on issues related to metadata and Bluetooth pooling (Davis et al., 2006; Nair & Davis, 2005). As he wrote at the time (2006), the collection and analysis of contextual metadata would "significantly improve image content recognition and retrieval", while through the technique of Bluetooth pooling, metadata could be "collected from multiple users" and work through "proximal users to create a more accurate record of co-presence" (Nair & Davis, 2005). (For further information, please see: http://www.ischool.berkeley.edu/research/projects/garagecinema) The transition from users to co-producers meant that the mobile device was no longer a simple receiver, leading to an active contribution by users for their context of use.

raising attention, both in the United Kingdom and internationally, with projects often and simultaneously involving “large scale installation, performance and gaming using virtual reality” (Blast Theory, 2012a). Their now long-term collaboration with the Mixed Reality Lab at the University of Nottingham was in its early stages, with *Can You See Me Now?,* produced in 2001, being one of the first projects to come out of it. The project – a mixed-reality game – signalled changes and developments going on within the field of media arts. While Blast Theory’s concerns went beyond locative media and mapping practices, *Can You See Me Now?* is often considered a reference work for the field (Tuters, 2012, p.268), partly due to the Golden Nica Award for Interactive Art that it won at the Prix Ars Electronica in 2003. The project “overlaid” a physical urban territory “with a virtual city”, in which online players competed against Blast Theory’s runners “on the streets” (Blast Theory, 2012b). Online players could track the runners on the screen, while these were supported by handheld devices (Blast Theory, 2012b). Players could “exchange tactics and send messages to Blast Theory” and “eavesdrop” on the runners’ walkie-talkie conversations, thereby exploring “ideas of absence and presence” (Blast Theory, 2012b). Bridges between two technically distinct environments were built, making harder the definition of their own boundaries. Being there, on-site, was as important as the connection and the unravelling relation to that same location. The way space was engaged went beyond the context of the game – GPS coverage, “black spots”, “high and low network connectivity” – fed into a less tangible engagement with that urban territory, playing with feelings of presence–absence (Dourish & Bell, 2011, p.121).

RIXC, the Centre for New Media Culture in Riga (Latvia), organised two important events in 2003 (Wilken, 2012, p.244): the “Media Architecture” conference, part of the *Art+Communication* festival that happened between the 15th and 18th of May (RIXC, 2003a), and a follow-up workshop a few weeks later between the 16th and 26th of July, which took place at the K@2 Culture and Information Centre in Karosta (Latvia) (Hemment, 2006; RIXC, 2003b; Tuters & Varnelis, 2006). The conference brought to the centre of the discussion “urban geographies and networked media”, “mapping-positioning and wireless networks” and “locative media and psychogeography” (RIXC, 2003c) while the follow-up workshop was taken as an opportunity to put the previously discussed concepts into practice. The concern with processes independent from traditional forms of architecture or the Euclidean city was an indication of new practices emerging in relation to location. Karosta, "an abandoned Soviet-era military city on the Baltic coast", was a peculiar location for the July workshop to take place. It actually meant that the workshop happened outside the usual global markets where location-aware technologies were already flourishing, at the same time that it was contextualised within the military context where many of these technologies were initially developed (RIXC, 2003a). The focus was on the elaboration of a mobile geography, practices of remembering and an attempt to produce informative maps with the precision of military methods, through the use of affordable receivers connected to positioning satellites (Tuters and Varnelis 2006) and made possible by the previous disconnection of the selective availability feature.

Less commented on is the *Cartographic Congress* that also took place in 2003 for a period of six weeks, from May to June, in London (Tuters, 2012; Mute editors, 2003). There were a few shared participants between Riga and London's events, such as Jo Walsh, Ben Russell, Marc Tuters and Karlis Kalnins.[20] This congress aimed at highlighting the importance of open data initiatives and counteracting the tendency of "governments and corporations" to appropriate and capitalise on public domain data (Mute editors, 2003). It took place in Limehouse (curiously so close to Canary Wharf, where the same boundaries between public and private space and data were being reshuffled) and was inspired by the text written in 1566 by Humphrey Gilbert, which described the search for the Northwest Passage (Mute editors, 2003). This same text had been used decades earlier by the Situationist International, in 1960, during a meeting also held in Limehouse, which had the objective of finding "new passageways" (Mute editors, 2003) "towards a new revolution" that aimed at "the conquest of everyday life" (Situationist International, 1963).

These events emphasise the momentum that was gathering around locative media in 2002–03. The mailing list was terminated in 2005, around the same time that smartphones were coming into wider use and the Google Maps API was

[20] Marc Tuters (2012, p.275) mentions the congress briefly in a footnote. The fact that this congress took place almost simultaneously as the conference and workshop in Latvia can help explain the momentum that was being built around locative media in those months of 2003. The overlapping of participants also indicates a small circle of people working in the field at that time.

released. The period previous to 2005 not only offered the opportunity to think about locative media, away from the traditional media art circuits of London and New York, but also was the chance to put the enabling technologies and supporting infrastructure at the centre of attention. The early days of locative media demonstrate how small projects that start on the fringes, in an irregular pattern, are slowly brought into the commercial arena, as their practices become more acceptable and technologies better adapted to the commercial context. Furthermore, the informatisation of space was becoming increasingly visible to the masses and urban dwellers through their use of mobile phones and other portable and networked devices. Users were made complicit and engaged with the process of informatisation by enabling it. They tagged data to geographic points and received tailored information. In this context, it could be argued that after this early period of development that finished more or less around 2005, locative media was already something completely different, much closer to the practices taking place within complex urban systems, as is discussed throughout this thesis. Changes and transformations were not immediate, but there was already a clear transition into commercial endeavours. The novelty of locative media practices had, from then onwards, to live side-by-side with the appropriation of its practices by companies such as Facebook, Foursquare and Nike. Nonetheless, a momentum had been created and a clear convergence of Internet with urban space had been initiated; urban computation had now turned networked and intensively locational. Digital urban practices were locative, datafied and softwarised, both in intentional and non-intentional manners, and visible and non-visible ways.

1.2.2. Urban space becomes informational

As this process evolved, from post-2005 onwards, locative media became part of many commercial projects throughout urban territories. What, at one stage, seemed like practices taking place at the fringes were slowly brought into the centre of attention – their approaches, ways of engagement and spatial exploration were embedded into the sphere of advertising, marketing and location-bounded services and referred to as location-aware media or geo-media (Russell, 1999; 2002; 2004a; Shepard, 2011b; Tuters & Varnelis, 2006). By the time this research started, locative media, geo-media services and mobile phone applications, relying on global positioning systems, had already become part of mainstream services and products, showing a good level of maturity[21] and common use beyond their initial context of development. The commercial shift meant that the emphasis was put on interaction and engagement with users, as *partially*[22] predicted by Ben Russell (1999; 2002; 2004a), as well as on how to capitalise on the location-awareness capacity of a given system. Concerns with the technical aspects that made locative media possible, and the technical systems within which they took place, were left to a secondary position, allowing what was the infrastructural to recede into the background.[23]

Ubiquitous computing, wireless networks and connected and portable devices led to privileging the capacity of locative media to pinpoint locations (by mapping out, tagging and tracking) expressed through images (Greenfield & Shepard, 2007, p.13). The image, together with its screen and user experience, became the primal points of consideration of services developed for locative media, as boundary elements between the enabling technical apparatus and its action and outcome within its environment. At the same time, images and the mobile activities of image taking, sharing and posting functioned as a way to structure and deal with the emergence of "the placeless flow of information" (Lapenta, 2011, p.2), as it allowed connections to be established between information and geographic points, events and locations. The image and the screen gained a privileged position at the centre of locative media, often positioning themselves as the only available entry-point to a given context, at the same time that they were "conducive to conveying a sense of virtuality and dematerialization" (Gabrys, 2011, p.53). This was the case

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[21] In the sector of technology development, reference is often made to the "Rogers' bell curve" when analysing the level of usage and acceptance of a certain product. The "Rogers' bell curve" diagram, introduced by Everett Rogers (2003), divides users into five distinct groups: "innovators", "early adopters", "early majority", "late majority" and "laggards". The third and fourth groups, representing each of them 34%, indicate a stage of high maturity and acceptance of a technology, innovation or product. In this case, it can be said that by 2010 geo-media were approaching this stage, as indicated by their use across mainstream products, services and projects.

[22] The use of 'partially' is intentional. Ben Russell celebrated a return to the outside as an opportunity for empowerment and community engagement (1999; 2002; 2004a). In the context of this research, it will be argued that such a return was made possible instead by data collection, technical development and intensive geographic enhancement in a push for informatisation and further commoditisation of space. Empowerment and community engagement was not the main objective or outcome of the events and transformations described throughout this thesis.

[23] The position of infrastructure receding into the background is discussed again in the following chapter. However, it is relevant to highlight that this role of invisibility carries with it an assumption of infrastructure as only limited to supporting and facilitating the workability of a given context. The interior dynamics of infrastructure are often ignored, left as secondary and seen as mere facilitators, both in urban and non-urban contexts (Bowker & Star, 2000; Weiser, 1993). Making invisible is to deny "the essential part" that these material elements play, both to that same infrastructure and to how those elements are thought through (Farman, 2014, pp.56–57).

with the events initially described: the screen at the bus stop and the computer screen used to follow the trackable parcel and navigate the public data on air quality. Nonetheless, it is also the case with other location-aware services that can be accessed through the touchscreen of the personal mobile phone, regardless of their scale and complexity. It is within this centrality of the screen and the image, as shown below with examples from Foursquare, Facebook and Nike, that the commoditisation and commercial turn of locative media took place.

By early 2010, mapping out, tagging and tracking locative capabilities had already been incorporated into social media platforms such as Facebook and Foursquare and were becoming an integral part of marketing strategies of companies like Nike.[24] The increased access to smartphones, cheaper data services and consequent boom in mobile applications pushed forward this incorporation. From practices of tagging (through scoring and checking in) visited locations as in the case of Foursquare (Summers, 2014), to tracking routes done while jogging or riding a bicycle (Montgomery, 2013), applications depending on locative systems quickly multiplied hand-in-hand with their integration with social media platforms and other portable devices.[25] Parallel to the development and expansion of location-aware services, wearable tracking devices and a move towards the quantified self[26] gained increased visibility. Easily compatible with locative media, wearable tracking devices started to make use of urban systems (The Economist, 2012; Wolf, 2010), creating entanglements between transitional spaces and vitality of users. The interweaving of supporting urban infrastructural capabilities with social media, marketing strategies and wearable tracking devices created bridges between the online and offline, public and private, as not seen before. More importantly, it defined a path of mutual dependency and allowed the introduction of commercial practices into areas previously understood as private realms of life: doing sports or meeting friends for a coffee became a competition, an engagement with strangers,

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[24] Around 2002, location-aware services were presented as ready to enter the market place, so "retailers and other service providers" could benefit from this technology – the only aspect missing was a great example of application of this technology so the public could become aware of its potential (Thomas, 2002).

[25] It becomes difficult to separate locative media and location-aware technologies as all of the described examples could easily be compared with previous locative media projects, simply developed and framed within a different context of usage.

[26] The quantified self refers to the wearing of devices designed to make possible "self-tracking", which in their majority fall into "the category of wearable electronics and/or multi-sensor platforms" (Swan, 2012, pp.219–220). These devices allow the user to track in real-time physical activity, heart rate or sleeping patterns, but they can also be used in health contexts (The Economist, 2012).

and a detailed recording of personal routines that were shared with the network of contacts and friends.

An interesting example is Nike. Its marketing strategies often rely on blurry boundaries between non-commercial and commercial undertakings by taking full advantage of gamification practices and emotional marketing.[27] Nike came to stand out by capitalising on locative media characteristics and simultaneously developing participatory projects closer to media art. This is visible in its running game *Nike Grid: Run Your City* – with two editions both released in 2010 (Casper, 2010; MacLeod, 2010). The running game took place in London on the 23rd of April for 24 hours across 40 postcodes and then again on the 22nd of October for a period of 15 days, this time expanded to 48 postcodes (Casper, 2010; MacLeod, 2010). In this game-event, the city was treated as a board game (divided into postcodes) where players were invited to take to the streets and run for their postcodes, accumulating points and badges for each additional run. Technically, it relied on the network of red phone boxes spread across the city, a mobile phone application and Facebook. The runner with the highest points in each postcode would win for that same postcode (Casper, 2010).

Another example from Nike, but without the gamification aspect, is the tracking and the quantified-self approach that can be encountered in some of its products such as the *Nike+* trainers and the *FuelBand* activity tracker. In the case of *Nike+* trainers, they have installed a "smart sensor" inside the shoe under the sole that "uses pressure data in combination with an accelerometer to calculate" movement, jump pressure or speed (Chan, 2012). The collected data is then fed to a smartphone, the *Nike+* account and mobile application, or simply into Facebook, allowing people based at different locations to compete with each other. A similar process of usage can be experienced with the *FuelBand* activity tracker that allows users to measure number of steps taken throughout the day, calories spent and how this relates to their personal fitness objective. In the *Nike+* account, users can have

[27] Gamification practices and emotional marketing imply the use of specific methodologies aimed at improving engagement, loyalty and self-identification with a specific brand. These have become very common in business, and they take full advantage of "the natural desire people have to compete, achieve, and win" by providing a structured system with an attractive participative and recognition model (Olenski, 2014). In the case of Nike, it is interesting how its marketing strategies bring together gamification, location-aware technologies and urban settings, reminding us of some media art projects such as those done by Blast Theory, mentioned earlier in this section.

the overview of the week, look at the historical data, compare or compete with other similar-aged users or share the data with their friends (Sullivan, 2013).

As these brief examples show, not only did the three companies have a similar approach to location and its networked elements but also their designed assemblages of networked products, services and devices aimed at locking the user in a spatial field where the boundaries between public and private, physical infrastructures and data being exchanged, and users and customers became eroded. For example, in the case of Nike, its products were not designed based on their relationship to urban space. However, all three examples simultaneously lead to multiple modes of engagement with urban space, as they feed into relational locations by adding attributes such as measurement, recurrence and competition to these same locations and by challenging existing perceptions on public and private realms. All of these projects turn urban space into a board game – a spatial grid, supported by more or less complex urban systems, where attributes beyond social and political usage, and the relationship between the user, the brand and the infrastructural space, become tangled. It is this set of relations, enabled by computational practices, that calls for the wider analysis of urban spatialities beyond the context of locative media. Attempts to separate locative media from their urban supporting systems, or assume that all locational expressions could be reduced to the practices of locative media, would necessarily leave aside the real urban impact of computation. The three examples demonstrate that there was an appropriation of specific spatial practices, but more importantly, they lead us towards significant changes in the way urban systems work. Systems were connecting, bringing other systems into their field of relations and interactions. Overall, the commercial practices by which locative media were appropriated also guide us on the context of complex urban systems, often enabled by public–private relations and engagements.

1.3. Between control and empowerment

When it comes specifically to urban contexts, *Headmap* (Russell, 1999; 2002; 2004a) offers an insightful perspective of what was happening during the early years of locative media (Tuters & Varnelis, 2006). Like the events that took place in Latvia and London, urban contexts were going through a transition in which the technical apparatus and protocols supporting infrastructural systems were challenged and transformed. Placed in an in-between position, between space and users, infrastructural systems offered a site where practices of empowerment and spatial appropriation could take place, at the same time that they were becoming a site of increased control and prediction (Gabrys, 2011, p.33). The self-published work of Ben Russell,[28] first written in 1999 and then rewritten in 2002 and 2004, in the format of a three-version manifesto (on locative media), offers the opportunity to contextualise the rise of digital systems and data-oriented technologies tied to location. The manifesto works like a bridge between locative media and wider transitions taking place at urban level. Although Ben Russell is not usually presented as a central player in the initial development of locative media (Hemment, 2006; Tuters, 2004; 2012; Tuters & Varnelis, 2006; Zeffiro, 2012), his three-version manifesto is well-aligned with the field's initial development and other technical transformations that were taking place throughout urban territories.[29] Each new version was built upon the previous version, reflecting the field's transformation – the concerns expressed each time demonstrated an increased maturity, and also a move towards more abstract and complex problems, demanded by an urban context where an increased informatisation of its own structures was perceptible.

In the first version of *Headmap* (Russell, 1999), there was a clear emphasis on land and property, aligned with a context of accentuated blurring between the private and public in terms of ownership and governance of urban space. It mostly reflected on practices of territorial appropriation through marking, graffiti and land disputes. Russell (1999) believed that these practices could offer a response to the unclear and disguised privatisation of public space and, simultaneously, an opportunity for the emergence of new concepts of ownership, away from land property and powered by augmentation and annotation of urban territories. A creative stance was seen as the only way to challenge assumptions already made at the urban level, mostly related to the right to own, restrict-access areas and tight

[28] Ben Russell was a self-published media theorist during the early 2000s, whose manifesto brought him a lot of attention within the field (Russell, 2005).
[29] The relevance of *Headmap* might also be supported by the fact that the text has been recovered through the Internet archive Wayback Machine, and it is now available in a PDF format through the blog *Technocult* (Klintron, 2010) and other platforms. The version usually available is *Headmap*'s third version, released in 2004. This version is much longer than the original, and it is also easier to read. A quick online search will lead to many pages related to the manifesto, as it remains a contemporary reference, easily applicable beyond locative media.

management of what was previously public space. This analysis was well aligned with the concerns put forward at the events in Riga and London.

In the 2002 version – *Headmap Localis(z)ation* (Russell, 2002) – the emphasis shifted towards the concept of "utility". This seemed a natural outcome of the privatisation and commoditisation of space, already highlighted in 1999. Space was being approached and contextualised in terms of commercial intentions and potential use (Russell, 2002). The technical ability of locative media to appropriate space in a symbolic way, through inscriptions and annotations, without the need for a clear objective or justification, challenged this same predominating utilitarian approach (Russell, 2002, p.8). The practices of spatial division based on its economic potential and zoning by types of usage were undermined by a media-oriented engagement with space, often made in an anonymous way. This meant that not all actions taking place within a territory resulted in a cause–effect or action–reaction process – symbolic living was about opening up new levels of engagement and forms of ownership beyond what was material within the city. It was also in this second version of the manifesto that software was considered for the first time. Russell (2002, p.21) presented it as conditioning users through its "conventions and methodology that govern[ed]" the environment of use. Even in contexts where software could be adapted to the user's preferences, defaults were only changed by a minority and therefore, all other users would "live under the tyranny of the software's defaults" (Russell, 2002, p.21). Locative devices were seen as an opportunity to put technological development at the service of local communities. Communities could, through exploration and engagement with locative media, find paths to challenge and override land ownership, access rights and software protocols.

Headmap Redux (Russell, 2004a), the third and last version of the manifesto, was published in 2004, the same year that Russell wrote "Locative media and social code" (Russell, 2004b) for *Receiver Magazine*[30] on "the social qualities of locative media". If in the manifesto's first version, Russell (1999, p.32) wrote "information is actively overlaying real space", in the second edition, three years later, he (2002,

[30] *Receiver Magazine* was a Vodafone project. It published short articles on all types of subjects concerned with communication technologies and their future development written by a series of influential figures from academics to artists, architects, technologists and journalists. The project was discontinued in 2010, with its last issue (22) being published in 2009. The published articles are no longer available online through the magazine's page.

p.17) stated that "the internet is about to overlay real space". This shift from information to the Internet, which was maintained in the final version of the manifesto, is of relevance, as it contextualises how interconnectivity was taking over urban space (Russell, 2004a, pp.i–v), both in technical terms and expectation from urban dwellers. In this final version, the objective was to consider in a detailed manner the implications and potential of locative media to interweave "Internet and cell phones" with "real-world objects, geography, and social and economic interactions" (Russell, 2004b, p.2). The aim was to establish locative media beyond a hype or short-term trend, so it could also create the conditions to offer a critique and engagement with urban space beyond new technical capabilities.

What *Headmap* (Russell, 1999; 2002; 2004a) demonstrates is a move towards the 'outside' together with a potential to engage and intervene within that same space in a context of tensions, paradoxes and fast technical changes. The layering of urban space with a new information capability (both through collection and processing), portable and networked devices, and multiple points of entrance meant more dynamism and a potential for novel models of spatial engagement. As Russell (2004a, p.1) explains, "the failure of the space programme, the closure of the frontiers, the rise of television, early computing, interiorised simulation and drug culture" led finally to a re-emergence of the outside facilitated by the technical developments taking place. Overall, the potential embodied by this indicates the idealisations surrounding locative media. References to it can be found in psycho-geography projects and in direct references made to the practices of *détournement* and *dérive* of the Situationist International (Tuters, 2004; 2012; Tuters & Varnelis, 2006; Zeffiro, 2012). Both of these concepts, originally applied by the Situationist International in a very different context[31] (Marcus, 2004; Wollen, 1989; 2001), are commonly referred to, within locative media, as "annotative" or tagging, and "tracing" or tracking (Tuters & Varnelis, 2006), directly implying the use of GPS or

[31] *Détournement* and *dérive* in the context of the Situationist International referred to an outdoors practice, with a strong political connotation attached to it (Marcus, 2004), but it also implied a move away from "individual art-forms" towards the creation of "*situations*, constructed encounters and creatively lived moments in specific urban settings", giving priority to the collective (Wollen, 1989, p.68). The urban appropriation by the collective, advocated by the Situationist International, was visible in the project *New Babylon*, created by Constant Nieuwenhuys, in which "the design of an experimental utopian city" included spaces of choice where "nomadic inhabitants could collectively choose their own climate, sensory environment, organization of space and so on" (Wollen, 1989, p.69), turning the urban territory into a space "only inhabited by transients" (Wollen, 2001, p.123) and therefore a context of continuous adaptation with mobility at its centre (Nieuwenhuys, 1974).

other geo-referencing methods.[32] They reinforce the primal objective of locative media as a way to bring back public space and social engagement to the centre of urban living. Nonetheless, they also expose a technical capability and complexity that becomes even harder to access as it recedes into the background. In part, it is this contested relation with the supporting infrastructure and its original context of development that worked as an incitement for action. Moreover, the work of Russell exposes a tension continuously present: the informatisation and digitisation of urban space leading to the continuous blurring of boundaries between private and public was counterbalanced by the potential of locative media to connect in new ways with space, as well as with other urban dwellers. The materiality of a previous public space now turned into a fenced private office block could be overridden, or at least challenged, by immaterial practices of spatial tagging and tracking.

1.3.1. The internal paradox

As Russell's three-version manifesto hints, technological development tends to be tense and populated with what is here defined as the internal paradox of technical systems. In the case of locative media, this paradox brings to the forefront the shared grid of operations with complex urban systems, but it also highlights a specific context of development with computation at its centre. On one hand, locative media came out of technology developed within the military context, which was aimed at command and control activities, and in many cases, surveillance. On the other hand, it enabled ways of spatial engagement and empowerment that were not possible before by opening up these same technologies and capabilities to citizens. With the emergence of mobile phones and other networked and portable devices, urban dwellers started carrying these in their pockets and handbags, slowly interconnecting with other urban elements, platforms and users, both in an intentional and passive manner. The internal paradox of locative media can be viewed through different lenses and contexts, in which geo-data is collected, shuffled and used. For example, there is the treatment of location as a way to organise and structure space into

[32] In the context of locative media, the use of both concepts is mostly related to a technical capability that is then explored within an urban context, moving away from the more political and experimental approach found within the projects and writings of the Situationist International. The use of *détournement* and *dérive* not only seems trivial but also reflects the appropriation of both concepts by commercial contexts and the process of commoditisation of urban environments.

different categories, like what is done by geographic information systems (GIS) (Gómez Delgado & Barredo Cano, 2005), and traceability of objects in order to keep track and also to unveil their trajectories (Mitew, 2008), and finally, there are spaces of location-aware devices as augmented and hybrid reality sites made possible by tiny sensors controlling aspects such as temperature and humidity (Graham, 2004a).

As already stated, locative media share with complex urban systems their wider spatial and "operational construct", which has been in development since the Cold War, when digital forms of computation became "integrated into command and control tasks and weapons guidance systems" (Crandall, 2004, p.46).[33] The spatial assemblage organised within this operational grid had as its main objective "an arrangement of power" (Crandall, 2004, p.47), made visible through prediction, analysis and pre-emptive action. When it comes to urban contexts, this results in two direct implications. Firstly, the operational field is mostly experienced in a similar way throughout a delimited territory,[34] even when the supporting infrastructure can be formed by private and public competing entities. Secondly, in the present context, it means that the lexicon in use, referring to acts of mapping and tracking, has a visible impact on how seeing and perceiving are understood, while sharing references to their military origin. The "actual space" (Duarte, 2015, p.78), the physical space where interaction happens, tends to not be explicit about its distinct layers of mobile, digitised and networked devices operating through its supporting physical and non-physical infrastructure. As this shows, mapping and tracking, even when used to bring communities and actions into visibility and accountability, puts these same communities under the spectrum of "command and control tasks" that Crandall (2004, p.46) talks about. The separation and non-interaction of the different technical layers sitting over a territory can never be ensured, as their coming into being is not always entirely clear as the detailed work of Paul N. Edwards (2010) on climatology, its technical systems and geopolitics, well exemplifies. Similarly,

[33] Although the reference to the internal paradox is being made here from the perspective of infrastructure, the historical analysis offered by James R. Beniger (1986) on the different control crisis up to the Control Revolution helps in better understanding how control is intrinsic to so many systems and that this same paradox can be found within management and bureaucratic practices. More precise examples are discussed throughout the thesis.

[34] This refers to the homogeneous navigation of the urban territory. As a delimited territory is turned into a grid of action, it needs to be divided and turned into an actionable field. For this to happen, it is necessary that a rearrangement of disparities takes place. As the field of action, a specific urban territory needs to be approached through the same tools even if it presents different geographic or architectural challenges throughout its territory, meaning that the division into a grid of action does not necessarily need to differentiate between public and private, old and new, richer and poorer.

Stephen Graham (2010, p.xxv) explains that, in the context of militarised urban territories (cities within war zones), "the military tasks of tracking, surveillance and targeting" become easier to pursue as the infrastructure needed is often already in place. More precisely, the military is only required to "appropriate the systems that operate [already] in cities to sustain the latest means of digitally organized travel and consumption" (Graham, 2010a, p.xxv), providing in this way a militarised field and a grid of action within the core infrastructural systems already in place. The infrastructure can, without too much effort, be put back to work within its 'original' objective and context of usage.

Tracking and tagging, as practices of spatial ordering, territorial division and incorporation of more information to specific locations, are also methods of geographic enhancement, due to the qualitative and quantitative data that they can anchor to a specific location. This enhancement happens at a technical level, but also at "the level of existential, inhabited, experienced and lived place[s]" (Bleecker & Knowlton, 2006), as it gathers both quantitative and qualitative data. Information systems built around practices of tracking and tagging bring together information that was previously encountered in separate and even independent systems. For example, a city government might design and own geographic information systems[35] around different types of objectives: information about aspects of landscape (soils, wetlands, flood plains, zoning and parcels); a mix of different information that might include data on landscape combined with other thematic information (land usage, elevation, parcels, streets and customers); and strictly social-related information compiled into generic or specialised areas such as security, health care, education and services for the elderly. Layers of previously distinct categories and formats of information are converged under these systems, forming new modes of knowledge. This datafied knowledge presents itself with increasingly tighter detail, precise location, and relational and comparative information; it is like overlaying urban landscapes with a layer of invisible and evolving information (Greenfield, 2006, p.124), fed by the practices of tracking and tagging.

The aforementioned practices of geographic enhancement have led to the emergence of understandings and experiences of space as mobile, hybrid or

[35] GIS databases actively feed, reinforce and sustain the formulation of knowledge about urban contexts through profiling territories and inform decision-making processes, leading to the intensification of geographic information (and sustaining the enhancement of location) (Gómez Delgado & Barredo Cano, 2005).

augmented,[36] in direct reference to a degree of fluidity, capacity to evolve and the coexistence of different spatialities formed by this evolving layer of information (Kroker & Kroker, 2010). Locative media, and other location-aware and location-oriented technologies, related practices and interfaces, have then added layers of dynamism and complexity to the traditional architectonic understanding of urban territories; they have reshuffled the relationships in place and the positioning of locations in relation to each other. Stories about locative media necessarily imply a network of locations, geographic enhancement and the internal paradox within the technical systems, simultaneously constraining and empowering. However, the scale and scope of locative media can only offer a limited understanding of urban territories and their spatialities, under the action of computational practices. Relational locations are more than these. The relations between computation, space and infrastructure require the consideration of wider infrastructural systems, to dig into their operation areas, dark and forgotten corners, so their narratives of emergence and evolvement can finally come forward.

1.4. Let's embrace relational locations

> Then four things changed. First, electronic sensors got smaller and better. Second, people started carrying powerful computing devices, typically disguised as mobile phones. Third, social media made it seem normal to share everything. And fourth, we began to get an inkling of the rise of a global superintelligence known as the cloud.
>
> in *The Data-Driven Life* by Gary Wolf (2010)

This introductory chapter began with the three events that took place in the winter of 2010: the lost multi-post bag, the bus that never arrived and the relocated air quality monitoring station. All of these events were the outcome of their own complex systems in action, in which portable and networked media were only a fraction of their assemblages. Nonetheless, this introduction continued with the

[36] For more on the concepts of "hybrid" and "augmented" space, see Adriana de Souza e Silva (2006) and Christopher Burman and Usman Haque (2010). Lev Manovich (2007; 2013) introduces the concept of hybrid in relation to media and moving image as a consequence of the softwarisation of multiple techniques previously analogue that have not only been translated but also been extended in their abilities and capacities, operating within the same software and working environment. These previously distinct techniques appear now deeply mixed, coexisting easily within the same image. Transferred to the context of urban spaces, hybrid and augmented start talking about the spatial outcomes of datafied and softwarised practices, deeply entangled with their context of action.

contextualisation of locative media in order to lay the framework of analysis that will feed directly into this body of work. It talked about a period of quick changes, mostly technical, that facilitated the emergence of locative media and which have consequently come to challenge the way urban territories are developed, experienced and conceptualised. As Gary Wolf (2010) wrote, the arrival of small and cheap sensors, and the wide use of powerful mobile phones, social media and cloud computing, have transformed the spatial qualities and dynamics of urban territories. They have challenged and redefined engagement with our surroundings and social relationships; at the same time that they have brought to urban territories practices and discourses on management, efficiency, sustainability and automation (Graham, 2004a). More importantly, what all of these elements demonstrate are the effects of computation, expressed and materialised throughout urban territories. By focusing on locative media, a few areas in need of further consideration have come to the forefront: contemporary urban territories as no longer having clear boundaries between private and public, as well as between inside and outside, belonging and disfranchised; the capacity to create and tag vast amounts of information to a geographic point; the internal paradox of technical systems, opening up their context of action, but also expressing their military potential; the increased tendency for systems to converge through computational processes; and finally, the extension of computation transversally throughout urban territories. What has emerged is a field of spatial tight relations between infrastructure, space, and computation. The derived complexity of this complicates the entrance to these same contexts, either through mapping or even by untangling the evolving relationships in place.

Overall, as already said, this body of work has emerged from the need to better understand what the computational conditions are that have led to the emergence of relational locations, and more precisely, the same modes of space resulting from the complex urban systems supporting the multi-post bag, the bus stop and the air quality monitoring stations. In a context where discourses on fluidity, speed, ubiquity and user-friendliness in relation to urban environments tend to be common,[37] such as the positive narratives of engagement and inclusiveness that populated the early days of locative media, it is urgent to focus on the

[37] This is particularly visible in dozens of online publications dedicated to the latest news and hypes on technology, innovation and start-ups such as *WIRED* (http://www.wired.com), *The Next Web* (http://thenextweb.com) and *CityLab* (http://www.citylab.com) among many others.

conditions leading to relational locations and what they tell us about computational practices. Although research has already been developed on different aspects related to these spatial structures and formulations, such as that concerned with the introduction of computation into infrastructure (Graham, 2005; Kitchin & Dodge, 2011), the specificities of software and data (Fuller, 2003; Galloway & Thacker, 2007; Mackenzie, 2006; Ruppert, 2012) and the topological behaviour of urban spatialities (Bratton, 2009; Lury et al., 2012), further research is needed on what remains in the background. This means, what are the dynamics in place from an infrastructural and material perspective? It is then necessary to consider the impact and role of computation within the existing dynamics among technical systems and their tendency towards concretisation, now accelerated and intensified. Moreover, it is also necessary to consider how computational practices have led to the development of relations of mutual dependency and continuous feedback with practices of standardisation and risk management, which are all highly location-oriented.

The chosen narrative and research path to develop this body of work presents its own contextual challenges, as it attempts to position this project as contributing to what can be defined as digital urbanism. This is understood here as sitting at the convergence of software studies, cultural studies and human geography, with a strong influence from science and technology studies. The relations and engagements that are taken on throughout this thesis are tangible and, at times, even populated with tension. In any case, even the most material aspect of our context of analysis – infrastructure – is presented here as being relational and malleable, aligned with some social construction perspectives: infrastructure is always "a fundamentally relational concept" due to its formalisation "in relation to organized practices" (Star, 1999, p.380). This formalisation will be shown to be a lot more flexible than the concept on its own may imply, mostly due to the difficulty in mapping all the involved actors and their boundaries of action (Bijker & Pinch, 2012, p.xvii). The evolvement of the context of analysis will be shown to not be a linear model like those "used explicitly in many innovation studies and implicitly in much history of technology", but one that behaves more in a "multidirectional" manner (Pinch & Bijker, 2012, p.22). Although the simplification of the multidirectional approach can always result in a linear model, the relevant point is that this linearity is not the starting point, allowing us simultaneously to question the choice of some paths over others (Pinch & Bijker, 2012, p.22).

The assemblages that are identified, as those of the complex urban systems supporting the three events from the winter of 2010, are then taken as necessarily dynamic and in continuous evolvement. Stability within a system, or assemblage in this context, is always relational and evolving according to the changes taking place throughout the entire assemblage. For example, from a system's theory perspective, all elements ("artifacts") in interaction with other parts of the assemblage contribute to the dynamics in place and "the common system goal", meaning that, in the case "a component is removed from a system or if its characteristics change, the other artefacts in the system will alter characteristics accordingly" (Hughes, 2012, p.45). Michel Callon, now from the perspective of actor-network theory, makes a similar observation: no "actor" within a "network" can be reduced to just itself, as they are always connected to other "actors" (Callon, 2012, p.87), so a change or removal of any of those connections will most likely lead to further "shifts and changes" (Callon, 2012, p.89). In this context, nothing within a given assemblage can exist in isolation or free of relation. John Law (2012, p.109), aligned with this perspective, affirms that a network requires "vigilance and surveillance" in order to remain as a unit and stable, as otherwise "the elements will fail out of line and the network will start to crumble." In this context, it is believed that the forming elements "hold together so long as those relations also hold together and do not change their shape" (Law, 2002, p.91). Or, as Law (2002, p.93) confirms as he discusses the vessel, "an object (for instance a vessel) remains an object while everything stays in place and the relations between it and its neighbouring entities hold steady". If this logic is accepted in the context of relational locations, challenges start to emerge as to how these same contexts should be approached and studied methodologically. The assemblages formed by the technical elements of complex urban systems will require then a multidirectional perspective that emphasises the relations between elements.

1.4.1. A brief reflection on methodology

This brings us to the methodology on how to approach the extension of computation throughout urban territories. Overall, the context of this thesis, as already made visible, brings together a range of material and non-material elements such as physical urban structures; technical and infrastructural elements connecting across urban territories; digital interfaces in public and private spaces; data that is collected, reshuffled and stored; a variety of pieces of software; technical standards; and practices of standardisation and risk management. Our urban context of analysis may lead, at times, to a sense of intangibility or immateriality due to the conditions already discussed throughout this chapter. Jennifer Gabrys (2011, p.58) describes a similar challenge when analysing the waste of electronics, implying "modes of materialization that render infrastructures imperceptible or ephemeral". This sense of the intangible is common and spans through many infrastructural settings as also the work of Lisa Parks (2005) and Paul N. Edwards (2010) demonstrates. In all of these cases, the authors need to go beyond the immediate and perceptible materiality of their objects, systems and contexts of analysis. As Gabrys (2011, p.2) summarises, the level of elaboration of complex (and often computational) systems can go unnoticed, yet it is within them that unseen consequences flourish. Computation systems and practices, although apparently free of material constraints, "still inevitably rely on material arrangements" (Gabrys, 2011, p.3), even if to reach their sites of materiality, one needs to look at their sites of production, storage or abandonment. When urban assemblages, like those of complex urban systems, are taken as a field of action, tied to traceable sites, it becomes possible to approach them through their own "complex temporalities and materialities", "material conditions" and a "set of processes and effects" (Gabrys, 2011, p.10). Nonetheless, specific challenges emerge, out of the context of analysis, as the relation of computation with other spatial dynamics becomes increasingly extensive, going beyond its area of action and scope. Its spreading leads to "the conversion of nearly everything, from media to human memory, into information", facilitating a computational translation through computational processes (Gabrys, 2011, p.32). The more sophisticated complex urban systems become, with their ubiquity, ephemeral transactions and continuous expansion, the harder it becomes to isolate them from their own context or look at them from a single-element perspective. This implies that the continuous extension of infrastructural systems, their scope and areas of targeted action allows them to become "increasingly a part of an empire of functions encumbered by a network of supportive elements" (Thrift, 2008, p.9).

Given this, two possibilities emerge as methodological approaches to our context of study: the appropriation of moments of transition and having as the departure point a small infrastructural entry-point. Moments of transition – such as the momentum that is created during a process of convergence, the introduction of new technical elements or moments of failure – are used as opportunities to enter a given system and gain a more detailed understanding of the spatial dynamics in place, during an explicit event. In the case of an entry-point, it refers to a small or even minor element, in relation to the scale and extension of the complex urban system it belongs to. It can be a public interface or an element placed as an obvious expression of the system in opposition to those remaining hidden away. In both cases, this approach can be justified by the challenge that retraceability and identification of a departure point pose in the context of urban complex systems. Philip Agre (1997) explains that contrary to technologies "employed in a specific site" and with "clear cause-and-effect stories", many ubiquitous technologies (like many employed throughout complex urban systems) pose the problem of "the departure point" – what is ubiquitous is intentionally forced to recede back and made secondary. For example, in the case of the event that took place in Madrid, related to the changes that occurred within the context of the air quality monitoring stations, which element should be considered as the starting point of such a complex system formed by material and non-material elements? Should it be one of the pieces of regulation developed at the local, national or international level? Or should the privilege be given to the faulty hardware in use? Or should instead the emphasis be brought back to one of the stations?

The elements highlighted through moments of transition and entry-points are approached as media objects working in mediated contexts. The concept of 'media' is used here with a broad perspective beyond what would be perceived through the traditional study of users and audiences and context analysis (Atkinson & Hammersley, 1983). It implies what is relational, a level of adaptability and capacity to change that is intrinsic to its condition of mediated and mediator. It refers to a degree of interface and engagement. The very use of the concept 'media' is aimed at opening up the infrastructural context towards action and dynamism. Media is then not simply understood as a bounded object; it implies the wider "connections" and "the networks of relations" in place across a relational location (Schapira et al., 2012). These objects, mediated and mediators, tend to lay hidden away within the context of analysis, often black boxed, where sitting "dependencies of objects, abstractions, representations, or systems" can go unnoticed (Fuller & Goffey, 2012b, pp.12–13).

As a complement to this, it is considered what Eyal Weizman (2012) describes as forensic architecture: a conjugation of two approaches aiming at "unpacking an object or a spatial condition" on one hand through what happens on the ground, and on the other hand, through a series of debates and discussions.[38] This implies a combination of fieldwork and on-the-ground mapping of a context with a theoretical contextualisation. As Weizman (2012) explains, the groundwork enables the reconstruction of "a fabric of multiple interactions" and the consequences of the relations in place between the material and the technical, between the "large territorial transformations and sometimes architectural details". It is from the small details and their wider contextualisation that new insights emerge, like in the case of the chosen entry- points. This context-oriented methodology means that in the case of relational locations a step can be taken outside of what clearly settles, arrives and leaves from a geographic point to look at a wider field only accessible through this multiple-perspective. The geographic point of a given entry-point becomes the departure, a way to establish and sketch "relations between things" (Weizman, 2015), tracing then their relations and degrees of change, departures and arrivals at that same geographic point. An on-the-ground approach would most likely be subjected to what was intentionally available or expressed by material relations. It is for this reason that a "forum-work" approach becomes necessary (Schapira et al., 2012), in a direct reference to the theoretic contextualisation provided throughout the case studies, and also by the initial theoretical chapters. In the context of the two case studies developed as part of this research project, the event is an object – an air quality monitoring station and a

[38] The approach developed by Eyal Weizman (2015) was done for very specific contexts, where the role of the architect is close to that of an eyewitness. However, this intentional double approach seems also relevant outside of extreme urban contexts.

parcel – respectively in the case of the first and the second case study. This means that in each case, the object works as the entry-point and the element through which its context is unpacked as well as the relations that have been established, strengthen and evolved with other urban elements. The on the ground mapping attempts to unfold the existing relations between space, infrastructure and computation, while at the same time it is used to identify what is in place in relation to each object.

1.4.2. The thesis

This introduction aimed to demonstrate the path and challenges encountered through the process of narrowing down the object of study. As it developed, it became clear the scale of transformations unravelling across urban territories, as a consequence of technological development and the extension of computation throughout different aspects of contemporary life, and more precisely, infrastructural and technical systems.[39] Having then defined this introduction as our entry-point, this thesis progresses into the two next chapters. It starts with 'Spatial relations', which analyses existing literature on the relations of space, infrastructure and computation, being for this reason divided into three main areas. Overall, this chapter demonstrates that there has been a locational turn, where specific locations and their geographic points have become central to the understanding of urban territories, their dynamics and relations with other territories. Space, and as an outcome of these relations, is shown to increasingly offer a sense of continuity, enabled and reinforced through coexisting practices of ordering and differentiation, in continuous relation with other locations. Infrastructure emerges as a set of elements that are increasingly easier to divide between backbone and add-ons, between crucial and strategic and additional areas that can afford higher degrees of differentiation, transformation and adaptation. It is within add-ons that computation emerges as particularly active. The increased presence and importance of code within infrastructure is shown, as an outcome of the extension of computation throughout urban contexts. The chapter

[39] Between 2012 and 2015, while working at Citymart, I gained first-hand experience of this through the work done with teams of local governments worldwide. Through our projects related to social and urban innovation and governance, we worked on issues such as public procurement, agile implementation, compatible and competing systems, data protection and reduced budgets for public provision. All of these projects presented challenges specific to the speed and complexity of computation in relation to the context of urban life and governance.

concludes with the analysis of the extension of computational processes and how these can reinforce processes of differentiation occurring throughout infrastructure.

The following chapter progresses then to the dynamics taking place within technical systems and among their contexts of action. It moves from a broader and contextual overview to an emphasis on technical systems, arguing that further research needs to be carried out at this level in conjunction with that established throughout the literature review. Chapter 3, 'The articulation of complex urban systems', departs from the conceptual framework on technical objects developed by Gilbert Simondon (Simondon, 1980; 1992; 2008), in order to propose that there is a path of development within complex urban systems towards concretisation. This tendency, it will be shown, has been accelerated and intensified as a consequence of the extension of computation throughout complex urban systems. Relevant is how this has been simultaneously sustained and reinforced by practices of standardisation and risk management acting within the context of action of complex urban systems. This chapter develops its argument through the analysis of an early example of convergence, more precisely, between the railway and the electric telegraph. These two systems, previously independent from each other, open up the discussion on possible outcomes of a process of transition moving towards concretisation. This moment of transition serves to highlight the impact of technical advancement in infrastructural systems, expressed through the convergence between communication and mobility and the opening up of new possibilities for management through increased informatisation. The path of development towards concretisation becomes then central to this thesis. This is achieved by demonstrating that in order to understand the wider impact of the extension of computation throughout urban territories and their complex urban systems, it is necessary to bring more attention to these existing dynamics within technical systems and what takes place at each phase of development.

The two case studies extend the initial reflection of Chapter 3. They begin from the understanding that is established about relational locations, infrastructural supporting systems, and computation. They take advantage of the same single urban territory, offering the opportunity to analyse distinct complex urban systems co-existing within the same geographic context, the metropolitan area of Barcelona. The city is, through these case studies, transformed into a field of analysis, where different levels of intensities, rhythms and degrees of concretisation are encountered. Our urban territory is, for this reason, approached from a different perspective in each case study. The modes of spatialities identified through the case studies become contrasted with the city's geographic static location, situated between sea and mountain and struggling to stretch sideways.

The first case study begins with an air quality monitoring station, in order to talk about the process of convergence between two important urban systems, more precisely, those responsible for the management of mobility and air quality. Starting from the air quality monitoring station placed close to my home, a wide assemblage of elements is slowly unravelled: air quality measurements, weather forecasts, academic studies correlating speed limit with road safety and traffic flow, international and national regulation, a vast array of surveillance cameras, LED screens, sensors and helicopters. The supervision and management of air quality becomes entangled with issues of mobility and traffic flow, while slowly expanding its scope of intervention into behavioural-related messages on driving safety, eyesight health or a car's mechanical condition. By looking at the process of convergence, initiated and articulated from a regulative perspective, this case study examines the role played by the interactions established between practices of computation and those of standardisation and risk management. It is shown that both sides create relations of mutual benefit and co-evolvement, and that the extension of computation goes beyond its area of direct action. The case study is divided into three areas of emphasis. It starts by demonstrating how the European directive on air quality (European Parliament, 2008) assumed from its outset an algorithmic translation into the field of action, not only facilitating the process of convergence that followed but also requiring the ability of the field of action to continuously adapt to new demands and regulative requirements. The C-32 road is then chosen as the example to analyse in more detail the topological unfolding that resulted from the converged complex urban system. As a way to push forward the reflection on the path of development, it is shown how those small entry-points placed at the fringes of the overall assemblage – the sensor and the mobile application – are also those in a better position to start moving towards concretisation.

The second case study starts out from a highly computational context, through which the city is encountered as an intensive operational grid, where there is a tendency towards an increased level of detail. Beginning with tracking of parcels moving around Europe and the logic of logistics and distribution, it considers the transportation and movement of goods within urban territories. It moves, in this way, further away from what could be understood as a traditional set of infrastructures towards overlaying and competing infrastructures of logistics and distribution, where public and private are interwoven, and analogue and digital live side by side. This chapter focuses then on the contexts formed by technical and material layers of transportation hubs, routes, neighbourhoods, drop-off and pick-up points, barcodes and RFID tags,[40] increasingly expressing a tighter encroachment on space and condensing of time. It brings to the forefront what is known as the last mile of deliveries, an area currently going through a process of amplification in search of a new operational model and spatial approach. The chapter argues that as systems become further softwarised and datafied, the infrastructure enabling and supporting their work also gains the ability to emerge as more relational and tighter to the context of action. In other words, it is proposed that as organisations operating within the field of the last-mile delivery try out new models, what is emerging is a field of action unique to each parcel – an infrastructural intensively algorithmic arrangement that comes into play every time a new barcode or order number is created, giving origin thereby to very ephemeral and highly location-oriented and time-bounded infrastructure.

In this way, the structure of this research project, together with its methodological approach, will enable the examination of the conditions and impact of computation throughout different aspects of urban territories. More precisely, new insights will be gained on the prevalent dynamics and logic that have arisen as an outcome of computation, by starting from the ongoing and evolving dynamics among different technical elements, which are part of complex urban systems. Not only will the consideration of the relations in place bring forward a mode of space that is deeply tied to location, they will also shed light on the tendency of technical systems towards concretisation and how this impacts on their own evolvement and spatial extension. Only this transversal, comprehensive and integrated understanding of complex urban systems, as that provided in both case studies, can allow a better

[40] It means Radio-frequency Identification.

envisioning of what is at stake and the level of transformation taking place throughout urban territories.

2. SPATIAL RELATIONS

2.1. The question of location

> A description of Zaira as it is today should contain all of Zaira's past. The city, however, does not tell its past, but contains it like the lines of a hand, written in the corners of the streets, the gratings of the windows, the banisters of the steps, the antennae of the lightning rods, the poles of the flags, every segment marked in turn with scratches, indentations, scrolls.
>
> in *Invisible Cities* by Italo Calvino (1997, p.9).

In *Invisible Cities* (Calvino, 1997),[41] the young Marco Polo describes to the Emperor Kublai Khan the cities he visited throughout the empire while away on his missions. The cities, all with female names, are described one after the other. As the stories unravel, they slowly gain a topological dimension, where borders and distinctions between them seem mere formalities, as if they were folding continuously onto each other. The Emperor Kublai Khan starts getting the impression that all cities being described are, in reality, one single city, with each city mentioned simply embodying a specific quality of that same territory. Marco Polo, without confirming or denying such suspicion, explains that to arrive at a specific city, it is necessary to start with all possible "exceptions, exclusions, incongruities, [and] contradictions" (Calvino, 1997, p.61), to then through deduction arrive at a single territory. The uniqueness of a territory is expressed by the details of its geography, spatial arrangements and infrastructural characteristics. In this case, "the windows", "banisters", "lightning rods" and "poles of the flags" (Calvino, 1997, p.9) are all of them external and visible elements of the supporting infrastructure. It is in the arrangement of these elements, their physical condition and spatial relations with other urban elements that the city gains its uniqueness and tells its history through time. Confirming the suspicions of the Emperor Kublai Khan, Marco Polo is indeed turning Venice into a city of many cities. The city embraces and makes possible the unravelling of multiple and parallel narratives about itself,

[41] The book's narrative takes place almost entirely through a dialogue between the two main characters – the young Marco Polo and the Emperor Kublai Khan.

while simultaneously constraining and interweaving these with each other. The city transforms and is transformed by these stories; it becomes a topological environment where multiple folds, intensities and speeds coexist and compete side by side.

