1. Introduction

> *Current technology requires information to be served from somewhere and delivered to somewhere. Heisenberg's uncertainty principle not withstanding, at geographic scales a bit always has an associated location in real geographic space. (Goodchild 1997, 383-84)*

The increasing use of mobile, digital and location-sensing technologies such as digital cameras, mobile phones, Global Positioning Systems (GPS), and web-based services in our personal and professional activities is changing our lives, not only in the way we communicate and interact with each other but also how we perceive our environment. We should add to this picture the webs of sensors, which monitor the environment, ourselves as part of this environment through our interactions with these novel infrastructures. Some of these interactions are explicit when a user knowingly operates a system to achieve a certain goal (e.g. to use of a navigation system, to georeference photos, to disclose one's location). In contrast, others are implicit when the user is not actually aware of them because he or she concentrates on more important activities (e.g. handovers on a wireless network when walking on the street, the log of the originating cellular antenna when making a phone call, driving with a navigation system in passive mode)

In consequence, the individual empowerment afforded by the ubiquitous availability of geographic information (geoinformation) is accompanied by an increased ability to create many new types of geographically referenced records that entangle the daily activities of each person into a dense web of data spread across time and space. However, there is still very little understanding on the implications of this ubiquitous presence of geographic information on people. Indeed, an extensive review of the domains of ubiquitous computing (ubicomp) and Human-Computer Interaction (HCI) shows that most of the research in those fields focuses on optimizing the accuracy of location sensing and aims at seamless interaction, prior to understanding how it could be better integrated into people's daily activities (see Girardin, 2007, for an extensive state of the art review). Some important aspects of the human interactions with ubiquitous geographic information are explored in

this thesis through five case studies, which have complementary approaches to the issue (see Figure 1 for an overview).

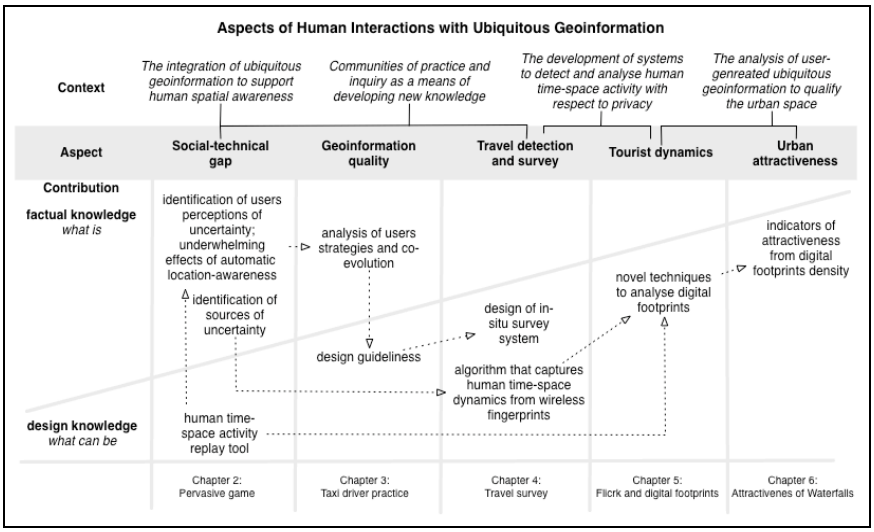

Figure 1. The articulation of this thesis through diverse case studies and their complementary contribution on human interaction with ubiquitous geoinformation,

One of the main contributions of this thesis is to provide evidences of what Bell and Dourish (2006) refer to as the "ubiquitous computing of the present". The case studies are part of the paradigm change in the research field, in the form of proving that "ubicomp" is already here, but does not have the form that was envisioned. In consequence, we consider the imperfections of everyday life as a central theme of research in ubiquitous computing, arguing further on the warnings of Bell and Dourish: "*The seamlessly interconnected world of future scenarios is at best a misleading vision and at worst a downright dangerous one*".