Like Marco Polo's folding and continuous approach to Venice, this chapter aims to map and contextualise relational locations from the perspective of the three areas central to this thesis. More precisely, it analyses existent literature within these areas – space, infrastructure and computation – in order to place the computational context of relational locations at the centre of our analysis. Throughout the chapter, it is highlighted how the reformulation of location has taken place through location-aware and location-bounded modes of working and processing. Geographic points, in this context, become easily "locatable and transposable within a global architecture of address" (Thrift, 2004, p.588), slowly changing the position of what is local and its visibility within global flows of information and relations. The three areas of analysis mentioned are not in reality entirely independent or separate from each other. The approach used is instead the outcome of a methodological decision, the objective of which is to facilitate the navigation of the existing literature as well as emphasise specific aspects unique to each of the areas mentioned. The aim is to establish relational locations as the prevailing mode of spatiality within urban contexts, enabled precisely by the extension of computation. This more general overview will allow the establishment of the wider context of complex urban systems, defining in this way the frame of analysis and navigation of the dynamics unravelling within these same systems.

I start by considering what it is to be locational and how geographic points sustain and enable multiple fields of action, derived from the working of complex urban systems. It is shown that within global flows there is a growing emphasis on what is local and specific to a territory, largely supported by computational and infrastructural practices. The conceptualisation of the global increasingly depends on the continuous feed of location-bounded information, often generated by and within these same systems. Overall, this is giving rise to a spatial dynamic closer to that of a network, leading to a context where the differences and hierarchic positions of what is local and global are replaced by a local–global intensive and extensive folding. In this sense, when it comes to relational locations, what stands out is topological and continuous relations across space (Bratton, 2009; Lury et al., 2012;

Parisi, 2012), resulting from the way space is understood and perceived, but also how it is designed and envisioned (Thrift, 2004; Thrift & French, 2002). Relational locations show, due to this, a tendency towards continuity, through ongoing evolvement and practices of ordering and differentiation.

As the spatial expression of complex urban systems, relational locations are the outcome of infrastructural contexts, and material and computational dynamics, deeply tied to specific locations. Infrastructure is the second area of review, where both physical elements (tunnels, antennas, roads, pipes, data farms, screens) and non-physical aspects (software, data, formulae, wireless signals) are considered. The objective is to demonstrate that urban infrastructural contexts have become increasingly computational environments, where hard and soft elements of infrastructural systems are closely interconnected by means of data and software. Furthermore, it approaches these contexts through a differentiation between hard and soft infrastructure, backbone and add-on elements. Building on the work of Stephen Graham (1999; 2004a; 2004b; 2005; 2010), Simon Marvin (2001), Mike Crang (2007), Ash Amin and Nigel Thrift (2002), and Martin Dodge and Rob Kitchin (2005; 2011), it is argued that computational processes, and more precisely those of softwarisation and datafication, have deeply transformed infrastructural systems into coded infrastructures. This has happened by increasingly shifting the position of add-ons and soft infrastructural elements towards the core of the system, enabled by the action of softwarisation – processes of digital transformation, mixing and hybridity of previously analogue practices – and of datafication, which is bringing into the realm of computation areas that were until then not accounted for or translated into data bytes. This shift has not only resulted in the replacement of certain material needs but has also deeply transformed the dynamics in place within infrastructural contexts.

When it comes to pieces of software and data collection, their relevance resides in the fact that they are the direct expression of computation, while offering unique qualities that allow the redefinition of areas of action and interaction. For this reason, they are approached from their role in constraining and enabling the way infrastructure works (Dodge et al., 2009; Kitchin & Dodge, 2011). Moreover, the work of computation is expressed through the continuous sense of running it offers, the capacity to bring attention to missed relations and connections, the rearrangement of elements towards the crystallisation of certain types of information (Codd 1982; Haigh 2006; Ruppert 2012) and tendency to smoothly expand their area of scope without causing much functional disruption. These qualities, it will be argued in preparation for the following chapter, work like a bounding element, and also as an accelerator and intensifier of particular dynamics within technical systems and their broader assemblages. It will be shown that the impact of computation becomes particularly visible through the already-mentioned processes of softwarisation and datafication, which are both discussed in detail later in the chapter. Both processes imply more than change or translation – they thoroughly transform and challenge their context of action.

2.2. Being locational

Relational locations are deeply tied to location and, in the context of this research, to geographic points both in a direct and indirect way, similarly to what was described in relation to the locational aspect of locative media. As a mode of urban spatiality, they emerge from the relations occurring between computation, space and infrastructure. Relational refers to evolving and ongoing spatial connections among multiple and often distant locations, as well as technical elements. These connections are not simply about bringing together two distinct elements, but how they co-evolve and influence each other in their own relations. Each location is a site of convergence of existing relations, spatially placed and pinned down through geographic points; at the same time it embodies a series of relations. For this reason, location is a context in reformulation, which tends to be experienced through a certain degree of continuity, where existing relations always imply more than going from here to there or the connection of two spatial points. Scott McQuire (2008) also argued for a relational spatial turn from a social and mediated perspective in his book *The Media City*. In his opinion, media cannot be fully "separate from the city" as urban spatialities and the experience of these are the result of "a complex process of co-constitution between architectural structures and urban territories, social practices and media feedback" (McQuire, 2008, p.vii). From this perspective, contemporary urban territories are the outcome of "the active constitution of heterogeneous spatial connections", both locally and globally, "linking the intimate to the global", but also of connections built between and within media objects at local level (McQuire, 2008, p.ix). I am aligned with McQuire's perspective on relational space when it comes to the continuous constitution of the dynamics and relations that give rise to relational locations. As a consequence, I look at how this spatial turn has been expressed, from the perspective of the relationships established exactly as an outcome of the spatial dynamics in place. I want to look at the interactions between technical elements, in order to contextualise the current position of local and global, as the first tends to be left aside and the second usually appears in the context of transnational flows, trading, circulation and so on.

Concerns with the nature of space have become stronger over the last decades, especially from the 1950s onwards, as the review made by Rob Kitchin and Martin Dodge (2011, pp.66–71) demonstrates. Although this thesis is not concerned with the prevalence of a specific nature of space over another, what is relevant to emphasise is the increased presence of perspectives that focus on the continuous and evolving characteristics of space. Without wanting to propose it as a direct outcome, it is important to highlight that this concern with the nature of space has happened in parallel with the emergence of computation beyond the military field and consequently its increased usage and extension throughout urban contexts. Previous to the 1950s, space tended to be used as a field against "which objects of study could be measured and mapped" (Kitchin & Dodge, 2011, p.66). From "the late 1950s and into the 1960s" this approach was slowly replaced by a more thorough "discipline focused on locational arrangement, geographical patterns, and processes" (Kitchin & Dodge, 2011, p.67). A more social constructivist approach only arrived "from the 1970s onward", introducing with it the concept of "relational space", relational here implying the role of people and how their "sociospatial relations" led to the development of specific spatial arrangements (Kitchin & Dodge, 2011, p.68). In the last few years, space has emerged as a "process of becoming", in which the emphasis is put on its "multiple functions" and "daily flux of interactions, transactions, and mobilities" (Kitchin & Dodge, 2011, p.68), largely supported by the extension of computational practices throughout urban contexts, but also by the conceptualisation of space through computational tools, especially possible since the 1980s (Gabrys, 2014, pp.30–31).

Michel de Certeau (1988) and Henri Lefebvre (2004) can be positioned, to a certain degree, as aligned within these changes. In both cases, space was presented as lived and performed, socially constrained, where outcomes were at times unexpected and unplanned, and "individuals actualize[d] spatial possibilities, making space exist as well as emerge" (Kitchin & Dodge, 2011, p.70). Certeau (1988, p.29) spoke of entanglement between different areas of life that were often conceptualised as separate, as is the case with "work and leisure". These two areas not only "flow together" but also "repeat and reinforce each other", implying an ongoing entanglement (Certeau, 1988, p.29). Lefebvre achieved this through his "trialectics of spatiality" approach, in invocation of "three different kinds of spaces" – the "*perceived* space", "the *conceived* space" and "the *lived"* space (Soja, 1996, p.10). Following Lefebvre's perspective, these three realms of space can be encountered and engaged with, in each urban context, in a direct reference to the space that unravels as the outcome of a social arrangement, the conceptualisation of that same space and finally, the symbolic realm, where the untold can be encountered (Soja, 1996, pp.66–67). Moreover, Lefebvre (2004, p.6) argues for an approach that departs from the concept to the individual, by emphasising rhythms through their "repetition" and necessarily the "new and unforeseen that introduces itself into the repetitive". In the case of both authors, there is a sense of continuity, of an urban living that cannot be constrained and delimited within narrow definitions. It necessarily needs to imply all other relations enabling a given context, and more precisely, the activities, experiences and intensities that unravel from, within and in relation to it.

Within this context, we can also think of Manuel Castells (2010), who argued, in his much-cited work on informational spaces and networks, that contemporary spatial arrangement is a "space of flows", directly dependent on computational dynamics and infrastructure and their interaction with communication systems. More precisely, this refers to "the material support of simultaneously social practices communicated at a distance" (Castells, 2010, p.xxxii). This space is "not a tangible reality" as its outcome derives from what was "experienced" (Castells, 2010, p.xxxi). Kazys Varnelis (2011, p.200) reads these flows as expressing the complexity of space, as well as areas of restricted access, meaning that this spatial arrangement is "already multidimensional, operating at simultaneous levels that cannot coherently map upon each other", where different nodes of importance structure existing relations.

Other perspectives offer us software-enabled and data-driven spaces as an in-between abstract space, which is a "representational space that exists between a person and a computer", as with mapped locations accessed through digital applications (Kabisch, 2008, p.225). In this case, the static map sustains evolving elements that continuously provide that same location with new characteristics (Kabisch, 2008, p.225), in a very similar approach to early mapping practices within locative media. The services offered through that same digital application inhabit somewhere between the screen and the geographic points to which they are connected to in a map. They materialise criteria established at the level of the "spatial databases", which can either provide a range of services based on location or allow search for specific services based on that same location. In both cases, it can be said that location and its unique geographic point "starts to organize the interaction" (Crang & Graham, 2007, p.795). In a sense, and in this new context, "physical encounters with space are mediated by the differential distribution of computational elements within that space", which can be placed in a static position or have a degree of mobility as in the case of portable and networked devices carried by urban dwellers, such as mobile phones (Dourish & Bell, 2007, p.424). The computational space speaks then of interfaces, maps, digital screens, geographic points, databases, portability and mobility.

All of these computational examples refer, in one way or another, to the context that Kitchin and Dodge (2011, pp.71–72) define as "code/space" – in a direct reference to "software-mediated practices" throughout space, which lead to transformations that take place "through an ongoing set of contingent and relational processes". The continuity and sense of being always in connection with other elements, offered by software and also data practices, is crucial. Nonetheless, as I argue in the following chapter, a perspective solely focused on the spatial outcomes of these arrangements remains limited, as it ignores much of the dynamics established between technical elements, as well as the existing relations with adjacent areas, which are referred to throughout this thesis as context of action. These areas are those that are not directly part of the scope of the algorithm in use within software applications and databases, but with which the algorithm can establish relations of mutual benefit by initially transposing its logic to its context of action.

As McQuire (2008, p.4) explains, "media and communication technologies have the capacity to reconfigure the spatial and temporal parameters of perception and experience". I will go a step further by proposing that computational practices reconfigure and transform what they touch or interact with, but that they also work in a viral manner, spreading their logic to areas not under their responsibility of action. This means that through processes like the softwarisation and datafication of a large array of areas and aspects of urban living, computation allows the position of location to be reinforced within the driving means of globalisation and dynamics that go beyond the scope of what is local (Tazi, 2000), due to this same capacity to extend impact beyond their area of action. Computational processes do not necessarily depend on location to act, being easily transposed to a multitude of territories without facing the limitations of other more material elements and without the need to acknowledge this same spatial transition between distinct territories. However, location can indeed reinforce the position and action of computational practices by assuming a degree of tailoring and adaption to that same context.

In any case, it is important to highlight that the strength of computational processes at local level are sustained by very material structures and expressions, as the conceptualisation of relational locations already proposes. These material structures often sustain, enable and simultaneously rely on unnoticed and unacknowledged local–global dynamics and complex processes of logistics, data exchange and standardisation. Detailed examples can be found in the work of Lisa Parks (2005) on satellites; Paul Edwards (2010) on weather forecasting, climate models and global infrastructure; and finally, Jennifer Gabrys (2011) on the materiality of electronics. In all of these cases, it is shown that computational practices are often supported by an "infrastructural globalism"[42] (in a direct reference to transnational sets of infrastructure), privileging specific interests and

[42] This is a concept only used by Paul N. Edwards, but it can be easily applied to the other two cases. Edwards' proposition (2010, p.23) of "infrastructural globalism" was inspired by a concept previously proposed by Martin Hewson (1999). Hewson's concept, "informational globalism", makes a direct reference, on one hand, to the rise of processes of "informationalism" led by the emergence throughout the centuries of the postal services, news, international expositions and world organisations, and on the other, to the more recent rise of multiple modes of telecommunications services, which have reinforced the "proliferation of transnational control mechanisms" (Hewson, 1999). Edwards (2010, p.8) speaks of the "*climate science as a global knowledge infrastructure*", which includes a vast range of technical and non-technical elements and their arrangements – "a sociotechnical system that collects data, models physical processes, [and] tests theories" (italics in original).

dynamics positioned at a global scale. Furthermore, these three authors show that the characteristics of the material arrangements encountered and making possible each of their contexts of analysis already reveal a storyline of development that is indeed very material.

As Edwards (2010, p.219) explains, in the context of creating an infrastructure to collect global data about weather conditions, only countries with global geopolitical objectives had an interest and priority in setting up such infrastructure, as was the case with the "American, Soviet, British, and French military forces [which] operated weather stations" internationally as a way to strengthen their hypothetical "military operations around the world." As this hints, the enhancement of location often hides more complex geopolitical and economic interests. In most cases, the vision of "the world as a unified, organically evolving cultural, economic, [and] political system" (Parks, 2005, p.2) has been sustained and pushed forward by very particular elements and interests. It is when very locational enhancements and material arrangements are contextualised within a broader perspective that their wider and global supporting material and infrastructural systems start to emerge. As also the analysis of Gabrys (2011) on electronic waste shows, these are not simply material arrangements; they express a logic of geographic displacement and rearrangement, showing how important individual locations (and their global relational dynamics) are in the understanding of technical systems. The material arrangements embedded in locations are expressions of much wider interactions and dynamics.

What I am trying to re-emphasise with this can be read at three different levels. Firstly, a reading of space, urban contexts and spatial dynamics through their sensed continuity and emerging and ongoing relations, as insightful as this can be, is not enough to fully comprehend what takes place within complex urban systems, and more precisely, the impact of the extension of computation throughout urban territories. Secondly, location and what is geographically enhanced become particularly productive when contextualised with their wider relations, both at local and global level, as many local actuations have been originated at distance and within a different context of action. Thirdly, the dynamics of local–global offer a broader and more far-reaching way to deal with the emergence of complex urban systems and their overall impact as is discussed next.

2.2.1. Local–global dynamics

This brings us to the discussion of local and global. It offers the possibility that what is specifically considered as local and global can be better understood if the approach taken leaves scales aside. With this in mind, and in a context where urban spatialities have been often defined in reference to continuity as discussed above, how can the position of location be conceptualised in relation to global dynamics? The infrastructural materiality of complex urban systems already speaks of a tendency towards infrastructural globalism, in the sense that they imply converged and complex systems that work across spatial jurisdictions, often transposing national borders. Therefore, what power have these same systems to "reconfigure the relationship between the local and the global" (Dourish & Bell, 2011, p.111)? It could be argued that the concept of global has become very ubiquitous and transversal, even more within the context of large metropolitan areas, where being global and positioned within global dynamics pervades all types of decision-making processes. This can result in the belief that from a computational perspective only global matters: companies sell their products across multiple countries with little adaptation (Levitt, 1983),[43] cities replicate services and models of management[44] and the key productive indicators of governments throughout the world are compared with those of other governments.[45] In all of these cases, there seems to be a tendency towards the strengthening of infrastructural globalism, making harder to trace these developments to their point of origin, or even to differentiate between what is of local and global character. Instead, I want to propose that the scalar and binary approach to local and global is being replaced by a local–global dynamic as both relational locations and the context of complex urban systems demonstrate. In other words, it appears to me that an emphasis on either level means an unnecessary restriction that is not reflected by the technical arrangement and dynamics of complex urban systems.

[43] The little adaptation refers only to the product – how it is positioned in the market through marketing and branding varies and it is adapted to the local cultural nuances (Ghemawat & Reiche, 2011).
[44] This is visible in the way multinationals such as IBM, Oracle and Microsoft sell their services to cities worldwide, but also through many networks of cities that have been established – one example at the European level is the EUROCITIES network (see http://www.eurocities.eu/).
[45] A well-known example are the reports presented by the Organisation for Economic Co-operation and Development (OECD) with the main economic indicators (MEI), while also providing data to governments on a range of areas that can experience daily updates (see http://www.oecd.org/std/oecdmaineconomicindicatorsmei.htm).

The extension of computation into different aspects of urban contexts has led to a transformation of location similar to that which occurred during the process of dissociation in the early Renaissance. During this period there was the emergence of "rational technologies of dissociation", such as "the printed book, movable painting panels, [and] navigational instruments" (Kwinter, 2008, p.110). These objects opened the door to the physical separation between location of production and location of usage, which meant that the place of production, its markets of distribution and consumption, and all other points of influence were encountered throughout different and often distant geographic points. These "rational technologies of dissociation" can be said to have given origin to "the first 'artificial' cities" (Kwinter, 2008, p.111), if artificial is here understood as implying territories where sites of production and consumption became separate and, at times, even not within the limits of the same territory.[46] The specific use of "dissociation" highlights the move away from a tight spatial–temporal connection, where production and consumption were part of the same chain of events. It implies a spatial division and extension of the field of action of a specific object. This dissociation is so entrenched and taken for granted nowadays that it would not even be considered as such, as is the case with utilities and supporting infrastructures of production, distribution and delivery (McQuire, 2008, p.4; Mitchell, 2003, p.20), but also with goods being produced on the opposite side of the world from where their consumption will take place.

With the extension of computation, there has been a reformulation of location, as that already discussed in relation to and enabled by locative media and other location-bounded and location-oriented technologies. This has allowed different types of locations, in importance and scale, to become part of the same traceable and mappable spatial grid, something that was only offered previously to more important spatial nodes of social, economic and political life. In general, the conceptualisations of local and global have tended to imply "cross-border economic processes-flows", strongly reinforcing a sense of internal and external, as if what sat outside these flows was external to processes of globalisation (Sassen, 2000,

[46] This dissociation also had an impact on the circulation of knowledge as it gave a tool for relevant 'experts' to ensure the circulation of their knowledge, mostly technical knowledge, through controlling the paths of circulation or who had access to it (Johns, 2000).

p.105).[47] However, the extension of computation challenges and forces us to redefine "older hierarchies" sitting within the nation-state. Internally, this refers to cases when too much emphasis is put into one single urban centre, as in the case of London within the United Kingdom. Externally, it implies moments when part of the national sovereignty is handed over to extra-national organisations, as is the case with the European Commission (Sassen, 2011, p.187). This means that computational practices and processes tend to take away barriers and a sense of crossing, in opposition to differentiating between geographic positions and hierarchic roles of importance. Take the example of a small company or a crafts seller, who can actually be a "microenvironment with global span", taking advantage and accelerating more transversal and cross-border relations (Sassen, 2011, p.187), by taking advantage of global selling and on-demand professional services platforms, social media and ways to move around small items without a compulsory stop at customs – or in other words, by reshuffling previous conceptions of local and global as opposed and fully differentiated entities. The positioning of the company or seller says very little about the dynamics in place, expressing instead a context of continuity between the local and the global (Sassen, 2000, p.109), or in certain cases, expressing a disregard by such a dualism. More than a geographic position and ability to move between the local and the global, what differentiates companies and sellers is their ability to attract attention.

What I am trying to propose is the consideration of local and global as part of the same process and flow, leading to a local–global context. Location reinforces in this way its relevance by capitalising on the transversal logic of the network, seeking a visible ground and position of equality within the global map. As the

[47] See list of "conflated binaries" implied by the binary of local and global that Marston *et al.* discussed in *Human geography without scale* (2005, p.421). Some of the examples are: "place/space"; "concrete/abstract"; "static/dynamic"; "authentic/produced"; "embodied/anonymous" and so on. It was in an attempt to move away from the heaviness of the binary concepts of local and global that Sallie Marston *et al*. (2005, p.427) initiated an exchange between a group of human geographers in 2005, where they proposed to discard scale in relation to the binary local–global altogether from Human Geography. Their objective was to discard "the vertical model" and "top-down structural constraints" in favour of a more horizontal approach (Marston et al., 2005, p.427). Relevant in the discussion that unfolded (Collinge, 2006; Escobar, 2007; Hoefle, 2006; Jonas, 2006; Marston et al., 2005; 2007) was the recognition that scalar conceptual frameworks are too constrained by their historical context when it comes to spatial territories. Scalar approaches usually mean separating realities by level, according to their position closer to micro or macro scale, attributing always more importance to macro views (Marston et al., 2005, pp.417–18). What was proposed by the authors instead was "an ontology composed of complex, emergent spatial relations", or a "flat ontology" approach, in direct reference to the work of Gilles Deleuze (Marston et al., 2005, p.427). Moreover, a less scalar approach would allow a shift in the emphasis from the local and the global as sitting on opposed sides of the scale, to emphasise instead what happens in between these positions and which dynamics are privileged within each site.

reference to transnational infrastructural systems already suggests, relational locations are necessarily positioned within the local–global dynamics. The transversal and relational positioning of many complex urban systems further sustains this argument. In this sense, territories of different dimensions and constitution position themselves within what looks like “fluid and contested landscapes, formed and mobilized by networks of integrating realities” (Mörtenböck & Mooshammer, 2008, p.15). Being part of the network becomes the prevalent “form of organization”, where the priority is given to “connections, processes and courses of action that create exchange and link things with one another” (Mörtenböck & Mooshammer, 2008, p.15). The network–logic becomes the prevalent organisational logic within the assemblages of complex urban systems, placed simultaneously and in a transversal manner in the local–global dynamics and flows. This is not a refusal to acknowledge multiple modes of existing disparity, inequality and highly problematic territories, often treated as secondary within the global dynamics. Instead, the objective is to encourage the creation of a critical context that is prepared to deal with the growing and solidifying dynamics of complex urban systems, enabling so many functioning and managerial areas of our urban territories, but with little differentiation between what is local and non-local.[48]

The network-logic embedded within assemblages of complex urban systems, pushing location into a local–global dynamic, does not necessarily imply the conceptualisation of these systems as horizontal with “a flat, nonhierarchical, [and] lateral flow” (Mackenzie, 2010, p.102). The operational context of complex urban systems can be messy, confusing and not entirely self-explanatory (Mackenzie, 2008; 2010; Munster & Lovink, 2005). The network-logic being implied is then close to the network-logic conceptualised by Alexander R. Galloway and Eugene Thacker (2007). This means a network-logic is no longer centralised or decentralised, but working in a distributed manner while simultaneously expressing inner structures of power, which often impose a specific mode of control based on modulation (Galloway & Thacker, 2007). As Galloway and Thacker (2007, p.3) explain, “processes of globalization have mutated from a system of control” through

[48] As the thorough work done by Stephen Graham (2010a; 2010b; 2010c) on the importance and position of urban infrastructure for military tactics tells us, there is no faster and more efficient way to bring an urban territory “to its knees” than by disrupting its infrastructural systems. These systems are the ‘air and blood’ of urban territories; they shape and speak of these same territories in myriad ways.

a few central points of decision-making "to a system of control infused into the material fabric of distributed networks". This transition between modes of control towards modulation is a direct reference to the notion of control proposed by Gilles Deleuze (1992) in his essay "Postscript on Control Societies".

In his much-cited essay, Deleuze (1992) highlights an essential transformation by means of which transition between different sites takes place. More precisely, he proposes (1992) that the disciplinary society of Michel Foucault (1977; 1998) characterised by sites of enclosure has been replaced by a new mode of control that is essentially of modular character. With this, it is meant that the "*analogical*"[49] and unique character of each site, even if they share "a common language", has given away to "a self-deforming cast that will continuously change from one moment to the other" (Deleuze, 1992, p.4), implying a sense of continuity as transitions take place. Furthermore, there is a "numerical language of control" specific to this context, which can be expressed as being able to have access or not (Deleuze, 1992, p.5). This language directly related to code and the numerical can be contextualised as making reference, simultaneously, to "management" and "digital networked technologies" (Hui, 2015a, p.75), which relation has already been highlighted by Beniger (1986).

From this it becomes visible how complex urban systems can be contextualised within these discussions not only in terms of scale and mode of working but also in how transition occurs between different locations brought together by the extension of computation and the different sites of complex urban contexts. Furthermore, and returning to the issue of scale, what emerges is a transition from scale towards a network, from the top-down and centralised discipline to a modular network model. In this context, the prioritisation is given to "the very distribution and dispersal of action throughout the network" (Galloway & Thacker, 2007, p.157), as what has been found is that "digital information networks produce a certain monotonous reduction of networks to systems of control" (Mackenzie, 2010, p.212). As Galloway and Thacker (2007, p.3) state, modulation as a form of control is "infused into the material fabric of distribution", thus implying a logic and a mode of work that often is present from the outset of a network. Overall, this means that modulation and its core numerical quality and

[49] Italics in original.

flexible character make irrelevant scale as transition between sites happens through flows and continuity, even if through differential, hierarchical and tense dynamics.

2.2.2. Relationality as a way of ordering and differentiating

As it has been possible to see so far, relational locations increasingly express a sense of continuity, accompanied by a move towards an understanding of space as in continuous evolvement. This has been supported by the conceptualisation of location beyond the binaries of inside–outside and local–global, positioning it within a context of network-logic, even if these same binaries remain in some cases the prevalent logic. What this means, as will be discussed, is that the sense of spatial continuity has also necessarily its own tensions, while evolving through intentional practices of ordering and differentiating. In a sense, and aligned with control as modulation, it represents the ability to deal with risk and the unplanned through its own probability, thereby giving, increasingly more often, space for a “probabilistic rather than predictive reasoning” (Ruppert, 2012, p.121). The probabilistic speaks of a plastic approach; it tends towards a topological perspective, which in the context of relational locations and complex urban systems means to consider elements through their continuous relations, where shifts within elements do not necessarily signify an end to that same topological arrangement of that given assemblage (Harvey, 2012, p.78). What I am trying to propose is that computation transforms the arrangements found within an assemblage of heterogeneous elements, by taming them to a certain degree of stability and by creating a layer that connects and mediates, resulting then in a topological continuity, even when facing a challenge to its own integrity.

Allow me to reconsider this for a moment from the actor–network theory perspective, more precisely, based on John Law’s (2012) understanding on how networks become formalised within a context of heterogeneous elements. He (2012, p.107) argues that the heterogeneous elements giving form to and sustaining a network are simultaneously shaped by the relations established and a direct outcome of those same interactions between different elements. This means that the network as it is depends on that same arrangement of heterogeneous elements in order to survive, resulting in a challenge to keep that same network together and under control as it scales up (Law, 2012, p.108). In order to remain successful, it requires "vigilance and surveillance" from within the network, as "there is always the danger that the associated entities that constitute a piece of technology will be dissociated in the face of a stronger and hostile system" (Law, 2012, p.110). When challenged, heterogeneous elements attempting to remain stable within a large and complex network face a strong pressure towards separation. Computational practices offer an additional level of stability to these same networks, making easier to adapt and tame differences, to modulate as needed. In this sense, computational practices increase the thresholds and affordances[50] of that same network, or in the case of this research project, of specific assemblages of complex urban systems. In other words, computation has the ability to increase the point at which the system has to react to pressure in order to remain stable (as a result of higher thresholds) and offer wider opportunities and possibilities to perform a certain action (through wider affordances).

What can be taken from this reflection is that computational practices enable continuity through the modulation of the elements involved, by also working through the stabilisation and enhancement of the thresholds and affordances of the different technical elements that are part of complex urban systems. More precisely, what takes place is a process of ordering and differentiation within that same continuity, where similarities are brought together or closer and high differential elements are made more expressive and visible (Lury et al., 2012, p.4), but without the need to be left aside or be made irrelevant. One way that this "ordering of continuity" becomes expressed, visible, and sensed is through "practices of sorting, naming, numbering, comparing, listing, and calculating" (Lury et al., 2012, p.4). The urban context, and in particular, the context of each complex urban system, becomes the territory of the continuous action of tables, reports, structured groups and action–reaction arrangements. The found and sensed continuity contrasts with the "discontinuous world" of the spatial and infrastructural arrangement (Lury et al., 2012, p.4) previous to the extension of computation into these systems.[51]

[50] Affordance is here used in a direct reference to the initial proposal of this concept made by James Gibson (1979) within a natural environment.
[51] The sense of continuity, much like circulation, has also become part of our expectations – we demand continuous battery power, access to the Internet, and flow of traffic and people, and continuous arrival and availability of public transport. What is not aligned with this expected continuity and imposed running of systems stands out; it is seen as faulty, running asynchronous or an external element in need of elimination.

Furthermore, topology refers to "speculative reason or reasonable guesses" – in mathematics, topology "does not start with a space but starts with a problem (an equation) then explores the space in which it has a solution" (Ruppert, 2012, p.121 cited Lury 2009). Topology allows us to think of space in a probabilistic manner (Ruppert, 2012, p.121), meaning that this enables "a new mathematical formalization of the relation between space and time" (Parisi, 2012, p.165). A problem-solving approach speaks of going through, of making things work out. It speaks of an active rather than passive spatial reformulation. This reinforces the notion of relational locations as the spatial outcome of complex urban systems, as computation offers a range of practices that allow, reinforce and stimulate continuity, while at the same time offering ways to solve problems and continuously extend through new or ongoing relations.

Space becomes a field where accentuated differentiations are highlighted and forced to stand out, so their monitoring, tracking and management becomes possible. This should not be misunderstood as incapacity to tailor and adapt different elements to specific needs and locations. For example, geographic enhancement happens within ordering and approximation; its departure point and final objective is always to segment contexts, between what can be brought together and what does not belong there. Data management and data mining is our way to make this possible. This can also be found within the use of parametricism as a way to design and solve urban challenges. Parameterisation comes from data modelling, and it refers to "the integration of observationally derived approximations into the 'model physics'", where different sources of data and theory are made to converge (Edwards, 2010, p.280). It is neither fully empirical or accurate, relying intentionally on grey areas of interaction and inference (Edwards, 2010, p.280). When it is transposed to architecture, a topologic field is designed with the reinforcement of differences by being amplified (Schumacher, 2009, p.16), while simultaneously creating and intensifying the "correlation of multiple urban systems: fabric modulation, street systems, a system of open spaces" (Schumacher, 2009, p.19), creating a sense of continuity simultaneously through ordering and differentiation. In this case, differentiation is welcomed, as it stands out, brings rhythm and intensity, and conveys specific messages. These aspects of spatial dynamics –

continuity through ordering and differentiation – become then transversal both to the experience, management and conceptualisation of urban space.

When it comes to the expression of complex urban systems through relational locations, we can think on the role played by mobile phones as daily interfaces and elements of these same contexts. On a recent trip,[52] when I was returning to Barcelona on an evening with heavy traffic, the mobile phone replaced both the hourly traffic feed of the radio station and the usual digital traffic information road screens (placed every kilometre), which lacked relevant information. In that context, the mobile phone offered the immediate point of information, as one would probably expect, but it also made visible wider spatial dynamics unfolding within that same context. In a quickly established assemblage by the mobile phones of drivers during that evening, Google's traffic feature, available in the Google Maps mobile phone application,[53] was able to provide real-time updates on the traffic conditions. Each mobile phone, belonging to a specific spatial point, and in relational and contextual interaction with all other mobile devices, acted as a mood stabiliser. It allowed preparation among the drivers, as well as managing their expectations about what lay ahead (in terms of traffic conditions, trip length, speed, safety and so on). Mobile devices worked as the sender and receptor; they were a vital part of the field of action expressing a topological behaviour that went beyond a process of data exchange. The intensity of the unravelling event found in each mobile phone a folding moment, in which each of the devices was brought into the same field of action, while simultaneously feeding into that same event.

The mobile phones were, in this case, portable and networked elements of the complex urban system sustaining the mobility within that same road approaching the city. This context of action, sustained by a similar assemblage to that which is discussed in Chapter 4, our first case study, was composed of the standard road infrastructural system, but also of GPS sensors and satellites, Google mobile application and its data server. These last elements played simultaneously the role of

[52] This refers to an event that took place on the 12th of November 2015, a Spanish bank holiday.

[53] When the GPS on the mobile phones is activated and the information about location is set to be shared, Google receives "anonymous bits of data" that allow the creation of real-time intelligence about traffic conditions (Barth, 2009), to which it adds historical data, open data available from governments on transport and traffic information and, finally, data provided by Waze's users (crowdsourcing traffic mobile application bought by Google back in 2013) (Etherington, 2015).

what sits at the periphery gathering data and at the centre leading the potential outcome, in a continuous and evolving manner by the action and interaction of mobile phones. As Bratton (2009, p.93) explains about the role of mobile phones in the computational city, they were in this case "a meta-interface, one comprised of many smaller tactical interfaces". Each mobile phone, a mobile spatial reference point, was one of the infrastructural elements involved in the arrangement of a relational location, contributing and expressing the intensity of a field of action, while continuing to hold its capacity to coordinate operations, multiple co-existing temporalities and fields of action. The ordering of continuity that this described complex urban system was putting into action that evening is one where computation was behind "decision-making", populating continuously that same context "with information" (Crang & Graham, 2007, p.792). The "*dynamically* changing information" fed real-time overtook the pace of delayed decision-making and information systems placed throughout the road (Crang & Graham, 2007, p.793). As I moved ahead, information was continuously updated on my mobile phone screen, based on my new spatial position and also in relation to all of the other elements of that complex urban system. My mobile phone was providing real-time information about my geographic position, how much I had moved in the last minute. It was also being fed relational real-time information, expressing the field of action where it was positioned in that same instant, unfolding continuously as I moved forward. In that instance, it was not about passive tracking or data generation. The mobile phone was part of a much larger complex urban system put into action within that specific context. This on-demand infrastructural response, as demonstrated in the second case study, is increasingly becoming more common.

Once again, the mobile phone demonstrates the connection between relational locations and the implementation and extension of computation across urban territories (Thrift, 2004), leading to a context of flexible and plastic interfaces away from icons, images and screens (Bratton, 2009). Through mobile applications, live feeds, machine-to-machine engagement and active objects, the urban context of complex infrastructural systems and portable and networked devices creates a distributed system, like what Bratton (2009, p.94) calls a context of "interaction-in-the-wild". Spatial interaction takes place in a context where the beginning and end of engagement, or even the field of action, are not clearly defined, both in time and spatial terms. In the case of the live traffic information, it could be said to be a continuous and evolving context of engagement, where the sense of continuity prevails over any moments of discontinuity. When the evening arrives and traffic is reduced significantly, the quality of the data may be lower, aligned with a lower density and flow of information. Nonetheless, the possible discontinuity of traffic information would be, most likely in that case, of total irrelevance. Who would check traffic information on a road with no traffic and in the middle of the night? The sense of continuity always prevails, as the system is designed to react specifically in those moments when it is needed.[54]

As can be concluded, I am proposing a type of continuity that implies a sense of smooth continuity, even when this is not in place – in part made possible by the designing of a distributed system that is expected to react when certain levels of action emerge. Furthermore, what stands out of these last paragraphs is that the continuity being made reference to is not simply a senseless flow. It is the outcome of intentional modulation, and at times constrained continuity, that presents very plastic qualities – it ensures stabilisation through ordering and differentiation by enhancing and reinforcing its own thresholds and affordances. Computation is key for this dynamic and, consequently, for the possibility of infrastructural systems to extend and connect. This continuity through ordering and differentiation also reinforces the enhancement of location and the visibility that it can gain within the overall system, and also in relation to the other related locations. More precisely, as I propose in the following section, computation makes this possible by working intensively through add-ons and secondary aspects of infrastructure, which allow its slow approximation to the core of the system, while segmenting, tailoring and enhancing specific qualities of each location and overall context of action.

2.3. Infrastructural systems

As has been shown so far, infrastructure is a key element in the consideration of the extension of computation throughout urban contexts. This section focus on the infrastructural dynamics and its expressions of materiality, in order to demonstrate

[54] One possible way to think about the practices of continuity and discontinuity would be to look at the times when software systems tend to be updated and the challenges found for those working at a global scale in a context of 24-hour demand.

how interactions and relations of mutual dependency and feedback, established between infrastructural material elements and computational processes are increasingly more important for the understanding of urban contexts. More precisely, the objective is to establish the context of analysis for the following chapter, by revising the positioning and meaning of infrastructure within the emerging and already discussed computational dynamics. By keeping infrastructure at the centre of our current analysis, it is possible to gain a better understanding of the relationships of proximity between infrastructure and spatial dynamics. This is achieved by considering the capacity of infrastructure to recede into the background and away from visibility (Bowker & Star, 2000; Sims, 2010; Weiser, 1993), the role of infrastructure as the 'backbone' structure of urban territories (Graham, 2010b) and finally, the infrastructural processes resulting from the introduction of computational processes with an emphasis on processes of communication and mobility (Amin & Thrift, 2002; Crang & Graham, 2007; Kitchin & Dodge, 2011).

Infrastructure embodies, through its materiality, dynamics that often go beyond its context of usage – it speaks of pressures, different coexisting rhythms and intensities. An inquiry targeting a specific set of infrastructure leads to "uncovering the unspoken conventions of everyday practice" and "unpacking the implicit relationships" among a range of actors that will vary in number and type according to the chosen perspective (Dourish & Bell, 2007, p.416). Infrastructure, in general, says more about its materiality and context than what is made visible. The overall outcome of an infrastructural analysis tends to be more than the sum of its visible elements. Due to its own characteristics, infrastructure is often "taken for granted" (Dourish & Bell, 2011, p.96), inhabiting its territories "in a naturalized background, as ordinary and unremarkable as trees, daylight, and dirt" (Edwards, 2010, p.8). As Geoffrey C. Bowker and Susan L. Star (2000, p.33) state: "Good, usable systems disappear almost by definition. The easier they are to use, the harder they are to see."[55] Within urban territories, infrastructure is usually the outcome of multiple networked and connected systems, even more so than the traditional conceptualisation of infrastructure of heavy systems "such as railroads, electric power grids, highways, and telephone systems", which were thought from their

[55] A similar statement is usually made about computation: "computers are most powerful when least noticed; and they are least noticed when most empowering" (Winthrop-Young, 2010, p.187).

outset as carriers for "flows of goods, energy, information, communication, money, and so on" (Edwards, 2010, p.9).[56] Traditional sets of infrastructure – "roads, lighting, pipes, paper, screws" – have then become slowly complemented, mixed and incorporated with what can be defined as a "second wave" of infrastructure – "cables, formulae, wireless signals, screens, software, artificial fibres" (Thrift, 2008, p.91). With these new elements, while the core functioning recedes into the background, digital interfaces, sensing environments and responsive objects that interact directly with the city and its dwellers have the potential to become or be made more visible (Böhlen & Frei, 2010).

Technically, urban infrastructure can be easily divided into core and secondary sets of technical elements, or into 'backbone' and 'add-ons'.[57] Core refers to the essential infrastructure that can be found more or less in every single functional urban territory, usually increasingly less visible as one gets closer to the centre of an urban territory. If the suburbs of a major urban territory display openly its industrial park, power station, airport, park & ride network, ring roads, train tracks, port and piled up containers, the same cannot be said about city centres. Not only do heavy and large infrastructures tend to be positioned within the suburbs, when present within the centre of urban cacophony, these infrastructures tend to go hidden underground, become disguised within the density of buildings and better integrated through the beautification of its outdoors interfaces. This means that backbone infrastructure and add-ons are conceptually distinct, both due to their scale and overall strategic level for their context of action. Core and secondary infrastructures have then differentiated spatial dynamics and distinct levels of capacity and speed to adapt to their own context and ongoing changes. It is within the secondary, or add-on services, that flexibility, tailoring and geographic

[56] All of these traditionally considered heavy infrastructural systems have already been radically rearranged and challenged by the extension of computation.

[57] The division of infrastructure between what is core (or backbone) and secondary (or add-on) elements is visible in how the market around infrastructure is divided. The backbone is usually seen as strategic for the functioning of a territory – engineering consultancies propose to design this level of infrastructure from scratch, ensuring in this way, fully tailoring to the context and ownership by governments. The investment and government ownership of the backbone infrastructure is also seen as an issue of national defence. All the add-ons make reference to additional services – such as the rubbish collection, or management of traffic and parking across the city, which can be easily outsourced to an external provider or allocated to a range of providers in a context where they will compete for a larger market share of the service. It is within this part of infrastructure where the use of computational processes is made more visible, but also where larger transformations have happened in the way these services are offered. The ownership of core infrastructure has also gained a new level of complexity with the increased liberalisation of the infrastructure market, with more and more public–private partnerships and privatisation processes coming into place.

enhancement can be mostly found. Add-on and secondary implies something that can be added at a later stage, which will have less impact on the overall system and which can afford higher levels of dynamics. The importance of this differentiation becomes more visible as we move forward in the thesis, mostly due to the fact that the extension of computation and the mode in which it takes place is largely influenced by the infrastructural difference.

Aside from this there has been a transformation within the roles mostly played by infrastructure. Supported by the change in nature of infrastructural systems, from the first wave towards the second wave, these systems have seen a transition from being carriers and connectors to becoming mostly mediators, managers and controllers, bridging the act of production and usage, with the exercise of management, forecasting and real-time adaptation (Greenfield, 2006, p.1; Graham, 2010a, p.263). What emerges is a site of control – of modular control (Galloway & Thacker, 2007) – as is discussed in more detail later in this thesis. In this way, the introduction and implementation of computational processes have had a lasting impact on modes of mobility, as well as on how knowledge is formalised and actualised within these same contexts (Castells et al., 2007; Graham & Marvin, 2001). Infrastructure, on one level, the framework underlying and supporting urban systems (Ascher, 2005, p.2; Varnelis, 2009), and now, on the other, a contemporary instantiation of computational expression, has moved away from being a symbol of stability with direct reference to the cartographic distribution of the city.[58]

Overall, all of these transformations have set the context for the privatisation of many areas of infrastructure and its commoditisation. The existing multiple levels of public and private infrastructures, and often an array of small providers competing for the add-on services, can be defined as a context of splintered infrastructure (Graham & Marvin, 2001). This commoditisation process (and splintering of infrastructure) becomes easier to understand through the analysis of the delivery of its services. By turning infrastructural systems into modular

[58] Stability refers here to a low level of change. For example, for the Romans, the organisation of their cities was key, as it was seen as a functional part of a wider network (the Empire), which for that reason demanded "efficient communication and exchange with other cities" (Andraos et al., 2000, p.11). Roman buildings were in part designed from the inside towards the outside, thus respecting their functions and requisites for their full flow and functionality (MacDonald, 1986, p.251), becoming then integrated into the wider network formed by the Empire. The spatial envisioning of Le Corbusier was also of high pragmatism and structure in order to ensure a fully functional environment (Carter et al., 2011, p.3).

structures,[59] it becomes possible to separate what is provided to the user into core and add-on services.[60] In the same way that the infrastructure is divided into core and secondary structures, the user is presented with a range of solutions not only tailored to his location but also open to further segmentation.[61] Similar to the logic in place within the development of infrastructure, what the user encounters is a two-tier system divided into core services, most likely offered as compulsory and areas protected during the privatisation of a previously public system, and add-ons, targeting higher-income users living in profitable areas (Graham & Marvin, 2001).[62] In this way, the user is offered different levels of service, distinct experiences and differential capacity to access the same set of services (Kane & Miller, 2009).[63]

Once infrastructure is privatised or becomes managed by the private sector, new services emerge (newly commoditised aspects of the basic service) and are slowly brought into use. The services being delivered by urban infrastructure are, as a result, used to divide and reinforce social inequality, and make distinction of neighbourhoods based on disposable income and type of property ownership, entering a vicious circle by becoming the basis for future decisions on investment strategies. Even if working separately, multiple grids of infrastructure, owned by distinct providers, end up creating a spatial infrastructural organisation that looks very homogeneous. Low-income families and migrant groups get stuck into pay-as-you-go systems, overcrowded and under-developed systems with basic requirements for service provision (Graham & Marvin, 2001).[64] In contrast, in contexts considered of major economic and strategic importance, a safety net for infrastructure is created

[59] The issue of modularity is discussed in more detail in the following chapter.
[60] This is often also referred to as 'must haves' or freemium and 'would be nice to have' or premium services.
[61] Market segmentation is actually a term used within marketing that refers to this exact process – the increased division of groups into smaller and "homogeneous" groups arranged around common tags and then targeted in an individual group, aiming at "the concentration of marketing energy and force on subdividing to gain a competitive advantage within the segment" (Goyat, 2011, p.45).
[62] The current economic situation in Southern Europe could provide immense material regarding this topic – the costs of basic services that have risen massively in preparation to make national infrastructural systems ready for privatisation, or the way users have been forced to move from government-owned companies into the private sector once the market is liberalised (Zacune, 2013).
[63] As Stephen Graham (2010a, p.4) explains, "market relationships" have been enforced throughout urban infrastructure, meaning that "public assets (whether utilities or public spaces)" are privatised and run within a "market-based" commercial framework.
[64] One common way to ensure service differentiation is through customer service. Cheaper services have premium (paid) phone lines to deal with customer issues, or have fewer available agents and stricter operating times to deal with inquiries, which leads to longer waiting times.

– an over-investment on infrastructure (in particular, Internet provision) in order to guarantee parallel alternatives in case of failure – resulting in redundant systems.[65]

The elements discussed in these last paragraphs are of major importance. They start speaking of a transversal logic that has radically changed infrastructure, but that has also moved it further away from its role as a carrier. The modular logic that goes from the blueprint of the infrastructure (divided into backbone and add-ons) to the splintering of services being provided and typologies of providers competing for the same territory speaks of a capacity to adapt, but more importantly, to continuously tailor to a specific location. As the mention of the second wave of infrastructure already hints, directly implicated with the radical transformation of infrastructure is the expansion of computational practices throughout its material and nonmaterial elements. As Keller Easterling (2011, p.154) writes, infrastructure is often today "the urban formula, the very parameters of global urbanism"; becoming infrastructure is this way another expression of "the historical entanglements of modern states with calculative practice" (Harvey, 2012, p.78), now transversal to its own habitat. The informatisation of space afforded by computational practices have reinforced the geographic enhancement by means of contextual segmentation and splintering into different sections, within a context of continuity.

Nonetheless, the question of location still is unanswered – how can location be defined when so many constraining and defining elements come into play? In this context, as described above, location has a different composition according to its position or even based on the perspective from which it is approached and what relations are made visible or secondary. Location becomes necessarily a different entity in each of its geographic points due to the multiplicity of its contextual settings. This means that location is always multiple from its outset, due not only to its geographic placing but also to its original infrastructural condition. Once the computational layer is brought into it, a range of new challenges emerge – it is about splintering and segmentation, as much as about evolvement based on ongoing and changing relations with other locations and infrastructural elements. As the effect of

[65] The initiative 100 Resilient Cities powered by the Rockefeller Foundation supports 100 cities around the world in building their resilience strategy. One of the objectives of this initiative is to raise awareness within local governments of the importance of redundancy in urban systems. Not only does redundancy allow the building of safeguards for when the system is under pressure but also disasters in cities emphasise the danger of having certain groups of the local population covered only by marginalised infrastructure. For more details about initiative, please see: http://www.100resilientcities.org/.

computation extends its scope and positioning within a set of infrastructure, moving from the fringes and add-ons towards the core of the infrastructure, it gains a plastic capability that becomes necessarily reflected in location. The relation with its context of action is necessarily transformed. Nonetheless, this becomes more visible if we focus in more detail on what it means to be a 'codified' and 'computational' infrastructure.

2.3.1. Coded infrastructures

It is in this context that we can discuss coded infrastructures, as referring to infrastructural systems, crossed by code, populated with digital objects and run by computational processes. Not only are coded infrastructures at the centre of complex urban systems, it is at this level that computational processes become more predominant and visible, as do processes of infrastructural segmentation, splintering and redundancy. "Coded infrastructures" is a concept borrowed from Kitchin and Dodge (2005; 2011) and its use here draws on their work. Following their understanding (Dodge & Kitchin, 2005; Kitchin & Dodge, 2011, p.6), "coded infrastructures" implies contexts that are formed by material and nonmaterial computational elements and that require a degree of programming in order to function – they are "networks that link coded objects together and infrastructures that are monitored and regulated, fully or in part, by software". These types of infrastructures are populated with "coded processes", often leading into supporting "coded assemblages", larger sets of distinct infrastructures finally working together (Kitchin & Dodge, 2011, pp.6–7). In the context of this thesis, coded infrastructures refer to complex urban systems, necessarily permeated by computational processes. As already stated, and as part of contemporary urban territories, coded infrastructures have the ability to sense, adapt and infer. They have the capacity to be in tune with their environment, adapt to it according to a set of pre-established conditions and open up new areas of management. In a context of distributed computational capacity, coded infrastructures embody a continuous search for equilibrium and better management, pushed forward by sensors, data collection, software and an alignment and convergence between the different urban systems in place.

Coded infrastructures, conditioning, supporting and defining relational locations, can also be contextualised within the work developed on "sentient cities"[66] (Crang & Graham, 2007; Shepard, 2011b), ubiquitous computing (Ekman, 2011; Greenfield, 2006) and software and its spatial practices (Dodge & Kitchin, 2005; Kitchin & Dodge, 2011). What tends to be highlighted in all of these is the dynamics between making visible and invisible, which can be interpreted as a strategy to be made accountable or remain in the background; practices of spatial reformulation impelled by software, be it through processes of inclusion and exclusion or intentional differentiation; and the need to make users implicated in the definition and constitution of their own territorial spatialities. Stephen Graham (2004b) defines some of these environments as "software-sorted geographies", in particular those that emphasise social sorting, highlighting the impact of software in feeding "invisible processes of prioritisation and marginalisation" that, as mentioned, are not always clear and visible to the end-user. Graham again, together with Mike Crang (2007), describes as "sentient" these networked environments – a space that 'feels' through data collection, has memory when it recombines and crosses different datasets or that is impregnated by small and often unnoticed ubiquitous computing devices. Kitchin and Dodge (2011, pp.16–17) use the concept "code/space" to refer to the moment software and space "become mutually constituted, that is, produced through one another". In this case, software formalises and constrains a type of space that can only take place through its working: a space that becomes defined by software and as it works away.