Indeed, a futurist vision of goals of the field has encouraged research into an infinitely postponed proximate future that eventually distracted the researchers' attention from what is currently being used and its implications. Our first work, on pervasive games, was not setup against a stage of the imperfection, but this came up as an unexpected research outcome. The study proved that experimental game development could produce research insights in ubiquitous technologies research. For instance, we could

explore the effects of automatic location-awareness on collaboration, the technological boundaries of location-aware systems and the users strategies to overcome the limitations and shortcomings of technologies. The publications on these insights contributed to the "*Are we there yet?*" discourse that questioned whether ubicomp was something yet to be achieved. Furthermore, this work not only helped to recognize the current impossibility of a completely seamless, invisible, ubicomp infrastructure but also suggested that users adapt to the limitations these technologies. Indeed, the presence of ubiquitous technologies on the streets (Greenfield, 2006) encouraged us in confronting real people in real everyday environments and move beyond the "fake" environments and missions of so many ubicomp studies. As suggested by Davis et al. (2005): "*developing a complex system is not a new problem. However, when looking at ubicomp systems, understanding the full complexity is often different and more difficult than in areas of more bounded scope*".

A first aspect of our results framed in a present ubicomp is the convenience of seamful interaction with location-aware devices rather than a seamless one, which is argued from the results of our case study number one (Chapter 2). Based on CatchBob!, the pervasive game we developed, we show that, despite location technologies having a degree of uncertainty, users develop intelligent strategies to cope with it. These strategies are based on understanding the way the technologies imperfectly work. A side, but important, result is that human communication on location can replace the machine sensed one, and this leads to a more immersive experience of the game (involving acts of communication carrying intentions). These findings were revealed with the development of a replay tool that visualizes the players' movements and interactions from the logged data and digital messages. However, this experimental approach limited the understanding of the real life interactions, in a wider context, with a wider range of applications, devices and artefacts, common for ubiquitous systems. Our second case study specifically analyzed this aspect.

Based on qualitative data collected from ethnographic observation, our second case study (Chapter 3) reports on the appropriation of location technology by individuals within a group of taxi drivers using satellite navigation systems and a variety of other artifacts, as

we show. This work further highlights users strategies to cope with the uncertainty and different levels of location granularity of the geoinformation. For instance, the individuals with less knowledge of the environment are unable to assess the quality of the information delivered by their location-aware system. Furthermore, we reveal that the automation of the wayfinding process alters the social practices that were at the source of learning the unofficial and provisional city from the interactions with their customers. In reaction, the taxi drivers rely on an ecosystem of complementary sources of city information to support their practice. These findings support that poor geoinformation quality, lack of timeliness and completeness, and inaccuracies challenge users in their decision-making, who handle this with both frustrations and new strategies to manage these situations. These strategies are evidences that reveal the presence of a social-technical gap formed by the discrepancies between the users' expected granularity of information and what the technology can deliver. In consequence, we interpret these findings to inform the design of location-aware systems. For instance, we suggest a seamful design approach that highlights the quality of the geoinformation instead of hiding it. Furthermore, we describe the implications of automating the disclosure of geoinformation on the user experience with the immersion, learning and social impacts. At a higher level of granularity, this work embraced a broad perspective that argues against the conception of technology as an autonomous, external force imposing societal change. Our focus on everyday practices, experiences, and interpretations of geoinformation gives evidences of a co-evolution in that these location-based systems alter individual's practice and in return individuals appropriate them in unexpected ways.

The design of our third case study (Chapter 4, mobility detection algorithm for an in-situ travel survey system) fed from these understandings of a) the technological constraints that generate a fluctuating quality in the location information and b) the individuals' strategies to overcome the uncertainty. While many computer scientists and engineers consider practical constraints as detrimental to the elegance of technological solutions, we instead view them as challenges and opportunities to rethink solutions. Based on these principles and the techniques developed in our pervasive game (Chapter 2), we designed and deployed a solution that captures individual's travel experiences as they occur

eliminating the recall bias of traditional survey solutions. Simple behavioural patterns, captured in this case as digital footprints, constitute a powerful unobtrusive alternative to complex technological developments of longitudinal travel surveys. This approach introduces a novel methodology of providing informative indications on human spatial dynamics from processing data sources far more reliable than traditional subjective surveys. However, detecting mobility and travel at a larger scale is difficult due to the challenge of building informative, yet unobtrusive solutions that respect privacy.

Another major contribution of this thesis takes upon that challenge. It builds on our first case study (Chapter 2, visualize logs of digital footprints) and three (Chapter 4, detect mobility from digital footprints) to explore the explicit and implicit digital footprints generated by individuals and groups to reveal their behaviours in space. Our fourth case study (Chapter 5) is a precursory analysis of the massive amounts of information that are being recorded and stored daily about people's behaviour, as they walk through the streets with their mobile phones, drive their cars and use the Web. This research went along the line of Bruno Latour who foresaw that the consequences of such information for Social Sciences will be enormous: they can finally have access to masses of data that are of the same order of magnitude as that of their older sisters, the natural sciences (Latour, 2007), adding:

I am sure that this accumulation of traces … is worth pointing out. The precise forces that mould our subjectivities and the precise characters that furnish our imaginations are all open to inquiries by the social sciences. It is as if the inner workings of private worlds have been pried open because their inputs and outputs have become thoroughly traceable.