This is particularly the case with ubiquitous computing.[67] As it moved towards the outside, computation became increasingly distributed (Weiser, 1993). Its distributed structures, defining and sustaining daily urban activity, entail a connecting capacity between all types of objects (Greenfield, 2006, p.11). It is due to the conjugation of affordable ubiquitous computing (increase in computing power combined with cheaper and smaller chips) with a tendency towards integration and

[66] Mark Shepard collects a series of essays on the *Sentient City* (2011) that approach what sentient might mean within the context of ubiquitous computing, sensors, digital systems, data processes and dynamic urban environments.

[67] Ubiquitous computing was described by Mark Weiser (1993, p.75) as reinforcing the power of computation by creating a distributed system of "many computers available throughout the physical environment, while making them effectively invisible to the user." This would mean that instead of being at the centre of the attention of the user, distributed and ubiquitous computational devices would become an enabler of specific events and contextual settings.

intercommunication of different levels of infrastructure that has led to what Adam Greenfield (2006, p.18) describes as "information processing embedded in the objects and surfaces of everyday life".[68] Ubiquitous environments, often interacted with through a variety of digital devices and screens, have come to mediate between infrastructure and different aspects of contemporary life, both digital and non-digital. In Ulrik Ekman's (2011, p.12) reading of Mark Weiser's "calm" computing, the calmness referred to is taken in a broader way than a strict serenity applied to all "computing and interaction". From his perspective, ubiquitous computing could be seen as implying "a varied and dynamic engagement with human economies at attention, oscillating between center and periphery" (Ekman, 2011, p.12). This reading proposes a ubiquity that can be more conflictive, challenging and even present, not necessarily going unnoticed. Nonetheless, ubiquity tends to be taken as allowing "an infrastructural disappearance, a form of easy habituation and invisibility in use that follows from casual familiarity" (Dourish & Bell, 2011, p.95). Ubiquity, when expressed through expectable outcomes, becomes, in most cases, taken for granted.

Overall, it can be said that urban territories are slowly but increasingly presenting infrastructural assemblages of computational machines, working under the logic of bringing together and shared capacity (Dourish & Bell, 2007, pp.414–415), privileging the ability for interaction – exchange and development of information and analysis of data in opposition to working in separation. They come across as often offering standardised and accountable contexts. With probably an overly optimistic perspective, Nigel Thrift and Shaun French (2002, p.309) speak of visions of integrated territories, enabled and offered by computational distributed systems, "sink[ing] into [their] taken-for-granted background", while also creating the conditions for "the automatic production of space".[69] The distributed computational machine, acting upon the world, brings the phantom of automation,

[68] For more detailed information on this, see also Ulrik Ekman (2011, p.5).
[69] Amin and Thrift (2002, p.81) describe a context like this as the "antecedent to the sustained work of revealing, the city minute on minute, [and] hour on hour". Revealing in this context refers to the act of bringing into visibility what was not available before. It talks about a transition, going from one state to the other, that is made possible by the working of the computational machine. However, even in this context of revealing, it is important to highlight that this does not necessarily imply openness or access to information – there is a transition in the state of the context, but not necessarily into a state that benefits all those involved in these same contexts or that guarantees improved accessibility. The combination of data, information and references to distinct aspects of what is related to a specific location does not necessarily imply more openness, even if the existence of vast amounts of new information may lead to that conclusion. Datafication does not need to be an equalitarian or democratic process.

offering a context "saturated with computational capacities" and "active environments" where communication is fluid and apparently intentional (Thrift & French, 2002, p.315). Even if many complex urban systems are often experienced like this, the events from the winter of 2010 described in the first pages of this thesis, demonstrate that exceptions always arise and take place, and that existing dynamics can be messy. Nonetheless, the discourses on equilibrium, coming out of this context, reinforce processes of urban management enabled by "*machinic* environment[s] orientated to the efficient use"[70] (Kwinter, 2008, pp.114–115). These have a direct impact on the way decisions are made and models of urban governance designed. The role of ubiquity (and remaining and receding into the background) should not be taken lightly in the context of prescribed equilibrium and continuity. Software in action is frequently only slightly expressed and felt in real-time across its urban territory of action, hiding its activities away within "the transactions and flows" of data (Kitchin & Dodge, 2011, p.6). The action and reaction of software and other computational processes[71] are often separated in time and space, taking place in disparity or parallel to each other, but often without a clear relation to each other. The continuous and repetitive activity of computational systems, with action and reaction happening separately, results in the experience of increasingly machine-defined environments as fuzzy, as separation and differentiation between activities is most likely hard to make, as our first case study demonstrates.

This refers to processes of calculation, adaptation and default systems, where "structures of repetition" predominate (Thrift, 2008, p.90), with tasks being repeated time and time again. Once computation is introduced to a system, its future development becomes tied to the intensification of its impact and increase of scope; it is inserted into a specific mode of action and logic of management, where the grid of operation is in continuous expansion and finer granularity. This finer granularity supports, through the actions of recording and storing, the building of profiles and the rearrangement of collected information into new modes of knowledge (Shepard, 2011b, p.31). It also shapes behaviours, actions to take and rhythms of life. It spreads a logic where the efficient machine punishes users for not fulfilling default behaviours, automatically emits fines and reminds us that it is never at rest. It

[70] Italics in original.
[71] Mark Shepard describes how software has been developed to go beyond the expected "action-reaction responses" (Shepard, 2011b, p.31) of manual tools.

becomes present across the urban territory, regardless of its origin within the private or public sector, commercial or non-commercial, with total disregard for the previous dynamics in place or spatial boundaries or action (Leong, 2000, p.191). The computational logic expressed in the arrangement of territories, living and working environments, with the capacity for multiple and variable combinations and the establishment of unexpected relations, becomes interconnected to other systems that "generate their own spatialization and arrangement of information" like "timetables, databases and maps" (Fuller, 2011, p.177). Complex urban systems, through coded infrastructures and computation, are then developing their own spatialities, unique to their own way of working.

This is trying to highlight that once computational processes enter infrastructural environments, it becomes difficult to step away from management, overview, control language and perception of that specific environment. What becomes highlighted is the ability of computation to act upon something. The operational control needs and consequently offers a high degree of plasticity in order to adapt and increase its scope. It needs to adapt to new forms of interaction between the actors in place within the territory. Control, more than through actions, is felt in the capacity to adapt, in an evolving continuity, through its modulation. At the same time, for every element that comes under the grid of operation of complex urban systems, another is considered not relevant or essential – it reinforces some realities while relegating others to the fringes (Leong, 2000, p.187). Overall, as already stated, the impact of this goes beyond a delimited territory of action: it informs decision-making systems (Crang & Graham, 2007, p.792) that are not always technical, such as social relations and health-measuring contexts, and it conceals specific memory structures and knowledge about places (Crang & Graham, 2007, p.812) that have long-term impact beyond its period and site of action–reaction. The extensive use of software, automated systems and digital interfaces within urban territories facilitates modes of doing that often remain in the background (Khan et al., 2007, p.4; Arthur, 2011). These tend to be only brought forward for brief instants through the surface of the screen or the interface as a reminder of "a more powerful command line" (Varnelis, 2009, p.126). Processes of softwarisation and datafication within ubiquitous environments can be seen as an additional layer that is "vast, silent, connected, unseen and autonomous" in the majority of its operations, increasingly behaving like it is “self-configuring”, “self-organizing”, “self-architecting”, and “self-healing” (Arthur, 2011).

Coded infrastructures are then as much about software as about data. They imply specific logics, modes of working and acting within spatial environments tied to computational practices. These infrastructures show that complex urban systems can be highly programmed and in tune with their context of action – through a distributed, ubiquitous and sensing capability. As the established relations between infrastructure and computation develop their own ways of working and spatialities, the locations placed within their context of action also gain new computational abilities, crystallised in datasets, reinforced by software applications and reshuffled as computation increasingly acts closer to the core of the infrastructure.

2.4. Software and data within urban contexts

As the discussion on coded infrastructures shows, infrastructure is where software and hardware come together and become entangled and dependent on each other (Fuller & Haque, 2008). Computational practices, as already established, have continuously extended their areas of scope and action and consequently transformed many aspects of urban territories. Their action, working logic, practices and particular characteristics, as those already discussed in relation to continuity through ordering and differentiation within space, have brought a new operational logic to urban territories. They have established a new spatial grid of action, but more importantly, there has been an acceleration and intensification of the existing engagements and interactions among the different technical elements, regardless of their material or immaterial condition. The implementation and extended use of computational practices have resulted in the increase of technical variables being considered across urban territories, a sense of continuity and ongoing evolvement. They have also led to the creation of relations between elements and systems that were previously separate and distinct in their way of working and acting upon their contexts.

Computational processes have then changed how knowledge is formalised, validated and further extended, allowing computation to enter the realm of management and governance of systems as it is discussed in more detail in the following chapter from the perspective of standardisation and risk management. Knowledge has in many cases been translated into computer-readable information (in order to become actionable), to then be re-structured based on collected data, enabled by the activities of data collection and mining, simulation models, forecasts and planning (Bureau d'études, 2003). This continuous feeding into each other – from knowledge to information and back to knowledge again – should be looked at from the perspective of urban management. Understood as an exercise and expression of governance, which can be traced through aspects like the management of air quality, this feedback loop between knowledge and information and then knowledge again, looks into the future (but also the past) as a way to manage the now. This is done through a probabilistic and pre-emptive approach towards the potential and the possible. It speaks of a balancing-out between small- and large-scale elements "by way of laws, formulas and norms that determine its productivity, means, and possible destinies" (Bureau d'études, 2003), where the dynamics between the past and the future help to formulate what takes place in the present.

It is through the capacity of computation to reorganise and move between large and small elements, what has happened and what will probably and potentially take place in the near future that new connections are made and new areas of urbanity brought into accountability. This accountability speaks of the possibility of bringing into the scope of management new areas like those that are less tangible and harder to pin down. Once under the grid of governance, accountability becomes part of risk and liability, working in both directions. This is similar to the network arrangement of the local–global dynamics found throughout complex urban systems, and also to the modulation mode of control that can be inferred from the dynamics and structures encountered and which have been discussed so far. This context is visible in our two case studies, as well as in the way local governments approach and manage pollution, traffic, pedestrian flows and noise – all elements that circulate, mutate and evolve, in continuous change according to the hour of the day or month of the year. All of these elements are difficult to contain within their own channels of circulation. They require elaborated approaches to become an object of management or even tangible to the systems discussed; they require an overview perspective that goes beyond what can be seen.

Computation needs then to be further contextualised and thought of within complex urban systems by taking into account its position as part of infrastructural systems running and managing key functional aspects of urban territories. Computational processes enable and reinforce a specific way of organising and separating, where calculative and continuous command and control functions enforce and normalise actions upon those contexts through modulation. What can be found is a "quantitative calculation" that varies in scale and complexity, which can range "from the very simplest operations like listing and numbering and counting through to various kinds of analytical and transformative operations" (Thrift, 2008, p.90). These processes transform the capabilities of until recently almost dumb infrastructural systems, overlay territories with a spatial grid through which they act upon, and finally track and tag those same activities. Through more or less autonomous systems, they have a degree of autonomy directly proportional to that attributed to the code sustaining the system, the level of input and output afforded by its coding and the ability to function to a certain degree "without direct human oversight or authorization" (Dodge & Kitchin, 2005, p.170). Autonomy of the system implies how sophisticated is the processing in "its environment and memory of past events" and "the range of outputs code can produce" (Dodge & Kitchin, 2005, p.170). For example, software is contextualised by how code is "read and by whom or what, that is, by person or machine" (Mackenzie, 2006, p.6) and by how it acts, what decisions are prioritised and what is ignored or left aside (Thrift, 2004, p.585). Concluding, the intrinsic logic of computation is connected to "calculation" (Thrift, 2004, p.590) and mathematical modes of problem-solving.

The mentioned calculation reinforces its position as working towards "qualculation" (Thrift, 2004, p.583), especially within urban contexts. This concept implies a process-based way of working that is directly connected "with number, counting, logic, and consequent forms of spatial and temporal configuration" and the outcome rearrangements of these interactions, transforming and often overriding previous logics of work and engagement (Thrift, 2004, p.586). Qualculation goes beyond the number as it contains a high degree of "judgement", "effort" and intentionality, while aiming at a specific outcome (Callon & Law, 2003, pp.3–4). It emerges, in the context of our discussion, at the convergence of different computational processes and their supporting contextual infrastructures, giving rise to new knowledge, interactions and qualities within their environments of confluence (Thrift, 2004, p.593). It can be said, for this reason, qualculation to be "mutually constitutive" through the actions of "calculation and non-calculation", implying that what emerges out of a qualculative unfolding can vary widely (Callon & Law, 2003, p.2).

It is this capability to conjunctively coordinate what is of qualitative and quantitative character that makes the extension of computation, often enabled by processes of softwarisation and datafication, throughout urban territories, so relevant as the way of working of theses processes is never entirely and simply a production or task-oriented outcome. It implies a new logic of acting, elaborate approaches to deal with elements that not only were previously not considered objects of urban management but also escape attempts to be contained within narrow channels. It can be said that I have spoken, so far, of mostly generic traits that computation brings with its ways of working and acting upon a context and within complex urban systems. I have covered the relations unravelling throughout urban territories from the perspective of space and infrastructure, as well as the impact of computation on these two aspects. What remains is to extend what has been mostly concerned with the impacts of the action of computational processes and more precisely, of software and data, by considering specifically some of their main traits when it comes to urban contexts. More needs to be said about their implications separately in relation to space and complex urban systems. This becomes of even more relevance when we consider the role played by computation and its processes in transforming infrastructure from a carrier to a site where new knowledge emerges and acts of judgement and intentionality can take place, taking complex urban systems immediately to a new position within urban territories.

2.4.1. The softwarisation of urban space

According to the position or perspective chosen on software, it is possible to find different approaches to and descriptions of what it is. In the case of this body of work, the proposed understanding of software is borrowed from Software Studies, and it sits between a cultural expression and its appearing role as a simple instrument within infrastructural systems (Fuller, 2003; 2007; 2008; Kitchin &

Dodge, 2011; Mackenzie, 2006; Manovich, 2013). Within urban contexts, software can come across as a mutable element, inhabiting the in-between, connecting and disconnecting, materialising through the way of working of the technical machine and functioning of infrastructure (Thrift & French, 2002, p.311; Mackenzie, 2006). Nonetheless, it can also be said that software is highly contextual as it depends on its own context of action to extend its existence as has already been discussed. If left without being updated, software will, in many cases, slowly fall into disuse and lose its applicability, due to its growing obsolete contextualisation. Software needs to be in constant adaptation to its surroundings and all existing relations, through "the constant arrival of new versions, updates and patches" (Mackenzie, 2006, p.12) and also through the action of a tech team reporting bugs, resolving incongruences and adapting to the changing needs of that same context. When it comes to the contemporary urban context of software, as complex urban systems demonstrate, it is already intensely softwarised and highly dependent on software, working as "the invisible glue that ties it all together", imposing simultaneously its own language of command and control and dependency on data (Manovich, 2013, p.8), largely contributing to modular forms of control.

Software working through urban contexts embodies this duality – dependent on its context in order to sustain its actualisations and relevance, yet also deeply constraining with its logic of command and control.[72] For this reason, even when approached from an instrumental perspective, software should not be taken as "neutral" or an isolated tool (Fuller, 2003, p.3). Its conditions of deployment, development language and interaction with other contextualised elements are always deeply entangled and mutually formalised. They speak of working processes, hierarchies, tensions, constraints and unique qualities of the chosen algorithm and programming language (Fuller & Goffey, 2012b). Furthermore, software needs to be understood as a commodity in many of its instantiations and contexts of development (Fuller, 2008, p.3), and how often its tailoring to a specific context is

[72] The logic of control can be traced down to the level of the algorithm – this is the level where computing becomes actionable and the "syntax [of the algorithm] embodies a command structure to enable this to happen" (Goffey, 2008, p.17). The algorithm embodies a pragmatic vision of the scope of action of software as its own construction is already "a precisely controlled series of steps in the accomplishment of a task" (Goffey, 2008, pp.16–17).

done exactly from this perspective.[73] The mentioned add-ons in relation to infrastructural systems can be one of these instantiations, making software of apparent easiness to attach and detach from an infrastructural structure already in place, or to be designed in order to maximise the profit of that same element and development of new avenues of income. The hype around technology hubs, start-ups, the digital economy, hackathons, accelerators and so on are all expressions of the same logic underlying the infrastructural add-ons, commoditisation and other infrastructural and contextual positioning of software.

In addition to this, it is important to consider the materiality of software and how this same materiality becomes expressed, felt and made tangible. This materiality is "operative at many scales" and can be traced from the very "language" used for the development of a piece of software to the design of the "interface", expressed through the structure of evolvement required, the bugs that emerge or even problematic areas of usage (Fuller, 2008, p.4). As Jennifer Gabrys (2011, p.62) explains about the material expression of software in the context of electronics, the objective of software is always processual in relation to "manufacture, calculation, [and] automation". Software becomes expressed in the very same logic of these processes – how they interact, unfold, structure action–reaction, and connect or disconnect with other parts of their context of action – but also in their conceptualisation within their context of action. The software that enables the expansion of area of impact and scope of a complex urban system is the outcome of specific material arrangements already in place before its arrival together with a degree of intentionality. It is not easy to separate it from the materiality that sustains and is activated by it – hardware (Gabrys, 2014).[74] The contextualised piece of software, emerged out of a specific material arrangement, is deeply connected with the success of its support. However, the contextual software "facilitates the increasingly refined programming of matter and exchanges"; it is dependent on this

[73] Fuller (2008, pp.2–3) highlights the importance of the split of the software and hardware sections carried on "by IBM in 1968", meaning that from then onwards "software was no longer to be bundled as a service or gratuity"; it became approached as another commodity.

[74] This conceptualisation of software takes us back to the famous statement and essay by Friedrich Kittler (1997) – "There is no software". Gabrys (2011) also uses this essay as sustaining her argument that software is always material, that its actions are not only enabled and sustained but also coming into realisation as the outcome of a very specific material context of action. In Kittler's perspective, software could not exist on its own – not only did software need a material context of action, this same context sustained its working – "Any transformation of matter from entropy to information, from a million sleeping transistors into differences between electronic potentials, necessarily presupposes a material event called reset" (Kittler, 1997, p.150).

same arrangement and simultaneously embedded with potential, due to the capacity and plasticity to continuously expand its area of scope to the detriment of additional material needs (Gabrys, 2011, p.63). The plasticity and adaptability of software, embedded from its outset or put into use through continuous updates, can lead to a reduction of liability of dumb structures that suffer from the action of time, weather conditions and usage, in the sense that through software these can be more reactive. Software can bring a level of dynamism, be implemented as a way to replace material exchanges and require a lower material updating of its context of action, as I discuss next through the consideration of the process of softwarisation.

Another possible way to grasp and work through the logic of the software in action is by opening up the code structure that sustains it – code "might show how software becomes invisible, how its occlusion from analysis occurs and how it nonetheless becomes at times very visible and significant" (Mackenzie, 2006, p.3). The code making possible what we experience as the running of software tends to be perceived as very detached from its outcome – as the guts of software, it becomes reduced to "relations and operations" (Mackenzie, 2006, p.4). What is important to highlight is that the act of coding takes place with specific objectives in mind for a determined context. It comes into being by making assumptions about its outcome and dynamics in place, the relations that it will establish and reinforce, and the operations needed in order to achieve its desirable outcomes. In this sense, and as Mackenzie (2006, p.9) argues, "code is agency-saturated". If the logic of code emerges through the action of software, the logic of software starts to become tangible during its interactions with its context of action. As mentioned in relation to qualculation, computational processes in conjunction with the infrastructure already previously in place can result in new forms of knowledge and feedback loops between this new knowledge and the information being gathered and formalised. This means that when it comes to complex urban systems, what emerges and the spatial relations that unfold cannot be taken lightly. There is a level of intentionality and self-reciprocity embedded into them, even if it does not come into full realisation.

As I have shown so far, software can be taken as the element largely responsible for the stabilisation of the system it becomes part of, extension of area of scope and increase of elements working within that same system. This is largely due to the process of softwarisation, already made reference to in an implicit way while discussing the materiality of software. Softwarisation is a concept developed by Manovich (2013) and it refers, originally, to the softwarisation of different modes of analogue media, which has taken place in the last decades, but mostly during "the 1980s and 1990s". It implies "the systematic translations of numerous techniques for media creation and editing from physical, mechanical, and electronic technologies into software tools" (Manovich, 2013, p.164). Translated media, once softwarised, have the ability to mix, interact and give origin to new hybrids – conjugations that did not exist previously, so they are creating something completely new (Winthrop-Young, 2010, p.192). This means that the combination of media that have already been softwarised is not simply a process of "convergence", as they lead to a new mode of media with unique capabilities and potentials (Manovich, 2013, pp.171–176). The softwarisation of previously analogue media is not a "simulation" or a digital replacement of these media: "What software simulates are the physical, mechanical, or electronic *techniques used to navigate, create, edit, and interact with media data*"[75] (Manovich, 2013, p.199). These techniques were previously closely tied and aligned with the affordances of their material medium – the "hardware" (Manovich, 2013, p.200). The techniques used with each material were specific to what allowances that same material offered. Now, once their softwarisation takes place, their affordances are transformed, as they also gain wider thresholds. Their translation into software brings new techniques, mixability and hybrids, as well as new softwarised potentials.

In addition to this understanding of softwarisation, it is important to remember that as what has been discussed regarding the extension of computation into urban contexts, the implications of processes of softwarisation are much wider than those offered by Manovich's perspective. As processes of softwarisation take place, they also start reworking on pieces of software, increasing the entanglement of the consequences that come out of these processes. Softwarisation also implies the ability to bring together "the physical and the ephemeral, the material and the ethereal, into a multi-linear ensemble" (Berry, 2015, p.3), resulting in the growth of complexity in relation to the material–immaterial relations. Processes of softwarisation imply a transformation of the nature of softwarised contexts (Berry,

[75] Italics in original.

2014, pp.46–47; 2015, p.3). Not only, once in place, software “helps” the functioning of what it works through, it “structures” what it works through (Berry, 2015, pp.3–4). The extent to which software transforms what it touches cannot be undermined, be it “hardware” or other already existing pieces of software (Berry, 2014, p.57). As David Berry (2014, p.57) synthetises:

> …software increasingly acts upon software producing new levels of abstraction and complexity in software systems. This recursive logic of softwarization in the development of computational systems is an important hallmark of computationality.

When transferred to the urban context, the concept of softwarisation, as formalised by Manovich and Berry, has important implications. It speaks of the codification of analogue actions and activities that required previously human coordination or participation, but also of an ongoing process of softwarisation that does not necessarily differentiates between the analogue and the digital. These actions and activities, previously carried by different infrastructural elements, become reshuffled as they can be converged, mixed, re-scoped, deleted and given a new level of importance or irrelevance. Not only can new functionalities be added, together with monitoring, tracking and management, but also softwarisation allows new capabilities to emerge, the ability for continuous evolvement through updates and a working logic based on priorities and available resources. Softwarisation connects what was previously separated; it allows the creation of new connections and hybrids – capabilities resulting from the arrangement, conjugation and mixing of previously disconnected elements of action, but also materialities of that same context. This can speak of a process of true simplification and differentiation – action and reaction, open and closed, allowed and not allowed, belonging and non-belonging – or the creation of the context favouring the emergence of qualculation. Part of the power of computation is this “ability to mix the formalized with the more messy – non-mathematical formalisms, linguistics, and visual objects and codes” (Fuller, 2008, p.6). In all of these cases, the process of simplification is indeed a process of informatisation and spatial and action-oriented translation. Softwarisation should never be misunderstood simply as a copy or digitisation of previously analogue processes.

Concluding, if we think of softwarisation as an algorithm translation and codification of relations, processes and outcomes, which at a later stage enables calculation to merge with intentionality and judgement, it will be possible to start envisioning the scale of the impact of urban softwarisation. In its combination with hardware, the process of softwarisation is able to combine and extend across both analogue and digital arrangements, giving rise to a fine coupling. As contextual hardware becomes softwarised, the dynamics and outcomes in place "can be intensified, copied, multiplied, and stretched or subject to a host of other functions that have become familiar from the basic grammars of applications" (Fuller, 2008, p.6). If we proceed with this line of thought and incorporate the already mentioned concept of "code/space" (Kitchin & Dodge, 2011), then the mutual formalisation and transformation that develops between software and its context of action starts to emerge. Software, in its relations with infrastructure and space, brings into concretisation a new way of relating. All relations in place are reformulated, both within technical systems and also externally. In this sense, what emerges is "the productive power of technology to make things happen", while simultaneously transforming its own context of action (Crang & Graham, 2007, p.793). Urban context thus appears as a functional context highly dependent on software; if software were taken away, that context would come to a halt, leaving it most likely without any other immediate alternative (Crang & Graham, 2007; Kitchin & Dodge, 2011).

2.4.2. The datafication of urban space

There is always a relation sustaining the work of software: "algorithms do not execute their actions in a void" as they depend on the existence of "data structures" and these are ultimately a "prerequisite" for the operation of an algorithm (Goffey, 2008, p.18). It is understandable then how software and data often appear side by side throughout this research, more importantly, how the processes of softwarisation and datafication depend on and feed off each other, in order to act upon, through and with their contexts of action. The technical, operational and extensive affordances gained through the softwarisation of technical assemblages lead to the increased datafication of urban environments. This same process of datafication implies either taking “a process or activity that was previously invisible and turning it into data” (Elliot, 2013) or transforming already existing data into data ““‘aggregated in a computationally manipulable format” (Strandburg, 2014, p.10); it speaks of something that was not previously computable and that has now been brought under the spectrum of computation. Datafication processes need to be understood under the context of the extension of computation throughout urban contexts and of processes of softwarisation, as both of them imply a dynamic that can be reinforced by the support of data. In this context, it becomes easier to understand that underlining the push for datafication is often a drive that believes that anything can be “measured and monitored and treated” as if they had a technical quality (Kitchin, 2014, p.181). In other words, datafication is the outcome of “the presumption that all meaningful flows and activity can be sensed and measured”, being this tendency specially visible within the governance of urban contexts (Mattern, 2013). The assumption made is that once a context enters a process of datafication, it is turned into an object that can be “tracked, monitored, and optimized” (Elliot, 2013), even if only at a later stage. In many cases, processes of datafication mean future potential uses “that may have been unanticipated or even technologically infeasible at the time of collection and are qualitatively different from the original purposes” (Strandburg, 2014, p.11). Like in the case of softwarisation, once a process of datafication is initiated the delimitations of its action becomes hard to define and secure, specially in the case of urban contexts where this process can gain an accumulative quality.

It is probably easier to envision the presence and impact of datafication on a smaller scale, as is the case with most activities and usages related to locative media, quantified-self technologies and other very specific locational urban interactions. Through the computational recording of “inputs” and “outputs” of information, provided intentionally and non-intentionally, consciously and non-consciously (Wolf, 2010), data flows happen at the level of infrastructural systems, as well as in relation to these through portable and networked devices and distributed computation. This can combine “mass production with individual identity”, gaining and building simultaneously the macro and micro view of multiple perspectives of urban territories (Gane et al., 2007, p.352). All the computational recording of input and output activities – from sensing urban elements – are continuously being translated, processed, stored, compared, tracked and tagged through data processes. Collected data is turned into lists, actionable structures, in order to become classified and ordered (Adam, 2008, p.174).

Given this, it is not surprising that both data collection and processing are at the centre of decision-making processes and urban management systems (Mackenzie, 2012).[76] Data gains major relevance when looked at from the perspective of data management systems, models and simulations, its working dynamics and complementing activities with software. Relational locations are necessarily datafied modes of spatiality, enabled by intensive geographic enhancement, which in itself is intrinsically dependent on databases and data collection and treatment. The urban context being discussed would be meaningless without numerous data-servers spread geographically in a real example of infrastructure going transnational and into a global scale. Although potentially tagged to its context of collection, data embodies the most important differentiation between site of production and site of consumption when it comes to its supporting infrastructure. Data is moved around entire metropolitan areas, countries and faraway territories, in order to be stored in databases kept at servers placed at distant, anonymous, often almost untraceable data farms. On-site data servers are becoming increasingly exceptional, as most of our data is already sitting somewhere in the 'cloud' – at a distant and unacknowledged data farm. Data has no need for a shared location of collection, storage and further usage, but it is nonetheless the often unspoken element, tying, connecting, relating, structuring and ordering so many of our interactions and decisions. When I speak of complex urban systems and relational locations, connections and evolvement is in most cases being done by data being activated through software applications. This means that data brings a series of complexities and variables into play that become transposed to complex urban systems in many ways that are not always tangible or able to be acknowledged.

[76] The centrality of data in decision-making at all levels and realms of life is indeed transversal and with a growing base of supporters. Two well-known advocates are Jeff Bezos, the CEO of Amazon, and Michael Bloomberg, Mayor of New York between 2002 and 2013. Amazon is well known for squeezing data out of every possible aspect from processes to the way employees interact with each other. It is possible to say that Amazon's stance on data, most likely, is that "data will eradicate ignorance and ambiguity" (Kantor & Streitfeld, 2015; Schrage, 2015). While at the Mayor's office, Bloomberg built around him a strong team responsible for making available and possible the collection of all sorts of data about the city, enabling a results-based and data-based management model and policy-making process to be developed (Feuer, 2013). This is particularly important as it takes data from its machine environment, endless reformulation and reorganisation, and lists and data warehouses onto the desks of those taking decisions often on the same systems that will constrain the development of the systems where this data sits, but also its interactions with adjacent elements of its ecosystem.

As stated, data measures all types and sorts of "activities and doings" of people and objects, actions and events (Ruppert, 2012, p.116). This, when coordinated and combined with other bits of data, can lead into specific "systems of *knowledge*",[77] more precisely, into "a new mode of governmentality" (Kitchin & Dodge, 2011, p.85), in which data plays a central role, as already discussed. Databases, through processes of aggregation, combination and correlation, move away from stable subjects to become concerned with relational engagements and connections: knowing becomes the outcome of "interactions, transactions, performance, activities and movements" between two subjects (Ruppert, 119, 2012). This means that databases offer a knowledge formulation that is not simply the result of the sum of its different parts. In addition, the flow and speed required for the decision-making process is tied to the degree of sophistication of the database and its management system, giving rise to a context where "real time production, lean production, logistics, supply chain management, human resource management", among other management processes, are simultaneously informed by the outcome of their supporting database managing systems (Gugerli, 2009). Databases maintain datasets waiting to be requested and retrieved (Bachman, 1973, p.655), meaning that decision-making processes are in many ways processes articulated and managed through software and database applications (Kitchin & Dodge, 2011, p.85). However, the internal management and processing that takes place within data management systems is generally unknown to the user using that same database to make queries (Codd, 1970, p.377; Haigh, 2006, p.33), leaving that role to the database manager. When it comes to the urban context, that interaction or querying is in most cases not even a possibility. The expression of the database is, for example, visible on screens, on systems allowing passage or entrance and through the changes of procedures and services tied to that same urban territory, but both the location and functionalities of the database supporting and enabling those transactions are unknown.

Often, the databases sustaining urban processes are relational databases, which since their development have come to occupy a crucial role in many digital systems, both from a "conceptual and material" perspective (Fuller & Goffey, 2012a, p.324). They are the "foundation" and a central part to "many contemporary

[77] Italics in original.

media systems" (Fuller & Goffey, 2012b, p.114). Relational databases were nonetheless firstly proposed by Edgar Codd (1970, p.377) in the late 1960s, the main objective of which was to "provide shared access to large banks of formatted data". Codd (1982, p.109) sought to design a system with easy access to the information located within the databases, while simultaneously incrementing "the productivity of data processing professionals in the development of application programs". Relational databases brought a significant transformation to the way data and information were stored, due to their storage capacity and shared approach to their internal logics by "users and programmers" (Codd, 1982, p.110), with a format that allowed them to be easily "accessed, interlinked, and queried" (Kitchin & Dodge, 2011, p.102). The main issue with previous data systems was their inability to be flexible in the arrangement of data, as small changes in the structure meant the need "to revise all programs that relied on the previous structure" – the internal and relational structure of the database became a concern of the system which had to "determine the details of placement of a new piece of information" and "select appropriate access paths when retrieving data" (Codd, 1982, p.111).

The implications brought by the introduction of relational databases, and the reason for their relevance within our discussion, is precisely their adaptability and ease of use when it comes to making queries and the establishment of new relations. In a context as what has been described and discussed so far in relation to urban contexts, the ability to change certain elements without the need for a thorough revision of all of the other data and the inter-relational model of inquiry offers a flexibility that if inexistent would result in a very different urban context. Even if new models of database organisation and management have emerged since then, the core objective of the relational database has remained and set a standard for the field, which underlies its importance. Furthermore, the implications of the flexibility attributed to how data is organised and divided into categories should not be undermined – "the genres of databases themselves have inscribed politics, as well as making algorithms essential information tools" (Gillespie, 2014, p.171). Relational databases brought into the field of information management an assumption of modularity, which implies the ability to adapt and recreate in relation to new entities and in this specific context, to urban space and its infrastructural systems.

Within the management of contemporary datasets, two challenges stand out as direct consequences of the applicability and importance of databases within all sorts of daily activities: how data is aggregated and the erosion of strictly categorised data (Mackenzie, 2012). With the increased use of cloud computing, the aggregation of data has gained relevance, as data management query systems require the ability to access simultaneously "selected parts of scattered domains of information, stored in highly organised yet flexible structures" (Mackenzie, 2012). A layer of complexity has been added to this by the erosion of "the boundaries" between different categories of data (Mackenzie, 2012). This can be found in terms of the context of collection and usage – "commercial, scientific, technological, and regulatory domains" – and also what is conceptualised as individual and restricted data or public and accessible data, a case particularly visible in the health sector – "personal health information and medical records" (Mackenzie, 2012). This is observable as "vertical aggregates", through which the objects of data are conceptualised as "lack[ing] both full unity" taking a "complete dispersion" form (Mackenzie, 2012). These processes force us "to re-think relations between one and many, between universality and plurality" (Mackenzie, 2012).

Adding further complexity is the process of data mining, the objective of which is "knowledge extraction, information discovery, information harvesting, data archaeology, and data pattern processing" (Fayyad et al., 1996, p.39). It refers to the exploration of data – it is an intentional search for new patterns, relationships and factors in large amounts of data (Fuller & Goffey, 2012a, p.327). As a process, it is a specific "step" of working with a specific dataset that needs to include "data preparation" and "cleaning"; it is "the application of specific algorithms for extracting patterns from data" (Fayyad et al., 1996, p.39). In this way, data mining enables access to "sophisticated forms of statistical inference", by both recurring to elaborated techniques and one or more simultaneous variables (Fuller & Goffey, 2012b, p.96). This positions large databases as centres of gravitational modes of knowledge and knowledge formulation, within which reasoning takes place through "probabilities", the "small numbers" and "the correlationist certainties of large ones" (Fuller & Goffey, 2012a, p.327).

Datasets become thereby not only able to be approached through flexible and adaptable perspectives, but they are repositioned as powerful members of urban infrastructures, laying calmly in the background while processing and acting. Geographic information systems, so commonly used within urban territories, often recur to data mining as a process of data management. In this manner they can highlight local patterns, social economic status, levels of crime, trade potential, growth expectation and so on. These databases gather information at a local or defined scale to be used afterwards within a larger framework of social and economic behaviour. For example, "consumer profile data" is nowadays an important part of the decision-making process for "store investment and disinvestment decisions" (Graham, 2004b) – the decisions taken on where to open a specific store, a bank branch or any other private services will have consequently a long-term impact for those affected communities, especially for those in disadvantaged areas that are considered inapt for investment return.

The centrality of data within relational locations may be, at first, difficult to grasp. However, it is important to remember that data not only supports the reinforcement and positioning of certain types of knowledge but also has a direct consequence on relational locations. Firstly, because there is a topological flow specific to data, which makes it in part responsible for the geographic enhancement that can be encountered and identified throughout a variety of urban territories, GIS systems being a clear example of this. Secondly, the process of datafication of space means that some elements are prioritised over others as not all areas of urban living are objectified by data in the same way. Many variables underline decisions concerning what is made visible or not, or simply the process used in order to identify patterns and areas of relevance ends up leading the way towards specific types of decision. The potential and downturn of data resides exactly here, within its ability to, on one hand, bring light to new areas or make visible until then unnoticeable patterns, and on the other hand, be used to reinforce and justify processes of decision-making that would not prevail in any other way. Furthermore, data remains challenging to those unfamiliar with its working models and structure. The outcome of data processes throughout urban territories does not tell us how databases are organised – this means how aggregations are made, relations established and patterns identified, what is made closer like a homogeneous group and what has its differences accentuated and is forced into a highly visible position. Our encounters with the outcomes and expressions of data tend to be very distant from data itself, be it in the way operations of a set of infrastructure are reorganised, how software is adapted to prioritise belonging to specific datasets or even how the material elements of a certain infrastructure are rearranged in order to give origin to pre-defined data outcomes, as was the case with the rearrangement of the network of air quality monitoring stations of Madrid back in 2010, mentioned in the first pages of this thesis. Meaning this, that data is not agency free or simply a side effect of computational environments.

2.5. More than spatial relations

The objective of this chapter has been to contextualise existing literature that can support the understanding of what is here presented as relational locations. Introduced as a prevalent mode of spatiality of contemporary urban territories, relational locations are the outcome of the extension of computation into urban infrastructure. For this reason, the emphasis was put throughout the chapter on the existing relations between space, infrastructure and computation. Not only has it been possible to highlight these relations and their role within complex urban systems (already softwarised and datafied urban infrastructures), it has also been shown how challenging it can be to analyse them separately from each other. As the chapter progressed, it became clear that there are a variety of accounts that have already reflected on and contributed to the three highlighted areas, which have reinforced qualities of continuity, differentiation, topology, network, extension and adaptability. These shared elements refer, in a more or less implicit way, to an urban context that has been transformed and reconceptualised as the extension of computation took place closer and closer to the core of its infrastructures. Overall, it speaks of a tendency that this chapter has attempted to set out, in order to build on the literature reviewed and contribute with a different perspective that starts from the dynamics taking place within complex urban systems.

What is relational in space has been shown to be formed by a context of action, defined by specific and connected geographic points, where geographic enhancement takes place and tailoring is made possible, always in relation to other geographic points. More precisely, the acceleration of transformations that have happened throughout urban territories has been shown to be a direct consequence of the introduction of computational capabilities into infrastructural systems, and simultaneously of the technical advancement that has led to increasingly smaller objects that have the capacity to sense, capture, and record. The conjunction of computational capabilities – expressed through practices of softwarisation and datafication – with infrastructural systems was shown to give origin to specific modes of space due to the capacity of such capabilities to express and create the sense of continuity and ongoing expansion, mostly through their ability to collect, reshuffle and calculate. If on one hand, datafication brings into visibility and accountability new areas of urbanity, softwarisation enables on the other hand the creation of entirely new techniques and ways of acting upon, with and through urban territories.

In opposition to what can be read as a simple reinforcement of location, such as in the tagging of objects or monitoring of volumes of pedestrians, the discussed geographic enhancement and reformulation of location have been shown to not contradict processes of globalisation. What has been transformed is the position of what has a local character. The dynamics between the local and global have come to reinforce "the logic of the system", embodied in the capabilities of computation and its capturing technologies, which when put into the global–local dynamics brings us to a system increasingly looking like "the logic of the world" (Thrift, 2008, p.92). This makes an implicit reference to the capacity of the technical machine to reinforce certain ways of working over other practices. It speaks of a naturalisation of specific infrastructural arrangements. The "metrics" and "standards" of computational environments tend to prevail over what is different – they "allow what are often different local frames to be crafted into a secure global assemblage" (Thrift, 2008, p.92). Flows and intensities take place through a level of ordering, of organised and structured encounters, which may be difficult to evaluate just based on what location presents us on-site, as geographic points are "a swirl of forces and intensities, which traverse and bring into relation all kinds of actors" (Amin & Thrift, 2002, p.83). The actionable aspect of relational locations is not only site-specific and bounded to its immediate surrounding context; it is also in relation to an external element. This refers to the capacity for action in real-time, influenced and constrained by a "'real-time' action-at-distance" (McQuire, 2008, p.4). This goes a step beyond the separation between the location of production and of consumption, as it implies urban territories to be "increasingly opened to events occurring elsewhere" (McQuire, 2008, p.4), folding and unravelling in relation to each other. Local and global, here and there, are brought into a local–global dynamic; they gain a network structure.

Complex urban systems have been established as being predominantly technical and infrastructural systems supporting urban operations and flows, regardless of their character and scale, as the three stories from the winter of 2010 exemplify. They are in many cases expressions of very specific material arrangements, sustaining, enabling and reinforcing their own softwarisation and datafication. Through their structural division between backbone and add-ons, extension of scope and strong tendency towards convergence and concretisation as a way to ensure their long-term sustainability, they rearrange their urban position and the dynamics of alternation between making themselves visible or remaining in the background. Complex urban systems have been shown to hold and reassert the logic of the computer – through their language of management and bureaucratic endeavours and demonstrations of accountability. Overall, this chapter has illustrated a transition towards a mode of control and management that can be defined as modular. Modulation as a form of control suits well the complexity of the infrastructural systems discussed – as they extend their geographic area and scope, and bring into their realm of action increasingly more abstract elements, modulation offers flexibility that implies a "constant and never ending *modulation*"[78] (or continuity), where the object is not implicitly material, but a range of "elements, capacities, potentialities" (Rose, 2000, p.325). Furthermore, as it has been pointed out, there is a numerical underlying to the way modulation works, making it a fitting mode of control both to complex urban systems and to the way computation operates.

Nonetheless, it is important to highlight that the context of action of management, accountability and modular control should not be taken as a fully normalised environment, where there is full pre-emptive expectation of what may unravel. A close analysis of a series of relational locations and their complex urban systems would show a group of distributed decision points, even in cases where that distribution is less visible or harder to pin down. Now, the higher this distribution is,

[78] Italics in original.

the higher also the possibility of finding a degree and residue of the unexpected. As will be shown in both case studies, the extension of complex urban systems does not always take place as planned. Many variables are at play, and the embedded potential or capacity to move towards a given direction may not come into being. What I am trying to say with this is that even after all of the aspects discussed, going from the ordering of differentiation to the way spatial and infrastructural segmentation and splintering take place, there still is a degree of unexpectedness. As Keller Easterling (2011, p.155) writes, the infrastructure of a given urban context "does not constitute an event" on its own, or even an exact and predefined set of steps and action–reaction cascade. It should then be taken as a setting within which "unfolding relationships inherent in its arrangement" come into being, expressing "potentiality, capacity, ability, or tendency" (Easterling, 2011, p.155). If we add to this the existing pressures it is possible to find within expanding infrastructural systems, a field of action that is as constrained as it can be; it can always unfold in ways not imagined and planned. This is to say that the contexts of action from which this thesis draws are more than fully controlled infrastructural locations, even if they are increasingly showing more signs of reasoning, calculation and probabilistic action.

Many of the points discussed and the literature reviewed refer to what I would define as externalities, impact and contribution of complex urban systems. They imply interactions beyond these same systems, extended spatially regardless of local and global positioning, where many variables come into play in the way relations evolve and locations become defined within themselves, as well as in relation to other locations. In a way, this chapter has been concerned with what happens as a consequence of the internal dynamics and tendencies of complex urban systems, meaning that much is left aside from this same line of narrative. I argue that new insights can be added to our understanding of contemporary urban territories, the tendency for both infrastructural systems to extend their context of action and computation its area of scope, if we change the starting point of our considerations. As the following chapter shows, by building on the elements already discussed here, a starting point considering the unravelling dynamics among the technical elements forming complex urban systems will bring forward a path of development towards concretisation, moving in a direction where tensions have been solved and complex urban system can easily recede into the background.

3. THE ARTICULATION OF COMPLEX URBAN SYSTEMS

3.1. Entering complex urban systems

As established, relational locations have emerged as modes of spatiality resulting from the extension of computation into urban infrastructural systems. This has meant that the extension of computation, in particular through the processes of softwarisation and datafication, has led to the increase of complexity throughout complex urban systems. These systems have been shown to express specific qualities and to result from evolving relations, as those discussed in the previous chapter, and which were shown to be increasingly transforming and constraining the development and experiencing of urban territories. However, as an extension to the previous chapter, I want to propose that this existing and analysed literature has not gone far enough in understanding these systems beyond their impact and the perceptible outcome of their functioning. Often work has been done on specific aspects that feed directly into complex urban systems as the division into space, infrastructure, computational practices demonstrated in the previous chapter. By this I mean further research is necessary from the perspective of how complex urban systems work, evolve and come to achieve a level of deep stability with their contexts of action.

This is required as we also need to take into account dynamics specific to the working of technical systems. New insights into how processes of computation extend and concretise within complex urban systems will be gained, and we will also make visible processes of receding into the background and seeming naturalisation of infrastructural systems deeply aligned with their context of action (Bowker & Star, 2000; Dourish & Bell, 2011; Edwards, 2010). Moreover, in a context where “software-mediated practices” (Kitchin & Dodge, 2011, pp.71–72) are increasingly gaining more relevance in the day-to-day running and experiencing of urban territories, opening new paths into how computational processes work, extend and interact with other urban infrastructural elements is of crucial importance. Finally, as these same processes extend their logic beyond their areas of action and impact, it is necessary to identify additional conceptual tools that will allow understanding of what I define here as the path of development towards concretisation of complex urban systems.

In order to achieve this, I draw on the conceptual framework developed on technical objects by the French philosopher Gilbert Simondon (1980; 1992; 2008), in particular, on the concepts of individuation, concretisation and associated milieu. By transposing these concepts into the context of complex urban systems and the impact of the extension of computation, I argue that these systems tend to follow a path of development characterised by four stages – convergence, amplification, stability and concretisation. Each stage offers specific characteristics and dynamics with their context of action, and they also provide the opportunity to envision the general tendency in place within each technical system at any time and understand what might unfold next. This narrative of development will be shown to provide new insights into contemporary urban territories and demonstrate that once computation enters technical systems, a new logic, speed and adaptability comes into play that not only transforms contexts of actions but also offers the possibility of accelerating the process of technical systems towards concretisation. Finally, as a system becomes concretised, meaning as tensions are solved between the technical system and its context of action (or associated milieu in Simondon's language), a sense of deep intertwining emerges, leading to a naturalisation of the technical system. As will be shown, this speaks of a difficulty in separating and differentiating the technical system from its context of action and a stage where they become fully entangled with each other.

The proposed path of development will then help to demonstrate how the context of complex urban systems and relational locations discussed previously gains a new meaning when brought back to our attention from the perspective of technical systems. I highlight four areas in particular that will stand out throughout the chapter:

- The extension of computation, its logic and way of working strengthens the tendency of technical systems towards concretisation as it enables the convergence between disparities from the outset of its extension into a specific system. By this, I mean that the affordances and thresholds specific to the way computational processes work result in the coming together of technical elements and systems that would not have done it otherwise.

– The continuity discussed through ordering and differentiation does not take place always at the same rate, with particular moments of intensification and acceleration that correspond to a specific momentum of development of complex urban systems. Moreover, certain parts of the assemblage can even present different dynamics from the overall tendency, due both to plastic and flexible qualities offered by infrastructural add-ons or secondary elements in relation to the overall assemblage.

– The extension of scope and areas of action allowed and facilitated by the processes of softwarisation and datafication feed into the need for stability of technical systems, ensuring a higher dependency on their existence and way of working.

– The locational aspect of complex urban systems speaks of concretisation, as it implies the ability to be tailored and adapted to its context of action, increasingly in a more naturalised manner. As a system becomes concretised, it also gains the ability to further recede into the background, be taken for granted and become a crucial part of the territory.

The conceptual exploration developed will not only offer insights into the dynamics unravelling within technical systems, mostly unaccounted for; it will also propose an understanding on the impact and transformations that the extension of computation has brought into the context of technical systems from the perspective of these same systems. I start by looking at the moment of convergence between the railway and the electric telegraph. As an early example of urban convergence between two separate systems, previous to the arrival of processes of softwarisation and datafication, this provides the opportunity to consider the wider implications of moments of transition within technical systems, both in reference to their coming together and further development. Given that the electric telegraph has been described as an early information system (Kittler, 1996) and the Victorian Internet (Standage, 1999), I reflect in the transformations that a previously contained system suffers in terms of working flow, autonomy and wider assemblage when a new element, with informational capabilities (as in communication) is brought in through a process of convergence. In this case, my aim is to analyse the impact that the telegraph had on the entire railway assemblage after its introduction as a signalling system, slowly developing similarities to what we understand today as being ‘digital’. It is shown that as well as having operational consequences, the use of the electric telegraph allowed the informatisation and modulation of the railway, both in terms of time and space, to occur, which led to an increase of its entrepreneurial activity and the opening up to new services.

The analysis of this early example of convergence offers the basis to how the rest of the chapter is structured, as it serves as a baseline to further develop my analysis and propositions. I proceed then with the analysis of Simondon’s conceptual framework (1980; 1992; 2008) in order to discuss the proposed path of development. As will be shown, this path offers new insights into complex urban systems that might help us to better contextualise them with urban territories, mostly within their context of action. This context is the site where external pressures and constraints acting upon complex urban systems can be identified. The emphasis is put particularly on practices of standardisation and risk management, which are shown as tools of management and modulation of the dynamics of local–global and wider urban territories. However, before we move on to the narrative on the convergence between the railway and the telegraph, let us consider for a moment the transversality of communication and mobility throughout complex urban systems, as this will help us to further contextualise the relevance of this chapter.

3.1.1. Communication and mobility

Transversal, and in many ways implicit to the chapter, is the underlying narrative of urban communication and mobility, showing the ongoing connections to many of the needs and desires that move technical systems towards long-term stability and concretisation. This means that urban systems tend to emphasise systems of communication or mobility, and often even both of them together. As becomes particularly visible within moments of transition, communication (exchange of information) and mobility (circulation and movement) play a core role within the evolving dynamics of complex urban systems, as many of the processes of transition are directly related to at least one of these aspects. Stephen Graham and Simon Marvin (1996, pp.40–41) explain that there have always been “close linkages between communications technologies and transportation”, which is visible in “the use and management of transportation networks”, coordination between the "production and distribution sites" and expansion of the "transportation informatics". The separation, mentioned earlier, between sites of production and of consumption also reinforces this.

Armand Mattelart (1996, pp.51–52) argues that communication has been tied to management "since the advent of the mechanistic model of organisation", aligned with the argument developed by James R. Beniger (1986) on the evolution of control. Throughout this evolution, as also the process of convergence between the electric telegraph and the railway show, control and its bureaucratic endeavours are central to "the new infrastructures of transportation and telecommunications" (Beniger, 1986, p.7). Furthermore, as is demonstrated in more detail in the case studies, complex urban systems necessarily establish relations of mutual cooperation and interaction with their contexts of action, within which communication becomes essential as enabling processes of feedback: "two-way interaction between controller and controlled" is necessary not only as a positioning of power "but also to communicate back the results of this action" (Beniger, 1986, p.8). As this chapter will show, long-term stability and concretisation within technical systems would not be possible otherwise.

When it comes to mobility, it is already rooted in the conceptualisation, planning and ongoing governance of contemporary urban territories, offering insights into the capacity of urban territories to absorb new modes and intensities of mobility (Swyngedouw, 2006, p.31). The locational entanglements giving rise to relational locations also continuously create, support and push for the circulation of goods, information, people, energy, waste, vehicles and so much more (Urry, 2007), driving the continuous development of new relations. Within the material and non-material affordances of technical systems there is a continuous "potentiality, capacity, ability, or tendency" to connect, relate and extend (Easterling, 2011, p.155). This means, and especially as a consequence of the extension of computation, that technical elements have become able to further extend their abilities, plasticity and even thresholds. More than about movement per se, these contexts are often about "unfolding relationships" (Easterling, 2011, p.155) exploring the mentioned affordances encountered: relations that are in most cases tied to their own contexts of origin and development. This means that the relations established are not simply casual; they speak of an ability to connect and engage and of a contextual and common objective of mobility and circulation. John Urry (2007, p.51) explains that throughout history "one major mobility-system" can be identified in each society. In this context, complex urban systems seem to embody the centrality of mobility within their contemporary urban territories. As each system evolves, it establishes close links with adjacent areas of interest, as well as with other "mobility-systems" through "adaptive and co-evolving relationships" (Urry, 2007, p.51). Thus both movement and circulation offer further insights into the evolvement of complex urban systems and their different moments towards concretisation.

3.2. The coming together of the railway and the telegraph

Returning to the question of convergence, it is approached here as a moment of transition. Transition implies the change from one state to another; in the context of this chapter, it is the coming together through convergence of two previously distinct and autonomous systems, leading to a new technical arrangement. Convergence as a process of transition is usually accompanied by a specific narrative or intentional construction of a desired context, even in cases where the coming together of two distinct systems was previously seen as an unavoidable outcome. As already discussed in the context of the methodological approach in the first chapter, transition can bring visibility within urban infrastructure to moments that would go otherwise unnoticed. These moments can be taken as opportunities to enter a specific technical system; they can result in entry-points to systems that were previously closed to inquiry and intervention. The emphasis on the process of transition makes visible the existing dynamics within a given context, which can go beyond the materiality of infrastructure. It also offers the opportunity to reflect on the transformations taking place within a specific context by focusing on three different stages: the moment previous to the transition, the process of transition and the moment immediately after that same transition. During these moments, more than a change in the infrastructure or a new capability being offered by a technical development, what matters are the wider consequences and interactions that unfold within and beyond these contexts, coming to provide new meanings to the technical arrangement (Parks, 2005).

For example, when the telegraph first arrived in the second half of the 19th century, it became used worldwide, leading to the sudden sensation of spatial shrinking of the world. Moreover, it created the sense that multiple and distant locations shared paths and histories, as was the case with Europe and the USA, finally connected by transatlantic cables (Standage, 1999, p.1). This same development led to the transformation of war strategy and how mail was distributed and news written (Standage, 1999). The transformations brought by the telegraph to those systems already existing throughout urban contexts were simply radical, being often referred to as the Victorian Internet (Standage, 1999). What started as a technical development quickly unravelled into a complex infrastructural system that connected to already established systems (Standage, 1999, p.96), finding its position within multiple urban territories and contexts. Its impact quickly went beyond the sharing of transatlantic messages between two points.

As the telegraph expanded, this new technical development led the assemblages it entered into new technical arrangements, dynamics and interactions. It was more than a new communication technology as its convergence with the railway shows. A detailed analysis of each of these assemblages would probably offer a different narrative on the Victorian telegraph, as new implications and outcomes unravelled from the new technical interactions. These implications and outcomes would, in many cases, not be directly attributed to the telegraph but offer instead a vision of how the telegraph influenced and transformed the technical dynamics in place: how its arrival meant a reshuffle of what was already there. It is with this same objective that I dwell on the process of convergence between the electric telegraph and the railway in the following section.

3.2.1. The process of convergence

As a moment of transition, the convergence between the electric telegraph and the railway offers an early example of the emergence of complex urban systems, helping to contextualise convergence as a technical push towards the long-term sustainability of the railway. Unique to this process of convergence is the fact that both infrastructures, as we know them today, were in their early days, even if both had already had earlier precedents. In the case of the railway, different types of tracks were previously designed for the "accommodation of wheeled vehicles" such as the wooden tracks and the iron rails developed during the second part of the 18th century (Simmons, 1986, p.10). The electric telegraph had been preceded by other visual communication systems that varied between smoke signs and the optical telegraph developed in France by the two Chappe brothers in 1791, in an assemblage of "black-and-white panels, clocks, telescopes and code books" (Standage, 1999, p.10). Both developments were already an attempt to solve the challenge posed by the circulation and transportation of goods and quicker and more efficient long-distance communication and exchange of information.

The impact of the telegraph as a tool beyond the transmission of information from an emitter to a receptor is of particular relevance here. The creation of optical telegraph resulted in "the first arm of the French State telegraph", which connected Paris to Lille (Standage, 1999, p.10). This infrastructure brought a new speed to communications, crucial for the maintenance of the military supremacy of Napoleon. Friedrich Kittler (1996) argues that the development of the telegraph was actually the answer to an already pressing and existing problem, instead of the initiator that led to the speeding up of the "command flow" reaching the armies at the front. This means that the telegraph was a technology of its time, emerging out of a specific need, instead of the technological invention that became so supportive of Napoleon's strategy. The telegraph's ability to share information across different geographic strategic points meant that wars could be fought more effectively and simultaneously, across multiple fronts, which turned the early telegraph into "an auxiliary of armies in the field" (Mattelart, 1996, p.47). More importantly, it shortened the time needed between decisions being made on war strategy and their implementation by soldiers at the front, reducing drastically the timescale for the command–action flow and action–reaction outcome. The shortening of time ensured speed, flexibility and quicker adaptability to the changing context but also compressed and intensified the advents of war, making connections more easily with other events taking place across the Empire. The technical development of the telegraph into a technology with capacity to spread across the world came decades later. The registration of the first commercial application of the electric telegraph happened in the United Kingdom during the 1830s, around the same time that the language that would come to predominate the telegraph was invented – Morse Code.

The electric telegraph was registered under William Fothergill Cooke's and Charles Wheatstone's names, initially as a patent for an alarm system (Mattelart, 1996, p.48). Almost simultaneously, Samuel Morse invented Morse Code in the USA (Mattelart, 1996, p.48).

Before the advent of the railway, in England, "route and means of transportation" were independent from each other; they had separate ownership and there was no constraint imposed on either as a result of a connection between them, as vehicles were either private or hired specifically for the transportation of goods (Schivelbusch, 1986, p.16). This was largely possible as there was no technical dependency on each other (Schivelbusch, 1986, p.16); they had not been built as an unit. Canals and roads were often accessed through the payment of tolls, but vehicles and boats could decide their timetables, routes, turns and speed of motion. It was the first time, with the railway, that both infrastructure and means of transportation were owned and managed by the same company. The rail track and the carriage were designed and conceptualised as an unit: the rail had been developed in response to the needs of the carriage and its engine, and they were supposed to adapt to each other in "harmony" and "reciprocal interaction" (Schivelbusch, 1986, p.17 cited Poussin 1839, pp. xi-xii). This was particularly visible through the early definitions of the railroad – "a machine consisting of the rails *and* of the vehicles running on them"[79] (Schivelbusch, 1986, p.16). As a technical assembly, the railway was the result of a fine-tuning process between its different constituting elements, in search of the perfect fit. The context of development of the rail and the carriage were bound together under "one machine" (Schivelbusch, 1986, p.17). The transition away from the unit towards the rail track and the carriage, as separately owned and managed elements, would only come about as a consequence of the convergence of the railway with the telegraph, implying from its outset radical transformations to the overall technical system.

The early stages of the commercial railway came with challenges regarding safety, length of journeys and low usage of the tracks. It is within this context that the electric telegraph arrived at the railway to become part of the signalling system, aligned with its patent's registration as an alarm system (Mattelart, 1996, p.48). The telegraph afforded a communicative capability to the railway, simultaneously

[79] Italics in original.

improving its efficiency as a mode of transport, while the railway made visible the commercial potential of the telegraph beyond its core service, as later applications would prove. The use of the telegraph had a clear objective – to improve railway management, increase rail traffic and radically transform security by avoiding further catastrophes (Schivelbusch, 1986, p.30). In the same year that the patent for the electric telegraph was registered, Cooke and Wheatstone built an experimental telegraph link (or signalling system) between the Euston and Camden Town stations with "a distance of a mile and a quarter" for the London & Birmingham Railway company (Standage, 1999, p.45). However, it was not until 1839 that this was applied commercially for the first time. The route of 13 miles between Paddington Station and West Drayton (Schivelbusch, 1986, p.30) marked then the beginning of a clear convergence between a communication infrastructure and a transportation system.

The telegraph converged with the railway, as already said, in a very specific technical context. Signalling and traffic control were core functions for the basic running of the railways, for obvious reasons, as these were tightly connected to safety and the smooth running of trains. Other signalling systems had been used before the arrival of the telegraph, such as the signalling system using hands and flags "without fixed equipment of any kind", which was followed by the first fixed signalling system that "consisted of boards on pivots which were turned at right angles to the track to stop an approaching train" (Simmons, 1986, p.192). However, these systems resulted in long waiting times for vehicles between sections throughout the line and a strict regulation of use, leading to a low frequency of trains and underused capacity of the railway tracks. There was then a need for a more elaborated system with a smaller margin of error, which would simultaneously allow a more intensive use of the existing infrastructure. The opportunity for the telegraph was then obvious from a commercial, safety and management perspective. The implications of this process of convergence would then extend well beyond the technical advantages that the electric telegraph offered.

As both of these descriptions show, the electric telegraph and the railway were, previous to their coming together, two distinct systems. The first was essentially a long-distance communication tool that came to transform the time–space relation and the conceptualisation of space, bringing with it an early version of real-time command flow and action-at-distance. The railway, however, was a mode of transport that was conceptualised as a unity and that suddenly brought a sensation of spatial encroachment by significantly reducing travelling time. In their own ways, they were already transforming their context of action, but it would not be until their convergence that they would rework the conceptualisation of time and space within the context of the new converged system. This means that by coming together, as very distinct technical systems, they forced a reworking of their new assemblage in many different ways, leading to a variety of new outcomes technically and also in how they worked. The process of convergence was then the first step towards something else – a distinct system – the outcome of which was more than the sum of their technical qualities.

3.2.2. Signalling and the possibility of control

As is discussed in more detail as we move through the chapter, the process of convergence between two systems tends to bring deep transformations to the assemblage that comes out of it, being a step closer to concretisation, and this case was not an exception. The telegraph was then not a simple signalling system; it brought an informatisation model to the railway, which later resulted in many other technical outcomes and infrastructural arrangements as I discuss below. This early process of infrastructural convergence resulted in the extension and stabilisation of the technical assemblage, leading to new material and non-material arrangements. As they converged, new potentialities emerged and capabilities were found and reworked in conjugation with the new technical assemblage.

The telegraph was introduced into the railway as an alarm system. Its objective was to replace less reliable signalling systems and improve safety throughout the track and frequency of trains in each line, allowing the incorporation of further automation. The advantages it brought in terms of the signalling structure were then of major importance. If early signalling systems, as those mentioned above, were based on "time intervals", the introduction of the telegraph brought a new approach based on "intervals of space" (Simmons, 1986, p.194), also known as the "block system" (Perkin, 1970, p.110). In practical terms it meant the division of the line into smaller sections, "each served by a telegraph transmitter", which would contact the following section once it was clear (Schivelbusch, 1986, p.30). The division of the line into sections covered by the block system ensured that once a section of space was clear, the next train would be allowed in, thereby maximising the use of space along the track (Simmons, 1986, p.194), and consequently making it possible to increase the frequency of trains. This did not require the addition of extended safety periods, as in the previous system based on time intervals, which did not offer the confirmation of clearance to proceed ahead. For this reason, in the case of delays or technical problems, the track would automatically become a liability for the safety of the train (or trains). What this starts to demonstrate is that by introducing a system such as the electric telegraph, the track started being treated like an information system.

The division of the line into small blocks of space had a direct impact on the improvement of safety levels, as it facilitated the management of these same blocks. When problems emerged, they could be contained or positioned within a specific block. The transition to blocks of space implied the informatisation of the track, by turning its management into a binary process – train allowed and not allowed to enter a block of space, and block of track available or not available for the entrance of the next train. This division also allowed a better understanding about the location of critical points along the tracks (blocks of space with higher propensity for delays) and the real capacity of tracks (possible number of trains to cross each block per hour).

This early process of informatisation opened the door to a new wave of entrepreneurial activity, during which carriages and tracks became separate and owned by different companies. This means that there was a move away from the railway as a single unit towards a system that offered more flexibility and that could be treated in a more dynamic and flexible way. The fine-tuning of carriages and the tracks was no longer essential for the functioning and management of the railway, allowing the emergence of segmentation and a separate ownership. The separation into distinct elements had the side effect of increasing the level of complexity. As the entrepreneurial activity grew, each element, from the carriage to the rail tracks and stations, had to work in a coordinated manner and fulfil their own role in order for the entire system to be functional (Urry, 2007, p.94). At the same time, this separation into different elements allowed more flexibility, segmentation and modularity of the system, all characteristics that tend to be associated with the 'digital', anticipating many of the qualities we associate with computation.

The introduction of the electric telegraph and the implementation of a block system also had a strong impact on the role of the driver. This new signalling system, managed spatially, allowed liability to be transferred from the "engine drivers" to the machine – the telegraph transmitter. During its early implementation, it was used, for this reason, side by side with the earlier management system based on time intervals. Sceptics about the block system claimed that it took away too much responsibility from the drivers and signalmen, promoting the reduction of their "alertness and sense of responsibility" (Simmons, 1986, p.195). The concern was not simply with the introduction of a new technical capability within a specific urban system; the process of convergence with the electric telegraph was, once again, a radical transformation for the wider railway assemblage. The engine driver moved from a central to a secondary role within the overall assemblage, as he was no longer the main decision-maker. What this means is a further alignment between the elements in the overall system, where automation and informatisation changed the dynamics in place and increased the sensation of a long-distance network.

If, in its early stages, the railway was defined by the fine-tuning between infrastructure and means of transport, as it matured with the arrival of the electric telegraph, the railroad gained a communicative quality that transformed the entire assemblage and existing dynamics. The move towards the block system led to a better and more detailed control of the infrastructure, even after including a larger group of elements in need of coordinated management. The breaking into blocks, increase of independent elements and division of the infrastructure into a model where each element could be modulated in order to better fit the entire assemblage radically transformed the context of the railway by facilitating its management and consequently monetisation.[80] Each independent element was part of a wider ongoing communication among the different elements. Therefore, the block system did not

[80] The subdivision of a structure into smaller parts, in order to make it easier to manage and more agile, is common practice. At the time, this had already been put into place for the delivery and distribution of mail outside of local areas. The mail routes were subdivided and multiple couriers and modes of transport were used in order to reduce the time needed for delivery: "This subdivision of the formerly unified effort caused the process to become intensified, but the system remained subject to the limits of physical capacity, even though this was now the sum of the physical capacities of all the individual relays" (Schivelbusch, 1986, p.8). The different relays throughout the route made the use of animals and couriers more efficient, as their new routes were shorter and more realistic given the resources they had before the arrival of the railway.

simply result in the tailoring of services and their consequent monetisation; it implied a better and more efficient control system that was simultaneously an ordering of risk.

When it is stated that the telegraph brought communication to the railway, it is meant that an information system was introduced to this infrastructural system. The role of the signalling system was, in the narrowest sense of its action, to transmit information. It was like a command–control task. Therefore, even if in this context information and communication could be conceptually separated, as communication implies more than mere messages, the rise of computational technologies has meant that "every communication system […] is an information system" as "communication too depends on control signals" (Kittler, 1996). This is especially true in infrastructural contexts where the level of complexity tends to be high. Historically, this separation has emerged, following Kittler's account (1996), as a consequence of the transition of communication from face-to-face to writing and then to technical media. The introduction of the electric telegraph to the railway meant that "for absolutely the first time, information was decoupled, in the form of massless flow of electromagnetic waves, from communication", making the relation of the telegraph with the railway one of pure information (Kittler, 1996). This to conclude that when it comes to the strict analysis of the telegraph as a signalling system, it was indeed an information system at work. However, in the context of the infrastructural system, the signalling system was part of an internal communication system – necessary for the coordination, stability and strengthening of that context with the consequences that have been discussed so far, at the level of control and risk management and the rise of the entrepreneurial activity.[81]

As established, the convergence between the electric telegraph and the railway had many more far-reaching consequences than those that could have been anticipated at an initial stage – they went beyond a simple improvement of the signalling system and safety. The telegraph brought into the railway a process of informatisation that transformed the overall technical system and opened it up to its

[81] The influence that the increased complexity of railways had throughout society was well beyond being a mode of transportation, especially for its conjugation between information processing, control and communication. This triad inspired the "electrical tabulation system" developed by Herman Hollerith (Beniger, 1986, pp.411–412). More precisely, he was impressed by "the use of punches to make [the railway ticket] unique to each passenger (by holding the passenger description" (Beniger, 1986, p.412). This inspiration resulted in "probably the world's first machinery to process information as a material flow", where different elements had to be coordinated among themselves, at a similar level to the emerging railway system (Beniger, 1986, p.412).

context of action, at the same time that it allowed the division of the overall system into smaller blocks. Many parallels can be drawn with how the extension of computation takes place nowadays and therefore the reason for this analysis. The different elements that are affected and transformed could result in similar outcomes through a contemporary process of softwarisation and datafication, as I will emphasise in the rest of the chapter. The process of informatisation implied that the railway model shifted from a linear approach, centred on the track and the ability to move the train from station A to station B, to a more distributed system – both at operational and management level. A direct consequence of this was that the railway was no longer an infrastructure of carrying and connecting – it became a system where modulation emerged, with a more flexible approach to control and management. It was turned into a mediator between a variety of providers and a diversity of entrepreneurial activities. It allowed a tailoring and segmentation of services to regional preferences. Altogether, this reflects many of the elements discussed in the previous chapter, as consequences of the computational extension into urban infrastructure, and it also allows new perspectives to emerge on technical systems when further contextualised within the conceptual framework that Simondon (1980; 1992; 2008) offers on the evolution of technical objects.

3.3. From convergence to concretisation

Following the analysis of the convergence between the railway and the telegraph, I would like to cover in more detail how the process of convergence is more than a simple coming together of previously separate technical elements. As already seen, convergence opens up new opportunities for extension and stabilisation of the technical assemblage, leading to new material and non-material arrangements, at times deeply transforming the affected systems. To proceed with this reflection, I draw on Simondon's concepts (1980; 1992; 2008) of individuation, concretisation and associated milieu in order to bring forward existing dynamics among complex urban systems and their general tendency towards concretisation.[82] More precisely, I

[82] It is important to highlight that the context of this research, as was discussed in the previous chapter, is very different from where Simondon positioned himself while working on his doctoral thesis, later published in 1958 as the book titled "On the Mode of Existence of Technical Objects" (2008). The role played in contemporary urban systems by the extension of computation would have been difficult to be imagined by Simondon at the

propose that this tendency is often initiated by a process of convergence, just like the process described. When we look at the dynamics unravelling among technical elements forming complex urban systems, what becomes visible is the existence of what I propose to be a four-stage process comprised of convergence, amplification, stabilisation and finally concretisation. The objective is to demonstrate, as stated at the beginning of this chapter, that by understanding how technical systems evolve, new insights and perspectives on the impact of the extension of computation will emerge, beyond the analysis of its outcomes on the experience of urban territories and those that come into contact with it. Overall, Simondon (1980; 1992; 2008) offers a conceptual framework that, when drawn on, technical systems emerge from as evolving assemblages desiring long-term stability and concretisation with their context of action.

By using this conceptual framework and path of development within the context of complex urban systems, trends will be found and tendencies will stand out in the way processes of softwarisation and datafication take place. It will be possible to position moments of intense computational extension with specific stages of the path of development. Similarly, it will also be shown how the extension of computation can be contextualised within ongoing dynamics unravelling between the technical elements of the assemblage, e.g. the way computational processes work through the infrastructural add-ons as a means to get closer to technical system's core, but also with the objective of slowly working out existing tensions within the technical system and between these and their context of action. This is of particular importance to highlight, as the concretisation of systems takes place nowadays largely by the action and outcome of computational processes. The extension of computation throughout different aspects of urban territories has had a very tangible impact on technical objects and their relational existence. As Yuk Hui (2015b) states in one of his many references to and analyses of Simondon's work, each period has its own type of concretised systems as they are necessarily aligned with their own contextual existence and timing. In the case of our

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time of his doctoral research, being for that same reason not part of the vast list of examples he provides throughout it. Nonetheless, it is important to mention that for Simondon, technical objects and environment (or urban territories in this context) were already deeply entangled and interlinked; they could not be taken separately or independently from each other (Neves, 2007, p.68). For Simondon, the real technical jump and revolution came out of the ability of machines to become auto-regulated and sensitive to other machines. This means it was their newly gained indeterminacy that transformed the rearrangement of technical systems (Neves, 2007, p.73).

contemporary context, he proposes it to be "the epoch of concretisation of relations in terms of data and metadata (i.e. data about data)" (Hui, 2015b, p.140). When it comes to complex urban systems, in addition to data and datafication, it is also necessary to consider the role of software and the process of softwarisation in their own concretisation. As will be shown, the path towards concretisation followed by complex urban systems expresses a clear acceleration and intensification that is both enabled and strengthened by processes of softwarisation and datafication. It will be revealed that these two processes help in taming tensions and working through differences by amplifying the affordances and thresholds of the technical assemblage and actively contribute to the system's concretisation.

3.3.1. Individuation, concretisation and associated milieu

The choice of drawing on the concepts of individuation, concretisation and associated milieu is not a casual one. They refer to three key aspects of complex urban systems and the implications of the extension of computation throughout their assemblages. It is important then to understand how Simondon's work is read and the perspective taken on it with this context in mind. Individuation, in this context, refers and implies the already discussed continuity and evolvement of complex urban systems. As will be shown, this process of evolvement has the objective of achieving a concretised condition that implies an alignment and attunement with a context of action (which Simondon refers to as associated milieu). In addition, the analysis made below aims at demonstrating how computational processes have come to reinforce and intensify many of the aspects conceived by Simondon in relation to these three concepts.

Let us start with the process of individuation, one of the key aspects of Simondon's work that has received more attention from philosophers and cultural theory (Boever et al., 2009; Deleuze, 2004; Hui, 2015b; Mackenzie, 2002; Stiegler, 2009; Toscano, 2007). Individuation is important in the sense that it refers to the continuous evolvement of technical objects towards concretisation. Individuation refers then to "ontogenesis" and "the very process of becoming of an individual" (Boever et al., 2009, p.37; Brunner & Fritsch, 2011, p.122) and in this case, of technical systems. It implies a level of evolvement concerned with solving existing tensions and “negotiating their future composition”, especially in those cases that offer more plastic characteristics (Brunner & Fritsch, 2011, p.122). Individuation, to be complete as a process, needs an associated milieu (a context of action), against which it can be “auto-regulated” (Simondon, 2008, p.85). Individuation is easier to find in living bodies as these have an “internal dynamic” that ensures evolvement and transformation (Rodríguez, 2008, p.11). However, due to the characteristics of physical matter, individuation happens here at a different speed and degree. It is important to understand that the process of individuation is never concluded within technical systems, as there is always a need for further stabilisation (Rodríguez, 2008, p.12). The objective to achieve concretisation is more like the aim to reach a state rather than the finishing line, implying the continuity of individuation.

In the context of complex urban systems and their relational locations, the concept of individuation helps us to understand these systems as non-static. Instead, they emerge as continuously seeking further stabilisation towards concretisation, in an ongoing evolvement aligned with their needs and the relations they establish. In the case of the railway, the process of convergence, initiated with the introduction of the electric telegraph, can be seen as a push towards concretisation, or as a moment of acceleration during this same process of individuation. By improving the safety levels of the railway journeys and the overall infrastructure, the risk was reduced; in these becoming safer, there was less of a challenge to the continuity and stability of the system. The process of convergence was then more than a technical convenience or casualty – it was a step closer towards solving a degree of tension existent within the system, which was putting this same system at the risk of falling apart. Besides, the process of convergence was followed by the opening up of the infrastructure to new providers, thereby creating new relations, opportunities to grow, higher dependency on the services being offered and possible paths towards stabilisation. The process of informatisation as described earlier and its range of consequences is shown to imply an evolution, the continuity of the system, previously shaken up by major railway accidents (Simmons, 1986). Within complex urban systems, as both the case studies will show, processes of individuation are often accelerated and intensified through softwarisation and datafication and their ability to connect, tone down, work through differences and find new ways of bringing in new elements.

Already with the transitional process of technical objects in mind towards more sophisticated and complex arrangements, the process of individuation as proposed by Simondon follows a specific genealogy of technicity, which is divided into three stages.[83] It starts with "technical" or "abstract elements" in reference to tools handled by the man, followed by "technical individuals", such as machines with no need of human intervention in order to work, and finally, "technical ensembles" like in the case of factories and workshops (Simondon, 1980; 2008). In this context, it is relevant to highlight the opposed position between the abstract object and technical ensembles. In the first case, it implies the tool directly handled by the man and put into action by himself, meaning that this tool is not integrated with its surroundings; it is simultaneously isolated from other objects and the outcome of a series of knowledge formalisations concentrated in that same object (Simondon, 1980, p.40).[84] The abstract object is at a level where it needs to work "as a closed system in order to function" (Simondon, 1980, p.20). Within this genealogy of technicity, complex urban systems can be placed within what Simondon describes as technical ensembles, as their assemblages of technical objects have already achieved a certain degree of concretisation, integration and adaptability and therefore have the ability to work like a large assemblage of diverse technical elements. Complex urban systems already imply, then, a large range of interactions among technical elements and a degree of openness to other systems and technical objects. Although already expressing a degree of concretisation, they will be taken here as assemblies working continuously towards further concretisation.

A technical ensemble becomes naturalised as it becomes concretised; it achieves concretisation through the process of individuation. In any case, it is important to retain, once again, that concretisation is not the end line and

[83] It is important to highlight that the technical lineage meant for Simondon the "internal operation" of objects and the "development that is led by the technical structure itself", very different then from "functional or instrumental progressions" (Mills, 2011). This means that the "steam" and "electric train" belong to different lineages, regardless of the fact that "they fulfil the same purpose" (Mills, 2011). In this context, the conceptual framework of Simondon is extrapolated to the dynamics of complex urban systems. What is being proposed is that the understanding of these systems can benefit from the conceptual framework developed by Simondon as a generic path of development shared by complex urban systems.

[84] Simondon also speaks of artificial elements. These elements should not be confused with abstract elements; they are not opposed to abstract elements or something that is already concretised. The artificiality of an object is directly related to its dependence on the man to protect it from the natural world. The artificiality of an object does not imply that it was entirely built or made by the man, but that it was modified by the man, such as the well-known example provided by Simondon of artificial flowers: they are produced in greenhouses with a genetically modified reproductive system, meaning that they no longer can subsist and reproduce within their natural environment (Simondon, 2008, p.67). They have lost their essence and the ability to survive on their own.

movements within that same state of concretisation can take place. Only nature is fully concretised as "all functional parts are [already] 'overdetermined'"; within technical objects there is always the possibility for further concretisation (Schmidgen, 2004, p.8). When it comes to technical objects, new needs can emerge, the context of action can require adaptation or other ensembles can come into competition, demanding new approaches. In the case of complex urban systems, this can also happen through elements that are added at a later stage to the core structure, not out of a necessity, but as a consequence of a commercial need or the desire to better tailor them to their own context. These non-essential technical additions (or also add-ons) can result in an increase of weight, stagnation and even viability to that same technical assemblage, but they can also transform and open new paths within it.

From Simondon's perspective, the addition of non-necessary elements is always negative as it is counter-nature to the technical object (Simondon, 1980, p.22). The personalisation of the object means, for example, in the case of the motorised vehicle, that "the body-work becomes loaded with accessories and the shape no longer approximates a streamlined structure", resulting in an external imposition that has nothing to do with the technical nature of the object or its own naturalisation and integration (Simondon, 1980, p.22). This can lead to a recession of the level of concretisation. Simondon's perspective on this can be described as one of extreme pragmatism and also very utilitarian. Nonetheless, as will be discussed shortly, these add-ons are common; they increase the level of uncertainty and openness of the system and allow novel ways to emerge, as well as the unravelling of new paths. They can provide new perspectives and insight into the dynamics of contemporary complex urban systems; non-essential additions ensure demand, increase of dependency upon that object and open the door to possible further processes of convergence and consequently concretisation. I argue then, in contradiction to Simondon's view, that add-ons are actually essential for the evolvement of complex urban systems towards concretisation. Add-ons and non-utilitarian elements are a crucial part of what pushes systems forward within contemporary urban systems. This can be potentially seen as a direct consequence of the extension of computation, as it forces the reformulation of add-ons as more than merely material elements adding weight and attrition to the overall system.[85] Furthermore, add-ons in the context of the extension of computation offer a low-risk way to transform and challenge installed dynamics.

As said, concretisation is both a process and a stage, and it refers to tensions and disparities being solved. It is a process of individuation that takes a tool from being handled by the man towards a context of integration with its surroundings. Concretisation is then close to a technical entanglement that slowly achieves balance and stability, as tensions become resolved; it implies the increased naturalisation of a system. Furthermore, it indicates integration as different aspects of the system stop operating separately or independently from each other, leading to a system "coherent with itself, entirely unified" (Simondon, 2008, p.45). From the perspective of contemporary complex urban systems, convergence implies a "structural unit" of "hybrid objects" (Vries, 2008) – objects that have been reformulated, mixed and brought together through the actions of computational processes, referring back to the discussion on softwarisation and datafication made in the previous chapter. These processes bring a more dynamic adaptation, an approach of working with and through their context of action. It could be said that the process towards concretisation takes place through a range of relations of mutual feedback and affordances with its context of action, now increased and amplified by computational processes. As a technical element (part of a larger technical assemblage) slowly adapts to its own context of action, it becomes released from its own origin, previous to being part of the assemblage. The technical object is reformulated; it is turned into something else, no longer defined on its own or by itself. It is through this range of affordances and openness that the object regulates and is regulated, solving its tensions.[86] Furthermore, concretisation is slowly achieved by the coordination and stabilisation of a range of processes that take place between the core and secondary parts of the infrastructural assemblage.

[85] In the case of complex urban systems, an assemblage fully formed by its backbone would result in a very closed system, without paths of alignments with its context of action or auto-regulation.

[86] It is important in this context to add a note on the difference between automation and concretised systems. Automation refers to closed systems, systems that are not sensitive to what is external to them (Simondon, 2008, p.33). In concretised systems there is always a degree of openness, of indeterminacy, as a system is never complete; it can always be found to have a degree of "sensitivity to outside information" (Simondon, 1980, p.13). Complex urban systems can arrive at a stage where they become automated systems, but in most cases they will always include interactions with other systems, a control room or moments of interface with their own dynamic contexts of action and evolvement. Utopian discourses on fully automatic and programmable environments can be found within the conceptualisation of smart cities and their top-down development plans (Gabrys, 2014).

Computation often enters these systems through their secondary elements, slowly making its way to the core of the infrastructure. As this process takes place, tensions can be solved as they emerge, resulting in a continuous degree of stability that ensures the functioning of the system.

Overall, concretisation does not mean complex or a higher level of complexity (Simondon, 2008, p.52). What can be found is the opposite – an over-determination, which implies "stabilising its functioning without aggregating a new structure", where each structural element covers more than one function (Simondon, 2008, pp.52–53). It implies sophistication. The closer the technical object gets to concretisation, the more over-determined its functions become (Neves, 2007, p.73). That is why over-determination is taken as "the natural effect of concretisation" (Vries, 2008), as a system can only achieve this level of functionality once it has reached a high level of maturity and experience. The extension of computation, through the processes of softwarisation and datafication, plays a key role in this. These processes have the ability to bring together previously disparate elements into the same processual dynamic. Therefore, when softwarisation takes place, the area of action and its scope can be extended without necessarily adding new elements. Its ability to mix, hybridise techniques and create new ones can also lead to the reduction of material supporting elements. Moreover, a higher functional complexity does not mean a necessary increase of more complexity within the system. It implies instead elaboration and sophistication of the sustaining code.

Now, in order to arrive at technical ensembles, it is necessary to have a set of contextual arrangements that sustain their evolving dynamic. This means that "the technical object increasingly requires a *technological milieu* in order to exist" – not only does the context of the technical ensemble imply "automation", "energy" needs and "remote control" (Simondon, 2010, p.234), but its computational reality implies a position hidden away in black boxes. Technical ensembles are often highly regulated sites – health and safety environments, internal surveillance, secured storage, recorded and managed accesses, technical redundancy and so on. Put differently, the existence of the technical ensemble already implies a transformation within the dynamics and relations established among technical elements, as well as within its context of action (referred to by Simondon as associated milieu). For example, as the assemblage of the railway evolved, time had to be standardised, postal services and newspapers were transformed and finally there was an increase in the entrepreneurial activity within the entire railway system. The individuation that took place was done together and in parallel with the context of action; both the technical ensemble and its context of action were sustaining and enabling each other. In any case, the description of the technological milieu necessary for the running and sustaining of the technical ensemble can be compared to complex urban systems and their territories of action.

The associated milieu implies, following Simondon's perspective, the context that constrains the technical object and which is simultaneously created by this same technical object (Simondon, 2008, p.78). As a technical ensemble becomes further concretised and naturalised, it also becomes more integrated with "the environment external to the functioning", resulting in an integration between the technical system and its environment (Bontems, 2002, p.5). This results in a "global functioning" – meaning that "what is first outside the object, as background or "associated milieu" becomes an internal environment inside the object" (Bontems, 2002, p.5), leading to a co-evolvement and co-stabilisation. The implication of this is that concretisation "always affects its environment or location" (Mackenzie, 2010, p.125). More than a simple context of interaction that is positioned externally, the associated milieu is also a "dense zone of potential, which shifts with each becoming of the individual" (Brunner & Fritsch, 2011, p.125). The position of the associated milieu is then of crucial importance, where moments of technical interaction can also be taken as expressions of the way of working of technical objects; therefore, this is the reason for my reiterated insistence on the context of action. The relevance is not so much the outcome of the complex urban system on this context as the co-evolvement and co-stabilisation that take place. It implies a context of action that is in the context of our analysis already infrastructural, computational and relational in the ways it sets the conditions for engagement and interaction.

This can only be properly grasped if the associated milieu, or as I refer to it, the context of action, is understood as a site of "resolution" for a concrete problem, which can be achieved "in two complementary ways" – "*internal resonance"* and "*information*" (Deleuze, 2004, p.88).[87] "*Internal resonance"* refers to the solving of

[87] Italics in original.

an internal problem or tension as has been discussed so far, while "*information*" is the process of communication between two distinct elements, in a direct implication of the internal and external, or between the technical ensemble and its associated milieu (Deleuze, 2004, p.88).[88] The co-evolvement of the associated milieu and the technical ensemble is enabled by this line of "communication between two disparate levels" (Deleuze, 2004, p.88). Without this communicative interaction and exchange of information, both co-evolvement and concretisation would be much harder. What will be shown later in this chapter is how the positioning of practices of standardisation and risk management, within these same associated milieus, takes advantage of this communication channel and how they work as modulators and constrainers of technical systems. In any case, the internal and external should not be taken as binaries.[89] As we have already seen, the process of ordering differentiation (and interior and outside or disparity) is compatible with the stability and evolvement of complex urban systems.

Placed within the context of action, practices of standardisation and risk management play an essential role in the long-term sustainability and concretisation of technical systems. Technical standards and computational protocols can be an exemplification of this, as they ensure the possibility of extending and connecting with other infrastructures. The process of coming together or convergence, like in the case of the railway, is to a degree enabled and pushed forward by the development and implementation of standards. The more complex the system gets, the more elaborated and embedded these practices become. In the case of standards, this becomes visible when a technical element is recognised as the industry's standard. From Simondon's perspective, the push for standardisation happens as a consequence of external pressures but also due to internal dynamics – as he explained, it is not mass production that leads to standardisation, but the internal need to work in wider ensembles that requires a degree of standardisation (Simondon, 2008, p.45). To achieve stability, both among technical elements and in the context of action, requires a series of 'controllers' and 'toning down' actions that facilitate the exchange of information and the overall flow of the system.

[88] Italics in original.
[89] See section and discussion on the local–global in the previous chapter.

Finally, stability in the context of infrastructure implies a low degree of change and transition – this means that as the system becomes stabilised, it also becomes harder to encourage transformation and evolvement within that infrastructural setting, allowing the strengthening of what has allowed that same stabilisation. Concretisation and standardisation share the same objective of stability. More precisely, concretisation is already the outcome of a previous process of stabilisation. As Bowker and Star (2000) already demonstrated, once settled and established, standardised systems become hard to change. Each element of a given infrastructure or technical system inherits a degree of what was already in place – there is an evolution, not a radical transformation or negation – as standardised stability creates inertia. Previously, when technical objects moved towards concretisation, they started by integrating with their surroundings – with other systems and their own context. As tensions were slowly resolved they became closer to their naturalisation. This does not mean, in the context of this research, that a complex urban system becomes and behaves like nature. It means that it becomes so integrated into its own context, taken for granted and unquestioned, that it recedes and becomes forgotten – it becomes experienced as an extension of its own environment. The receding adds further inertia to what was already working towards its own stabilisation. This would help to explain the difficulty in introducing significant transformation to systems that have not been challenged for a long time, as can be the case with some traditional urban infrastructures.

Given what has been discussed, it is possible to see how these three key concepts developed by Simondon as part of his conceptual framework on the evolution of technical objects offers us the basis to start looking at complex urban systems, the extension of computation and their context of action from a different perspective. As many elements are at play when a complex urban system develops, it becomes clear that it is the ultimate desire of these elements to achieve a deep level of concretisation with their context of action and this, simultaneously, ensures an important level of stability and long-term sustainability. Next, I attempt to take these reflections to the context of the proposed path of development of complex urban systems. Together with what has already been discussed, the importance of location and how its enhancement takes place will gain again more visibility.

3.3.2. The path of development

As it is possible to see, the objective has been so far to use Simondon's conceptual framework as a way to think through complex urban systems and the existing dynamics among their technical elements.[90] Henning Schmidgen (2004, p.11) proposes that the conceptual framework offered by Simondon allows us to think on technical objects or open their "black box" from two perspectives – firstly, through the understanding of the "dynamic co-evolution" of individual or group of elements, and secondly, through how certain groups evolve "within larger totalities or ensembles." Although both levels are of interest and aligned with this chapter, I would like to add a third perspective which emphasises the path of development towards concretisation and then the interactions established between technical systems and their associated milieus. More precisely, this is a perspective that dwells on each stage of this path in order to understand what processes can unfold within complex urban systems and what this means for their unravelling throughout urban territories – their outcome, impact and way of acting upon their objects of concern (see Table 1). Following this, if we were to retell the story of the railway and its posterior development as we have discussed so far, it would be possible to do so through the placing of the narrative within the already mentioned four stages of development: convergence, amplification, stabilisation and concretisation.

Before I move into the analysis of these four stages in relation to the process of convergence that opened this chapter and our general concern with complex urban systems, I would like to propose a short detour to innovation theory and in particular to three points that seem of special relevance to our discussion: the issue of linearity, the possibility of coexisting multiple stages of development within one single complex urban system and the need for openness in order to achieve long-term stability. When we think of innovation theory, the proposed four-stage approach to the development of complex urban systems can seem redundant at first sight, as much has already been done on innovation paths used in relation to infrastructure and technological development (Edwards, 2010; Hughes, 2012; Pinch & Bijker, 2012). However, it is important to take the path of development that I

[90] The conceptual framework of Simondon has already been extended and applied before within social and cultural contexts as it is possible to see in the work of Adrian Mackenzie (2002), Simon Mills (2011) and Christoph Brunner and Jonas Fritsch (2011).

propose as offering a thorough understanding of complex urban systems from the perspective of their own dynamics that necessarily takes account of how the extension of computation has fed and transformed specific infrastructural dynamics. This means that the objective is not so much an understanding of the evolution of a technical object *per se*, like in the case of innovation theory, but rather of how a group of technical objects come into concretisation within urban contexts and the wider consequences on the overall spatial dynamics.

Linear models of technical development seem to share an implicit challenge from their outset, as they are concerned with narratives that tend to be very irregular. If the linear model can seem productive in a textual format (like the way the development path is presented in this thesis), when paths of development are analysed contextually, this linearity automatically becomes too reductive and even inaccurate. For example, what tends to happen within complex urban systems is that different elements evolve at distinct speeds and establish a range of relations that will not achieve stability until a much later stage. In part, this happens due to the ability of these systems to host disparities and integrate new add-ons without that meaning the inability to proceed. For this reason, one of the issues with linear proposals is that they assume that there is a level of unity and coherence that is shared and preserved throughout the evolvement process of technical development. This unity very rarely is established from the very beginning of the technical object, as otherwise it would block the continuous need of technical objects to adapt and solve tensions in order to achieve a stable arrangement (Pinch & Bijker, 2012, pp.15–16). With this, I am stating that the path of development presented here as a linear arrangement is a necessary resource to explain more complex dynamics, as I will have the opportunity to further explore throughout the two case studies.

In the case of innovation studies, these have often not paid enough attention to their technical dynamics, own materialities and interaction areas. For example, a linear "model of the innovation process" will often look like the following sequence – "basic research", "applied research", "technological development", "product development", "production" and finally "usage" (Pinch & Bijker, 2012, p.17) or "invention, development, innovation, transfer, and growth, competition, and consolidation" (Hughes, 2012, p.51). In both cases, the object of concern is presented as a stable unity that is maintained as it goes through its evolution path, unless it fails at some stage. There are no stages within these paths that include the possibility of new arrangements, radical detouring or deep challenges to their unities. However, if we think about these processes from the perspective of individuation, it is possible to see that they are generally not linear, with the existence of moments when different directions are taken or there is a splintering within the system. Individuation works through tensions; it already assumes that changes and evolvement will take place. As technical systems become further concretised, they arrive at a stage where they need to be aligned with their own context and that may require quick and radical adaptation. In the specific case of innovation development, what usually happens is the "overlap[ping] and backtrack[ing]" of the mentioned stages (Hughes, 2012, p.51), even if such events are not made visible in its development path. This means that "invention" and technology "transfer" may not take place at the moment initially set out and planned (Hughes, 2012, p.51). The path of development that the electric telegraph went through during its early years confirms this iteration and quick adaptation; otherwise how could it have been used beyond its early patent as an alarm system?

When it comes to concretisation, both a technical and engineering perspective show that this can only take place as the outcome of "phases of continuous progress (adaptation)", which are then balanced out by "other phases of saturation during which major improvement must emerge as a global reconfiguration of the structure (invention)" (Bontems, 2002, p.2). This further emphasises that a linear evolvement towards concretisation is very unlikely, as the rhythm and intensity of evolvement depends on "ruptures of gradual evolution" out of which innovation emerges (Bontems, 2002, p.2). As said before, invention and technological transfer might occur at different stages as breakthroughs happen or new lines of evolvement become visible. The rhythm with which invention happens within "a technical lineage" demonstrates that the process of concretisation is not necessarily equal throughout the system as different elements develop at different speeds according to technical development (Bontems, 2002, p.2). What at some stage might seem as fast-forwarding towards concretisation can then enter a moment of temporary stagnation as it attempts to solve frictions and tensions in place.

This can be interpreted as an implicit reference to openness, as concretisation requires a system that offers throughout its path of development the ability to work out what was unexpected and a channel of communication and auto-regulation with its context of action. As Thomas P. Hughes (2012, p.47) explains, only by bringing "environment into the system" can "sources of uncertainty" be reduced. This openness to their context of action from technical objects allows a quicker response and feedback mode (Hughes, 2012, p.47), like in the understanding developed by Simondon on the associated milieu. As we saw before, a system close to concretisation means that it has already developed and strengthened a range of relations with its context of action. More precisely, this means that both of them, the system and context of action have already achieved a degree of co-evolvement. Besides, this co-evolvement ensures that tensions can be toned down and finally solved. A closed system that is too focused inwards slowly becomes increasingly more similar to an abstract or automatic technical system, feeding into and depending on itself to generate interaction and continuity.

What can be concluded and transposed to the context of complex urban systems is that there are variable speeds and diversity of intensities throughout their path of development. Moreover, as a system, it is not a homogeneous group moving together through its path of development towards concretisation. The extension of computation plays an important role in these characteristics due to elements that have already been discussed: the move from the fringes towards the core of the system, the differences between core and add-ons, the ability to order difference while maintaining shape through continuity and the division of the system into parts that become modular, among others. In addition, the computational processes of softwarisation and datafication allow the introduction of new variables that facilitate the extension of the affordances and thresholds of the system.

Returning to the path of development (see Table 1), I want to start by reconsidering again the process of convergence that was already briefly covered in the context of the electric telegraph and the railway. As was seen, the entrance of a new technical element into an already existing assemblage generally leads to the rearrangement and transformation of that same assemblage (Law, 2012). This process tends to be initiated with a clear objective, or as a way to deal with already existing needs and tensions. When two technical elements or systems come together by means of convergence, they are seeking a way to solve tensions or problems. For this reason, convergence, as a rule, brings with it a push towards concretisation, as it offers the possibility of continuity.

As discussed earlier, the telegraph was brought into the railway as a signalling system aimed at improving security and the efficiency of the rail tracks. In reality, it worked as an early information system, which once in place, fed into many transformations at the entrepreneurial and control level of the assemblage. It allowed a further stabilisation while opening the doors to new potentials. The extension of computation into complex urban systems, which in many cases happens through what can be described as convergence processes, has a similar outcome. It achieves this by taming heterogeneous elements and existing disparities, due to its ability to work as a bridge and a mediator between opposed elements by means of computational processes. When in the previous chapter it was discussed how computation brings a sense of continuity and topological relations among different geographic points, in reality, it means that computational processes are working through and with a specific technical arrangement, enabling relations that would otherwise not be possible to maintain or even establish. Computation has radically transformed the potential of convergence beyond a process of summing two technical abilities, by establishing those same relations that would be described as unexpected and transforming, mixing and creating new hybrids.

For the railway, what followed the initial moment of convergence was a new spatial and operational approach to its own technical assemblage; smaller blocks of space and the separation of the track from the rail brought a new layer of accountability, where different elements could be dealt with separately and in a more modular way. Nonetheless, in parallel to this level of control, new opportunities to open up the system were created. The railway entered then a moment of amplification as the conditions for a new wave of entrepreneurial activity were created: new players came in as service providers – infrastructure owners and other organisations, such as the postal services – which used the railway infrastructure as a way to improve their own services (Simmons, 1986). Suddenly, the company managing the railway was distinct from the one owning and managing the rail carriages. The process of amplification allowed an increase in the number of companies delivering services, as well as the range of services on offer.

Amplification is then the second stage of the proposed path of development, and it implies an intentional opening up of the technical system to the outside, more precisely, to its context of action. If at an initial stage, it is about exploring potentialities, as it moves forward, amplification becomes a way to extend scope and create dependency upon itself. It aims at creating a degree of dependency, by means of activating the dynamics among technical elements and the interactions and relations with its own context of action.[91] This process could be seen as an intentional drive towards a position of 'too big to fail'. To open up or amplify the context of action implies an intensive engagement between the technical system and its context of action. It increases indeterminacy and potential, which can lead more variation and further concretisation at a later stage (Mills, 2011). It is then at this stage that the associated milieu starts playing a crucial role in the stabilisation of and concretisation with the technical system. The opening up requires necessarily an ability to adapt and enter into relations of mutual benefit and cooperation with the technical system's context of action, so amplification can take place. Processes of data mining, creation and expansion of location-bounded services and use of qualculation as a way to become further established can all be seen as expressions of amplification. The process of datafication is in most of its versions a way to open up new scope, areas of management and forms of knowledge. Finally, it is important to also consider how important it is strategically for a system at this stage of development – it has the potential to create new records and logs of knowledge that can be revisited later on.

As risk and uncertainty increase as a consequence of the process of opening up, there comes the need to narrow down the openness of the system. This refers to the stage of stability. In practical terms, this means a reduction of the relations established by external elements with the complex urban system. This often becomes reinforced through the imposition of stricter standards and regulations, squeezing out smaller players or those with weaker positions. The objective is to create a context that, on one hand, faces less uncertainty and risk, and on the other,

[91] Carlos Barreneche (2012, p.342) gives the example of Google Places and Google Maps. Google Maps became "the *de facto* mapping platform of the internet" through a very aggressive strategy. By "offering a free-of-charge platform with an open API to attract developers", it reinforced simultaneously its privileged access to all types of metadata; it built traffic for its services benefiting in this way its main business area – online advertising; and it improved the services on offer (Barreneche, 2012, p.342). Thus Google quickly populated an ecosystem of locational systems, all directed in one way or another to its own platform.

is propitious to the creation of a monopoly where only a reduced set of strong external actors interact with a specific technical system. In the case of the railway, if the process of amplification allowed new services and small and larger players to compete side by side for a market share, when the system started looking for stabilisation, the number of players was intentionally reduced.[92] Stabilisation expresses then a higher level of integration with the context of action – there is already a degree of dependency between the technical system and the context of action. In practical terms it becomes expressed through elements such as default settings, technical standards, algorithm dependency for actions to unfold and so on.