Geographers have a similar description of the phenomena and opportunities under the name of "new digital geographies" (Dodge et al., 2004) or "next generation Digital Earth" (Craglia et al., 2008). However, the reach of such an objective demands tools and technologies to effectively mine vast quantities of ubiquitous geoinformation (Microsoft, 2008). In the fourth case study (Chapter 5), we develop tools and analyze georeferenced information, explicitly provided by users (in fact, users' geotagged photos in

Flickr); this study was initially motivated by understanding human expression of geoinformation in the context of improving interaction. But this explicit information offered even further human traces that could be analyzed to understand human in many ways. We developed new concepts and methods for retrieving, analysing and visualising this information, which offered both geographical and temporal traces of activity. The tools were used to map tourism and non-tourism related behaviour, again going far beyond what has been traditionally coming from surveys, with an unprecedented large scale and with publicly available data. This work shows that innovative developments in spatialization, information visualization, and geovisualization are altering the nature of maps, which become tools for exploring data rather than static representations for communicating results.

This explicit and voluntary information provides a wealth of results. However, the same explicit character indicates a potential bias that motivated further exploration. Therefore, we combined and compared implicit and explicit digital footprints that visitors leave behind them in Rome, ItalyThe results show that these data sources offer probably complementary aspects, complementary human behaviours, rather than confirming through another data source the initial results, which was our initial assumption.

Nevertheless, this work showed that the analysis of these user-generated spatio-temporal data has the potential to supply high-level human behaviour information valuable to urban, travel and tourism studies. In an effort to demonstrate this potential, our fifth case study (Chapter 6) exploits these evidences as indicators of the evolution of the attractiveness of the urban space. The case study took place within a project to quantify the impact of the New York City Waterfalls exhibit on the attractiveness of the waterfront. It was made possible with the development of an interpolation model of network activity to map cellular network statistics. For that objective, we measured the relative density of digital footprints as evidences of the evolution of the attractiveness and popularity of points of interests.

In this thesis we present several aspects of implicit and explicit human interactions with ubiquitous geoinformation. Through quantitative and qualitative lenses, it discerns the implications of the

integration of location-aware technologies in the framework of their human use and appropriation. It provides answers on the strategies to cope with spatial uncertainty and how this automation of geoinformation delivery alters the social dynamics, the learning process of the environment and the human engagement with it. We also explore the massive amount of ubiquitous geoinformation generated through people's explicit and implicit interactions with mobile devices and wireless infrastructures. In this context we develop new concepts, tools and techniques to extract the individuals and groups spatial dynamics, while respecting users' privacy. As a result, we show the applicability of these methods in the domain of market research and urbanism. This thesis dissertation presents these contributions through a compilation of the following articles:

Chapter 2: First case study on "The generation and user perception of uncertainty in ubiquitous geoinformation".

Girardin, F., Blackstock, M., Dillenbourg, P., Finke, M., Jeffrey, P., Nova, N. (2007). Issues from Deploying a Pervasive Game on Multiple Sites, In *Common Models and Patterns for Pervasive Computing Workshop*, 5th International Conference on Pervasive Computing, May 13, Toronto, Ontario, Canada.

Girardin, F. and Nova, N. (2006). Getting real with ubiquitous computing: the impact of discrepancies on collaboration. *e-Minds International Journal on Human-Computer Interaction*, 1(1):60–64.

Chapter 3: Second case study on "The appropriation of ubiquitous geoinformation"

Girardin, F. and Blat, J. (Submitted to *Pervasive and Mobile Computing Journal*). The co-evolution of taxi drivers and their in-car navigation systems.

Chapter 4: Third case study on "The implicit interactions with wireless infrastructures as source of travel detection and survey".

Girardin, F., Nova, N., and Dillenbourg, P. (Submitted to the *Journal of Location-Based Services*). Detecting air travel to survey passengers on a worldwide scale.

Chapter 5: Fourth case study on "User-generated ubiquitous geoinformation as evidences of tourist dynamics"

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

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

Chapter 6: Fifth case study on "Digital footprints as evidences of urban attractiveness"

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

A full list of papers presented before the thesis submission can be found at http://www.girardin.org/fabien/publications/thesis/