What tends to follow is long-term stabilisation, where a complex urban system finally arrives at a position close to concretisation. Here, the system is understood as being deeply integrated with its context of action. A concretised technical system is a complex urban system taken for granted. When this stage is reached, tensions and problems have low impact; it is as if they were only concerned with maintenance. At this stage the main objectives are no longer innovation or market share. The complex urban system becomes about something else. By framing the evolvement of these systems within a general path of development, it helps in understanding the processes that usually occur during that same path and also at each stage, facilitating then the framing of the unravelling dynamics. The relevance of these stages becomes further visible throughout the case studies. In any case, the ultimate desire of concretisation shows that the highest objective is always the stabilisation of the system – between the different elements of which it is composed, but also with its context of action.

Overall, the path of development offers us a way to read the evolvement of complex urban systems from a different perspective. With its four stages, it tells us that the development of complex urban systems and the way that they evolve within their urban context is not always the same – their internal dynamics and the stage of development will have direct impacts on their outcomes and the spatial arrangements that they bring into being in each moment. The extension of computation has transformed these dynamics, but more importantly, it has brought

[92] This point is of major importance, and it can become easier to grasp if we think of the transnational market created for telecommunication companies within Europe as a process that followed the initial liberalisation of the market (the presence of Orange and Vodafone are now almost ubiquitous throughout the Euro zone), or how the implementation of tight technical standards and interoperability becomes used by multinationals as a way to squeeze out competition of future contracts in the same field.

into the system ways to accelerate and intensify each stage. In any case, the evolvement of complex urban systems would not be possible without the development of close relations and interactions with their context of action. It is, for this reason, important to reflect on the constitution and implications of these same contexts.

STAGE	WHAT TAKES PLACE	THE RAILWAY
Convergence	Two previously separate technical elements or systems converge and start working together.	The electric telegraph converged with the railway as a signalling system.
Amplification	The technical system is opened up to the outside – it can happen through a technical aspect or the liberalisation of the market. The context of action is key in this process.	The rail track and the carriage became independent from each other, while the track was divided up into blocks. This meant opening up to new entrepreneurial activity. More trains could use the tracks, and different companies could own different parts of the infrastructure.
Stabilisation	Once the technical system creates demand and dependency on its offerings, it starts an intentional process of closure. The intention is to reduce the number of players or competition in the field, ensuring a position of almost monopoly.	After an initial openness, the system had to reduce the services being offered, due to a growing risk of instability. Larger railway companies bought out competitors and practised aggressive pricing models in order to force out smaller providers.
Concretisation	The technical system has been stabilised, its working is taken for granted and it can easily recede into the background.	Existence of only a reduced number of large railway companies. They control both the service level and pricing model. They establish, define and control the standards in place.

TABLE 1: The path of development towards concretisation

3.4. Contexts of action

The conceptual framework of Simondon (1980; 1992; 2008) has given us the opportunity to consider what processes are taking place within complex urban systems as these expand their scope and scale throughout urban territories. By drawing on this same framework, I proposed a four-stage path of development towards concretisation. Its aim has been to understand what processes unfold within technical systems and the role that computational processes play within these same dynamics. However, one aspect remains to be discussed – the context of action – and its role in relation to concretisation and the emergence of relational locations.

The emphasis given to this comes from the perspective on two practices in particular – those of standardisation and risk management – that are here considered key to contemporary complex urban systems, urban territories and the way concretisation takes place. These practices are essential to the way technical systems are sustained and developed, and also to how relations between technical systems and their contexts of action are established at multiple levels. Practices of standardisation and risk management are shown to play a key role in the path of development towards concretisation. These two practices ensure that once a system has gone through a process of amplification, its potentialities can be contained to a certain extent and modulated into productive and stabilised ways of working and evolving. Processes of softwarisation and datafication have come to play a key role in the way relations are established and evolved into mutual dependency and co-evolvement. Expressions of segmentation, services tailoring and location-bounded services (Graham, 2004b; 2005; Kitchin & Dodge, 2011; Thrift & French, 2002) can be seen as part of the outcomes that emerge out of this interactivity.

Practices of standardisation, together with those of risk management, play an important role in the path towards concretisation of technical systems. They can be understood from the perspective of institutional management and externalities acting directly upon technical systems. They transpose to these systems the logic of "the "3C" thinking (command, control, communication)" which simultaneously implies "to be in charge of, and take responsibility for" (Fuller & Goffey, 2012b, p.33). This transposition means that as technical systems co-evolve with their context of action, practices of standardisation and risk management transform the ongoing interactions, relations and dynamics within these systems in order to feed into them a logic of control and liability. As these systems grow closer to concretisation, the separation between these practices and technical systems becomes harder to make, as they emerge increasingly more integrated and aligned with each other. They develop relations of dependency, co-evolvement and mutual benefit. Therefore, standardisation should be understood as implying more than a tendency towards alignment, as it is an intentional pressure imposed upon a system, often with a clearly pre-defined objective. Similarly, risk management refers directly to insurance and liability assessment. It tends to be materialised through 'terms and conditions' and the compulsive requirement of insurance. This implies the use of techniques that have the objective of "estimating risk in actuarial terms", expressed through "the *practices* of restitution and indemnification of damages"[93] (Ewald, 1990, p.141). The convergence of the electric telegraph with the railway was from its outset an active dealing with risk, while ensuring simultaneously a step closer to a more mature and stabilised system. As the system moved towards a more concretised condition, both standardisation and risk management came to play increasingly more important roles. Accountability increased proportionally to the level of informatisation and the ability to monetise different aspects of the overall assemblage. Without this transversal logic, the running of such a complex and diverse system would not be enforced. Both standardisation and risk management were like taming elements, a way to create the conditions for stabilisation and continuity.

3.4.1. Practices of urban standardisation

When it comes to practices of standardisation, this needs to be looked at from a broader spectrum, as standards also privilege and bring specific ways of working. Furthermore, once a system starts moving towards stabilisation and concretisation, standardisation gains a transversal position, as was also the case with the railway. For example, this was particularly visible in relation to the track gauge and the enforcement of a rail time that later became the standardised global time.[94] Standardised processes were also used for the issuing of tickets, signalling and management of the tracks, preparation for arrivals and departures at each station and

[93] Italics in original.

[94] Even with a signalling system in place, enabled by the convergence with the electrical telegraph, the railway remained a technical system too complex to be managed properly due to the lack of a shared time across regions and even regional towns – with each location keeping their own specific time such as "Reading time" and "Exeter time" (Urry, 2007, p.96). Previous to the standardisation of time in the United States, a traveller would have to set his watch "over two hundred times" throughout the journey between the east and west coast (Kern, 1983, p.12). The railway time arrived in the UK a few years after the introduction of the telegraph, in 1847, when "the railway companies, the Post Office and many towns and cities adopted Greenwich Mean Time" (Urry, 2007, p.97). The process that led to a shared global time was not easy, and it took decades to ensure alignment, being finally proposed by 25 countries during a conference in Washington in 1884. During this event, Greenwich became "the zero meridian" giving origin to "the exact length of the day, divided the earth into twenty-four time zones one hour apart, and fixed a precise beginning of the universal day" (Kern, 1983, p.12). The global standardisation of time was not immediate and would not completely arrive until the use of the electric telegraph was spread widely. In the context of the railway, the normalisation of time across the railway's field of action brought with it "the military mode of organization" (Mattelart, 1996, p.50). More precisely, it brought a command–control flow approach to communication (Mattelart, 1996, p.50). This was achieved by putting time and all time-recorded activities at the centre of the technical system and by transforming an action space into a functional grid of action (Mattelart, 1996, p.50).

so on. In addition, it is important to remember that the material expression of standards – imposed and applied through regulation, norms and classification – tends to go unnoticed or remain invisible (Bowker & Star, 2000, p.285). Standards become actualised through settings, defaults, supporting code and software, hardware connectors, protocols and so on. They are "a way of classifying the world" (Bowker & Star, 2000, p.13), "the glue" that often holds technical systems together and allows them to be productive (Cairncross, 1997, p.161), while ensuring "uniformity and quality control" through simplification and homogenisation (Timmermans & Berg, 2003, p.8).

Overall, standards tell stories about decision-making processes, unspoken objectives within a specific context and material limitations constraining their development. They, as in the case of many classification systems that have become standardised with the passing of time, are never "simple" – embodying a particular "*spatio-temporal segmentation of the world*"[95] (Bowker & Star, 2000, pp.10–11).[96] They carry reminiscences of the systems that preceded them, incorporating "traces of [their] technological ancestry" (Bowker & Star, 2000, p.126). More importantly, standards have a specific "inertia" embedded into them, meaning that once they are established, it is very difficult to make future changes (Bowker & Star, 2000, p.14). In part, this happens because standards are not just technical arrangements – they "form a juncture of social organization, moral order, and layers of technical integration" (Bowker & Star, 2000, p.33). They become a deterrent for radical changes, providing consequently a hypothetic ongoing stability to the overall context. This becomes even more perceptible if we think how complex urban systems become further embedded into their context of action as they get closer to concretisation. Stability and practices of standardisation move forward side by side.

The inertia and context of emergence of standards make them supportive of environments propitious to the appearance of monopolies, where the best-positioned

[95] Italics in the original.
[96] Already during Roman times, standardisation was seen as a process to facilitate the general consent in relation to urban use and display: each Roman city had "a set of standardized components used to assert and maintain Imperial authority" (Andraos et al., 2000, p.10). This was visible and expressed through its spatial organisation, which followed a set of principles and rules, facilitating the navigation of the city, but also its management. More importantly, it kept a formatted image – each building had a set position in relation to surrounding buildings ensuring a similar structure to all the cities of the Empire and managing proactively the expectations and social dynamics and relations of these cities.

players can influence and set the standards to be used (Cairncross, 1997, p.156).[97] This, as already discussed, can be particularly visible in a context where the technical system moves towards a stage of stabilisation.[98] Moreover, standardisation shows itself to be a productive tool that acts upon the development and concretisation of technical systems. What is prioritised, or the standards that prevail in the end, speak as much of technical preferences and affordances as of pressures being exerted upon the context of action of specific technical systems.

One element that exemplifies this position of taming and control (and impactful influence) is the role played by the 'default' setting. A pre-defined or default setting means "a preset standard" (Kelly, 2009). The default sheds light on the assumptions of usage that have been made during the design of a given system, meaning that the level of these assumptions increases exponentially as the system becomes more complex (Kelly, 2009) but also more embedded within specific contexts of usage. The objective of a default setting is not only usability or the improvement of the flow of a system; it embeds a series of contextual and cultural assumptions and specific desires of usage. Even in cases where some of these settings are open for change, they are often hidden away, "inscribed at the deepest levels of design" and only able to be accessed by those with "the knowledge, time, and other resources to do so" (Star, 1999, p.389). Default plays an essential role in complex urban systems as it controls available options and possible outcomes (Kelly, 2009); it steers use into a specific mode of engagement and interaction.

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[97] The reinforcement of contexts of power through the monopoly of standards within infrastructural systems can also be found at the level of European institutions, as is visible through the established close relationships between different European governments and private providers. These relationships and dynamics have made it possible to work on "integrated supra-national infrastructure networks", leading to the development, in parallel, of "competitive markets in telecommunications, transportation and energy services" across the European Union (Graham & Marvin, 1996, p.287). This was achieved mostly through "a standardised voltage across Europe" in order "to facilitate new competitive markets in electricity production and supply" (Graham & Marvin, 1996, p.287). Since 1996 much has happened within the European Union. The national markets of telecommunications, transportation and energy have surely been conquered by a handful of European multinationals working in these fields and that were previously, most of them, public companies in their countries of origin. In recent years, the European Union has actually made their "top priority" the "standardization of basically everything tradable" (Timmermans & Berg, 2003, p.12), this trend having been highly accelerated since 2007, especially throughout Southern Europe, where there has been a huge push for the liberalisation of any services held by central governments.

[98] For example, when it comes to urban infrastructure previously owned by the state, it tends to be a messy transition from public to a liberalised market. The previously state-owned company starts from the privileged position of owning the majority of the infrastructure placed both above and below the ground. In this way, combined with the dynamics that lead to the establishing of standards, processes of market liberalisation (or also amplification) lead in many cases to a further technical concretisation. The conditions for the initial opening up and amplification of the ecosystem are created, which are then followed by a quick reinforcement of the position of a reduced group of players.

In addition to the role played by the default setting, privileging specific uses of technical systems, we can find what Frances Cairncross (1997, p.157) defines as "gateways".[99] These are generally technical elements within an infrastructural system that give the owning organisation the power to implicitly "steer customers to particular products and services", and which are in most cases either essential hardware, software or unique produced content (Cairncross, 1997, p.157). These "gateways" are crucial control elements that steer dynamics and accelerate the positioning of certain organisations over others. This already privileged position, when combined with the capacity to establish and influence standards that are basically the connectors of the company's core service, puts this given organisation in a very powerful position where the domination of scale ("the economics of networks") and proprietary software ("the predominance of systems") becomes easier to achieve (Cairncross, 1997, p.159). The ownership of gateways can lead in most cases to a massive reduction of the elements forming a complex system, reinforcing the power to steer future dynamics into desirable arrangements and the power that standards have within processes of concretisation.

As described earlier, processes of standardisation occurred in a transversal manner to the railway assemblage. What is of relevance to our discussion is the relation of mutual dependency and co-evolvement that some of these processes adopted. For example, the entrepreneurial activity was intensified and strengthened throughout the railway as a consequence of the standardisation of time. With the alignment of time throughout the country, continuity and coherence in relation to the moving train was made possible at the level of operations, logistics and other entrepreneurial activities – such as "changing trains" and "transferring goods from one line to another" (Schivelbusch, 1986, p.29). This meant that long-distance travelling, as part of the modes of transportation, was brought into one shared grid of accountability and relation. The strengthening of a specific standard (such as the time) reinforced then other standards and the wider grid of operations already in place – it ensured stability and a further concretisation of the system with its context of action. The combination of the different standards into a normalised context of

[99] This conceptualisation of gateways is distinct from what Paul N. Edwards describes as gateways in the context of complex urban systems. Edwards (2010, p.11) presents it as being connectors allowing the interconnection of different elements, not always necessarily "technological", but if possible automatic. Gateways, from this perspective, are enablers of convergence processes, leading to the establishment of "*networks* or, at a higher level, *webs* (networks of networks, or internetworks)" (Edwards, 2010, p.11).

operations led to the improvement of the overall technical system's productive capacity, its "efficiency" and "effectiveness" (Graham & Marvin, 1996, p.284).

Finally, the role played by processes of standardisation in the context of the action of technical systems becomes particularly visible when a technical system starts to expand its territory of action. This means that it was when the railway expanded and interconnections between regional services started operating that shared standards became crucial. The pressure for the standardisation of the railway services, infrastructure and technology used was mostly felt when expansion happened beyond local contexts and across regional and national borders. The railway systems had to develop towards general shared standards, so integration with other foreign and non-local systems was possible.[100] In this sense, it could be said that practices of standardisation and scale are always closely interwoven with each other. More importantly, they allow the creation and strengthening of the context of action, which is primordial for the stabilisation and concretisation of a system. As tensions become solved through a relation of mutual benefit, the context of action and the technical system can extend, reinforce the extension of the logic in place over other possibilities and mitigate future and unexpected problems. It creates a path of continuity that is constrained into a certain direction through the reinforcement of specific standards, leading to the position of monopoly discussed earlier.

3.4.2. Risk management

Risk management also plays a key role in the stabilisation of complex urban systems as it supports the expansion of their territorial positioning, while exerting external pressure with specific objectives in mind. It is directly related to practices of standardisation. Through a relation of mutual benefit and often co-evolvement, risk

[100] The problem of standardisation of the railroad remains to this day – the current policy framework across Europe was initially designed in the 1990s and includes a vast range of agencies working together towards "a harmonization policy to increase the performance of the European Rail System" (Tilière, 2011, p.18). Nonetheless, shared technical standards remain so far an unreachable objective, due to economic costs in renovating infrastructures, political opposition and very disparate interests from different operators across so many countries. A well-known case is the gauge used solely in Portugal and Spain, known as the Iberian gauge, and the barriers encountered to replace it with the European Standard Gauge, which has meant that even when new infrastructure is created, the Iberian gauge remains the elected choice (García Álvarez, 2010). It is possible to find three main types of gauge being used across the European Union – the standard gauge used in most Western countries, the Iberian gauge (in Portugal and Spain) and finally the Russian gauge used in the Baltic countries and tightly connected to their geopolitical history (García Álvarez, 2010).

management frequently demands a way of acting upon risk that implies the imposition and implementation of specific standards. Together, as I propose below, they have a performative way of working in their relation to each other as well as to complex urban systems through their context of action. This often is made perceptible through data models, normalisation of operational processes and implementation of distributed data collection. These same expressions tend to feed or be the outcome of probabilistic approaches as a way of managing the future, as does reasoning through qualculative practices, and a modular way of working. If risk management is often made visible to the outside of technical systems as a 'terms and conditions' statement, within the dynamics of complex urban systems it takes place through processes that are often numerical, being in many ways deeply entangled with the extension of computation and its ability to record, reshuffle, calculate, combine and enlist. Risk management becomes then of relevance for its way of steering complex urban systems into paths of stability and concretisation which, in conjugation with computational processes, privileges the calculation of probabilistic outcomes.

In general terms, risk management has come to be mostly associated with the management of possible negative future events and more precisely their probability of taking place. However, it is not specifically concerned with precise events or the probability of them taking place. The object of concern of risk management is more generalist, towards a tendency where "anything can be a risk" – implying that risk evaluation is not an exact science as it "depends on the way the danger is analysed and the potential event is evaluated" (Ewald, 1990, p.142). Different perspectives on risk would lead most likely to different readings of its potential and likeliness of happening. In the process of defining and scoping risk, a context goes through the process of "disassembling, reconstructing, and organizing certain elements of reality" (Ewald, 1990, p.142), giving priority to certain lines of narrative.[101] Computation and the power and sophistication of data models have revolutionised the field of risk management, as calculation of risk is often an algorithmic activity engaged in the calculation of prediction and probability models. These data models

[101] Similar to the role of the norm within the disciplinary society (Ewald, 1990), risk management is then an important behaviour modulator within the contemporary context. It is possible to find practices of normalisation within the way risk management and standardisation become expressed; they both feed and are constrained by "the production of norms, standards for measurement and comparison, and rules of judgement", putting measurement at the centre of this context (Ewald, 1990, p.148).

support policy decisions according to the variables used, steering the practices of standardisation and risk management down specific paths, directly related to these same variables. In this way, computational processes act as normalisers of a field of action.

The rise of this approach to risk – as calculation, probability and modular variables – has led to risk being taken as something that needs to be dealt with proactively, before it takes place (Rose, 2005, p.15). Risk is being tackled as an abstract potential or probable tendency. The approach to risk within medicine is particularly telling about the prevailing implications of this tendency and probabilistic understanding of risk. This is particularly visible in the approach to DNA and genetic history – resulting in what Nikolas Rose (2005, p.15) calls the "pre-symptomatic diagnosis", turning all of us into objects within which potential risks need to be contained. Managing risk has become, in medicine, a proactive way of "refusing to live with uncertainty" (Rose, 2005, p.18); it has been turned into a continuous act of unfolding the future to come. This pre-emptive action on potential risk is the consequence of the rise of "risk awareness", which it is possible to encounter in all realms of daily life, while largely fed and sustained by the recording and forecasting capabilities of the computational machine (Luhmann, 1993, p.28). As Niklas Luhmann (1993, p.28) states, "the more we know, the better we know what we do not know, and the more elaborate our risk awareness becomes", feeding in this way into a risk-aversion or risk-paranoia context.

All of these references to risk imply pre-emptive action and continuity, aligned with a practice of risk management closer to that of active modulation. Like in the modular dynamics of complex urban systems, risk management also acts through smaller parts of the technical system. It evaluates and calculates their risk in relation to their context of action, overall level of instability and the other technical elements. Risk becomes like an adaptable tendency that unfolds as time goes by, bringing into its grid of calculation an increased number of elements positioned within its targeted context. Risk is then transformed and changed according to its departure point (Luhmann, 1993, p.3); it becomes relational in its relations within its context and a site of continuous variability. Relevant too is how this perspective is reflected and embodied in its "performative" way of working: how risk is enacted and therefore experienced as "something to be guarded against, avoided, managed, reduced, if not eliminated" (Rose, 2005, p.14). 'Risky' is to not deal with risk in an active manner, where risk is embodied in actions that deter future possibilities from coming into the present. The resilience of a technical system is based on preventing, anticipating and preparing the safeguards against risk.

In the context of urban territories and their complex urban systems, risk management is about building a safety net that does not allow the escalation of risk, through a pragmatic activity of "risk assessments" that connects individual elements or characteristics of the overall technical system "to specific hazards" (Arup International Development, 2014, p.3). Risk becomes a probabilistic as much as management and control activity; it needs to name and identify hazards, contextualise their potential way of working and ensure their neutralisation. It needs to contain what brings uncertainty, such as the context created by the opening up of a complex urban system while it is going through a stage of amplification.

It is then within these mentioned plastic qualities that risk management becomes connected with practices of standardisation. In both cases, they share their ability to modulate and be modulated, acting from and through the context of action of technical systems. Furthermore, they push for a level of normalisation[102] to ensure continuity and productivity – their aim is to apply "simplification, unification, and specification" in order to guarantee stabilisation (Ewald, 1990, p.150). Normalisation is in this context a performance-driven process that makes possible what could be called a form of discipline translated "into a mechanism" (Ewald, 1990, p.141). It integrates and develops interdependencies with processes of standardisation, which are, to an extent, the outcome of normalisations and classifications that have become crystallised. What has been normalised faces limited risks and a reduced level of indeterminacy, as risks tend to happen outside routines, averages and acceptable thresholds. The concept of indeterminacy emerged along with the history of statistics, normalisation and formulation of the notion of

[102] Processes of normalisation can be traced back to the medieval period (Amin & Thrift, 2002, p.95). These processes, together with statistics, are part of what can be described as the fertile "new territory for practical science" (Mattelart, 2003, p.12). The origins of probability theory and other measurement practices such as statistics were developed by Blaise Pascal and Christiaan Huygens (among others such as Johann Peter Süssmilch, Antoine Deparcieux, Richard Cantillon, Marquis de Mirabeau and Marshal Maurice) during the second part of the 17th century (Mattelart, 1996, p.44; 2003, p.12). The word statistic is attributed to Gottfried Achenwall, who during the mid-18th century defined it as "the detailed knowledge of the respective and comparative situations of states" (Mattelart, 1996, p.44). The use of probability theory and statistics prepared the ground for "the emergence of 'population' as an economic and political problem" in the 18th century (Foucault, 1998, p.25).

population.[103] More precisely, the objective of probability theory and statistics was to reduce from its outset the excess of "indeterminacy": "from the potential of this excess of indeterminacy, statistical analysis draws out coefficients of probability […] as a measure of risk" (Clough, 2012). Computational practices have allowed indeterminacy to be worked with in a much more proactive way, as they afford a certain degree of the unknown, while being able to compute a much larger input of variables.

As a way of concluding, I want to reinforce that risk management, more than standardisation, is deeply connected to the practices of softwarisation and datafication. These practices have allowed its entrance to levels of detail not possible before the prevalence of distributed computation or small sensors recording the activities of technical elements spread through a complex urban system. The way risk management acts upon technical systems and becomes deeply entangled with them is particularly visible through the action of the insurance industry. Not only is this industry particularly interested in new ways to model risk through a much more dynamic approach, but with the arrival of the Internet of Things (distributed computation to a very fine scale), risk becomes calculated based on feeds from "IoT's real-time data collection" (Reiss, 2016). In this way, the responsibility for outcomes can be shifted, and what could be previously a risk becomes less of a risk, by passing part of the liability to other technical elements or to positions external to this same system (Reifel et al., 2014, p.3). This also means a detailed customisation at the level of location and real-time calculation of what is considered an active engagement with risky activities or the unravelling of risky dynamics.

What I have intended to demonstrate with this reflection of the context of action of complex urban systems is that this context should not be seen as lacking agency or pressure points. Even as the dynamics of the technical system evolve and it moves closer to concretisation, the alignment between this system and its context of action is very detailed, as tensions have been solved and the system has slowly receded into the background. With processes of softwarisation and datafication intensifying and accelerating these dynamics, the concretisation of complex urban

[103] The compilation of statistical data dates back to the "1870s and 1880s" and corresponds to the first use of "information-processing and computing hardware" in order to enable the processing of larger sets of data in a more efficient way, leading as a consequence to "strengthen[ing] the control maintained by the entire bureaucratic structure (Beniger, 1986, p.408).

systems demands that we challenge what standards have prevailed and what happened to those elements that were left aside as the system became more stabilised. The same applies to risk management – what level of steering was done and into which direction.

3.5. The acceleration and intensification of complex urban systems

This chapter came out of the need to understand complex urban systems beyond their areas of impact and outcomes. It proposed that by having as a departure point of analysis the internal dynamics of technical systems, new insights could be gained on how these systems emerge and extend their scope of action. More precisely, this perspective would allow us to consider in detail the impact of the extension of computation into urban infrastructural systems and the transformations that have occurred within these systems as well as in the way they work in their contexts of action, leading us consequently to the emergence of relational locations. With this objective in mind, I drew on two main elements to start the chapter – the process of convergence between the electric telegraph and the railway and the conceptual framework developed by Simondon (1980; 1992; 2008) on technical objects – in order to build a proposition for a path of development towards concretisation, shared by complex urban systems.

As discussed, the convergence of the railway with an early information system – the electric telegraph – completely transformed the assemblage of the railway into a system that could be described as being more dynamic, modular and open to entrepreneurial activity. The choice of such an early example of infrastructural convergence was twofold. On one hand, it offered the opportunity to revisit the impact of a process of transition and technical convergence, in a context where the two involved systems were in their early days. This also meant that the scale of the elements involved and level of encountered complexity had a dimension that was workable in the context of this chapter. On the other hand, the opportunity offered by the electric telegraph as an early information system (Kittler, 1996) and Victorian Internet (Standage, 1999) meant that its overall context of development and impact on the railway could be aligned, to a certain degree, to what usually we tend to associate with the 'digital'.

When the telegraph took communicative capabilities (information) to the railway, it completely transformed how it was experienced. The rearranged railway became a new and more complex assemblage with different levels of accountability. The creation of a modular block-based management system, which led to the decoupling between the track and the carriage and increased externalisation of liability, brought the railway into a position where other new dynamics came into play. The emphasis on processes that intensified the informatisation of the railway brought simultaneously a push for the standardisation of time and infrastructure, and for a more proactive approach to risk management. What this narrative of convergence gives us is a context where unravelling dynamics that came to define a system started to provide us with broader arguments in favour of the chosen approach. Instead of focusing on consequences and then retracing them back to their origin, this approach emphasised technical dynamics and evolvement in order to contextualise their outcomes.

This is necessarily aligned with the conceptual framework I drew on from Simondon (1980; 1992; 2008), whose work was concerned with the evolution of technical objects. In the context of this chapter, I concentrated on three concepts – individuation, concretisation and associated milieu – that were shown to be productive in opening up the existing dynamics within complex urban systems. Starting from there, I proposed as a central point to this thesis a path of development comprising four stages, each presenting specific degrees of openness, uncertainty and stability. The objective of this proposition was to go a step beyond the internal dynamics of technical systems and demonstrate that these present specific tendencies, which can be contextualised according to their stage of development and integration with their context of action. This path of development particularly feeds into three aspects related to complex urban systems that have been transversal to our considerations, and which I would like to re-emphasise: the role of continuity, the overall impact of the extension of computation and finally relational locations as a mode of urban spatialities.

As a complex urban system evolves through continuous individuation, during which tensions are solved and a higher degree of integration with its context of action is achieved, it goes through a path of development. Continuity is therefore intrinsic to these systems and their desire to achieve long-term stability and concretisation. This sensed continuity was also discussed during the analysis of the existing literature, where through the relations between space, infrastructure, computation, topologic dynamics emerged spatially. The contribution that this chapter has brought to our understanding of continuity is that this is intrinsic to the dynamics of technical systems (as a push towards stabilisation and concretisation), but that it is also fed and constrained by practices of standardisation and risk management, placed within the context of action. The level of acceleration and intensity varies then according to the internal stage of development, as well as in relation to external points of pressure. As the system becomes concretised, continuity becomes toned down – its progress is made in the background, within an accentuated degree of inertia and effortlessness. The extension of computation has come to accelerate, intensify and in most cases enable these dynamics to take place.

In this sense, processes of softwarisation and datafication can be seen as particularly essential in the facilitation of dynamics that allow processes of convergence and amplification to take place. The extension of scope and areas of action of complex urban systems as well as their scale and integration of disparity would not be possible without computational transformation. During these two stages of convergence and amplification, in particular, technical systems are required to deal with uncertainty, disparity and even competing elements. Computational processes offer a way to work through these by ordering and differentiating and taming into continuity what would otherwise be under too much pressure to hold together. This occurs due to the ability of processes of softwarisation and datafication to open new potentials, create multiple bridges of communication, achieve a quicker reduction of tension and establish relations of mutual benefit and co-evolvement with the context of action.

Altogether, this leads us to the question of relational locations. Although they were not discussed directly, we can see how the dynamics and processes that were discussed lead to an enhancement of location. What takes place at the level of the context of action of each complex urban system causes us to arrive at this conclusion. As it becomes concretised, a series of communication channels are established between the technical system and its context of action in order to ensure alignment and stability. These are, at one level, mediated by practices of standardisation and risk management that have the ability to steer the system into a desired position, while at another level, they ensure a contextual attunement that turns out to be location-bounded and context-specific. Supported by computational processes, complex urban systems become concretised by means of tailoring, segmenting, adapting and customising them in relation to each context.

In addition to these three transversal areas of relevance, I would like to propose that mobility and circulation offer simultaneously a two-sided perspective on our object of study when considered through the activities of computation. On one hand, enabled by processes of softwarisation and datafication, the acts of connecting, relating and extending are intensified. On the other hand, this ongoing linkage is also an expression of technical systems moving towards concretisation, by slowly bringing together different elements into a shared technical system closer to stabilisation. Movement and circulation should then be seen in a context wider than the implicit and strict moving around of goods. They express the need and desire to relate, connect and extend. Processes of softwarisation and datafication support the continuous establishment of relations by offering a degree of flexibility and adaptation higher than material structures. They allow a new level of openness as seen in the case of infrastructures by making possible and intensifying the division between backbone and add-ons.

Finally, standardisation can also occur in a much subtler way, by the processual action of computational practices. This refers to a processual standardisation more than a default set. Data and software support the reinforcement of certain realities over others, slowly turning a classification and normalisation process into a standard, while making this same process become internalised by the system. In the context of our complex urban systems, data is collected through a network of urban apparatus – sensors, tolls, CCTV cameras – but also in combination with other databases that manage entries such as type of vehicle, annual inspection, speed limit and residence address (Ruppert, 2012, p.117). Databases thus become one of many elements of the urban management apparatuses aiming at being “a solution for taming and dealing” with the variety and competing elements of urban life (Ruppert, 2012, p.118). More importantly, the database offers a set of characteristics that make it more flexible and adaptable through time. It does not need to be a static technical arrangement. It is the double capacity of the database that makes it so relevant – on one hand, it has the capacity to “materialize a conception of population as a space of relations consisting of multiple aggregates of individuals with fixed metrics (biographies)", and on the other, it offers the adaptability to deal with "complex and always-varying ones (transactions, conduct)" (Ruppert, 2012, 130). More importantly, it offers a way to form variable knowledge that is based on recording of connections, interactions and relations, through which beings can be "made and remade" and "composed and recomposed", leading to a "multiplicity" (Ruppert, 2012, p.126). New relations can always be made and entities emerge as new sets of interactions are established.

Nonetheless, further work needs to be done in relation to the propositions made throughout this chapter. Complex urban systems have their own specificities and even different sittings between public and private realms, traditional and heavy structures and more dynamic, largely software-based ones. The objective is then to move on to our case studies and understand how these propositions might stand, but also what else can be learnt from specific contexts and their own narrative of evolvement. Through the analysis of a process of convergence and a second one of amplification, we will have the opportunity to see how the discussion that was developed throughout this chapter can be applied to specific contexts, internally and through their relations with their context of action, and what additional insights we can gain when we move towards specific complex urban systems and paths of development.

4. FROM AIR QUALITY TO FLEXIBLE SPEED LIMIT

4.1. The air quality monitoring station

FIGURES 1 & 2: Air quality monitoring station, Barcelona (Carina Lopes 2015)

This case study departs from an air quality station. This station works both as an entry point to a wider complex urban system and as the element embodying specific moments of transition, more precisely of convergence, as described in the previous chapter. The objective is to look at the wider context of a process of convergence enabled by the continuous extension of computation throughout a specific urban context where the infrastructure to monitor air quality and the road management system come together into a newly converged system. The chapter looks at computational processes as boundary elements that both transform what they touch and accelerate and intensify the tendency of technical systems towards concretisation. The way of working of these processes starts looking like the prevailing logic (Thrift, 2004, p.586), structuring all adjacent relations through their perspective (Fuller, 2008, p.4). By focusing on the process of convergence between two systems previously independent from each other – the network for the monitoring and forecasting of air quality and traffic management system in suburban roads – it is shown that computational practices enable and prioritise relations of mutual dependency, influence and benefit among different elements of a given assemblage and its context of action (also referred to as associated milieu, in a direct reference to Simondon's conceptual framework (1980; 1992; 2008) or practices of standardisation and risk management). Aligned with the discussion presented in the previous chapter, it will be shown that coding practices, pieces of software and databases are powerful expressions of intentional spatial arrangements, and they also embody dynamics within complex urban systems that cannot always be planned in advance (Mitchell, 2003, p.4). As Beniger (1986, p.62) demonstrated with his work on control crisis and bureaucracy, computational processes always feed, to a certain degree, into the intensification, sustaining and extension of processes of spatial bureaucratisation and management.

This case study builds then on the dynamics of technical systems already discussed in the previous chapter by highlighting the role of softwarisation and datafication in the development of increasingly more complex urban systems and their evolvement towards concretisation. More precisely, this chapter starts by navigating the initial convergence between the air quality monitoring and the road management systems, from the perspective of practices of standardisation and risk management, in order to ask how software and these mentioned practices come to work together to then modulate and push each other forward. It is shown that this interwoven engagement is the consequence of the co-dependency established between the algorithmic potential and the management apparatus. Although not uncommon to find close and co-evolving relationships within tight assemblages, contexts such as what will be described here are always necessarily enabled and sustained by a vast array of elements working in relation to each other, with different levels of materiality and vested interests (Edwards, 2010, p.17).

In this way, the current converged assemblage will be shown to be intensively local – through a process that could be described as detailed spatial gridding, where disparate elements are brought either into a central location of management and data treatment or made to speak to each other. In this instance, Barcelona becomes a territory mapped continuously through topological models that can vary in intensity according to the time of the day or the season of the year. The spatial intensities unveiled by this case study will finally demonstrate that softwarisation ensures and simultaneously needs a deep co-dependency with the systems it integrates and their own context of action. It will be shown that, in the long term, softwarisation leads to continuous and evolving processes of amplification and concretisation of the systems under its ruling.

Methodologically, the entry point to this case study – an air quality station – works as the departure point of a wider event that unfolds through a series of relations that are attempted to unpack throughout the case study. The chapter starts by asking, from the perspective of the station, how it came to be what it is in terms of geographic, material and relational positioning to the rest of its technical assemblage. The station allows questioning how the convergence of both systems took place, and in this case, how its regulative framework has led two previously separate technical assemblages into convergence. The chapter moves then to the context of the road C-32 as the site where the outcomes of the converged system were first put into place. By tracing the infrastructural elements in place it allows to carry an on the ground analysis that is contextualised with the wider assemblage. What follows the analysis of the C-32 is a reduction of scale and complexity, by considering two elements placed on the fringes of the system – in this case, an air quality sensor and a mobile phone application. Overall, this case study also highlights and makes visible the limitations and difficulty in accessing certain aspects of complex urban systems such as pieces of software and levels of automatisation embedded in the system and how their sitting in the background is reinforced and sustained by this same difficulty.

The air quality station works in this way, simultaneously, as an entry-point to the context of this chapter and the air quality assemblage extending throughout the metropolitan area. It plays the role of a host to sensors, collecting and recording, while also supporting the unveiling of and reaching out to other types of entry-points. The station helps to open up an assemblage of distinct material and non-material elements: an array of air quality measurements of different chemical components; weather forecast in real-time; studies correlating speed-limit with road safety and traffic flow; international and national regulation on air quality; and a vast range of technical elements such as surveillance cameras, LED screens, sensors and helicopters. The station offers an insight into the existing wider dynamics among the technical objects composing this now-converged complex urban system. It speaks of material and non-material urban interactions that make statements beyond their own technical arrangement. Moreover, it is as much about a specific spatial arrangement as it is about tiny evolving particulates, mixing and engaging, finding deep allocation within fragile lungs (Shepard, 2011a, p.14).

The mentioned air quality monitoring station is located 250 metres away from my house (see Fig. 1 & 2) (officially known as Sants Air Quality Station placed at Can Mantega Gardens). It is one of the seven automatic stations belonging to the Government of Catalonia monitoring air quality within the city of Barcelona (Generalitat de Catalunya, 2015).[104] It belongs to a much wider assemblage of static and mobile stations collecting data, both automatically and manually, on air quality throughout Catalonia. This assemblage is officially known as the Network for the Monitoring and Forecasting of Air Quality[105], and it is co-managed, in the case of Barcelona, by the City Council and the Government of Catalonia (Ajuntament de Barcelona, 2008, p.43; Barcelona Regional & Gerència Adjunta de Medi Ambient i Serveis Urbans, 2015). Located at the edge of a small neighbourhood park (see Fig. 1 & 2), graffiti-tagged with the passing of time and with a very closed structure, the air quality monitoring station works away without the need for visible interaction or engagement with its surroundings, beyond the running of its sensors. From the outside, the only visible elements, apart from its boxed structure, are the sensors placed on its top, which have varied throughout the length of this research project. The station is also similar to the stations that were geographically reorganised in Madrid during the winter of 2010 as described at the beginning of this thesis. Overall, the data collected by my local station expresses (and represents at a larger scale) the air quality experienced by urban zones close to areas of high traffic density within the city of Barcelona. Up to 70% of the emissions of nitrogen oxide (NO_x) come from traffic, the biggest source of pollution within the city (Barcelona Regional & Gerència Adjunta de Medi Ambient i Serveis Urbans, 2015, pp.13–14).

With the arrival of the first regulation piece on air quality in Catalonia in 1983,[106] the first two air quality monitoring stations were installed in two local parks – Ciutadella Park and Josep Trueta Gardens – respectively in 1984 and 1988, so the

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[104] The station only collects automatic data on NO_x (nitrogen oxide). All other elements are collected manually – PM_{10} (particulate matter up to 10 micrometres in size), metals, benzene and benzo(a)pyrene (Generalitat de Catalunya, 2015).

[105] This is known as the XVPCA in a direct reference to its original name in Catalan.

[106] This regulation, published on the 21st of November 1983, was specifically concerned with “the protection of the atmospheric environment”, including for this reason “some measures to improve air quality”. The current network of stations that measures and monitors air quality was first established by this same piece of regulation (Ajuntament de Barcelona, 2008, pp.42–43).

concentration of pollutants could finally be measured, evaluated, compared and used as a basis for future decisions (Ajuntament de Barcelona, 2008, p.42). Since then, the levels of each pollutant have changed in the same way that heavy industry has given place to very dense traffic (Ajuntament de Barcelona, 2008, p.42); the smoke from the manufacturing factories was slowly replaced or superseded by the emissions of private vehicles. The challenges encountered on the ground and possible solutions changed, side by side with wider transformations throughout the urban territory, facilitated by the intense urbanisation of the metropolitan area and beyond, turning previously rural areas into new densely populated urban areas (Cox, 2012).

Two zones of special air quality protection were created in 2006. These zones include 40 municipalities, mostly surrounding the cities of Barcelona and Tarragona (the second biggest city in Catalonia), thus giving priority to those parts of the territory that do not fulfil the guidelines on air quality (Ajuntament de Barcelona, 2008, p.42; Generalitat de Catalunya, 2007, p.2), also aligned with the requirements of the European legislation. For our case study, only zone one is of concern – it includes Barcelona and tackles both NO_x and PM_{10} (Generalitat de Catalunya, 2007, pp.2–3). This territory, as an object of intervention, became further redefined through a group of "73 measures" approved in 2007 by the Government of Catalonia (Generalitat de Catalunya, 2007). These approved measures had the objective of reducing the levels of NO_x and PM_{10} through "the management of terrestrial, air and maritime modes of transportation, industrial and energy-related activities, [and] domestic related" activities and pollution fonts (Generalitat de Catalunya, 2007, p.2). Within the dozens of agreed measures,[107] it is possible to find a group of them addressing specifically land transport. It was within these measures that it was proposed for the first time to introduce a complex and coordinated system of flexible speed limits throughout the main roads of zone one, directly addressing traffic congestion and air quality (Generalitat de Catalunya, 2007, p.6).

Nowadays, the management of air quality is central to the multiple levels of public governance (central Spanish government, Catalonian autonomous government and city council), but also transversal, covering areas from industry to mobility and urban planning, in a clear demonstration of the complexity that both air

[107] It includes, more precisely, 73 measures (Generalitat de Catalunya, 2007, p.6).

pollution and air quality embody. The monitoring and forecasting of air quality throughout the metropolitan area of Barcelona means today approximately "131 measuring points, 456 contaminants analysers, which provide 9,000,000 data/annually" (Gil Pérez, 2009). It is believed that a considerable improvement in air quality could lead to a reduction of more than 1,000 premature deaths every year and a significant reduction in asthma attacks and lung infections, both in adults and children, resulting consequently in considerable savings to the public health system (Ecourbano, 2008; Künzli & Pérez, 2007).

4.2. What lies beyond the station

The station is a material element, seemingly static, placed in its specific geographic coordinate. On its own, its message is limited, even lacking a meaningful contextualisation. As part of the network responsible for the monitoring and forecasting of air quality throughout the city, the station emerges as a relatively small-scale element; it appears as being placed at the fringes of this now converged technical system as its sensors work away, passively, in a one-way channel of communication. Once you start enquiring about the history and context of the station, what stands out is how intensively regulated is the technical system enabling and surrounding it, as is discussed throughout this section. Regulation states the positioning of the stations (distance from road and pavement and height of sensors), which pollutants to monitor and the recording format of data (format and method to share information) (European Parliament, 2008). All elements seem to fit the requirements of a tightly designed table with apparently little space for local adaptation, as regulation moves through the international context down to a national, regional and finally local setting. Air quality comes across, within the management apparatus of urban governance, as a complex element populated with many variables; it emerges as an element that has been the object of continuous calibration over the last decades and the context of which has been designed and set up to proceed with this path of continuous evolvement. The first step then taken in the development of this case study was exactly to unpack the coming into place of this air quality monitoring station, as the entry point to the analysed converged system.

This was done through the analysis of a series of regulative documents emitted at European, national, regional and local level.

This section focuses then precisely on the regulative structure that surrounds the Sants' station, in order to open up the narrative on the air quality assemblage and converging elements, its context of development and the unravelling dynamics among its technical objects. Regulation will be shown as offering a bureaucratic mapping tool, together with the local station, of an assemblage that would be otherwise hard to trace, in this way bringing a set of disparate elements into visible coherence and convergence. Moreover, this emphasis on the regulative apparatus reinforces the proposition of an existing coupling between practices of regulation and computation, not only feeding into each other, through the establishment of a relation of mutual dependency, but also directly supporting the concretisation desire of complex urban systems. This makes, as will be shown, an implicit reference to "the migration of software imperatives into everyday life" (Fuller & Goffey, 2012b, p.69), here done in an intentional manner and expressed through the structuring of the regulation tackling the field of action concerned. Further, it is shown that this coupling has a direct impact on the formulation and organisation of complex urban systems, especially in the context of the European Union, with a very hierarchic and normative decision-structure.[108]

What is encountered is a context where infrastructural evolvement and regulation go hand in hand, largely enabled by already existing structures and processes enforced by "governmental, judicial, and economic institutions" (Dourish & Bell, 2011, p.106), which are also responsible for the creation and development of the regulative framework. This means that the convergence experienced is also the outcome of a large range of steps and decisions (Dourish & Bell, 2011, p.106), where both practices of standardisation and risk management play a central role. The regulation discussed expresses multiple lines of classificatory segmentation, slowly overlaying each territory with a layer of action and active transformation.

[108] Two points stand out here from what has already been discussed. Firstly, we could think how during the Roman Empire the standardisation of buildings and organisation of the city was put at the service of the higher objectives of the Empire. Standardisation was beneficial to the management of their network of cities, as well as to the management of the expectations of its inhabitants. Secondly, this statement can take us back to the local–global dynamics discussed in Chapter 2. The regulative approach discussed here shows that locations become defined by their fitting into specific categories, more than by their local character. By the means of these practices of regulation, the European territory is flattened out and treated as a grid of action, in a continuous connection with the regulation taming, constraining and defining its not-yet-arrived future.

4.2.1. Subjected to management

Although heavily regulated, the field that manages (mostly through monitoring and forecasting) our air quality can be said to be relatively young in its tight and detailed contemporary formulation. Legislation on air quality, as already seen, is only few decades old[109], and it has gained more relevance recently in large metropolitan areas due to new and stricter regulation and penalties, brought into place by the Directive 2008/50/EC approved on the 21st of May 2008 by the European Parliament and the Council of the European Union.[110] The first piece of regulation on air quality in Spain dates back to 1972 (Jefatura del Estado, 1972), and in the case of the region of Catalonia, back to 1983 (Ajuntament de Barcelona, 2008, p.43). Nonetheless, it could be said that it was the introduction of tight reaction timelines, and detailed specifications of action and compliance, that have brought this topic to the front page of newspapers and public squares. The legal obligation to inform the population when pollution exceeds established safety limits might have also played an important role in the visibility it has gained. Through their articles, updates and replacements, regulatory pieces, as those discussed here, draw a field of action that is nowhere else made this explicit and mapped out with so much detail. The actors involved and tools available to act are compiled, coordinated and packaged within the pages of these regulatory pieces, with the aim of providing the vision of a homogeneous field of action, populated with a few exceptions. Even then, the act of mapping out is pushed to the limit through a complex language of bureaucratic references, mentions of previous pieces of legislation and standards, and the requirement to comply with previous decisions about related and affected elements as is the case with the greenhouse effect (European Parliament, 2008).[111] When put side by side, the different pieces of regulation start to offer a complex mural of air quality, greenhouse effects, global warming, industrial manufacturing control, sustainable energy and so on.

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[109] It dates back to the 1970s at European level (Gemmer & Xiao, 2013).

[110] Please see http://ec.europa.eu/environment/air/index_en.htm for further information on air policy and other related developments. Although the World Health Organization has been concerned with the quality of air for "more than 40 years", the first guidelines specifically addressing the European context were only issued in 1987 (World Health Organization, 2000, p.vii).

[111] See for example point 18 from the introduction, which requires that "coherence between different policies, such air quality plans should where feasible be consistent, and integrated with plans and programmes prepared" for "the assessment and management of environmental noise" (European Parliament, 2008, p.3).

The European directive from 2008 aimed at the gradual improvement of air quality through the establishment of "a common approach" and "common assessment criteria", so high pollution events and the regularity with which these occurred could be reduced, leading consequently to the lowering of their negative side-effects on human health (European Parliament, 2008, pp.1–2).[112] In other words, the directive aimed at the creation of standardised practices of mapping, monitoring and evaluating, based on the advice provided by the World Health Organization (WHO) (European Parliament, 2008, p.1). Furthermore, it aimed at designing a context where tracking, listing and compliance could be recorded, compared and penalised, in a clear procedural logic of governance (as risk management) through a set of standardised practices. Thus this piece of compulsory regulation brought a mode of governance and its specific practices of control into the field of air quality management. It also simultaneously brought the logic of computation. What was established was a crucial connection between the objectives of the European directive and the potential offered by the algorithm, under a format that allowed the formalisation of the prescribed practices into one or more pieces of software supported by data systems and a large array of sensors.

Through a series of formalisms and intentional design of a field of action emerges a mode of contextual structuration that is coordinated by "action at a distance" and imposed from "centres of political deliberation and calculation" (Rose, 2000, p.323). Crucial is the fact that from the very starting point, this decision-process has attempted to flatten out very divergent contexts, leading consequently to a field of relational heterogeneities. This takes us to a differentiated field throughout the extended European geographic territory, which becomes layered with a logic forcing the building of bridges and collaborations, and the sharing of methods and formats for data collection, storage and availability. Overall, the story provided by the European directive speaks of a slow construction of an infrastructural globalism (in this case, only at a European level) (Edwards, 2010). It covered the spatial arrangement and design of action plans for targeted areas; occasional exceptions "where conditions are particularly difficult" as in the case of Barcelona and Madrid; regular evaluation and update of legal pollution limits;

[112] Having a centralised decision made on a sensitive and also location-bounded issue such as air quality is seen as problematic by many European countries. In the case of the UK, the Government argues that these measures go against its coal industries, which present particularly high levels of "sulphur content" (Neslen, 2015).

shared criteria on "the number and location of measuring stations"; and the importance of modelling "to enable point data to be interpreted in terms of geographical distribution of concentration" (European Parliament, 2008, pp.2–3). Altogether, this offered a top-down arrangement transposed to a field of action that was assumed as flat, treating without distinction what is concerned with European and national territory and what is collected at local level.

In the same way that the directive defined the format of the data collection, storage and sharing, it established the minimum number and type of stations each territory is obliged to have, based on its population and track record of pollution levels. For example, it stipulated the proportionality of each type of station (e.g. structural pollution monitoring stations could not be twice as many or as few as traffic stations), which were also segmented based on their urban and suburban geographic position, and type of main source of pollution such as traffic, industrial or structural (European Parliament, 2008; Letón, 2011).[113] This level of structuring of the field of action was even further extended to the exact positioning of each station, so lower level details such as distance from source of pollution and height of sensor could be controlled, in order to ensure a more homogeneous data collection. The data collection throughout vast geographic areas always brings many challenges, mostly due to existing divergences within the processes and sites of data collection (Edwards, 2010).

The process of standardisation happens then at many levels, working like a structuring-at-distance element and covering a wide range of elements, from more tangent aspects to those more immaterial. Nonetheless, the approach chosen by the European Commission was stricter and almost opposed to the advice offered few years earlier by the WHO (World Health Organization, 2000). In WHO's report, it was proposed that the standardisation of the field of air quality should be proportional to the ability to enforce the defined standards (World Health Organization, 2000, p.42). The objective was to account for a period of adaptation with a more flexible implementation, which should be incremental and take into consideration the "context of prevailing exposure levels, technical feasibility, source control measures, abatement strategies, and social, economic and cultural

[113] In the case of Madrid, previous to the rearrangement and reduction of the number of stations, there were mostly what would be considered as traffic stations and a lack of representation of recently urbanised areas (Letón, 2011).

conditions" (World Health Organization, 2000, p.4). Going further, the WHO report also proposed the use of standards as an active tool of risk management, the imposition and level of detail of which should be proportional to the impact of the negative consequences. In other words, this meant that the higher the perceived risk of a given pollutant, the stricter should be the framework defining its monitoring, evaluation and overall improvement (World Health Organization, 2000, p.48).

The approach to standardisation chosen by both organisations take us back to the earlier discussion on the context of action of complex urban systems. These approaches reinforce the understanding that practices of standardisation and risk management are closely connected, acting intentionally upon technical systems and their spatial arrangement and interactions. They work like bridges and impact upon each other, exploring each other's affordances and their limits and positioning in relation to the overall assemblage. The definition and outcome of each exercise of practices of standardisation and risk management is always unique, as they continuously adapt to their context of action, but also in relation to each other. As can be seen with the example of the standardisation of the air quality monitoring station, it is within these constraints expressed mostly on the ground through standards that multiple temporalities, speeds and fields of action start to emerge. Each type of pollutant is treated according to its own constraining – the type of sensor used, collection method and how data is treated and analysed posteriorly. Different pollutants have a distinct timeline regarding compliance, based on when pollutants were last revised, their level of impact on public health and previous identification of safe thresholds or lack of their existence, like in the case of PM_{10} and $PM_{2,5}$ (European Parliament, 2008, p.2).

What I am trying to argue is that the coexistence of multiple temporalities, speeds and fields of action indicates a computable assumption from the outset of the directive. Even before becoming translated into the technical system, which in many cases will have to be rearranged, created or even designed from scratch, the European directive already incorporates a computational language into its design. This means that the level of complexity and structural arrangements being created assume a computational translation into the territories being tackled. It is expected then for a process of translation to occur, from regulation into a set of software applications. These applications will be responsible for the collection, treatment and historical analysis of the data produced and the development of spatial models and behaviour-induced arrangement of pollution levels' throughout the territories.[114]

Beyond the elements being regulated in their various dimensions and qualities, space and location have a primordial positioning. This means a differentiation between what is local and reinforcing its geographic positioning and uniqueness, and what belongs to the generic, pushing for a more homogeneous appearance and placement within global dynamics. The management and analysis of air quality within a given territory is based on population density and geographic characteristics – the relevance of a territory is, from the outset, firstly based on the scale of its population and only secondly based on the presence of industry or other important sources of emissions. This implies, from the outset, the division of local urban territories into smaller areas according to their own characteristics, in terms of population density, source of pollution and type of predominant pollutant. Like in the railway, with the arrival of the block system, accountability is seen as the ability to oversee smaller areas of control, allowing comparison and tracking at local, regional, national and finally European level.

When it comes to scale, the emerging structure can appear as a hierarchical agglomeration of regulatory practices unfolding from the European Union into the national state, and in the case of Spain, to the regional government to then arrive at the level of the local context, the city of Barcelona. It is within these two last levels that the regulatory framework becomes actualised, embodied and often even reconfigured. Decisions and compliance can appear to happen at four distinct levels, but if we think of this context, its computational logic and final objective as a field of action under continuous modulation, then what emerges is very different. The computational logic that becomes materialised through software applications and data collection processes, put into action within delimited territories and sustained by a distributed material assemblage of elements, hints at a different context away from a pure scalar arrangement: local–global (or European) dynamics of monitoring and management of air quality that express continuity of action. Computational

[114] The methodological reference at the European level to understand the type, number and pollution level of vehicles on the road is called CORINAIR/COPERT. This is a standard requirement used throughout the European Union and which was last updated in 2009. The complexity of these calculations remains because of the fact that there is verified difference between cars registered and cars circulating on the road, requiring specific considerations into the variables introduced into CORINAIR (Ajuntament de Barcelona, 2008, pp.68–69).

practices build bridges between institutions, provide cycles of adaptation to the different elements involved and become intensively localised within defined territories of action. Instead of emphasising what differentiates the practices of each site of action – be it regulatory or a station measuring the ozone present in the atmosphere – the prioritisation happens at the level of what is collected, processed, organised and turned into expressive outcomes of actual intensities and developments unfolding within a delimited territory. The European directive could be just another expression of an entangled computational context of software, measurements, databases, stations, sensors, air particles and sun interaction. What happens within the directive impacts the processing that takes place within my local station, in the same way that new calibrations within defined locations are fed into new updates, changes and additions throughout the European territory.

Thus, the events unravelling within a specific territory, continuity and endless calibration are then deeply ingrained in the way that a piece of regulation is developed. Air is not a static element, and maybe for this specific reason it has an intrinsic level of risk, uncertainty and contingency. It is always the outcome of numerous interactions. The regulative assumption that an enduring solution had been found would open the door to unexpected claims and liabilities. The lack of stability of the context tackled requires a continuous evolvement and consequently ongoing attention from scientists, policy makers and citizens. Moreover, how could something that moves, trespasses borders and deteriorates buildings and plants be dealt with? Would not a plastic approach be the only possible solution? As the approach chosen and defined through the directive, only a plastic solution can allow the specifics of the evolving target to be accommodated.[115]

4.2.2. Delimited territorial action

The proposition being made here is that the European regulation on air quality creates the conditions for an embedded territorial and computational logic. This is

[115] In part this takes place due to scientific reasons, but if standards and requirements do not express a degree of plasticity, they also become very hard to enforce. Furthermore, once one enters the details of the data collection and posterior processing that leads into data models, it can be seen that both averages and thresholds are misleading – they flat out both peaks of high exposure. WHO highlights this same challenge stressing the importance of the long-term impact of working with averages, as "the typical pattern of repeated peak exposures is lost during the averaging process" (World Health Organization, 2000, p.19).

ensured in the long term by the establishment of a relationship of mutual cooperation and co-dependency between the directive, software applications and material apparatuses, working towards the designed regulatory framework. The expression and actualisation of the software becomes particularly visible when attention is brought into delimited territories of action. It is at this level that what has been referred to as relational fields of action become visible through nodes of emphasis, which can be identified and understood, in better detail, often as small islands of intensive and concentrated dynamics, as is the case of the C-32 road that is discussed later in the chapter.

In the context of our case study, we can depart from Catalonia as a generic territory to then consider its two zones of special protection. This can be followed by the city of Barcelona and its network of measuring devices according to source of pollution, to finally arrive at the vast amount of geographic points used to pin down the pollution data model developed for the entire city. The field of action encountered at the level of the city, sustaining relational engagements among nodes of air quality measurement (in this case, air quality monitoring stations), is actually the outcome of multiple efforts towards standardisation of many of its constituting elements. Within the specifics of each node, consequence of its locality, tendencies are imposed and reinforced through relational intensities of continuous updating and modulation, but also of standardisation. Three main characteristics are visible in each geographic node of action: an already established and delimited territory of action, the increased standardisation of each of its elements and tensions between practices of ordering and differentiation.

Let us start with the definition process of the territory of action. The European directive establishes guidelines on how each national context should be approached and defined according to specific characteristics of the local population and inherent ecosystem – "population density" and "geographic distribution of concentration" – to then divide the territory into specific zones according to source and level of air pollution (European Parliament, 2008, p.2). In cases where there is a track record of low air quality, those areas should be approached through a specifically designed action plan. In the case of Catalonia, this refers to the two areas of special protection already mentioned, with one of them including Barcelona and most of its metropolitan area (Generalitat de Catalunya, 2007; 2011a). These two areas, purposely defined, do not necessarily follow other territorial jurisdictional delimitations already in place and have been defined based on their topography, social context, main industrial areas, climate and, finally, historical data on pollution (Generalitat de Catalunya, 2011a, p.1).[116]

The territorialisation of the field of air quality and its tight connection to its own localities is done in this way, through a process of making visible similarities, but also by leaving aside what is considered less relevant (in this case, areas where level of pollution is lower than regulated limits), as accountability is enforced through a more granular process. What takes place is a process of intentional differentiation through the homogenisation of similarities (by bringing them together) and intensification of differences (by forcing them to stand out), like what is enabled by parametricism. This process of intentional differentiation is enabled by the intentional actions of toning down similarities and emphasising differences. Relevant is how this same computational logic of continuity through ordering and differentiation, as discussed in Chapter 2, becomes transposed and embedded even within the material arrangement of this technical system.

The arrangement of the stations is decided through the delimitation of a geographic territory, type of location and type of point of measurement. Their disposition must always be aligned with the overall objective of protecting the population's health and providing generic data on pollution at macro-scale, as opposed to hot spots with very specific and localised sources of pollution. As the directive states, "sampling points shall in general be sited in such a way as to avoid measuring very small micro-environments in their immediate vicinity", requiring in addition to this that "the pollution should not be dominated by a single source unless such a situation is typical for a larger urban area" (European Parliament, 2008, p.18). The homogenisation of a transversal and shared air quality of the majority takes over what is specific and intrinsic to the minority (or what would stand out), meaning that the very busy (but isolated) road or heavy industry (outside major industrial sites) is left aside in favour of a more extended territory and homogeneous

[116] In addition to this, and working like an additional computational layer, there is also a further territorial division of the entire Catalonian region into 15 areas. The objective of this additional spatial division is to facilitate the evaluation of its air quality through modelling techniques, in this case, offering the forecast of pollution levels 48 hours in advance, which includes the analysis of 13 different pollutants (Generalitat de Catalunya, 2014a, pp.1–2). The existence of multiple levels and layers of monitoring and modelling demonstrates that systems with responsibilities for elements such as air are characterised by tension, often over-layered and competing among each other.

view. Overall, the objective is to have a proportional diversity of stations (in relation to the type of location and size of population) divided between suburban or rural stations (measuring structural pollution), and urban stations collecting data on real levels of exposure that populations have to atmospheric pollution (Letón, 2011). In the specific context of the city of Barcelona, these requirements have led to the existence of six measuring points for NO_x, 10 for PM_{10} and finally three for $PM_{2.5}$ (Ajuntament de Barcelona, 2008, p.43).

The standardisation of data also has a direct effect on how the geographic location of a measuring point is decided and the type of measuring point installed (European Parliament, 2008, p.19). The framework of data standardisation is tight and makes one wonder how compliance is enforced. As already seen, it sets requirements on the free space available around the sensor, its distance from "buildings, balconies, trees and other obstacles" and how high above the ground it should be, among other requirements (European Parliament, 2008, p.19). In an urban context such as Barcelona, with such a high density of population and buildings, some of the requirements strongly influence the position of the stations and other mobile measuring points, leaving us to wonder what requirements prevail – a geographic positioning based on probably problematic pollution areas or the strict positioning in relation to the other urban elements. In the case of my local station, located in a neighbourhood of narrow streets with mostly low buildings and trees, only its current location seems like a feasible position. However, its location within the most open space of the entire neighbourhood makes a weak case for it to be representative of the traffic pollution that most of the population is exposed to.

Measuring points can be fixed (offering continuous measurements) or mobile (collecting sporadic or regular measurements), the data being collected in a manual or automatic way. Manual collection implies that the material collected is stored and then analysed at a laboratory, providing general information about the day's average of "concentration levels" and "emission levels" (Generalitat de Catalunya, 2011b). Automatic collection is done by equipment providing real-time data, which means that data is collected and analysed simultaneously, allowing a quicker response if that is necessary (except for those pollutants that do not allow this technique) (Generalitat de Catalunya, 2011b). Our main concern is the automatic air quality stations, which compile data for every 10 or 30 minutes in daily folders, which are passed on to their local centre of analysis and then posteriorly transferred to the Centre for Data Reception and Coordination (Generalitat de Catalunya, 2011b). All the data produced by automatic stations is 'publicly' available for a period of six months (Generalitat de Catalunya, 2011b). The decision about whether to use automatic and manual collection is influenced by the technical requirements for each pollutant, the cost and available techniques, but also based on the legislation in place for each pollutant (Ecourbano, 2008).

All other geographic data points, for the rest of the territory, are calculated through a modelling process. Data collection is afforded a level of uncertainty – "maximum deviation of the measured and calculated concentrations levels" – in fixed points between 15 and 25% according to the pollutant being measured, while both "indicative measurements" and those calculated through "modelling" are allowed a much higher range, in certain cases, going up to 50% (European Parliament, 2008, p.14). Data and "simulation models" are central to many aspects of urban governance, having taken the role within contemporary contexts of informing decisions and steering regulation, all while sitting in the background of the interface, largely remaining unnoticed (Eglash, 2008, p.55). In the case of the pollution forecast, the analysis of data through models is the outcome of "a vast family of mathematical techniques, algorithms, and empirically derived adjustments to instrument readings", the use of which has been evolving for a long time (Edwards, 2010, p.xv). These models have become increasingly sophisticated, taking into account and allowing for the changes that infrastructure and methods of data collection undergo, leading to modelled contexts sourced from "highly heterogeneous, time-varying observations" (Edwards, 2010, p.xv).

It is important to remember, in any case, that "the history of the atmosphere" is long (Edwards, 2010, p.xvi). Even before the concern with the impact of air pollution was turned into an element subjected to management, scientists were working towards global data models to study weather and global warming. This has been mostly achieved by "re-examining every element of the observing system's history, often down to the level of individual measurements" (Edwards, 2010, p.xvi). In practical terms, such an exercise implies solving all those constraints affecting the quality and reliability of data – "*metadata friction*"[117] – by considering

[117] Italics in original.

possible origins of problematic sources and mitigating the impact of these in the overall data sets (Edwards, 2010, p.xvii). This is nowadays done through and with software (Edwards, 2010, p.14). It is not just standards that allow the reduction of data friction mentioned. Software makes this possible, on one hand, by turning "heterogeneous, irregularly spaced instrument readings into complete, consistent, gridded global data sets" and on the other hand, by providing calculated "data for areas of the world where no actual observations exist" (Edwards, 2010, p.188).

The data model used in Barcelona, different and in many ways overlapping with other European systems, had at its core a model of dispersion of pollutants based on geographic and weather conditions, the already known history of emission sources and structural pollution levels. Given the urban density and the architectonic specificities of the city, besides the dispersion model and the accountability of chemical reactions, it also calculated concentration based on the typology of the architecture of each area of the city (Ajuntament de Barcelona, 2008, p.134). In technical terms, it implied a wider area of application than the city itself due to the movement of pollution, an intensive grid of "150,000" points, which required "12" computers working non-stop for a period of "30" days (Ajuntament de Barcelona, 2008, p.135). The data was then calibrated and adapted based on the existing data collected by the network of stations existing in the city.

The standardisation of the field of air pollution and its management can be understood as the active management of an important source of public health problems and a desire to have transnational shared approaches to the same problem so results can have a higher impact. However, as already proposed, this could also be understood as the reinforcement of a computational logic that extends across the regulation-making to the spatialities to which it will be transposed. What is left aside is the messiness specific to urban territories – in the sense that they are not simply clean, available and prepared contexts that standardisation requirements suddenly fit into adequately. Moreover, the standardisation of what is material directly contradicts other affordances made central to the field of action, such as the level of uncertainty allowed to each type of sampling point. If the arrangement of stations is tied to a required number of metres away from the road or buildings, geographic points with spatial-bounded data within data models are allowed a 50% deviation as stated in the European directive (European Parliament, 2008). The level of detail being sought through the regulative piece of paper is then passed on to the arrangement of infrastructural territories, preparing these same territories for a very specific approach, one that allows the intensification of their capacity for 'software-doing'. More important is the fact that the tight coupling between regulation-making through the practices of standardisation and risk management and the computational logic is not limited to this aspect of urbanity. As I have been proposing in the context of complex urban systems, computation has been extending into different aspects of urban territories, taking advantage of the porous context of action of technical systems.

The preference for the more homogeneous and transversal perspective over a more detailed map of urban pollution and its hot spots also raises some important questions, mostly in the case of urban territories and the impact of traffic pollution. This means that groups of population exposed to very high levels of concentrated pollution, whose bedrooms and children's nurseries face main roads, will not find in this method a source of support for their campaigning for better air quality. The conditions are created for a rather opposed context – the tight standardisation and risk description assumed by the European directive will undermine any claim regarding the possible existence of hot spots. Firstly, they are not accounted for, and secondly, it is not even possible to demonstrate their persistence over the proportion of a more homogeneous overview. It could be said that part of the civic science projects concerned with air quality are born out of this context (Costa, 2007) – under the current framing of air quality, their specific context is toned down through practices of averaging, homogenisation and overview. The need for a more homogeneous perspective over a wider territory, where there is a sense of flow and continuity, overrides the potential existence of intense differentiation within these same territories. This also means that differentiation encountered within the data models used is intrinsically toned down.

4.3. From convergence to concretisation

I started this chapter with a review of how practices of computation and its logic became extended beyond their own areas of direct action, as was shown with the design of the European directive. Its starting point was already an algorithmic materialisation; it intended to be transposed into a computational logic to then overlap multiple and diverse territories. Furthermore, it was shown that practices of standardisation, which are often initiated within a regulatory and institutional context, tend to have a stricter approach to what is material than to more immaterial data models. In this case, they generally offer more flexibility and broader error thresholds. Moving forward, this section focuses on the assemblage to which the Sants' station belongs and that is now the outcome of the implementation of the European directive, together with a process of convergence, and posteriorly, of amplification. Throughout this section, practices of standardisation and risk management are left aside, in order to focus on the evolving dynamics of the converged complex urban system. More precisely, it focuses on one of the sites of the assemblage where the full intensity of the converged complex urban system can be experienced – the C-32 road, not only a major thoroughfare to get to Barcelona but also the first site of implementation of the flexible speed system. The C-32 road is then analysed both from the perspective of infrastructural apparatuses and the context that it enables to create. The overview of this road and context of action allows comparing what is encountered on the ground together with the theoretical framework designed by the regulative apparatus. This means that through a analysis of news articles, regulation, on the ground analysis of the infrastructure in place, access to videos produced and made available by the public agency responsible for the management of this road, a contextual analysis is built.

As has been already discussed, the extension of computation has meant, on one hand, the acceleration and intensification of the path of development towards concretisation, and on the other hand, its transition into areas beyond its own scope of action. The wider outcome of this is numerous moments of transition, often through the convergence of previously separate systems or technical elements. These are also, simultaneously, opportunities to better analyse the technical elements involved and their coming together (Parks, 2005, p.9). What occurs is a process that is more than a set of "recombinations"; it leads to "shifts in the discursive construction of technologies that pre-exist the convergence and those that emerge as a result of it" (Parks, 2005, p.9). In the context of this case study, this has three visible implications: to perceive the differences between what appears to exist on the ground and the narrative told by the directive and the transition process; the constraining of the process of convergence by a set of regulative documents that indicated already an algorithmic assumption; and finally, the role of computational processes as "boundary elements" (Bowker & Star, 2000) and "gateways" (Edwards, 2010), but also through their processes of softwarisation and datafication, accelerating and intensifying the connection and relation of disparate elements. As this case study shows, once the field of action is designed and conceptualised, the narratives they offer are almost turned into "self-fulfilling prophecies" that quickly become more than infrastructural "understandings, expectations, and predictions" (Dourish & Bell, 2011, p.135). However, certain sites of intense action tell a different story, where their dynamics contradict what brought them into being in the first place.

As we get into the details of the newly formed assemblage, it becomes noticeable that the narrative behind the European directive is distinct from what could be assumed from looking at its on-the-ground arrangement. Its structure, interfaces and areas of visible impact seem to speak of a process of convergence where the assemblage of air quality was brought into the traffic management assemblage. However, as already discussed, both the European directive and the local policy and strategy documents demonstrate an opposing contextual reality. The starting point and key area of intervention is the already existing assemblage monitoring and evaluating air quality. The implementation of a flexible speed limit can be understood as being a consequence of the imperative need to improve air quality throughout the metropolitan area. The 73 action points designed by the Government of Catalonia introduced a technical context where the speed limit was just another variable element and in need of continuous adaptation, turning it into another measure of what is understood as a much wider field of action (Generalitat de Catalunya, 2007). However, within the specific location of action, what is experienced is the technical assemblage of traffic management, modulated in real-time according to pollution measurements, weather forecast and on-site traffic conditions.

The territorial and spatial action of the process of convergence is then made visible through the management of the main roads approaching Barcelona. Nonetheless, and as will be shown, once converged, these two technical systems – the air quality monitoring network and the traffic management assemblage – become entangled and interact based on the narrow field of pollution measurements and models. The vehicle and its driver slowly become constrained by their own pollution, having their own field of action folded back into them as their speed is rearranged, continuously calculated and adapted according to real-time emissions. The driver's desire to speed up and arrive quickly at their destination is toned down in accordance to their vehicle's own emissions. The flexible speed-distributed computational arrangement turns into a very specific mode of experience and "of inhabiting places" (Mackenzie, 2008), through which different expressions of the converged system are made visible and perceptible with variable degrees of intensity.

4.3.1. The case of the C-32

The project of convergence, embedded within the implementation of the flexible speed-limit system throughout the main roads connecting the suburbs and the wider metropolitan area to the city of Barcelona, started by being tested on only two roads to then become extended to the wider network over the years. With the objective of focusing on and understanding the dynamics unravelling within the different technical elements, our attention is centred on the context of the C-32 road. This road was part of the first stage of the process of convergence. As a priority target from the perspective of traffic congestion, it has been a key element for many years due to recurrent hold-ups and contamination resulting directly from this (Pérez, 2009). Moreover, together with the C-31, both roads "concentrate 53% of the incoming and outgoing traffic in Barcelona" (Generalitat de Catalunya & Servei Català de Trànsit, 2008). Any significant improvement within these two roads would result in visible outcomes to the overall context. The reduction of pollution brought by fewer hold-ups, as "engine stop and go" is minimised, would potentially lead to a 20-25% reduction of emissions (Generalitat de Catalunya & Servei Català de Trànsit, 2008). In addition, and as a consequence of an optimal speed, driving conditions would improve together with the improvement of travel times (Generalitat de Catalunya & Servei Català de Trànsit, 2008).

Overall, it can be said that the impact would go beyond the improvement of air quality: reduction of petrol consumption, less traffic noise due to lower speed and increased road capacity (Generalitat de Catalunya & Servei Català de Trànsit, 2008). The choice of 80km/hour was, for these reasons, the result of an equation between the evaluation of air emissions, speed, traffic fluidity and road capacity.[118] The implementation of the flexible speed limit started initially with a fixed maximum of 80km/hour, as opposed to the 120km/hour stipulated for motorways in Spain, covering 84km of road accesses to Barcelona, throughout which this maximum could be reduced in certain conditions (Generalitat de Catalunya, 2012). The initial public reaction was very negative, as the 80km/hour speed limit did not seem to take into consideration periods of low congestion. It was changed to its current format shortly afterwards, as a consequence of a change in the Catalonian government.[119] The strict speed limit was replaced by a range of maximum speed limit between 80 and 120km/hour, according to the specific conditions of certain parts of the road and how close it was to Barcelona,[120] in addition to the real-time air quality and traffic congestion (Generalitat de Catalunya, 2012).

Nonetheless, it can be said that the implementation of the flexible speed limit always aimed at more than its own scope of action, especially when it was changed to a more dynamic and modular system. Together with the objectives already mentioned, it also aimed at turning the wider flow of vehicles into an object of management. With less congestion and higher average speed, drivers would be forced into using a higher gear, leading consequently to lower levels of emissions (Cerrillo & Muñoz, 2012). In addition to this, a variable speed limit would mean that it could also be adapted to the traffic conditions at each time of the day (Molins, 2011), allowing better management of the flux of vehicles entering and leaving the city. Once the infrastructure was in place, especially through the support of the LED screens (see Fig. 3), extending the scope of action became very easy. These screens not only are used to show the variable speed limit but also provide a wide range of information not directly related to the management of traffic, but rather with its context of action. Messages tend to cover risk of fire alert, recommendations about

[118] It has been said that the speed for maximum road capacity is within 83-87km/h (Ecourbano, 2008). A fluid road at its maximum capacity allows vehicles to travel together each in their own lane as a pack without major disruptions (Ecourbano, 2008). The lower speed difference between vehicles in a situation such as this also leads to higher road safety (Ecourbano, 2008). Furthermore, if vehicles manage to maintain a constant speed of between 65 and 90 km/hour, both congestion and accidents can be considerably reduced (Pérez, 2009).

[119] This coincided with a period of elections and a newly elected government at regional level, the same body that is responsible for the management of these roads.

[120] In general terms, the speed limit tends to become stricter as the driver gets closer to the city centre.

eyesight, personal safety, or car mechanical check-up (see Fig. 3 stating in Catalonian that "You cannot be replaced").

FIGURE 3: LED sign at C-32 road, Barcelona (Carina Lopes 2015)

The implementation, enforcement and management of the flexible speed limit, which has been in place in all road accesses to Barcelona since 2014, is the responsibility of CIVICAT – the Catalan Centre for Road Information – itself under the responsibility of the Government of Catalonia. The operations centre of CIVICAT is located in central Barcelona in one of its main avenues and from there extends itself across Catalonia, with a special emphasis on the metropolitan area of Barcelona. Formed by a large and complex network of electronic devices, it works non-stop 365 days per year (Pérez, 2009). Similar to the objectives of the implementation of the flexible speed limit, it aims to enforce safe mobility and work towards the reduction of traffic incidents with the support of real-time information about road and traffic conditions. The service provided by CIVICAT is made possible and supported by, beyond its operations centre, a network of CCTV cameras; over 175 LED message screens that show real-time speed limits and also useful information for drivers; analogue security material that is placed on the road during special events; reversible and priority lanes; and a system that allows the collection of data about vehicles – how many vehicles, their speed and current traffic density – installed approximately every 500 metres (Generalitat de Catalunya & Servei Català de Trànsit, 2008; Pérez, 2009). In the case of extraordinary events, additional aerial means of transportation can be used.

This material assemblage is activated and made to connect by the action of two distinct software applications. The first software application collects and processes the information gathered from the vehicles passing on a specific road – speed, how many and density – to then be processed by an algorithm which regulates speed limit and updates information in all LED screens across the access roads (Pérez, 2009). This software, known as the congestion algorithm, can be put into use both manually and automatically, based on time of the day, and it analyses unexpected changes of speed, so flow can be modulated to ensure stability (Pérez, 2009). The second piece of software, here of major relevance, is responsible for “the dynamic control of the speed management system”, and it is comprised of “two main control algorithms”, one specifically concerned with “congestion” and the second designed to deal with “pollution” (Generalitat de Catalunya & Servei Català de Trànsit, 2008). Two aspects are of relevance in relation to these algorithms – they were presented as an open project that would be improved and changed as necessary and that the algorithm concerned with pollution would only work in moments without major congestion as “the congestion algorithm takes prevalence” (Generalitat de Catalunya & Servei Català de Trànsit, 2008).

Within the initial area of implementation, LED screens were installed “one kilometre apart”; the system was made possible through the development and installation of “a fibre optic communications network”; “several data-gathering stations” were placed approximately every 500 metres; the travel time by each vehicle was calculated by registration plate reader equipment; and two new air quality monitoring stations were put into place that could measure PM_{10} and NO_x on-site (Generalitat de Catalunya & Servei Català de Trànsit, 2008). Speed changes take place by intervals of “10km/hr”, and they are able to catch the drivers’ attention through a “flashing signal” (Generalitat de Catalunya & Servei Català de Trànsit, 2008).

The context of the C-32 road emerges as a deep entanglement between distributed material and non-material computational elements, working for and in relation to each other. This means that as a vehicle crosses the C-32, it is accounted for and traced every 23 seconds if it maintains an 80km/hour speed, and it can receive feedback about the evolvement of that same assemblage every 45 seconds through the LED screens positioned centrally every single kilometre. The vehicle not only feeds into the two existing algorithms; it is consequently constrained by their feedback and adaptation of the continuously in-formation context. The screens, placed both as entry-points to the overall technical assemblage and real-time interfaces of ongoing evolvements, can be seen as bringing together “software and hardware” (Cramer & Fuller, 2008, p.149). The interface simplifies all the interactions and calculations being made every second; it translates complex algorithms and material assemblages into direct and short messages. The LED screen, every time it flashes with a newly updated speed limit and posts messages external to the act of driving, speaks of a contextual control and direct action upon a delimited territory. As Florian Cramer and Matthew Fuller state (2008, p.150), interfaces can express and underline “the representation or the re-articulation of a process occurring at another scalar layer, while the term language, in a computer context, emphasizes control”. The LED screen has the role of modulating a field of action, even if the surrounding material arrangement is also working towards the monitoring and enforcing of this desired field.

When we use the concept of traffic management, this is necessarily inscribed within a much broader concept – that of mobility. This implies a quite complex system of dynamic relations and side-effects of unexpected events – it is not simply about vehicles moving through static elements from one position to another, as it includes broader considerations of this same activity (Urry, 2007). When it comes to urban context, the analysis of mobility tends to start with the underlying reasons for displacements to then include aspects like logistics, pedestrian flows, parking facilities, public transport and the usage of private vehicles. Central to the understanding of contemporary mobility are “integration” and the possibilities offered by computational systems (López Torrent, 2010). Integration is partly driven by the desire to have a complete overview, to control and be aware of all variables, and to minimise risk and liability. Like in the system sustaining the management of the bus fleet by Transport for London, discussed at the beginning of this thesis, all aspects of the system share the desire to provide an overview and minimise what is unknown.

The technical and material arrangement built throughout the C-32 cannot be seen solely as an objective project seeking better traffic management. When it is tied to air quality, car mechanical safety and the condition of the eyesight of drivers, the complex infrastructural system imposing a logic of road usage modulates drivers as they approach the metropolis; it prepares the path to enter a field of accountability and what is defined as intensive gridding. Mobility is, at this stage, turned into a fluid flow that needs some level of overseeing and controlling. It becomes a field that "focuses on adaptation to continuous variability rather than selection among discrete options" (Dourish & Bell, 2011, p.134). The flow that enters the metropolis "implies a continual reshaping or shape-shifting in changing circumstances", adapting to the local context and real-time conditions, be it an episode of heavy air pollution or disproportionate heavy traffic due to bad weather conditions (Dourish & Bell, 2011, p.134).

4.3.2. Flows, intensities and variable speed

The implementation of the flexible speed limit could seem, from the perspective of the road users, like a discussion mostly placed within the realm of local politics. However, as it evolved and the use of the flexible speed limit came into place, the C-32 became primarily the real-time expression of a complex urban system that is activated and coordinated through a series of algorithmic interactions, enabled by a large range of sensors and cameras, and mostly expressed through LED screens. The context of the C-32 emerged, from what has been presented so far, as a context defined by its own flows, intensities and variable speeds that 'somehow' were constrained and converged with the network monitoring air quality throughout the metropolitan area. I intentionally say somehow, due to the difficulty in tracing the already acknowledged and existing process of convergence within its own context of action. Throughout the C-32 there is always a sense of intangibility; what connects the different elements and the previously separate infrastructural systems are software applications, the activity of which has very little expression outside the inner activity of the overall system. These software applications are difficult not only to challenge or unpack (in the sense of opening up their embedded agencies, objectives and assumptions) but also to place from the perspective of their outcomes throughout the urban context. The access to the software and its placement within the operations room of CIVICAT is closed off, the details of the operational dynamics are left unanswered.

From a viewpoint that considers the entire field of action of the C-32, the evolving context of action is like an extended field where folds take place, where the possibility of continuous adaptation materialises through the sensing-reaction and calculation-reaction of the levels of real-time traffic congestion and air quality. Nonetheless, from the perspective offered by the European directive and then local regulative framework, the context of the C-32 is about ensuring a field of action aligned with a transnational vision where air pollutants are not only subjected to management but also actively steered into assigned classifications and homogeneous, with regard to our understanding of them. This variation of contextual reading that we are able to encounter according to the entry-point used to this assemblage is very telling about the difficulty of approaching urban systems through what they do and outcomes of this same way of working. Moreover, the C-32 is a tiny portion of a much wider, complicated and continuously developing complex urban system. The same can be said about the implementation of the flexible speed limit, which represents one of the 73 generic action points defined by the Government of Catalonia to tackle issues of air quality (Generalitat de Catalunya, 2007).

Returning to the C-32, from the software being used, the large array of sensors and CCTVs, to the control centre that oversees it all, it can be concluded that the overall objective is to slowly move the converged system towards a modular and probabilistic context of action. This means to coordinate the field of action unfolding within the C-32 as a relational system that becomes expressive in the entanglement of traffic congestion, air pollution and road safety. Not only is each element working in relation to at least one other element throughout the C-32, that same field of action continuously unfolds through the action of each vehicle. The level of pollution and the speed limit allowed in each moment continuously adapts and is a consequence of what is taking place. This clearly speaks of continuity and modulation, as well as of active actions seeking the ordering and differentiation of the different elements, both static and mobile, such as the passing vehicles. The two software applications reasoning and calculating the field of action can work in a manual or automatic way. They can infer or ask for confirmation of their actions. Nonetheless, the path up to the moment of inference was already designed to continuously coordinate the different variables in order to achieve stability; the feedback loop was designed a priori to ensure continuity. As discussed in Chapter 2, from a topologic perspective, the ongoing calculation is that of a probabilistic account that ensures a degree of stability; the probabilistic action is already working upfront on what could turn into a problem if left to follow its own path. The vehicles of the C-32 are made then accountable and objectified; they are never left to be on their own or self-organise.

The role played by the software applications is then essential as it can be argued that these pieces connect disparities; they are boundary elements across disparate fields of action (Bowker & Star, 2000, p.297) or specifically designed gateways (Edwards, 2010, p.11). Software, within this context, can be said to be transversal to two previously distinct complex urban systems. What was not previously part of either system came into place in order to support the convergence of these systems. Software worked through the establishment of elements of connection, in order to become a core part of the newly converged complex urban system as well as have a transversal meaning to all technical elements involved. This occurred due to software's potential adaptability, which allowed the inclusion of contextual needs, specific actions upon defined exceptions, "yet robust enough to maintain a common identity across sites" (Bowker & Star, 2000, p.297). Software, supported by a range of material, computational and digital elements, tames and coordinates dynamics between different elements, while accelerating a process of convergence that would be otherwise, mostly likely, very challenging. Its stability is ensured by the regulative framework that slowly shapes its algorithmic interactions throughout a European, national and finally local perspective (Bowker & Star, 2000, p.313).

The analysis of the C-32 helps then to better contextualise the implications already discussed of the extension of computation into complex urban systems, and more precisely through the processes of softwarisation and datafication. Software is, in this context, not only the element that allows convergence to take place – by acting as a boundary object or a gateway – but once in place, it enables a further expansion and consolidation of what is already unravelling. Software accelerates a process. This was reinforced from very early on, by the policy framework developed at European level implying an algorithmic application, facilitating the conceptualisation of the field of action and overall objectives. The intensification of the field of action occurs through the intrinsic possible flexibility of software. More precisely, because software does not need to be a complete or limited element, it has an intrinsic ability to continuously expand its own capabilities – affordances and thresholds – slowly either bringing under its scope of action new areas or transforming those areas through its logic. In addition, if on one hand an algorithm can be presented as "a finite set of steps for solving problems", its attractiveness lays exactly within the knowledge that "the specification of an algorithm can change" (Fuller & Goffey, 2012b, p.83).

Returning to the issue of agency, even in a context where the software seems to start from a regulative framework that clearly attempts to design a transversal, homogeneous and replicable field of action throughout the European territories, the question of where agency lays still matters. As Mackenzie (2006, p.10) stated in relation to the field of action of wireless technologies, the position of agency within software is particularly complex in contexts of distributed computation as "agency distributes itself between people or between people and things in kaleidoscopic permutations". In contexts such as this, dependent on and only functional through distributed computational assemblages, agency offers a degree of uncertainty, of plasticity and lack of sureness about its own positioning, actuation and intention (Mackenzie, 2006, p.10). Contexts like that encountered within the C-32, and even more, of the converged complex urban system, involve so many technical elements that they necessarily imply changes, adaptations, alignments and the solving of existing tensions. The same software will be subjected to regular updates, fixing of bugs and possibly addition of scope. The coming together of two previously disparate systems is often preceded by the opening up of this same context, in a search for elements that can balance out emerging tensions. This means that the intangibility sensed from the different pieces of software also applies to the difficulty in placing agency (Mackenzie, 2010, p.206), in part due to that same incapacity or difficulty in pinning down what exactly is occurring.

Agency is not only placed in the way relational interaction happens; it can also be found within the designing and conceptualisation of the system. This means that standards are also a site where agencies play a role. As seen before, standards can embody expressions of power dynamics, with specific traits according to their context. One example is the role played by protocols within computational practices – simultaneously implying "an apparatus that facilitates networks and a logic that governs how things are done within that apparatus" (Galloway & Thacker, 2007, pp.28–29). In this particular example, protocol allows "distributing [of] agencies in a complex manner" while "concentrating rigid forms of management and control", implying a form of power that is less about "discipline" and "more about control (modulation, distribution, flexibility)" (Galloway & Thacker, 2007, p.31). Protocol is of particular relevance for complex urban systems, due to their dependency on computational processes, which are often owned and distributed worldwide by large corporations, with very strict policies on compatibilities. These systems, often connecting and interacting with other systems, are therefore dependent on protocols and internal modes of control (Galloway & Thacker, 2007, pp.54–55) that ensure the exchange and passing on of information, as well as the conditions under which these activities take place. Software, when simultaneously acting as a boundary and gateway, is enforcing specific protocols in order to make the differential context be redirected into a shared way of working.

4.4. Placed within the fringes

While the C-32 can be said to exemplify the primordial context of action of the converged complex urban system that is the object of our study, what remains and takes place on the fringes still is of key importance. By fringes, I mean elements placed within what can be considered as secondary or in marginal positions in relation to the main outcomes of the complex urban system. These elements can go easily unnoticed, both due to their scale and passive role, working through a one-way channel of communication. More precisely, it refers to what can be described as being peripheral to the areas of higher intensity of action. This is the case with one of the many sensors positioned at the top of each air quality monitoring station and the mobile application "Aire Cat"[121], developed by the Government of Catalonia. In

[121] In English, its title means literally "Catalonian Air". For more information on the mobile application, please see: https://www.gencat.cat/mobils/eng/natives/airecat.htm.

both cases, their one-way channel of communication makes them easier to access and unpack. Connected to the Sant's station in one way or another, they are derived from it as an entry-point to a much larger assemblage. The station represents a node of action that can go easily unnoticed, which through its one-way channel of communication opens up to other relational elements, also working in a very locational and at-the-fringes position. Both elements – the sensor and the mobile application – are relatively small objects with limited aims within the complex urban system they belong to. Their unpacking becomes for that reason easier to carry on.

The scale and positioning of the sensor and the mobile phone application implies a marginal position in relation to the converged system. While the sensor sits on the top of the station and emits a low buzz signalling that it is functioning, like the one at the Sants' station (see Fig. 4), the mobile application is part of a communication and risk management strategy, and it has become part of my mobile application's library. In both cases, their sitting on the fringes is balanced out by the computational systems connecting the sensor to the central data system and enabling the visualisation of the regularly updated air quality data for the city of Barcelona and overall Catalonia on the mobile phone. These systems work, once again, as bounding elements of divergent contexts, enabling the continuous evolvement of the convergence process. The sensor feeds into the overall assemblage time-tagged measurements, while the mobile application provides access to this same data, already treated, compiled and massively simplified.

More importantly, these two elements, due to their common and direct relation to air quality, gain a level of additional relevance. As has just been discussed, the visible outcomes of our converged complex system take place mostly within the surrounding roads approaching Barcelona and the implementation of the flexible speed limit. The emphasis that has been put on the variability of speed is misleading, as it positions the monitoring of air quality and consequent modulation in a secondary position; or like in the case of the sensor and the mobile application, within the fringes of a very large technical arrangement. Nonetheless, even if their relation to air quality can seem to bring both of these elements together, they remain very different in character. The sensor works towards compliance with a legal obligation, and it emerges out of a highly regulated context (European Parliament, 2008). It is a compulsory measure regulated to a high degree of detail, while the mobile application is an upfront strategy of dealing with liability and a probabilistic future risk. It represents the effort of the regional government to become more accessible, by providing simple visual information about such a complex topic to its own citizens, in addition to the alerts it is obliged to make every time the air quality exceeds certain legal limits (European Parliament, 2008, p.39).

As we move through our analysis, computational processes continue to gain an increased relevance in the unfolding and existing dynamics sustaining the convergence process. In the case of the sensor and the mobile application, they are deeply connected and dependent on the algorithmic way of working, simultaneously sustaining and enabling them in their position within the complex system. It is also through computational processes that both of them become folded into the field of action and are made essential within a large array of distributed technical elements. Computation implies in this way a step beyond connecting or establishing nodes of interaction. It actively resolves the problem of positioning, by to a certain degree, flattening down the field of action towards a network context, in the sense that it becomes active through the enabling of computational processes, bringing together what is central to the field of action and what sits in the fringes of the system without making a differentiation.

Before we can focus on the specificities of the sensor and the mobile application within the overall assemblage, it is important to dwell again on the issue of modulation. More specifically, the issue of spatial governance through distributed computation becomes especially visible through small-scale elements such as the sensor and the mobile application. Spatial governance allows us to further extend our understanding of the context of action, and it also brings forward the role played by elements positioned at the fringe of the core system. The positioning at the fringes not only means a marginal position or a possible secondary contribution to the overall systems but also implies the existence and possibility of a distributed reasoning. In this context, the sensor and the mobile application can be seen as embodying the role of "action at a distance" (Rose, 2000, p.323) from two different but complementary perspectives. On one hand, they actively contribute to what takes place through the expressive points of the assemblage, even from their position at the fringe, while on the other hand, they are the outcome of a regulative framework that from its outset conceptualised a specific arrangement of dynamics and desired objectives where the local emphasis and the global overview coexist.

The context of action where both elements are placed was designed from the perspective of the network of stations monitoring the air quality of an already identified geographic area. However, as it moved down through the different levels of decision-making – from the European Commission, to the Spanish Government, then to Government of Catalonia and the City of Barcelona – it was turned into a context that became expressed through the implementation of a flexible speed limit. In this sense, this can be interpreted as "action at a distance", implying a loose design of a field that, it is already assumed, will take its own shape, or the shape necessary to achieve both stability and its own objectives (Rose, 2000, p.323). This assumed and non-problematic continuity and evolvement makes an implicit reference again to modulation. The loose evolvement of a context is taken as a variable setting that can be modulated and adapted as new needs emerge or new pathways are defined.

This context of action of the converged system assumes and expresses qualities of what Gabrys (2014, p.30) has referred to as "programming environments". The programming here implies the programmability of a context of action, in which "control through modulation" is applied in a distributed mode – leading to the "environmentality or the distribution of governance" (Gabrys, 2014, p.30). Within this distributed computation and programmability of the environments, one aspect that stands out is the duality of intentions. As has become visible throughout this case study, this duality is expressed in the contradiction often encountered between intention, application and expression of the distributed elements of a complex urban system. What is conceptualised and designed as a specific field of action, under an already algorithmic assumption, is able to undergo transformations and adaptations without losing its ability to maintain its overall objective at its core. Furthermore, the mapping on the ground would greatly differ from that of the field that was intentionally designed, most due to the affordances of computation. It can allow this contradiction as what matters is the ability to control from a distance, where the designed field and the sensed outcome are shown to match.

Control as modulation is, when it comes to complex urban systems and their context of action, applied to different elements of this distributed assemblage, as well as through the context of action (or associated milieu). Modulation, within this context, is not so much about "individual subject to be governed", but a context that is "articulated *environmentally* through the distribution and feedback of monitoring and urban data practices"[122] (Gabrys, 2014, p.32). What is at stake is not so much who uses and experiences that specific territory, but how a designed context may take to a specific and planned outcome. The control being made implicit here is one of "flows" that do not deal with detailed specifics, but that are concerned instead "with elements, capacities, potentialities" that are made to relate to other "bits of information" (Rose, 2000, p.325). I particularly find productive the expression of "atmospheric attunement" that Kathleen Stewart (2011, pp.445–449) uses, as a way to refer to flows and modulation of an environment. She implies with it a way to explore "an intimate, compositional process of dwelling in spaces that bears, gestures, gestates, worlds". In a way, it refers to a degree of intangibility, where flows, tendencies and forces merge together. The expressivity of Stewart's "attunement" speaks of something that is open to new unfoldings and what has not arrived yet, but the potential of which is already there – " a capacity to affect and to be affected that pushes a present into a composition, an expressivity, the sense of potentiality and event" (Stewart, 2011, p.452). The modulation and control mode that the distributed and converged assemblage assumes also speaks of potential and ability to reinforce certain outcomes. The difference here is that it is often assumed to be a context of certainty and totalitarian ability to define unravellings, outcomes and ways of working.

[122] Italics in original.

4.4.1. The sensor

FIGURE 4: Air quality monitoring sensor, Barcelona (Carina Lopes 2015)

Placed at the fringes of the technical assemblage feeding into the flexible speed limit across Barcelona's network of suburban roads, the Sants' station can easily remain as part of the unnoticed infrastructural system working away from the main areas of action. It is placed away from the sight of the urban apparatus, citizens more sensitive to air quality and even away from the drivers experiencing changes in the speed limit regularly updated throughout the LED screens. From this perspective, the material scale of the sensor placed at the top of the air quality monitoring station can seem insignificant in relation to the wider assemblage. Nonetheless, the sensor can still express and embody the wider dynamics of ongoing large data collection, software running and spatial inferring systems. It can offer too some insights into the converged technical system, the geographic enhancement taking place, the areas of amplification that were chosen over other possibilities and the relational space unravelling from that specific location.

Positioned within a distributed computational context, it is part of a more complex environment, in which a range of sensors collect data through different "registers" (Thrift, 2014, p.9). Through their distributed action, they contribute to the unravelling of a territory that becomes constrained to the objectives of these same sensors. They are "starting to actively shape their environment" by prioritising a specific narrative of their context (Thrift, 2014, p.9). Slowly, they build a real-time skewed vision, but they also start constraining what will come in the future. Sensors activate an action or reaction to what they sense; they are also recording reactions to their working, which will feed into their future acting upon the world. Sensors allow the mapping of existing spatial and technical relations in more detail – what their object of concern is, how they become activated or if their work is always continuous, and how they relate to the other elements of the assemblage (Gabrys, 2012). In this sense, the potential of connected sensors resides exactly in "the ability to understand the complex interactions and relations within ecosystems in greater detail" (Gabrys, 2012), but always from the perspective that they have their own sense of the narrative. The various registers mentioned by Thrift necessarily are about choosing one path over another, or one line of potentiality over others.

The wider consequence of this is that the role of sensors is also generative. The data they collect becomes the basis for future decisions, as the European directive already assumed (European Parliament, 2008), meaning that they actively construct the narrative that will follow and condense potential within a narrower path (Gabrys, 2012). The role of sensors can be interpreted as being more productive than descriptive, and as Gabrys (2012) explains, this means that the data collected is "less descriptive of pre-existing conditions, and more productive of new environments, entities and occasions of sense." It can be assumed then that once the distributed computation and reasoning is in place, what comes out of their locational placing and context is not simply a reading of their surroundings. There is a performative and line of narrative specific to the computational, infrastructural and spatial arrangement put into place.

Going into this in more detail, and based on what has been discussed in relation to this case study, it is possible to think on three aspects of the entanglement in place within the convergence of the air quality measuring network and the traffic management assemblage that necessarily lead to the construction of a more-or-less defined line of narrative. This line of narrative always leads back in one way or another to the sensors placed at the top of each station. Firstly, there is the specific distribution, arrangement and placing of the stations as defined in detail by the

European directive (European Parliament, 2008). Secondly, the type of pollutants measured by each station vary according to a pre-defined proportional balance, the available resources and ability to measure certain pollutants by manual or automatic means (European Parliament, 2008). And finally, there are the established standards for data collection, treatment, processing and sharing, together with specifically designed methodologies also stated within the European directive (European Parliament, 2008). When combined, these three lines of constraining necessarily lead down a specific narrative path.

When it comes to the monitoring of air quality, there is scope for a delayed action–reaction, in this case through the alerting of the population about pollution being above legal limits (European Parliament, 2008). This means that a sensor is not simply an object of measurement; its positioning and role varies in relation to its context of action, offering for this same reason "distinct insights into the complex interactions and processes" taking place throughout the assemblage it belong to (Gabrys, 2012). Furthermore, once data is collected, it enters a new dynamic arrangement, in which it is transformed, adapted and aligned with a specific material and immaterial arrangement. This needs to be understood, nonetheless, within a context where there is a high level of variability – each pollutant is treated differently, different types of sensors have distinct temporalities and more direct or indirect action upon their context of action. Therefore, it can be said that although "sensors are physically proximate to what they sense", what unravels once data moves through the "channels of algorithmic detection and processing" varies greatly (Gabrys, 2012).

On one hand, sensors tend to have different levels of sensibility and programming, meaning that they are always open to further calibration, while on the other hand, there is "a tendency to smooth and fuse data" (Gabrys, 2012), aligned with the proposal made earlier that these algorithmic arrangements work towards ordering of continuity through an active differentiation. Generated data needs not only to be manageable and productive – or generative – but also to bring close similarities in order to force into visibility what stands out. Concretely, not all pollutants need to be or are treated equally – their measurements often require different emphasis based on the type of pollutant and which varies from hourly to daily to annual averages. Even then, the results made public have multiple sources with different levels of data quality and reliability. These measurements are divided into "fixed" (on-site data collection by specific sensors), "indicative" (collected on site but through not fully approved collection methods) and finally, "data not valid for evaluation" (data collected through non-approved methods to ensure fully data quality (Generalitat de Catalunya, 2014a, pp.9–10). For example, the tendency with particulate matter (PM_{10} and $PM_{2,5}$) is to, as time moves forward, make their legal limits stricter, as the threshold of safety has not been identified yet (Ajuntament de Barcelona, 2013b). In the case of ozone (O_3), measured by automatic systems, it is the outcome of the combination of other pollutants when in contact with the sun, meaning that a higher temperature average and "solar radiation" leads automatically to the worsening of its levels (Generalitat de Catalunya, 2014a, p.28).

The limited number of stations and therefore measuring points means that the city is forced to analyse the overall air quality through data models. The latest plan designed by Barcelona City Council to support the continuous improvement of air quality was based on a model built to forecast the pollution levels from 2013 to 2018 (Barcelona Regional & Gerència Adjunta de Medi Ambient i Serveis Urbans, 2015, pp.66–67). Once created, different measures (variables) were introduced in order to calculate the impact of each one of them, supporting the design of measures that would ensure the set objectives were achieved. When data becomes compiled into data models, "latitude and longitude" gain a new meaning – they move way from being static positioning points to be turned into "numerical" and "circulation models" where fluidity and evolvement imply "a qualitatively new status" (Edwards, 2010, p.253). Between their static positioning at a specific geographic placement and the arrival of the data model, all data points need to be translated "into new data calculated for the model's demands" (Edwards, 2010, p.253). The station used as a baseline and the closest representation of the air quality that most inhabitants are exposed to is located in the city centre in one of its old town neighbourhoods – Raval. It is this station and its data collected on site (throughout 2013) that directly fed into the calibration of the model developed (Barcelona Regional & Gerència Adjunta de Medi Ambient i Serveis Urbans, 2015, pp.66–67).

The scale and calibration of the data collected is then, once again, essential. Modelling requires sophisticated calibration, so it is fully aligned with the measurements being taken by fixed points. The calculation of models needs to account for not only levels of pollution and its source but also possible events that will put pressure on acceptable air quality and the expected level of air quality behaviour throughout the different seasons, due to specificities of the Mediterranean climate. In this case, the model developed for the city of Barcelona and used by the local authorities is considered to have an accuracy of "99,1%" for NO_2 and "97,4%" in the case of PM_{10} (Ajuntament de Barcelona, 2008, p.142).

Given a specific positioning – longitude and latitude – what becomes established, in either inwards or outwards relational process, is that the nodes or interconnection points of different relational planes are mostly defined "by their variability and impermanence" (McQuire, 2008, p.23). This means that location as a point where the air quality station is placed in a specific street is one singular point in a fixed geographic coordinate crossed by many other planes that take its limited stability to a new level of variation and change. In material terms, what matters to the local authorities is not simply the air quality station, but its own system and assemblage of elements that go from policies and strategic priorities to maintenance, and interlink with other systems. In the specific urban context, the air quality station is tied to and embodies the relation with the rest of the network, how the network is connected with other air quality measuring elements, variation of pollution levels within its vicinities and according to periods of the day, season and even year, and process of maintenance.

4.4.2. The mobile application

The data that is collected by the sensor placed at the top of my local station ends up feeding into the mobile application created by the Government of Catalonia, Aire Cat.[123] As the receiving and converging point of air quality throughout Catalonia that consequently becomes translated visually, this mobile application is characterised by its passive role as interface for data visualisation and distance from the intensive dynamics of action unravelling throughout the suburban roads, and more precisely, the C-32 as presented earlier. The mobile application expresses the moment when data on air quality goes social – as it moves to a mobile host, the available information is also made shareable throughout social media. It allows users

[123] For more on the mobile application visit: https://www.gencat.cat/mobils/eng/natives/airecat.htm

to track considerable changes in air quality and share that information with their friends. Although designed and placed as a public information point, the mobile application can also be understood as an active way of dealing with future liability. It informs and provides transparency and easy access to data that would be otherwise difficult to track. It could be said that it attempts to cover possible weakness points of the interaction of urban dwellers with bad air quality, by controlling and managing "uncertainty" (Rose, 2000, p.333). The mobile application informs on level of risk in practising sports and outdoors activities, based on two groups – those that are considered as being more sensitive to high exposure and the general population. In this way, it passes responsibility to the population to plan activities based on the prognostics provided two days in advance. In any case, the mobile application can be seen within the context of the directive, which states the obligation to provide "up-to-date information on ambient concentrations of the pollutants" in the format of average levels of each regulated pollutant or as alerts if these same pollutants exceed the established "thresholds" (European Parliament, 2008, p.39).

By being placed at the fringes, it implies a degree of detachment and distance from the context of action. Although the user of the application can always be positioned in relation to the nearest station, as long as it is within the Catalonian territory, the application positions itself as the end point. There are no reminiscences of the converged system. It attempts to present itself as the representative and outcome of the collected data. This strictly conveys the wider context of action by narrowing it down to a set of screens that present visualisations that have been highly simplified in order to convey a message within a range of three colours – red, yellow and green. The filtering of information to a level that can become readable by a tri-colour scale almost contradicts the context from which it emerges. Similar to the station, it contradicts and uses a different language in relation to the regulative framework from which it emerges and the logic supporting the development of data models. In the case of the mobile application, it is not about detail or an intensive grid of visualisation – in clear opposition to this, the city of Barcelona becomes divided into a territory equivalent to its seven stations owned by the regional government. The mobile application sits on a diametrically opposed position to the data model, through which missing data geographic points are calculated so a complete model of the territory can be achieved. Based on a territorial subdivision into seven stations, the mobile application provides an overview of the general territory and then detailed information on each station with automatic measuring techniques. In the case of my local station, it indicates which type of station it is and provides regular updates every two hours on the levels of NO_2, always indicated through the tri-colour scale.

The spatial unfolding enabled by the mobile application is then more condensed than the data model, but also dominated by more centralised points of emphasis, as it reduces the entire territory into seven points of emphasis. The software that gives rise to the ordering of these visualisations opens up the mesh of intensive gridding with the objective of "overcoming the distance" between the complexity and intangibility of the pollutants and a reading that attempts to ground the floating particles (Wright, 2008, p.79). The data that is connected and the ordered and tri-coloured visualisations attempt to ground what has an intrinsic intangibility (Wright, 2008, p.79). In addition, it can be argued that the mobile application offers an emphasis on location – it is necessarily articulated with the converged system and the European assemblage, but it attempts to resolve tensions at the local level by facilitating access to data about the air quality throughout the city. To a certain degree, both the sensor and mobile application seem to offer the opportunity to access the wider assemblage of a more concretised endeavour. Their one-way channel, at the fringe positioning, and the simplicity of their objectives, enabled and supported by the action of computation, means that they have a context of action with less friction, where their positioning and logic of action has been established.

4.5. Spatial intensities and intensive gridding

This chapter has given us the opportunity to consider the assemblage and dynamics of a converged complex urban system from three different perspectives – the regulative framework that gave origin to the process of convergence, the unravelling spatial dynamics within a context of intensive action and, finally, what it means to be part of a converged system for those elements sitting within the fringes of a much broader technical assemblage. Transversal to all of these three perspectives has been the position of computational practices and the role they play in defining, constraining and guiding future unravelments. The process of convergence is shown to have been the outcome of the continuous extension of computation; this same extension is also shown in action as it continues to extend the scope of action of computation once the process of convergence has come into being. Furthermore, it is revealed that the computational logic has a deep impact on the context of action of complex urban systems, as it transforms those touched or positioned next to it. The European directive is proved to be a precise example of this same process, by demonstrating that from its outset it had already assumed a translation into action that would have an algorithmic materialisation. Computational practices are shown to increase the difficulty of entering complex urban systems or understanding where their agencies sit or what their overall objectives are – therefore there is the need to use specific entry points as a way to both circumvent and overcome this difficulty.

The process of convergence between the network for the monitoring and forecasting of air quality and traffic management assemblage encountered in suburban roads was preceded by a spatial conceptualisation of a field of action that could monitor and improve the air quality throughout the European territory. What has been possible to demonstrate is that the European directive, and the technical arrangements proposed by it, ignored to a large degree the context of action already in place throughout the territories where it needed to be applied, like in the case of Catalonia, where the first regulation on air quality dates back to 1983. It assumed then from its outset the necessary arrangement of an infrastructural context in order to fit into a formalised conceptualisation of a field of action. Once the first wave of rearrangement takes place, a series of measures come into place in order to become aligned with the designed framework. The process of convergence that has been outlined throughout this chapter describes this same process, so as it moves closer to concretisation, it also simulates as much as possible the conceptualised field of action. This means that, in the long term, the directive will have a direct impact on how this converged system will become concretised – as already discussed in the previous chapter, the system moves to a more concretised position by simultaneously co-evolving with its own context of action.

From this perspective, the role played by computation happens at multiple levels: it is intrinsic to the design of the directive, it is needed in order to implement that same spatial conceptualisation, and finally, it will support, accelerate and intensify the converged system as it moves closer to a concretised position. This becomes particularly visible through the elements positioned at the fringes, such as the sensor and the mobile application, which with the support of computation can slowly solve its tensions and become aligned with its context of usage. Furthermore, the material arrangement of the infrastructural system, in combination with the already assumed algorithmic arrangement, leads to the prevailing of a specific narrative over a given context. Overall, this is also possible due to the already assumed algorithmic arrangement, but also the intrinsic affordance of computational processes and outcomes to be adapted and tailored as required and as the needs of a given context evolve, in order to achieve the conceptualised field of action. Computation has then been shown again as working transversally and as a bounding factor. Its processes allow to bring management to the level of the molecular, endless modulation, entering the space of behaviour and interaction with what has not arrived yet. Going a step further, regulation-making and computation-concretisation are shown here to have created a co-dependency that supports their continuous evolvement and expansion of each other's area of action, consequently reinforced by cycles of updating, adaptation and calibration inserted already in the policy statements.

In any case, what the example of the C-32 shows us is a deeply locational context and complex urban system at work. This implies at one level a specific material arrangement that was designed and implemented for that location, and at another level, pieces of software specifically designed and accounting variables unique to that same context. Simultaneous with this, within the same converged system, there is the network of stations collecting data that is later fed into the software working throughout the C-32, but which also feeds data to transnational systems. The context of the converged system is therefore deeply locational and transnational at the same time, in a direct relation to the concept of local–global discussed in Chapter 2.

What was not discussed throughout this case study is how this converged system will look once it is concretised. As I cover and dwell on this case study, the regional government works on a new measure that would probably mean a further concretised assemblage. It takes both air quality and mobility to a new level, by converging into one single card all the activities related to mobility across the metropolitan area. This new measure present in the strategic plan for the improvement of air quality designed by the Government of Catalonia is called "T-Mobilitat" (T-Mobility) – aimed to be launched during the second semester of 2016 (Generalitat de Catalunya, 2014b, p.156). Materialised in a magnetic card to be used across all available modes of transport within the metropolitan area, this project aims to put mobility at the core of citizens' lives. "T-Mobilitat" will not only incorporate a sophisticated algorithm that will charge the user based on the frequency of use; this card will be used to cover all aspects of mobility – motorways included – transforming users into mobile nodes where all modes of transportation, both private and public, converge in a single card carried at all times (Generalitat de Catalunya, 2014b, pp.155–156). But what does this card mean in the context of this case study and what we have discussed? It means to take the concept of mobility as a transversal mode of management of urban territories into the experience of users; it means to layer the entire metropolitan territory with an algorithm that computes all movement of users, tracking habits and attempting to influence decisions made through the offering of a flexible pricing system. "T-Mobilitat" will offer reduced prices in zones of special protection, and more importantly, it will be used as a modulation tool in the events of higher levels of pollution. During these events users will be offered higher discounts for using public transport as opposed to the private vehicle, so emissions can be reduced at a faster speed. In the case of non-regular users of public transport, but who are required to own a mobility card in order to pay the tolls of a motorway, for example, one can imagine these specific users being personally targeted to replace their vehicles with public transport for few days (Generalitat de Catalunya, 2014b, pp.155–156). This implies the convergence into one single grid of action and management of different modes of transport, both from the realm of the private and public sphere, and it also brings modulation of behaviour into the open as an active mode of urban dynamics. More importantly, it has software at the core of its infrastructure, 'connecting all of the dots', transversely, from the local to the European context.

5. ENABLING THE DELIVERY OF PARCELS

5.1. The last mile

TRACKING CODE	COUNTRY OF ORIGIN	COUNTRY OF DESTINATION	DATES & REGISTERED PASSAGE-POINTS
RF058926773ES	Spain	Croatia	08/10/15 – Parcel is posted. 11/10/15 – Leaves international sorting office in Spain. 12/10/15 – Arrives at international sorting office in Croatia. 12/10/15 – Leaves to final address. 19/10/15 – To be delivered soon. 20/10/15 – Delivered.
RK002752475FR	France	Spain	25/11/15 – Parcel is posted. 28/11/15 – Leaves international sorting office in France. 02/12/15 – Enters Spain. 02/12/15 – Delivered.
RK826765524FR	France	Spain	10/03/16 – Parcel is posted. 12/03/16 – Leaves international sorting office in France. 12/03/16 – Leaves international sorting office in Spain. 16/03/16 – Being delivered. 16/03/16 – Delivered.

TABLE 2: Tracking record of international parcels[124]

Three parcels travelled separately through Europe during a time frame of five months (see Table 2), either leaving from or having my home address as their final destination, as part of the on the ground work that supported the building of this second case study. They were all sent as recorded mail, just like the multi-post bag that left Lisbon, the unfortunate outcome of which has already been described in the first pages of this thesis. The recording of these parcels implies a degree of trackability and accountability that is translated into a series of key steps through which each international parcel has to go. Some of these steps are made accessible online, by means of a 13-digit international code that ensures some level of similarity in the treatment of these parcels across transnational contexts. Like other

[124] The tracking record of these parcels can be checked at: http://www.correos.es/ss/Satellite/site/pagina-inicio/info?idiomaWeb=en_GB.

examples already discussed, the parcels also navigate a standardised grid of address as they move across borders. As they leave my local post office or are sent to my home address, they all have to go, at some stage, through a major warehouse where the sorting of the mail takes place. This is done at the country of departure and then of arrival, working like key "passage-points" (Graham, 2010a, p.145) into or out of a territory. As the parcels move between the post office and the main warehouse or between the local distribution centre and my home, they all become part of a larger load of parcels, where for moments they are part of a wider unity; they are addressed and managed as a group of parcels sharing an international destination, a region, a city or a postcode.

Thousands of parcels move daily around the globe and across any type of urban territory. However, as they get closer to their final destination, a new challenge emerges, distinct from those faced by the logistics of transnational and global goods. Suddenly, one large load of diverse parcels arriving at a specific urban context as a unity (a load) needs to be redistributed within a narrow time frame to a large variety of addresses. This last stage of logistics not only is very labour intensive but also demands high levels of coordination and operational local knowledge; it is deeply involved with the cacophony of urban rhythms, weather conditions, rush-hour traffic, planning of neighbourhoods and even the availability of stop-and-drop parking spaces. This is known as the challenge of the last mile, and it is mostly concerned with densely inhabited and vast urban territories. This chapter focuses precisely on the context of the last mile and on infrastructural systems supporting and enabling the management of this context. It considers the process and path of moving goods between two distinct points at urban level (Conlumino et al., 2014, p.3), in order to look at the development of infrastructures supporting this same movement. More specifically, it considers the process of amplification that they are currently going through, in order to consider the type of emerging infrastructural arrangements and their temporal and variable qualities. It uses the Spanish postal service as a base to the analysis, by looking at how it deals with space, time and ultimately parcels. This is done so I can also consider the arrival of new approaches to the last mile based on on-demand services or that rely on the disintermediation of the process previously in place.[125]

It is in this context that the chapter aims to propose that computational processes can transform significantly the conceptualisation of urban infrastructures, as well as, in certain cases, replace a high degree of heavy and traditional material arrangements by algorithmic existences. The last mile of logistics will be shown to be a good example of this as what can be increasingly encountered, even within the traditional setting of the Spanish postal services, is a pattern of relational infrastructures that unfold and reorganise every time a new parcel needs to be delivered. In this case, logistics will appear as being intensively "software-based", at many levels, organised and enabled by a series of interconnected systems (Urry, 2007, p.273), supporting one or another logistical process, through a range of steps of interaction and communication. Instead of the parcel proceeding through a stable and defined set of material and algorithmic arrangements, around it emerges a location-bounded and temporal infrastructure, specific to its needs, constraints and demands. The complex urban system coming into usage varies for every single barcode or order number that is created, even if underlying it there is an elaborate group of algorithms executing repetitive and already defined and foreseen series of tasks. Overall, the infrastructural arrangement coming into play every time a new parcel is ordered or posted forces into question what defines infrastructure and "how big, or deep, or old, or widespread" it needs to be in order to become considered a complex urban system (Edwards et al., 2009, p.366). What I propose with the analysis of this case study is that as computation further extends into deeper and more ingrained aspects of traditional infrastructure (as in heavy and large infrastructure or the case of the Spanish postal services), it slowly gains the ability to replace increasingly larger parts of material arrangements for flexible and codified models that rely on more intangible processes, as is the case with disintermediation and on-demand services.

[125] There is an ongoing discussion about the separation and differences between, on one side, sharing economy or collaborative consumption, and on the other, on-demand or disintermediation services. This is important to point out as some of the organisations mentioned within the context of this research actually describe themselves as being part of and placed at the forefront of 'sharing economy' and 'collaborative consumption', as is the case with Uber and Lyft. However, from a logistical perspective – which has at its centre concerns with labour relations and grey areas of regulation (Rossiter, 2011; Zehle & Rossiter, 2016) – this presents at a very pragmatic level a clear case of on-demand services in existence, which it could even then be argued benefit from tapping underused resources and taking advantage of potential already in place.

The parcel becomes in this way an entry-point to a context that is in fast development, within which a process of amplification is taking place. As an entry-point, like what has been already discussed in relation to the methodology used and the first case study, the parcel offers a way to contextualise and inquire about the system it belongs to. The parcel works as an entry-point to a much larger and complex system of distributed computation, comprised of a range of technical elements that present a level of location-oriented and location-awareness capability. Similar to the case of the multi-post bag that never arrived at its final destination in London, the parcel is part of a technical system set up with the objective of managing the movement of a very large number of goods, boxes and parcels. This is done nowadays by means of tagging and tracking, logging of different passage-points, intensive spatial division, automatic creation of barcodes and order numbers, RFID tags and a series of operational steps that involve some sort of classification and sorting activities. The parcel is then used as the object to build the research methodology of this case study. The tracking of the different parcels (as shown in Table 2) opens the door to start understanding the underlining infrastructure. This is then further supported by a tour to a USE (a small node of distribution in Barcelona for urgent parcels owned by the Spanish postal services) where an interview was carried out about the processes in place and a demonstration of the different systems used. The examples selected to work in comparison to the Spanish postal service exemplify a tendency that shares a spatial and operational logic beyond their geographic placing.

Like in the previous case study, Barcelona is presented as the territory of action. At the start, the city is understood as a topographic entity, where multiple layers of maps and jurisdictional divisions coexist, belonging to different perspectives taken on the city (Moore, 2015, p.26), from regional to the local government, and from the post code to geographic points. In this way, the chapter starts by considering how the division of space takes place within the context of the last mile of deliveries. What begins to emerge is an intensive spatial gridding, where different types and levels of specification of spatial division unfold. The delivery of parcels emerges as in continuous and relational evolvement, tightly connected to the specifics of its own location and context of action, but also in relation to all the other parcels en route for the same area. Processes of classification and sorting become in this way entangled with type of delivery, weight, size and positioning within the area of delivery.

Once all of these variables start coming into play, the territorial space becomes closer to a grid of action, a space with the potential to increase its level of detail and intensity. It is within this grid of action that the infrastructural arrangement emerging around the parcel will have to act, tagging and tracking the parcel as it goes through key passage-points or becomes connected with a specific delivery arrangement. It uses a complex algorithm that defines routes, drivers, vans and drop-off approximate times. I suggest within the context of this research that there is no better expression of relational infrastructures than those embodied by the parcel, entangled within an infrastructural assemblage that presents a high degree of softwarisation and datafication. The parcel with its barcode and order number opens the door to a new way of reading spatial enhancement as well as understanding the conceptualisation of infrastructure. It speaks of highly variable infrastructural systems that come into being and visibility when they are needed. This is particularly visible in the case of the emergence of on-demand delivery services such as Glovo and Cargomatic (this last only USA based) (Glovo, 2016; Manero, 2015; O'Reilly, 2016; Rodríguez, 2015), which follow in the steps of Uber and Lyft. Although at an earlier stage of development and concretisation, both Glovo and Cargomatic express the same logic approach to urban space, users and all the other much-needed variables, such as their 'independent' and self-employed drivers.

Nonetheless, as has been discussed in different places in the thesis, even in a context where the computational presence is growing and radically rearranging the complex urban system it belongs to, imposing a growing sense of intangibility, there still are strong underlying material expressions, taking us back again to the work of Edwards (2010), Gabrys (2011) and Parks (2005). With small mobile devices at the centre of the overall assemblage, connecting all of the dots, a full circle is completed, as this case study gets closer to its conclusion. The traditional and heavy infrastructure, to which some of the systems described throughout this thesis belong, such as the railway or suburban roads, comes into play side by side with less static but nevertheless very material expressions and points of reference. Through the barcode, the handheld device coordinating and tracking the work of the driver and the database sustaining all of these, while tagging operational information with its space–time specificities, a series of materialisations are created. Lastly, as locative media have shown from their early days, there is always potential beyond their military context of origin, as already discussed in Chapter 1. As complex urban systems become closer to the user by means of a mobile phone, new areas of openness also appear that allow group action or appropriation of methods and arrangements that would otherwise be felt as being too distant (Lee et al., 2015).

This case study provides then a sense of full circle, as it takes us back to the starting point of this thesis where I began with the contextualisation of locative media. It makes us wonder if the role of portable and mobile media is ultimately this closer connection to what lies underneath. When it gets to this level, the extension of computation allows complex urban systems to become further distributed, but also closer to the fringes – in the sense that they become accessible from a larger variety of entry-points. The existing differentiation mentioned between backbone infrastructure and its add-ons seems to become less relevant in contexts that are from their outset already intensively algorithmic. Spatial evocation, as said in Chapter 1, brings a new meaning to space – when a complex urban system calls upon a location or makes it implicit in its way of working, it implies both a degree of movement and continuity in the relation to that same location. It makes explicit its locational endeavour and centrality. The question of location is then central to the overall unfolding of the logistics of the last mile.

5.2. Logistics and the division of space

Location is central to this thesis. Throughout this project I have looked at different ways complex urban systems reinforce and adapt themselves to each location through their way of working, but also in relation to more global dynamics. As discussed, the extension of computation into urban systems has brought with it technical abilities that make possible the enhancement of what is local through a range of diverse practices such as splintering, segmentation, tailoring and location-based feeds. However, more needs to be said on how computation transforms, from within, those same systems that had already been designed and organised around specific locations and spatial divisions, as is the case with the logistics of the last mile. In this section, I analyse how location, as spatially defined by geographic points, has the ability to allow the coexistence of multiple and competing approaches to itself. This means that location supports and embodies, simultaneously, technical elements that present high levels of adaptability or that have been defined based on pre-established classifications and jurisdictional spatial divisions. Location, in the context of the present discussion, emerges as being part of a wider process of technical amplification, where new dynamics are being opened up to change and transformation, bringing with them a series of novelty elements, risky coding practices and stories of trial and error. Within this process of amplification, computation is not only reformulating but also recreating a new field of action where location, I propose, may well come out with a new, even further enhanced conceptualisation. This provides the opportunity to consider complex urban systems working through contexts that already have location as a central point, while looking at how location is being reconceptualised by the extension of computation into the technical system enabling the last-mile logistics.

When it comes to logistics, the tendency is to think immediately of warehouses, movement of goods from offsite locations, ships crossing the globe, containers, ports, cranes and all types of delivery vehicles. However, underlying all of this is the objective of ensuring that logistical arrangements put into place "efficient movement and undisrupted flow" of goods across extensive fields of space (Cowen, 2010, p.69). The origin of the management and logic of logistics can be traced back to the "military" context of "the eighteenth and nineteenth centuries", but its importance would not gain the dimension it has today until "after the Second World War" (Thrift, 2004, p.589). Nowadays, logistics is as much about the optimisation of processes as flows, managed by what can be called a "technology of address" (Thrift, 2004, p.589), implying by this the production of a range of calculations concerned with tracking and control of flows. This emphasis on flows contrasts with the lack of explicit mention made to the management and division of space itself. From the site of production to the site of consumption or final delivery point, spatial accountability and division takes many forms – organisation and allocation of routes and detours, compulsory stopovers and customs offices, checking in at national distribution centres and local nodes of distribution. In each of these moments, different constraints tied to organisational space come into play, even when the majority of the process has already been automatised. Returning to logistics, in generic terms it emphasises specific “methods of organization” that are then used for the management of “production and patterns of mobility” (such as the flows mentioned) of all types of goods in order to ensure “communication, transport and economic efficiencies” (Neilson & Rossiter, n.d.). Conceptually distinct from industrial logistics, the last mile needs to be understood from the perspective of a highly distributed, splintered and location-oriented context, where modes of spatial division come to play an even more relevant role. Location and spatial management tends to be taken for granted in all of these cases; it is common to all aspects of logistics but often the unmentioned element beyond routes and delivery routines.

In addition to this, the intensive spatial division and level of accountability found within the last mile that is often not made explicit can be interpreted as another extension of the “securitization and fragmentation” of urban territories (Graham, 2010a, p.145). This means that these territories can become easily objectified by modes of calculation, accountability, adaptability and modulation. Furthermore, there is a level of intrinsic and perceived danger within logistics – the foreigner and the outsider (even if only to that location) enter a territory that might be hostile to their presence. It is within this context that Graham (2010a, p.145) puts forward reasons for the growing importance of what he calls “passage-points”. These points, much like borders, are moments of legitimation – of a process and transition of the parcel – but also the right to enter or belong to a specific context (Graham, 2010a, p.145). As he argues (2010a, p.145), these points are not so much about discipline (in Foucault’s sense (1998)) or control (like that proposed by Deleuze (1992)), as much as about an upfront way to “stipulate legitimacy – whether of presence or of circulation – in advance of movement”. Passage-points mark then moments of transition through spaces of tension and friction – ports, customs, centres of distribution – where goods can lose their track, be blocked, diverted or simply moved to the pile of non-allowed goods. Up to the arrival at the node of distribution responsible for the last mile, the parcel has to cross a series of points where it becomes acknowledged (as shown in Table 2); it is generally part of a much larger load of elements. The individuality of the parcel starts emerging as it gets closer to its final delivery point. As we move forward in the chapter this level of individuality will help us to understand why the last mile has become a fertile ground for testing new spatial approaches.

Within any territory of the last mile, as in the case of Barcelona, urban divided territories are a context where competition for the same streets, parking spots and efficiency of the first attempt at delivery takes place. The approach of each provider directly crosses the others' paths every day, leading to an entanglement of their approaches and use of space. As I show in the next section, one single location can be addressed through its jurisdiction, postcode, section or GPS reference. This is even possible to encounter under the umbrella of the Spanish postal services, which has created a range of companies that focus on niche markets of the last-mile deliveries and which consequently compete with the services provided by the mother company.[126] Like in any other type of logistics, the last mile is conceptually and operationally organised around three core elements: "the management of orders", storage and distribution nodes, and lastly, "transportation" (Bologna, 2014).[127] This means that within each main aspect of the cycle, a variety of approaches and spatial arrangements can be found, through the articulation of these three elements. Such articulation is made visible through the way the frequency of deliveries is organised based on the scale and density of population, the location of storage and distribution centres, and the different modes of transportation used and their chosen routes. Each element contains then a series of variables, the combination of which indicates how the delivery of a given parcel will take place.

Therefore, the individuality of each location and the parcel becomes slowly visible, as the parcel gets closer to its final destination. As demonstrated later in the chapter, what emerges is increasingly closer to a real-time context of action that is kept functional through standards and the action of specifically designed "algorithm apparatuses" (Rossiter, 2011, p.1). These ensure the integration and flow of information throughout the circulation of the parcel, even within more traditional settings, such as those of the Spanish postal services, where analogue and digital operational processes live side by side. The last mile of logistics is turning its context of action into a "real-time, data-base enabled city" where spatial-bounded

[126] The mother company has the legal obligation to provide universal basic postal services to the entire country. For additional information visit: http://www.sepi.es/default.aspx?cmd=0004&IdContent=17038&lang=&idLanguage=_EN&idContraste=.

[127] A fourth element that does not figure in this case study, but which is in any case central to the understanding and functioning of logistics, is the question of labour. Intensive labour is essential for the running of logistical systems, but it is easily left aside and made secondary (Bologna, 2014). In the case of this case study, labour is sometimes referred to in an implicit way, as it is not central to the chapter's core objective, and it is an issue that would require its own dedicated research from the perspective of logistics – black market, offshore sites, precarious conditions, disintermediation and so on.

data is continuously created through tracking and tagging, cohabiting with narratives on "urban activity" (Bleecker & Nova, 2009, p.10). In this way, "real-time synchronized data, plus clever computational algorithms" ensure a context that presents itself as being "more operationally and instrumentally efficient" (Bleecker & Nova, 2009, p.10). As discussed below, the space that unfolds does it in relation to the parcel – it ensures the creation of a field of action that envelops the parcel. The context of action, where the infrastructural arrangement supporting the moving-through space of the parcel, is, on one hand, already divided, and on the other, a path of action that becomes defined in relation to the parcel. Its unfolding becomes relational in answer to the needs in place and the main variables constraining it: how orders or parcels sent are processed, to which node of distribution or storage they will move next and how transportation or picking up will take place. As variables are arranged and coordinated, delivery times are set, drivers allocated and parcels loaded into the back of a vehicle. As will be seen, the spatial field of an urban territory becomes then, in this way, layered with a variety of unfolding dynamics derived from the logistics of the last mile. Each company operating in this context of action makes decisions on spatial strategies that vary according to the technical system in place and dominating spatial approach. In any case, common to all of them is their take on the urban territories as contexts of action that can be made accountable and profitable through their informatisation.

What I have been attempting to demonstrate is that in the case of the last-mile logistics we are dealing with a series of complex urban systems that share the same territory of action. In a current process of clear amplification, they compete and try out new approaches at different levels that go from how the passing through space is recorded and divided to how it is targeted. Furthermore, this is a context that has to cohabit with already existing spatial divisions and pre-conceptions of what they are, in addition to the structure already imposed by the Spanish postal services that can be used as a starting point or a point of comparison. From the perspective of the parcel, for those sent and received over a period of five months (see Table 2), the legitimacy and recording of their path of transition is made through a series of passage-points that at times also mark boundaries and borders of existing spatial divisions. Nonetheless, these passage-points also make the system accountable for what goes through it, pointing to moments of no return in the process of delivery of the parcel. Spatial division and location stand out in this way, once again, as more than a simple layer to which parcels are tagged or tracked upon. They embody their own sets of meaning, agency and even of operational justification, in an attempt to making accountable each point of passage in order to reduce liability.

5.2.1. Spatial division and the arrangement of routes

Even if location embodies multiple ways of approaching and conceptualising space, how does that same differentiation take place? How can the approach to the last mile allow so many competing ways of encountering space? In this section I attempt to cover the main existing variables that lead to the formulation of location beyond its geographic point. This is done from the perspective of the Spanish postal services, as being the expression of a technical system where areas of analogue approach cohabit side by side with computational processes. The objective is then to understand how a process of spatial enhancement and accountability is reinforced through location, before moving to consider the implications of new approaches that are repositioning the role of the parcel beyond a good being moved across space. In this way, when it comes to location, it is possible to say that its definition is achieved by three levels of variables that then become conjugated in different ways. These levels of variables can be divided into the operational strategy, urban spatial divisions already in place and the characteristics of the parcels.

Let us start with how spatial arrangement becomes tightly connected to the operational strategy – in other words, how it is directly related to and dependent on its own technical system. The technical specificities of its system, such as the arrangement and distribution of its network, define how spatial arrangement happens and consequently routes of distribution become organised. For example, in the context where major warehouses are placed on the outskirts of the city or region, vans leave from there once a day (Van Audenhove et al., 2015, p.5), meaning that a daily route is organised and the driver will be out the entire day in the field. Parcels need then to arrive at the warehouse and be sorted before drivers depart. Although the Spanish standard mail is delivered similarly to this – one delivery organised first thing in the morning – when it comes to its parcels, the approach is more flexible

(Correos, 2010). In the case of the parcels, these depart to their final mile from small nodes of distribution that are strategically placed throughout the city – called USEs (see Fig. 5)[128] – in order to ensure a quick delivery and the ability to adapt to any last-minute requests. The same infrastructure is used for telegrams and the delivery from hand-to-hand of important documentation. Loads are organised twice a day. A more immediate approach is that taken by companies providing mobile platforms for on-demand services, where goods can be placed directly in the hands of drivers that will take them immediately to their final destination, which is the case of Glovo[129] and Cargomatic,[130] discussed in more detail later in the chapter.

FIGURE 5: Inside USE 2, Barcelona (Carina Lopes 2016)

What these examples show is that the entrance of the parcel into its last mile is directly dependent on the operational approach to the metropolitan area: as a whole unit, smaller units which together form the whole territory and lastly as a variable and flat field of action where senders and deliverers are put into direct contact. Therefore, it is within the last mile that multiple, differential and tailored

[128] There are 10 points of distribution for these parcels in Barcelona, and they are denominated USE (unity of special services), reflecting in this way how much the postal services have changed over the last decades, as parcels were previously considered special cases.

[129] Glovo is a Barcelona-based company that accepts requests for delivery and pick-up services from local citizens, as its model is based on on-demand services (Glovo, 2016).

[130] Cargomatic offers, through a mobile application, a way for companies to request the delivery of goods locally from delivery drivers that are nearby and with space left in their vans (O'Reilly, 2016).

approaches start to emerge. This takes place mostly because from the moment that the parcel is sent up to its arrival at the metropolitan area, regardless of the similarities of the supporting technical systems, what prevails is the objective to "optimize the total distance travelled" (Van Audenhove et al., 2015, p.5). I am attempting to demonstrate with this that the chosen conceptualisation of space has a repercussion throughout the entire system, but that it is also constrained by the system itself and its context of action. Even more importantly, this becomes more obvious as the need for individual response increases – the closer the parcel gets to its final destination, the higher the entanglement required between the context of action and technical system.

Regardless of the technical system and its distribution spatially, it always becomes in one way or another confronted and challenged by forms of already established spatial divisions. In the case of urban territories, the most common are the local jurisdictional divisions and postcodes. The city of Barcelona is divided into 10 districts, which are then subdivided into a group of neighbourhoods, forming a total of 73 neighbourhoods (Ajuntament de Barcelona, 2013a).[131] This level of division is mostly felt at the level of interaction with the local government. When it comes to postcodes, they were created by the national post services in each country, and their history varies for that same reason. The first postcodes were established in Spain in 1981, and nowadays 11,752 different postcodes exist throughout Spanish territory (Correos, 2013).

What is important to highlight in relation to this is that organisations that manage and define each layer of spatial division are not static, meaning that these two coexisting layers do not necessarily fit or overlay each other in an orderly fashion or that relations between them are kept over time. In practical terms it means that the initial spatial allocation of postcodes, which in many cases respected the jurisdictions in place, may no longer be aligned with them. When it comes to last-mile logistics and the delivery of parcels, the layer of spatial division used can vary, or be a result of both. Division of space matters; it implies and embodies more than moving from one area to another. Spatial divisions are taken into account when

[131] This spatial arrangement has a strong influence on the flows of the city and the logic of proximity that prevails in the city at the level of urban governance. The division of the city into neighbourhoods and then districts ensures a better approach to the distribution of public services, meaning that all areas of the city need to have access to the same level of public services from schools to libraries, health centres and sports facilities among others (Ajuntament de Barcelona, 2013a).

tagging spatial information, working through GIS data systems. As already mentioned in Chapter 2 they also become slowly defined by the action of layering of informational systems that attempt to stabilise knowledge about these same territories (Graham, 2004b; 2005).

In any case, the advent of postcodes marked a crucial point in spatial division and how this logic was then passed down to other contexts distinct from the delivery of post, entering as a classificatory element into GIS systems, for example. In addition, postcodes became an element of major operational importance – they meant that mail could be codified into barcodes and then classified through automatic processes (Ascher, 2005, p.140). Sorting warehouses are nowadays vast spaces of conveyer belts, scanners, crates and vans where most of "the processing operation is automated" and takes place before a final allocation to metropolitan areas (Ascher, 2005, p.138). The automation of processes within the Spanish postal services is also done at this level, where every single item becomes standardised through a barcode (if there was not one already in place) (El Confidencial Televisión, 2014) that is then used for tracking and to allocate workload, measure productivity of each section and deal with liability claims. If these vast centres of coordination and distribution are understood as the core of the technical systems enabling the delivery of parcels (and other goods) (El Confidencial Digital, 2016), as these same elements get closer to their final destination, they also move further into the fringes of the system. It is at this level that the parcels come to require a more individual approach, but also the position where the technical system can afford the coexistence of more multiple approaches based on type of mail and other variables specific to these.

If up to this level there is a coordination and entanglement between the technical system and the context of action, it is as the parcel enters its very last mile that it gains a new dimension. It moves from being part of a large group to gaining a degree of uniqueness, where suddenly its qualities require going beyond its barcode or order number. With this I mean that the parcel imposes on the system the necessity of going a step further than the layer of spatial allocation. The uniqueness of the parcel refers to the variables that characterise each parcel and that induce an additional process of sorting – type and time of requested delivery, type of packaging, level of fragility, weight and size. These variables become increasingly visible as we start asking how the last mile is conceptualised, designed and even brought into place. As each postman arrives in the morning to his node of distribution, at an USE office, and prepares his load for the day, parcels become divided based on mode of transportation and affordances intrinsic to it – on foot, by motorbike or van – in coordination with the very specifics of each parcel. The level of sorting gets tighter as it approaches its final destination, leading us to question the ability of processes of classification and sorting to deal with these same specifications.

5.2.2. Reconsidering classification and sorting

The transition of the parcel through different spatial arrangements and divisions, and its requirements for a more individual consideration as it approaches its final destination, leads us to reconsider the role of classification and sorting. On one hand, there are the operational needs directly related to the technical system working in alignment with the affordances specific to the context of action, while on the other hand, there is the parcel that starts expressing its individuality as it gets closer to its final destination. This individuality contrasts with the levels of spatial division that I have described, together with the slow degree of adaptation found throughout the Spanish postal services, which was largely conceptualised as an analogue technical system. In addition to this, there is a layer of extra information embodied in the parcel that usually remains in the background, as the parcel is generally originated within a distinct assemblage. This hidden layer speaks of aspects such as online shopping peak-hours, client details and profile, level of existing stocks or even what it contains (Conlumino et al., 2014, p.9). This layer of non-explicit information, together with the unique characteristics of the parcel that demand individuality as it approaches its destination, leads us to consider an implicit algorithmic presence, even if at some stages the parcel goes through analogue transitions. It is from this perspective that I propose that the process of classification and sorting of parcels needs to be reconsidered.

Generally, as the existing levels of spatial division showed, classification and sorting of parcels tend to fit predefined requisites that correspond to one or another path of delivery. They do not lead to tailored paths that might even then correspond to previously defined segmentations or groups of priority. The assemblage that makes possible the delivery of goods is embedded into a complex technical system that is also managed through a series of classifications and sorting practices, which tend to go from generic geographic divisions to the level of postcodes and mode of transport based on size of the parcel. Moreover, these systems tend to have a spatial and temporal embedment, speaking of a specific "*spatio-temporal segmentation of the world*" that is usually "*consistent*", "*mutually exclusive*" and "*complete*"[132] (Bowker & Star, 2000, p.10), implying a strong degree of inertia. In other words, it can be said that these systems are generally bounded by their contexts of emergence and usage, and once in place, they show a high degree of stability as direct outcomes of their own contexts. In the case of the delivery of goods, the classification system in place is a warranty for the achievement of the objective. The classification system should work like "a set of boxes (metaphorical or literal) into which things can be put to then do some kind of work" (Bowker & Star, 2000, p.10); they should leave doubts aside and facilitate the reading of the context, of the objects that you have in front of you and that are under the spell of their classification system.

However, both the parcel's barcode (and its embedded informational potential) and the emergence of on-demand services within the last mile suggest something different from the inertia referred to. In the same way that barcodes and order numbers tell us of structures and practices embedded into the system, such as the long-term implications of practices of standardisation and risk management, they also express that these same practices may not be fit for the flexibility that parcels increasingly request. As the level of individuality of the parcel becomes greater, due to the diversity of origins that it can have, it may present a growing number of challenges for a system that has the core of its structure very concretised. Being more precise, the level of adaptation that an organisation such as the Spanish postal services requires to transition from the letterbox to the parcel delivery means an evolvement that goes beyond the fringes of its technical system. That is probably the reason behind the creation of three companies specialising in deliveries under the same umbrella and which can deal with niche markets and the specifics of each parcel (Grupo Correos, 2015, p.5). This means that the classifications and sorting practices implicit in the parcels through their own barcodes or order numbers are

[132] Italics in original.

simultaneously tools to keep the system fulfilling its expectations and points of increased tension.

In the context of logistics, the existence of standards and classifications throughout their operational line speaks of a much more complex story. As Paul Clarke (2015), Director of Technology at Ocado[133], describes, the simplicity of a smooth online shopping and delivery process hides a complex and disproportionate level of elements that need to be brought together – "data, algorithms, machine learning and software" that support the business and ensure the ongoing evolvement of an extremely complex and sophisticated technical arrangement. Behind the confirmation of purchase online there is a massive warehouse where over "7,500" containers circulate at any time through 25 kilometres of "conveyor belt" (Clarke, 2015). The sophistication and scale of the system is not only ensuring an economy of scale; it is also continuously producing and collecting gigantic amounts of data that is then fed back into the system (Clarke, 2015). With this, it is intended to highlight that when a system already emerges as an algorithmic entity, the role of the material technical elements gains a different dimension. Everything seems to fit a very specific position in relation to the objective and logic of the algorithm within the narrative of action. The challenge of the last mile is not only that suddenly the amount of parcels has grown exponentially; it is also that the first systems to take responsibility for their delivery (such as the national postal companies) emerged out of a very different context of action, being for that reason involved in ongoing dynamics that require their openness, transformation, adaptation and re-finding of their position.

In a context such as Ocado, that is from its outset a software-based infrastructural arrangement, the barcode plays a central role. Its ability to encode a variety of information and specifications allows it to work as a bridge between the digital and the material, the order and the delivery, the tracking and the management of bonus for the workers (Ocado Media, 2010). This not only connects all the backstage activities to the object of concern (in this case, the parcel) but also contains within itself all necessary elements that ensure its flow through the system up to the final delivery. The barcode takes us back to the issue of passage-points and how the process of going through them opens up a new field of action ahead that is

[133] Ocado is the UK-based "world's largest online-only grocery retailer" (Lawson, 2015).

defined by that precise moment, but also by the requirements embedded in the barcode. Every time a passage-point is passed, a new process of classification and sorting takes place – this means then that the act of going through a passage-point is, on one hand, the embodiment of an implicit process "of calculation and processing" (Fuller & Goffey, 2012b, p.74) and, on the other hand, a relational evolvement that is deeply connected to that process, location and time. However, this perspective on passage-points also implies fewer static and material-related transitions as much as processes. The barcode becomes in this way an embodiment of an infrastructural arrangement that I propose next to come into play every time a new barcode is created.

5.3. Relational infrastructures and the tracking of a parcel

I have described how the intensification of location and spatial division often takes place as the outcome of different levels of variables. Many of these variables have been sustained by stabilised classifications and sorting practices, the aim of which is to guarantee the flow of parcels as well as the optimisation of a system that becomes more concerned with detail as it moves to its fringes and the parcel gets closer to its final destination. However, due to the unique traits of the parcel, often entering the system already embedded with a series of requirements and specifications, pressure is building for an approach that is defined by fewer static passage-points, the configuration of which can emerge in relation to the parcel. It is within this context that I propose that the last mile is increasingly looking like a series of agglomerations of relational infrastructures that unfold and reorganise every time a new parcel needs to be delivered. It is increasingly growing more variable, in parallel with the sophistication of its algorithm. At the centre of this is the barcode.

Opening the way for this infrastructural approach are on-demand services that often work through the disintermediation of the previous context of action. Not only are on-demand systems transforming the way the system unfolds in relation to the parcel; they are also pressurising already existing technical systems by challenging their own conceptualisation of operational flow, classification and sorting models, and finally the materiality of passage-points. They are defined and run by what has been described as "algorithm management" – "software algorithms that assume managerial functions and institutional devices that support algorithms in practice" (Lee et al., 2015). When it comes to the parcel, and the system it calls into play, there is the emergence of location-bounded and temporal infrastructure that is unique and relational to the specific condition of the parcel. This means that a specific infrastructural arrangement occurs in a direct response to the parcel's specific needs, constraints and demands – or based on operational specifics, size and weight of parcel, type of packaging, how fragile, location and final destination. In this way, I move away from the Spanish postal services, and I specifically emphasise this algorithmic constitution that consequently will affect the services offered by the postal services, but also any other company working within the last mile of logistics.

Parcels are not only tied to space through tracking and tagging, and other spatial divisions already in place; within their relation to space they start expressing both time–space dynamics and deep entanglements that come into being in relation to what the parcel embodies. The parcel in this context is not very different from locative media – in the sense that through its barcode, it embodies a series of processual, locative and tracking elements that come to define the parcel, but also the unravelling of its context of action. As Ned Rossiter (2011, p.1) highlights, to understand logistics it is necessary to place it within its context of action – "the logistical city is different from the global city"[134] in the same way that international logistics is distinct from the characteristics and challenges posed by the last mile. The logistical territory is in one way or another "driven [and defined] by computational systems oriented around managing the mobility of things", but simultaneously a territory that forces into continuous reconfiguration those connected to it from the position of suppliers and deliverers (Rossiter, 2011, p.1). Of major importance, similar to the process the parcel experiences as it gets closer to its point of distribution is the "diagram of relations" that it creates, unique to itself

[134] What Rossiter (2011) fully understands as "logistical city" and "global city" is not clear. Here the position taken is that within any major metropolitan context there is an overlaying of multiple coexisting cities, similar to the narrative of Marco Polo describing his dear Venice (Calvino, 1997). In the case of Barcelona, it could also be defined from a perspective of, among other qualities, a logistical, global, local, touristic or gentrified city. However, there are also urban spaces that were fabricated with a clear objective in mind that end up looking like a city, but the starting point of which was that of an "enclave" (Easterling, 2014). Keller Easterling (2014) refers to these spaces as "extrastatecraft" areas, which tend to be, in one way or another, deeply constrained by their logistical arrangement. These are often free trading zones, and with the passing of time such a zone became able to "absorb[ing] more and more of the general economy within its boundaries" (Easterling, 2014, p.14). They are "zones" turned into cities that often remain defined by their main initial objective – "outsourcing and offshoring" – never really able to leave aside a sense of "enclave" (Easterling, 2014, pp.19–20).

(Rossiter, 2011, p.1). Not only is the entire chain of logistics increasingly forced into a quicker speed and capacity of change as demand and needs shift, when it comes to the parcel, each one is unique to its context – especially in those cases where it is delivered by a company specialising in all sorts of deliveries. For example, a two-hour delivery request is necessarily distinct from that a parcel that fits into the letterbox and was purchased under the cheapest available delivery option.

Part of what is being referred to here, as what was discussed in relation to convergence in Chapter 3, is the role played by integration and information in the establishment of diagrams of relations and the overall set of mobile dynamics, in a direct reference to the bringing together and joint management of previously separated systems both at a technological and geographic level (López Torrent, 2010). Integration and information have various implications as they enable a genuine convergence of previously separate systems. In the case of the delivery of parcels, they refer to a tendency that moves towards intangibility, grey areas and computational integration that make it much harder to even define what constituted the process of integration. All existing technical elements, ready to be put into use, only become materialised once a new barcode demands their reorganisation. The level of coordination, integration and convergence is only made explicit through the infrastructural arrangement that comes out of specifications embedded in the parcel's barcode. If suddenly there were no parcels to be delivered, the system would stay indeterminately on hold, slowly moving into an outdated system until it would be replaced by another technical arrangement. With each barcode, a new diagram of relations is designed – the centres of distribution and nodes of delivery to use, postcodes or neighbourhoods of delivery, drivers, vans, loads, sensors, scanners and client's signature.

Let us discuss concrete examples of what is being presented. Ocado, the online grocery retailer already mentioned, delivers a daily average of "12,000 orders" that are organised around the barcode that is produced when the order is complete online (Ocado, 2016, p.2). As the grocery delivery gets ready to be dispatched, it becomes supported by "satellite navigation" available in each van and "hand-held computers to speed up doorstep transaction", and "SMS alerts on delivery day" sent to the client (Ocado, 2016, pp.2–4). The objective is to create a smooth flow from order to countertop in the client's kitchen, during which all sorts of metadata are collected on each task, activity, time taken and so on. When it comes to Ocado, it is not only its warehouse that is entirely run through algorithms designed, tested and corrected with the support of data simulations – the entire process from order to delivery unfolds from the barcode that then feeds back into the data system (Ocado, 2012).[135] The different logistical algorithms unfold and envelop all relations within its context of action. Slowly, it becomes about the logic of "optimization" throughout the system that is also measured on the strength of the smooth flow. The seeming simplicity and ease of use of the entry-points to the system, such as its online shopping platform (Neilson & Rossiter, n.d.), contrast with a range of very complex and sophisticated algorithms that ensure the variability and elasticity of the system. The easiness of interaction when the customer purchases online is only a tiny part of an assemblage designed exactly to remain at a distance from its context of impact. The early history of large supermarket stores was already about a separation between the buyer and the logistics. The store was designed to guide the buyer through all of the products placed on shelves up to the paying moment (Beniger, 1986), separating intentionally "desire" from the "back-end work of the structure" (Fuller & Goffey, 2012b, p.71).

With on-demand services concerned with the moving of goods and people from A to B, this separation is even more accentuated. The driver is connected to the client through the mediation of a platform, which allocates services and makes matches possible based on different algorithms that vary according to the company. The drivers are independent workers, running their own vehicle, and I would say that they are often subjected to the agency of the algorithm as if they were simply another variable to be managed and tailored as I discuss later in more detail. Amazon Flex (Reuters, 2016), Uber (Tepper, 2016), Lyft (Matias, 2015), Cargomatic (Manero, 2015) and Glovo (Rodríguez, 2015) all work under the same logic of on-demand services. The complex urban system sustaining each of them has at its core algorithm variations and conjugations that become engaged with through mobile phone platforms, unique to each company. Under the services offered by each platform, on-demand drivers deliver door-to-door parcels (or people in the case

[135] The in-house-designed algorithm of Ocado manages the move around of thousands of plastic and colourful boxes in an orderly way. They are envisioned based on a "high-fidelity" and "real-time" simulation, which is also the base for testing new software and variables and finding any emerging problem by playing back that same simulation (Clarke, 2015).

of Uber and Lyft) without intermediaries, being able to attend to the specifications of each case. In part, this is possible due to the processing beforehand of matching needed resources and availability of drivers.

The emergence and strengthening of on-demand services used for deliveries have probably occurred in response to the fact that "the 'last mile' portion of delivery" is generally the "most expensive stretch of a package's journey", as it cannot be treated as part of a larger load (Reuters, 2016). It requires the level of uniqueness and individuality mentioned earlier. It is easy to see how this contrasts with what is involved concerning the parcels being delivered by the Spanish postal services. Not only is the process less location-based and the origin of each parcel varies greatly, but drivers have been assigned specific and delimited areas, and it is up to them to define their route each day. Although deliveries are recorded based on time of acceptance by customer, the driver's work is managed through a block of time during which they have to ensure a specific number of deliveries (Fuentes, 2016). There tends to be little rotation in relation to areas of delivery (see Fig. 6), meaning that drivers know their context of action in detail, in some cases even being able to identify the best moment to deliver based on the customer. This level of organisation happens beyond what can be defined as the clear "frame" of classification and sorting offered by the postcode (Fuller & Goffey, 2012b, pp.74–75) and the different and compulsory passage-points that parcels go through up to their final node of distribution. It is a process that is deeply embedded into the knowledge gained on the ground (the informal knowledge accumulated by drivers throughout the years). Nonetheless, the tendency, even within the Spanish postal services mode of working, is to increase the levels of spatial and delivery accountability, in a continuous search for further optimisation and operational efficiency.

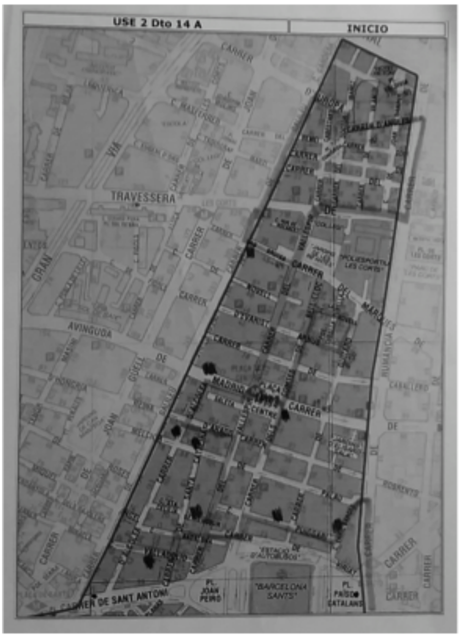

FIGURE 6: Map of route A for postcode 08014, Barcelona (Carina Lopes 2016)

5.3.1. The transformation of the last mile

The algorithmic concretisations taking place within the last mile are the outcome of a computational arrangement aimed at "calculating the material properties and organizational capacities of infrastructure" (Neilson & Rossiter, n.d.) in order to give origin to a new infrastructural context. More precisely, these concretisations are taking place at various levels from the perspective of computation, going from how the algorithm is slowly displacing the centrality of material elements, in order to prioritise more variable and flexible dynamics among the different technical elements, to how the barcode of the parcel is increasing its capacity to concentrate encodings that refer to and collect metadata as the parcel travels up to its final destination. Algorithms are entering aspects of technical systems that go from the detail to the general, and from small scale to aspects that are common to the entire system. As Brett Neilson and Ned Rossiter (n.d.) stated on the role of algorithms within logistical settings, reinforcing its centrality:

> Algorithms build computational systems of governance that hold a variable relation between the mathematical execution of code and external environments defined through arrangements of data. Algorithms instruct

> things to do things to things. Algorithms create patterns. Condensing code and sociality, algorithms generate movement through data processing, scraping and forecasting.

Algorithms coordinate and indicate then how relations unfold and evolve – what tasks are done, the workflow steps that have been followed and which interactions take place between different parts of the system. Within the intensively computational complex urban systems, everything seems to necessarily start and finish with an algorithm. The parcel about to be delivered enters a spatial field that has been calculated and optimised numerous times, all in name of the seamless and efficient workflow towards delivery. It enters a field of action where the bureaucratic algorithm – counting, recording, ordering – meets the automation algorithm – tracking, tagging, deleting, isolating – giving rise to contexts of action that can rapidly evolve and be adapted to environmental aspects such as weather conditions or market demand and supply dynamics (Fuller & Goffey, 2012b, p.95). This means that the computating of the context of action altogether with the system supporting the parcel bring significant changes to how space, location and spatial division are approached.

Two aspects should be highlighted in relation to this: tracking and how movement is calculated based on this. As already stated, the last mile is largely about optimising, coordinating and managing in an active way the move from location to location, or from departure to arrival. When it comes to tracking, the context of action where this movement takes place has become understood as a field subjected to spatial-mathematical reasoning. This is a step beyond the tagging of specific geographic coordinates and interpretation of urban territories as a flat surface of action. Tracking implies in this context a way of "looking [that] has come to mean calculating" (Crandall, 2006). When deliveries are tracked, it is not just about knowing where they are, regardless of how important and crucial that may be for the entire assemblage. Tracking is a process that focuses on the present while simultaneously taking into account the past and collecting data already looking into the future. The action of tracking almost always aims at learning and actively contributing towards the calculation of efficient routes, workers' productivity, and best modes and time frames for deliveries. It is also a way to make accountable every step and location that preceded the delivery of the parcel. In most cases, these steps are legitimised by the passage-points that the parcel went through. Nonetheless, the relational accountability and unfolding of the process of logistics and, in particular, of the last mile is based on the premise that it can be retraced, recalculated and further optimised, like in the case of Ocado, where the real-time data simulation is used to track how the entire warehouse is working, test new updates and reply when problems emerge (Clarke, 2015).

Jordan Crandall (2011) argues, in relation to tracking, that it contains an intentional level of anticipation and knowing ahead of time when it becomes part of spatial calculation. A parallel connection can also be established between the calculative character of tracking and the increased importance of probabilistic calculation within data systems (Ruppert, 2012), as well as in urban contexts, hinting at a tendency where computational calculation and probabilistic action prevails. The additional objectives of tracking beyond geographic coordinates and the recording of the path followed by the parcel can also be understood as indirect consequences of practices of standardisation and risk management and the pressure these exert as modes of control and management upon complex urban systems. Altogether, the context of action of the last mile becomes increasingly a site of ongoing calculation about the best route to follow, detours for last-minute requests or real-time coordination and organisation of resources. This ongoing calculation enables new forms of entanglement between the context of action and the technical system – a level of alignment that, in the future, will lead to further concretisation of calculative algorithms.

Overall, it can be said that this gives origin to what can be defined as an intensive spatial grid of "operational construct[ion]" – more precisely, "an assemblage of computer-assisted operations through which objects are analyzed, tracked, and negotiated" (Crandall, 2004, p.46). It refers to a context of action that aims at an immediate action upon what unfolds, a level of coordination of action–reaction that can only be brought into play if tracking and calculation have already been merged together. The operational context and assemblage of the last mile attempts then to envelop "space and time" and all sort of key elements "as if they were [only] one" (Crandall, 2004, p.47) into a topological field of continuity. This can be read as if the parcel becomes detached from a fixed place, to be instead calculated about as part of a continuous topological field of action, ensuring its moving forward towards its final destination (Crandall, 2006). Thereby, the movement of the parcel that is the object of these calculations is based on how it flows through space and in relation to all other technical elements and locations it has to go through, instead of being the result of the linear sum of all distances between the different passage-points. An example of this continuity and flow can be provided by how shipments arriving at large ports are treated. When a shipment arrives at a port, it no longer needs to be processed through "registering arrival, checking manifests, filling out paperwork, and telephoning forward destinations to let other people know" (Arthur, 2011). Instead, it passes swiftly through "an RFID portal" meaning that with a quick passing-by this same shipment is "scanned, digitally captured, and automatically dispatched" (Arthur, 2011).

From this perspective, the conceptualisation and function of passage-points within calculative and computational contexts are also transformed. The process of legitimation no longer needs a break within the movement, an intentional checking and clear authorisation to move forward. It is done as a process taking place in the background, where data is cross-referenced, shipment received checked against provisions and already authorised entrances. Only that which is different stands out, such as those shipments that do not fit the expected variables, their affordances and thresholds. The ordering of continuity acts at the port as a passage-point that was previously a moment of forced interruption and inspection. In this way, there is an ongoing conversation between the different elements throughout the path that will be followed by each parcel, as a way not only of preparing the ground for its reception but also to ensure a smooth flow through each passage-point (Arthur, 2011). It implies a means of ordering a flow of continuity as well as a strategy involving "reconfiguring routing if necessary to optimize things along the way" (Arthur, 2011), while being prepared to deal with what stands out and is different.

The variability, calculability and ordering of continuity have been shown to take emphasis away from previous material arrangements that were often part of analogue processes, shifting, as a consequence, the attention towards the parcel. With this, I am attempting to point out how the parcel is made the central point of an infrastructural context that becomes variable and flexible in relation to each parcel. This means that as the parcel gets closer to its final destination, and moves from being part of large group up to being a single unit, the infrastructural and technical assemblage, although already in place, is only called into action as needed and always in relation to the specific requirements of the parcel. This centrality becomes particularly visible within the context of on-demand services and those processes that have already gone through previous disintermediation as I discuss next.

5.3.2. On-demand and disintermediation

The context that has been described, both in relation to the parcel and the technical systems that were already in place before the extension of computation, implies the amplification of a context that was previously stabilised and which has been challenged by the arrival of the Internet, online shopping, tracking of objects and online service reviews, together with processes of softwarisation and datafication. The challenges faced by the technical system enabling the operational activities of the Spanish postal services are very distinct from those encountered by companies such as Cargomatic and Glovo, or even by Uber and Lyft. The process of individuation and evolvement of each of these organisations is necessarily distinct, as their level of concretisation and already well-established technical elements vary greatly. In the case of the postal services, these started out as analogue practices, into which were slowly incorporated new ways of operating, managing and optimising resources. On-demand and disintermediation services have had necessarily a completely different starting point.[136]

Both of these services begin with the assumption that the technical system and its context of action have to necessarily support a high level of variability, which in practical terms means the ability to adapt to the unique needs and requirements of each parcel. The emphasis on the parcel brings with it another important transformation within infrastructural systems, as it requires a shift of the organisation from a centre–fringe structure to a network of elements that are all highly dynamic and without a separation between core and secondary, or backbone and add-on. For example, Cargomatic has goods in need of delivery at the centre of its mobile platform, meaning that it connects shippers with van and lorry drivers (Manero, 2015). It presents itself as overlaying urban space with a technology layer

[136] From Simondon's perspective this comparison would not even be possible, as these systems do not share a technical lineage (2008).

that enhances the profitability of the last-mile logistics, by enabling drivers to fill up the space left available inside their vehicles when working (Manero, 2015). The specifically designed digital platform brings together “shippers and truckers in real-time”, where drivers can bid real-time on loads to be delivered at local and regional level. Here the parcel or the load concerned is the connecting point between shipper and the driver; it is around it that connections are made possible and the technical systems needed are brought into action. Without parcels to be delivered, the system is made irrelevant, becoming restricted to a group of algorithms and a mobile platform.

Dynamic arrangements imply one or more algorithms working together and in relation to each other, each focusing on a specific variable essential for the overall functioning of the system (Lee et al., 2015, p.1,603). For example, in an on-demand taxi service, autonomous drivers “are algorithmically matched with passengers” and the conditions of that same match is calculated based “on where passenger demand surges” (Lee et al., 2015, p.1,603). The algorithm at work is actually a group of three distinct algorithms segmented by “passenger-driver assignment, the dynamic display of surge-prices areas, and the data-driven evaluation that uses acceptance rates and ratings” (Lee et al., 2015, p.1,604). Here again, the emphasis is on what needs to be moved from one place to another. Every time a new ride is requested, different variables come into play to offer an arrangement that takes into account the overall conditions of the context of action in that exact moment. Each algorithm offers a different perspective on the context, and it is through their conjunction that an outcome – or path of delivery – can be formulated.

Finally, what this shows is how location and context-based algorithm is and how it works when called into action, even if its agency is not entirely clear (Lee et al., 2015). In on-demand services it becomes visible that the algorithms in action privilege “one ordering at the expense of others” (Mackenzie, 2006, p.44), or a series of outcomes and contextual arrangements that necessarily benefit the system itself. To be more specific, when price varies based on time, location and demand, there is a certain pre-conceptualisation about the ideal context of action coming into place. How that calculation is done is not entirely clear in the same way that drivers argue that work allocation is not always based on proximity, or even reviews-based (Lee et al., 2015). What algorithms are doing in this context is contributing to the concretisation of “certain orders” while simultaneously reinforcing “certain movements” (Mackenzie, 2006, p.44).

Nonetheless, this intentional action by algorithms always encounters some friction; it does not occur as a seamless outcome. In the case of the Uber and Lyft drivers, it was found that they had a series of strategies and tools at hand to circumvent the algorithm, which were often coordinated and shared through online forums or by intentionally ignoring the request for certain rides, so drivers located closer to pick-up points could take advantage of them (Lee et al., 2015, p.1,607). However, the ability to circumvent the algorithm varied greatly, for the same reasons as those already stated in Chapter 3 in relation to default settings. System standards together with default settings are powerful tools in modulating behaviours as not all drivers are available or have the necessary knowledge and understanding to play with the boundaries that a technical system offers. As Min Kyung Lee et al. stated, “supply–demand control algorithms” came out of a context aimed at “optimization problems that involve non-human entities”. When this same logic is transposed to an on-demand context, where part of the assumed variables are humans, friction naturally emerges.

5.4. Material/immaterial

As the emergence of a variable and adaptable infrastructural system around the parcel shows, we are no longer talking about an informational layer that is invisible and evolving, placed above space and fed by practices of tracking and tagging as the early projects of locative media would present it (Greenfield, 2006, p.124). The informatisation of the context is already embedded into it. Even if the layer of information was, in relation to locative media, already of high detail, tied to location and offering ways to compare information, the technical system that is currently being formed around the last mile is deeply defined by its algorithmic condition. This means that the context of the last mile begins with an already sophisticated level of concretised computational context of action. Many of the computational aspects that are brought into use had already been tried and tested in the context of organisations such as the Spanish postal services – the centrality of the barcode, the automatisation of the mail sorting centre, the higher flexibility attributed to the operational structure supporting the distribution of parcels or even the use of PDAs[137] by the postmen.

Based on what I argued in Chapter 3, we are speaking of a technical system going through a process of amplification, but which expressed already as a starting point a deep entanglement and alignment between the technical system and the context of action at the level of computational processes. This means that, in part, what is being discussed is not entirely new or an external element finally entering a technical assemblage. We are then speaking of a degree of already existing algorithmic naturalisation of a context of action. Furthermore, when I propose that the infrastructural arrangement comes into play in relation to the parcel and every time a new barcode is produced, this does not mean that the context being discussed and proposed is immaterial and that somehow the parcel flows through these intangible spatial arrangements. As has been argued throughout this thesis, complex urban systems are always deeply entangled with and dependent on material arrangements; what varies is their constitution and spatial placing, implying that this context is not an exception. When it comes to the context of this case study, the dynamic of material–immaterial is of particular relevance from three perspectives. Firstly, as has been shown, what appears to be immaterial is always bounded by very material consequences and supported by material infrastructures that lead to a context of action aligned with the needs of the overall technical system. Secondly, logistics is already about moving material goods from one location to another, deeply tied to communication infrastructures, so the process can be optimised, adapted, tracked and made accountable. Thirdly, the context of the last mile can be presented as a field of in-betweens, as the emphasis is always put on what happens between the locations of departure and arrival and everything else that unfolds out of this.

It is due to the relevance of these dynamics of material–immaterial mentioned that I reflect in this section on issues around this dynamism in order to propose that this context might actually provide both a higher number of entry-points and chances to appropriate and create impact beyond the pre-set definitions established for the entire context of action. More importantly, the reflection on

[137] It stands for Personal Digital Assistant, and it is actually a small handheld computer where deliveries can be confirmed and clients sign to confirm reception.

material–immaterial will bring back locative media to this research project, leading to the completion of a circle opened up with the introduction. As Crandall (2006) proposes, the duality of "the diffused and the positioned" and "the placeless and the place-coded" is nowhere made as visible or as noticeable as with locative media. Not only do these devices have the capability to embody, support and work in coordination with complex algorithmic contexts, but they also have the ability to "weave together degrees of temporal and spatial specificity" (Crandall, 2006). In the context of the last mile, these devices can easily be found in the hands of the postmen, as well as drivers and users of on-demand services. These devices not only allow the tracking and calculation that takes place; they also help to make sense of what is unravelling and to establish linkages between the technical system and the context of action.

Recapitulating, I first raised the question of material and immaterial in relation to locative media. Russell's work already aimed to expose and explore this duality and increasingly intensive entanglement – by making reference to an existing tension between the informatisation of urban territories, with the blurring of the private and public boundaries, and the spaces offered by locative media to explore these same developments (1999; 2002; 2004a). In addition to this, as has been highlighted in relation to the work of Edwards (2010), Gabrys (2011) and Parks (2005), often the sensed immateriality is actually supported by off-site and distant materialisations such as control rooms and data farms. The question of material and immaterial within complex urban systems and the context of this case study keep taking us back to those same reflections already made in relation to locative media, throughout Chapter 1, on the role played by portable and connected devices within urban territories and in relation to complex urban systems.

These devices, carried by drivers and used by consumers to order and track parcels, imply conjunctively with the parcels a topological unfolding where time and space are bound to each other through the continuous production of data on steps taken, spatial position of the parcel and time–space of delivery. Locative media devices seem to form a diagram of connections and relations where they represent more than an interface to the powerful system and algorithms lying beyond the screen as usually stated in relation to locative media (Greenfield & Shepard, 2007; Lapenta, 2011; Russell, 1999; 2002; 2004a). When systems arrive to the level of computational arrangement that the last mile and on-demand services require, these devices go beyond their work as a system human–computer interface, positioning themselves instead, I propose, as the being the system itself.

Let me be more specific: the role played by locative media is no longer that of an add-on with its position at the fringe of the core of the technical assemblage, but rather one that represents and expresses the centrality of the technical apparatus. In the context of the logistics of the last mile, the mobile phone and other portable and networked devices are core to the unravelling of the delivery; they have become more than an entry-point to the system. This indicates a transformation to the dynamics existing among the technical elements as it implies a repositioning of what was earlier discussed as the add-ons, enabled by the context of development of the system. Its starting point as an already heavily computational system makes the arrangement and positioning of material elements move into a secondary role, as they no longer depend as heavily on it as in the case of traditional sets of infrastructure such as the railway.

5.4.1. Material unravelments

FIGURE 7: PDA used by postmen, Barcelona (Carina Lopes 2016)

There are two portable and networked devices that tend to stand out within the field of the last mile – the PDA used by the postmen (Fuentes, 2016) and other delivery drivers working for one single company, like in the case of Ocado (2011), and then the personal mobile phone, used in most on-demand contexts (Manero, 2015). In the first case, the PDA offers a strict context of use, designed with the objective of being aligned with the requirements and needs of the overall technical system. It tracks, in the case of the Spanish postal services, time of delivery of the parcel and person that received it (Fuentes, 2016). In the case of on-demand services, the mobile phone comes into use after the installation of a specific mobile phone application, where drivers and users can gain access to a platform within which all variables are made to work together. Drivers and users have access to different parts of the platform, specifically designed for their role. These platforms set the standards of engagement and usability as in the case of Lyft, where customers are an active part of "creat[ing] a social culture" between them and drivers, by being invited "to sit in the front seat and greet the driver with a friendly 'fistbump'" (Lee et al., 2015, p.1,604). The platform, as already stated, expresses the calculations and outcomes of a group of algorithms that have specific objectives, which working together bring into action the envisioned context of action (or something close to that).

The screen of the device works as the interface between the different types of users (drivers included) and the processes of computation that lie underneath. This interface, although here presented as limited to the size of the screen, exists at different levels of the context of action, and it should not be strictly understood as simply belonging to this immediate instantiation (Fuller, 2003, p.103). Interfaces are often distributed throughout their context of action and implicit in many interactions that take place in addition to those between the driver and the device, like those embodied in the parcel (Fuller, 2003, p.99). Like other entry-points, they can be made to look as if belonging to highly defined structures with central and secondary roles. However, as was shown in the previous case study, entry-points (and interfaces) can be appropriated, defined and challenged by users. With this I want to reinforce the argument that even within very algorithmic contexts there are material occasions that challenge that same sense of intangibility.

What matters is how these same contexts, such as those formed by on-demand services, are engaged with and interpreted. This takes me back to the concept of hybrid briefly mentioned in Chapter 1. This concept, connected with the process of softwarisation (Manovich, 2007; 2013), allows us to envision the action of the algorithms discussed working towards a context where continuity and its ordering prevails and where interfaces are presented as being both key elements of modulation and simplified moments of interaction with a much more complex system. When it comes to the screen of the platform, this specific interface needs to be understood as an expression of a range of mixed layers and techniques. This means that the interface is not a closed or complete set where interaction is supposed to take place, to start and end. Its hybrid origin, as the outcome of previously different "techniques, working methods, and ways of representation and expression" (Manovich, 2007), reinforces the belief that areas of unaccountability necessarily exist within that same interface.

In addition to the screen as an interface, the driver (and other users too) are faced with different buttons that represent the material–immaterial quality of the overall context of action and the screen as the sole point of interaction with the algorithms that lie underneath. The driver can intentionally not press the button and miss the opportunity to confirm that he wishes to take or reject the job. Nevertheless, the button is also there when accepting payment, doing ratings, concluding the job. The digital pixelated interface is simultaneously an action-inducing element and a data-recording; when the button is pressed, a direct outcome takes place even if distant from the interface (Pold, 2008, p.31). For this reason, buttons not only are crucial for the technical assemblages but also "signify a potential for interaction" that has been designed and placed with a specific outcome in mind and as part of a context of distributed computation (Pold, 2008, p.31). In many cases, the digital button is accompanied by an analogue reference, even reproducing a sound equivalent to it being pressed (Pold, 2008, p.32). However, like in the case of Ocado, the simplicity of this interface hides a disproportionate complexity of the algorithm and software applications sustaining it (Clarke, 2015). What this means is that the digital button attempts to hide the lack of visible action–reaction, through the imposition of "binary choices", as there is no "hardwired" connection between the interface of the platform and the continuous calculation unravelling in the background (Pold, 2008, pp.32–34). The interactions with the immaterial–material arrangements of the distributed context are very much focused on these locative devices, meaning that in the same way that they signify a constrained context of limited interactions that are supposed to result in action–reaction throughout the system, they also become a site of contention.

5.4.2. Tangible immaterialities

The question of contention is of relevance. The fact that the last mile tends to be the most expensive and labour-intensive part of logistics is very telling about how algorithms are being designed and in which parts of the previous system and model of delivery the emphasis was being put on. If on one hand the system is developed with the parcel at its centre – as a way to ensure that specific conditions, requirements and tailored services can be met – the algorithms in place focus on the coordination of delivery, as well as on guaranteeing that there are enough drivers available when requested who are willing to take any job that comes up. Therefore, we encounter a technical dynamic that is of operational character, but also searching for a way to bring stabilisation by working through a series of standards and risk management actions targeting specifically, in one way or another, the driver.

The last mile, as a site of contention, where the driver is positioned as a boundary element between two possible outcomes, can take us back to the question of qualculation and, in particular, to the tension that builds up between "qualculative spaces" and "non-qualculative" (Callon & Law, 2003, p.13). Michel Callon (2003, p.13) argues (while replying to Law) that non-qualculative spaces "work in one way or another to refuse the provisional capacity to enumerate, list, display, relate, transform, rank and sum", leading us to consider how the application and reinforcement of a logic of delivery can be imposed on sites antagonistic to the implementation of "resources" that will enable a spatial and operational accountability. With this I am trying to demonstrate that contention may also be the outcome of an intentional denial of a formulated action under the ruling of the algorithm.

The analysis of the last mile from a different perspective has given us the opportunity to consider the challenges it brings to traditional infrastructural settings, at the same time that it reveals the areas of tension emerging out of highly algorithmic contexts. For this reason, the complex urban systems working within this field present a degree of immateriality and intangibility that is not experienced in the same way with other infrastructural systems that were discussed throughout the thesis. This degree poses its own specific challenges on how to encounter and navigate such contexts. It is at this level that the dynamic material–immaterial gains relevance and provides the opportunity to raise a series of questions in relation to existing entry-points. Locative media return again to the centre of our concern due to the possibilities and potentialities they offer to reconfigure the system and find ways around it, as in most cases this is the only material interaction drivers have with the system that governs their labour, movements, productivity and willingness to collaborate with it.

To challenge the converged system of air quality and the road management system in Barcelona could seem almost an impossibility – the available entry-points tended to be passive and working in a one-way-only direction. Furthermore, most activities were concerned with either sources of air pollution and their monitoring, or the management and maintenance of traffic flows. However, when it comes to the last mile, the source of contention is the drivers and how their position is taken as being just another variable that has to be brought into line in order to ensure the smoothness of the activities taking place. The mobile device at the centre of the interaction between drivers and the parcel or between drivers and algorithms governing their work becomes then the focus of the search for alternative 'routes' – ways to go around the intention of the algorithm. As the study carried by Lee et al. (2015, p.1,607) demonstrated, this can take shape in a variety of ways: drivers intentionally chose times and areas within which to be available for work, shared online information about "bad passengers", attempted to obtain repeat customers by sharing contact details, when on the road kept their distance from other drivers to avoid too much competition and so on. All these strategies of putting the algorithm to work for their own benefit or finding ways around the operational arrangements imposed by the system were done with or through their mobile phones – the same locative device used to work and be part of that technical arrangement.

What I am trying to demonstrate and emphasise with this is the way the technical system is appropriated and made to deviate from its own objectives, similar to the early uses of locative media. Of course, the level of familiarity with the system was a major element proportional to the type of potentialities encountered and exploited. In any case, what it highlights is the impossibility of heavily and densely populated technical systems with algorithms fully preventing the unexpected, misuse and appropriation. If the tendency of urban systems is to move towards these contexts, we may also have a way to make them a bit more malleable – ultimately, as the early days of locative media showed, there is a paradox embedded into locative media that makes them simultaneously an element of control and surveillance, but also of the unexpected. This can also be contextualised in relation to Fuller's findings (2003, p.28) on the reinvention of possibilities and appropriation of software by "rather insignificant non-experts – teenagers, illegal workers, gossip-mongers", meaning that these "non-experts" often find ways to explore the paths and "powers of connection, of existing in a dimension of relationality rather than of territoriality". What this is trying to say is that the contexts discussed in this chapter are also populated by the unexpected and potentials that might or might not become concretised in the near future. These potentials often start from technical interactions and within the inner dynamics of technical systems, and in some cases, they can be promoted intentionally as the amplification and opening up of their own contexts of action take place.

5.5. Algorithmic intensities

This case study has focused on the last mile of logistics as a context going through many transformations, in addition to presenting a high degree of computational presence within its enabling technical systems. In generic terms, it has been concerned with complex urban systems and their contexts of action that have gone through intensive computational processes or even that have already started out as the outcome of a conjunction of different algorithms. The case study began by looking at how spatial divisions took place, in particular, at the combination of operational needs with systems of spatial division already in place. The objective was to consider the relations created between nodes of distribution, processes of calculation and the role of passage-points, in order to propose that the extension of computation led necessarily to a repositioning and redefinition of these three aspects. More precisely, they all gained a sense of intangibility and immateriality, as part of the elements supporting each aspect were, to some degree, replaced by software applications and data collection processes.

The extension of computation into the context of the last mile forced infrastructural arrangements, like those existing within the context of the Spanish postal services, to become more flexible and open up to their context of action, as a way to counterbalance existing inertia and be able to encourage more dynamic relations. In this way, and as result of the extension of computation, the operational systems supporting the last mile of deliveries become more variable and gain the ability to come together only when required. With this it is meant that the parcel becomes central to the technical arrangement, as well as the element that activates this same arrangement. Nonetheless, the origin of a complex urban system determines the dynamics unfolding around the parcel, being the level of flexibility, adaptability and variability proportional to the existing degree of computational extension.

When it comes specifically to computational arrangements, it was shown that the technical arrangement of core infrastructure and add-ons is replaced by a more flexible diagram of relations. Computational infrastructural arrangements speak of a different form of infrastructure that is not necessarily dependent on traditional material structures that have a high level of inertia due to their own integration and alignment with their context of action. The new diagram of relations implies that what was previously considered an add-on moves away from the fringes closer to the core of the system. Overall, this speaks of a moment of strong amplification, and how the field of logistics and its last mile will become stabilised is not entirely clear. The outcomes will be most likely related to how on-demand and disintermediation contexts unfold, in particular to their approach to variables and level of transparency of their algorithms. These contexts and their infrastructural systems still need, in most cases, to find a sustainable technical system where frictions do not build up and variables are not so strictly designed. Although not part of the objective of this case study, the role of workers and how they will come to define their position within these systems, which often equate them with another variable, will have a huge impact on the stabilisation of the complex urban system supporting the last mile of deliveries. This is left as a point for future analysis and in need of further attention and research. In the meanwhile, research done by Lee et al. (2015) and

Rossiter (2011), together with class actions taken to court in the US (Tepper, 2016) and Spain (Gozzer, 2015), already indicate that there will be a long way to go before a level of stabilisation can be found in relation to this specific issue.

Spatial enhancement is tightly connected with spatial metrics as it assumes a field that somehow is enabled to be both mapped and trackable; spatial enhancement needs a delimited and pinned-down field of action in order to take place (Crandall, 2011). Now, as the parcel and its evolving infrastructure tell us, being trackable is not only about the recording of an event or, in some cases, even the visualisation of patterns and routines. It can be, instead, a way to ensure that everything proceeds within the expected – this means all passage-points have been crossed correctly and on time. Alerts are only raised if this does not occur. Contrary to what Crandall (2011) argues in relation to tracking, this is not simply about knowledge and power ahead of time with the objective "of gaining some kind of strategic advantage." Furthermore, even in cases like the parcel, where its own tracking benefits itself, as in preparation for the field ahead, this process is not about being "fundamentally an anticipatory perception -- one that offers up a predictive knowledge-power, a competitive edge" (Crandall, 2011). As Ocado shows us, the system in place needs that same tracking and surveillance in order to keep itself stabilised. The unfolding technical arrangement sees tracking as an assurance of continuity and in continuous interaction with all other elements of the assemblage it belongs to.

6. CONCLUSION

6.1. Contextualising the extension of computation

As the introductory chapter already stated, this research project has been through many detours and conceptual arrangements since the events of the winter of 2010 took place. Those events not only marked a turning point in my own understanding and engagement with urban territories, they also framed this research project in relation to technical systems and my curiosity for the dynamics supporting and enabling contemporary urban contexts. As a result, this research project set out with the objective of examining how computation has become part of different aspects of urban contexts, in particular through the processes of softwarisation and datafication of these territories, and consequently focused on the conditions that have favoured the emergence of new modes of urban spatialities. More precisely, it aimed to consider how relational locations, proposed as the prevailing mode of spatiality, have emerged out of existing dynamics within complex urban systems and then between these systems and their context of action. The objective has been to look at different specificities of computation, their overall impact on infrastructural systems and finally their spatial unfolding and direct impact on spatial dynamics. The events that took place during the winter of 2010 and the two discussed case studies remind us that there is a recurrent difficulty in opening up and unpacking the systems underlying and enabling the continuous running of urban territories. To identify and gain access to the entry-points and moments of transition of these same systems is often a complicated task. Part of this difficulty is due to an existing degree of intangibility, immateriality and intractability. This difficulty can be perceived through the impact of computational processes at the forefront of urban life while positioned within its background, together with their ability to connect unexpected and disparate systems and make use of coordinated and sophisticated algorithms.

One aspect that stood out, almost in a clear contradiction to the sense of continuity and extension of computation, was how these same characteristics were supporting the reinforcement of what is locational. It is within increasingly computational urban contexts that location and its ongoing and unfolding relations are presented as essential to the understanding of the extension of computation. Location, as I have demonstrated, implies more than a geographic coordinate, as an outcome of computational processes. Its formulation is essentially relational, always in relation to and with dependence on other locations, technical elements and other ongoing dynamics. Location appears then as increasingly tailored, splintered, segmented, calculated and as a probabilistic equation of past–future. It emerges as a context that can modulate and be modulated. In addition to this, location-bound and location-aware dynamics can be directly related to the material–immaterial tensions and frictions that characterise the intensification of computational practices spread spatially. This relation to location is often expressed through the use of locative media and infrastructural add-ons as well as a diversity of data systems working through information tagged to a variety of locations. More importantly, through its ability to connect, build bridges and extend scope of action as well as spatially, computation has shown to have shifted the dynamics of what is local and global into a local–global network. Without a consideration of location, our narrative of the extension of computation would necessarily be incomplete.

The urban contexts discussed were shown to be increasingly run and defined by complex urban systems, the composition of which is often unclear and where distinct aims, ways of working and realms of management seem to converge under one single system. Think, for example, of any of the systems that were visited throughout the thesis – the air quality monitoring assemblage in Barcelona and the growing relational and algorithmic infrastructures coming into place every time a new parcel needs to be delivered. All of these systems required an intentional approach in order to identify and force into visibility their entry-points or processes of transition. Only then, through these elements, was it possible to start unpacking their dynamics and technical formation. Furthermore, any attempts to map them out led us to the tight relations between space, infrastructure, computation, which only helped to reinforce the central role played by computational processes in the coming together, running and maintenance of these same systems. Therefore, the context of this thesis is one where complex urban systems, at the core of contemporary urban territories, have become a growing expression of a new computational logic that has been increasingly expanding and establishing relations of mutual benefit and co-evolvement with its contexts of action, expressing in certain cases already high levels of concretisation and naturalisation.

As the research project moved on, two main areas of possible contribution to the general field were identified. These areas are concerned with the perspective taken on complex urban systems and how the different elements involved are brought into consideration. It could be said then that they are both related to methodological choices – the position to enter a certain context and what scope to consider. As the literature review showed, the emphasis is generally put on what is external to technical systems – it tends to focus on their impact, the outcome of their actions and what becomes perceptible from their interactions (Graham & Marvin, 2001; 2005; Greenfield, 2006). Although of relevance, as I highlighted before in Chapter 2, I believe this to be a narrow approach as it takes technical systems to be elements with no agency, intentionality or ability to evolve beyond what has been socially imposed upon them. This perspective leads necessarily to ignoring or bypassing the existing dynamics among the technical elements within complex urban systems as well as their respective stage of development, as proposed in Chapter 3. It is at this level that Simondon's contribution (1980; 1992; 2008) gains so much relevance, precisely for his approach on the evolution of technical systems and the way they move towards concretisation, while solving existing tensions with their context of action. Moreover, a position of analysis starting from the assumption that technical systems do have dynamics that influence their development and work within urban contexts means that processes like those discussed of convergence, amplification, stabilisation and concretisation can be made accountable and included in analyses of urban territories.

Returning to the second main area of contribution, I would like to highlight how often research focuses solely on one of the elements that are enabling these systems to develop. This is not a direct criticism of such work; rather it is a reiteration of the implications and needs that result from attempts to deal with complex urban systems. As the structure of Chapter 2 highlighted, extensive work has already been done on the impact of computation in space and its sense of continuity; the same applies to infrastructure and codified infrastructural elements, and finally, to computational processes as those of softwarisation and datafication. Nonetheless, one question generally remains unanswered. What happens when these different sets of relevant literature are forced together for the sake of unpacking and dealing with the extension of computation into complex urban systems? What can they say about the emergence and consolidation of complex urban systems as central to the running of any urban territory? How can they deal with the paradox of control and participation, visibility and background, local and global? As I have attempted to demonstrate throughout this thesis, I believe that these questions required a more inclusive methodological approach – as in looking at the different elements brought together by the relations between space, infrastructure and computation – so new perspectives and understandings of our research subject could emerge.

Therefore, as I moved through the literature review, it became clear that although many of the aspects of concern had been covered in one way or another by existing work, they were generally dealt with separately. By this I mean that such issues had been explored in ways that acknowledged the evolvement and continuity of these contexts, but without entering their dynamics from the perspective of technical systems. For example, the revised work of British human geographers on infrastructure and software has definitely been concerned with our object of study, but it has often tended to stop short by covering mostly the impact of these same systems at a social level (Amin & Thrift, 2002; Graham, 2004b; 2005; 2010c; Graham & Marvin, 2001; Thrift & French, 2002). When it came to urban systems and computation, it became clear that not only did the existing literature tend to be sparse (Dodge & Kitchin, 2005; Dodge et al., 2009; Kitchin & Dodge, 2011; Shepard, 2011a; 2011b), but more needed to be done both on the impact and outcome of these systems, especially from the perspective of the technical dynamics evolving within the different technical elements.

Nonetheless, as I stated in Chapter 1, the narrative of this research was designed with the objective of contributing to what can be defined as digital urbanism, sitting at the convergence of software studies, cultural studies and human geography. Many of the main concepts discussed throughout this body of work came necessarily from software studies, and the reflection on the implication of computation within urban systems would not be possible without the available framework already developed within that field (Fuller, 2003; 2007; 2008; Fuller & Goffey, 2012a; 2012b; Galloway & Thacker, 2007; Mackenzie, 2002; 2006; 2010; Manovich, 2001; 2007; 2013). Cultural theorists working within software studies will necessarily continue to develop work on issues related to practices of coding, algorithms, programming languages, software aesthetics and so on. However, it is important to remember once again that our object of study is necessarily urban, and it is within this context that additional research will be necessary on computation, in particular on how the concretisation of computation evolves within complex urban systems.

In the rest of the chapter, and building on what has already been discussed, I attempt to bring together the main points of contribution, discussed already in the context of Chapter 3 and then further extended throughout the case studies, by presenting them divided under four main areas – the extension of computation, the path of development towards concretisation, the context of action and, finally, the increased immaterialisation of urban contexts. This will give us the opportunity to look at this thesis's contributions in more detail, while considering future research and the limitations both experienced as a result of the perspective taken and as a consequence of the choices made throughout the project.

6.2. What has been found

As the opening of this thesis described, the research context of this work emerged out of the three events that took place during the winter of 2010. These events brought into perspective the limited understanding that locative media could offer on computational technical dynamics and related modes of urban space that were unfolding as outcomes of these same contexts. They brought to the forefront what has been defined and discussed as complex urban systems. Sustaining and enabling the operations and dynamics of the three events, these systems demonstrated that they have similar technical arrangements, evolving in increasingly more complex ways due to the extension of computation and, in many cases, moving towards macro infrastructural systems that tend to go beyond delimited jurisdictional territories or predefined scopes of action (Moore, 2015, p.26). The arrangement of these technical systems showed an increased dependency on computational systems, meaning that the computational logic had become embedded into them in one way or another.

What stood out from an early stage was how complex urban systems were formed by tight relations between space, infrastructure and computation and that in order to enter these assemblages, intentional strategies of dealing with material and immaterial technical elements were necessary. The extension of computation was shown to have been pushed forward by processes of softwarisation and datafication that implied new techniques and ways of knowledge formulation, as well as the intensification and acceleration of existing dynamics between technical elements. This takes us to the proposed path of development towards concretisation borrowed from Simondon's conceptual framework (1980; 1992; 2008). As shown, the extension of computation had significant implications regarding the development of this path and how the different transitions between each stage occurred up to the concretisation of the system with its context of action. This is due to the adaptability and variability that computation offers but can be also a consequence of its extension. A particular example of this is how processes of softwarisation and datafication allow the introduction of new variables that consequently lead to the extension of the affordances and thresholds of their targeted system. More important, the path of development with its four stages offered a valuable overview and understanding of the internal dynamics occurring during each stage of development and their consequences throughout the technical systems as well as in the interactions with their contexts of action. In any case, allow me to reflect on the main findings that can be taken from the proposed and analysed path of development in relation to complex urban systems and the extension of computation as well as considering the consequences.

The path of development, comprised of four stages – convergence, amplification, stabilisation and concretisation – provides a conceptual tool to understand what processes can unfold within complex urban systems, what happens within these processes and how they can be related to specific interactions, outcomes and way of acting upon their objects of concern. The internal dynamics of complex urban systems indicate to us each stage of development towards concretisation and a group of generic tendencies. More than about a linear process of development, this proposed path is about placing the dynamics unravelling within the different technical elements in relation to their context of action. What I am trying to say with this is that each stage is characterised by a specific level of openness, stability and integration between the different elements and with the system's context of action. The scale and extension of many complex urban systems necessarily imply that on certain occasions, different levels of concretisation can be found throughout the system.

Besides the level of openness, stability and integration, the path of development and its stages can support us when analysing the dynamics and positioning of core infrastructure and its add-ons and what is placed at the centre or within its fringes. When computation gets extended into large systems that have a high degree of concretisation, the process of extension tends to happen through add-ons due to the already existing inertia within the core infrastructural arrangement, meaning that future concretisation under the new conditions might happen first through the elements positioned at the fringes of the technical system. However, in the case of contexts that are scoped as being already computational, the smaller material elements such as locative media are placed much closer to the core of the system. The diagram of relations that emerges does not contain the level of differentiation (between core and add-ons) of more traditional sets of infrastructure. This consideration, together with the specifications of each stage of development, allows us to position any complex urban system within its path of development and use this framework as the starting point of our analysis, as was done with both of the case studies.

The extension of computation into urban infrastructural systems has gone well beyond the rearrangement of the systems it entered, meaning that it deeply transformed how urban spatialities unravel, flows are managed, spaces are conceptualised and even how regulation is designed. The extension of computation, done mostly through processes of softwarisation and datafication, has had significant consequences for the overall dynamics of urban territories. On one hand, these processes have brought acceleration and intensification, while on the other hand, they have allowed different elements and systems to talk to each other, interact and co-evolve. This implicit decrease of material and fixed infrastructural elements, due to the work of computation as a boundary, glue and gateway element, has resulted in less tangible environments. The unity of complex urban systems is for this reason not necessarily thematic or structural, but maintained and continuously connected through software applications and data systems. In addition to this, computation has been shown to play an essential role in expanding the area of action of complex urban systems, through the above-mentioned activities in conjunction with its ability to extend its scope without provoking major tension within the system and by establishing relations of mutual benefit and co-evolvement with its context of action. The extension of computation is not only about the practicalities of its actions and what affordances and thresholds it brings into action; it is also about a logic that gets spread and extended, which slowly becomes naturalised as well as normalised.

Nowhere is this naturalisation and normalisation of the logic of computation made more visible than within the contexts of action of complex urban systems. Contexts of action play an important role in the stabilisation and concretisation of technical systems. They are the site where relations of mutual benefit and co-evolvement are established with complex urban systems, where the uniqueness of a location becomes significant and the feeding into its geographic enhancement takes place and, finally, where external pressures to the technical systems are exerted. It is within contexts of action that technical systems become then increasingly stabilised and integrated as they move towards concretisation. It can be said that contexts of action are where urban territories meet technical systems and external dynamics meet computational processes. Here, the position of location becomes reinforced and geographic enhancement happens. Computation and its capture and tailoring capacities allow contexts of action to enter into a process of feedback that leads to alignment with technical systems. This takes place through activities such as those of data mining, development of location-bounded services and ongoing qualculation (Callon & Law, 2003). Practices of standardisation and risk management are exerted from the context of action of technical systems – in a way, they reinforce the action of computation or create the conditions for higher levels of stability. Furthermore, the implementation and management of standards, much like the case of systems' defaults and protocols, give rise to control of the context of action by having the possibility to impose compulsory standards that can benefit certain types of players or create very high entry levels to the field.

As we close the circle that was initiated with locative media, what emerges is a very different context from that predicted by Russell (1999; 2002; 2004a) on the potential of locative media to enable a return to the outside and enhance social empowerment and community engagement. Many of his predictions can indeed be identified within the outcomes and impact of complex urban systems and as I have shown, locative media have gained an important role within these technical systems. Locative devices often reinforce the extension of computation throughout complex urban systems by supporting how technical systems are rearranged, leading to their increased immateriality and extension of their contexts of action.

6.3. Where to go next

As we come to the conclusion of this research project, I would like to briefly consider future research by also taking into account the limitations of this project, as well as those aspects that were not possible to cover and consider due to their context or lack of direct relation to the topic being discussed. Let me start by suggesting that the propositions made throughout the context of this thesis should be further tested against concrete examples. The two analysed case studies, although offering two very different urban narratives on processes of development towards concretisation and the extension of computation, were also limited in scale, scope and time frame covered. It was not possible or even realistic to attempt a perspective of their entire path of development towards concretisation. This has meant that the scope of the case studies was necessarily time and space constrained.

Further research will also be necessary on how the concretisation of computation will take place – a brief perspective was already provided throughout Chapter 5, and elsewhere Hui (2015b, p.140) has argued that contemporary concretisation happens within technical systems at the level of metadata. Although I agree with this, I do think that the concretisation of computation throughout urban systems will also happen at the level of algorithmic arrangements and processes of softwarisation. What remains to be seen is exactly which format this will take. Intensive processes of computation do not occur without a level of friction and tension; the computability of urban environments where anything can become objectified has important implications. On one hand, there is a flattening out of the levels of importance and relevance encountered throughout urban contexts of action, and on the other hand, everything comes under the 'tyranny' of the algorithm regardless of its computability or not, as in the case of the drivers. As I showed earlier, processes of softwarisation and datafication help to mitigate tensions and work out differences by amplifying the affordances and thresholds of technical assemblages and building bridges between disparate elements. However, contexts such as those of on-demand and disintermediation services discussed in Chapter 5, will result in new challenges. As I discussed, the objectification of anything to the ruling of the algorithm as that done to the drivers of Lyft (Lee et al., 2015) will not occur without contention. In addition to this, the interaction of material and immaterial brings necessarily new opportunities to access systems that are scoped from their outset as being quite close – in part, their existence as online or standalone platforms already indicates this conceptualisation, like in the case of Cargomatic, Glovo, Uber, Lyft and so on.

One element that necessarily stands out as missing throughout the thesis and the mentioned context of action is 'citizens', as mentioned in the introduction. Their non-presence was intentional as the precise aim was to emphasise technical systems. This thesis covered many aspects related to the impact of technology within urban environments, which implicitly means a direct impact on citizens. However, the intention was to leave a user and citizen perspective aside, as that would have resulted in a different research project, but it would also have raised once again the issue of focus. Much has already been done and probably additional research needs to go further into the grey areas of interaction, usage, engagement and appropriation with complex urban systems. Spaces are already populated – when computation enters the realm of built infrastructure and inhabited spaces, it encounters challenges and opportunities. This thesis intentionally made its object of concern limited, in order to avoid dispersion into a wide net of urban elements, experiences and social practices. The expectation is that this thesis' contribution to our understanding on the internal dynamics of technical systems can feed into further research on the experiential realm of urban territories, not only as a user of a service but also as being in place as an active element of the described assemblages and contexts.

7. GLOSSARY

Add-ons

Technical elements that are added to infrastructural systems after their initial conceptualisation and implementation. They are often an afterthought or considered non-essential elements.

Affordance

A range of wider opportunities and possibilities offered by computational processes to perform a certain action.

Amplification

The second stage of the path of development towards concretisation followed by complex urban systems. It implies the openness of the system to its context of action.

Algorithmic

A condition or status that assumes an underlying support and programmability run by algorithms.

Backbone infrastructure

The key structure of an infrastructural system responsible for its overall functioning. It can also be referred to as core infrastructure.

Complex urban systems

Infrastructural systems that have been embedded and transformed by computation, expressing a high degree of complexity and the ability to converge with other systems.

Concretisation

A key concept of Gilbert Simondon. The last stage of the proposed path of development followed by complex urban systems. It implies a condition of alignment and attunement with a context of action, as if it had been naturalised.

Context of action

The spatial and conceptualised area where infrastructure acts. It constrains and is simultaneously defined by infrastructure.

Convergence

The first stage of the path of development towards concretisation followed by complex urban systems. It implies the coming together of two different technical systems or objects.

Core infrastructure

See backbone infrastructure.

Datafication

The process of turning into data an event or context which was not previously computable.

Disintermediation

The reduction of intermediaries in the provision of services or access to information.

Entry-points

Small infrastructural elements that provide access to the structuring and logic of a specific infrastructure.

Fringe

The periphery of an infrastructural system. It can also imply add-ons or secondary technical elements of a complex urban system.

Geographic points

Geographic coordinates that can have a fixed or mobile quality.

Informatisation

The growth of information associated with specific areas. Once in place, it tends to become key in decision-making processes. Datafication feeds directly into informatisation.

Modulation

A mode of control and management that has the ability to work continuously through adaptation and calculation.

Network-logic

A distributed way of working with the specific inner structure of power encountered within complex urban systems.

On-demand

A service available upon request.

Passage-points

Key moments of legitimation of specific events. The site of registration of the transition of a specific object from one context or site to another.

Path of development

The process of development that complex urban systems go through as they move closer to concretisation and which is formed by four distinct stages (convergence, amplification, stabilisation and concretisation).

Relational locations

The spatial outcome and expression of assemblages formed by complex urban systems, directly related to computational processes.

Secondary infrastructure

See add-ons.

Softwarisation

The ability of software to translate previous analogue media at the level of techniques, bringing new qualities, capabilities, hybrids and affordances to those same techniques.

Stabilisation

The third stage of the path of development towards concretisation followed by complex urban systems. It implies a reduced level of tension and instability between a complex urban system and its context of action.

Threshold

The point at which the system has to react to pressure in order to remain stable.

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