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USE AND CONSEQUENCES OF PARTICIPATORY GIS IN A MEXICAN MUNICIPALITY: APPLYING A MULTILEVEL FRAMEWORK

Uso e consequências de um SGIS participativo em uma municipalidade do México: aplicando um modelo multinível

Uso y consecuencias de un SIG participativo en un municipio mexicano: aplicando un modelo multinivel

ABSTRACT

This paper seeks to understand the use and the consequences of Participatory Geographic Information System (PGIS) in a Mexican local community. A multilevel framework was applied, mainly influenced by two theoretical lenses – structurationist view and social shaping of technology – structured in three dimensions – context, process and content – according to contextualist logic. The results of our study have brought two main contributions. The first is the refinement of the theoretical framework in order to better investigate the implementation and use of Information and Communication Technology (ICT) artifacts by local communities for social and environmental purposes.The second contribution is the extension of existing IS (Information Systems) literature on participatory practices through identification of important conditions for helping the mobilization of ICT as a tool for empowering local communities.

KEYWORDS | Participatory Geographical Information Systems, local communities, structuration theory, social uses of technology, social consequences of technology.

RESUMO

Este artigo busca entender o uso e as consequências do Sistema de Informação Geográfica participativa (SIGP) em uma comunidade local mexicana. Uma estrutura de múltiplos níveis foi aplicada, influenciada principalmente por duas óticas teóricas – a visão estruturacionista e configuração social da tecnologia – estruturada em três dimensões – contexto, processo e conteúdo – de acordo com a lógica contextualista. Os resultados do estudo trouxeram duas contribuições principais. A primeira é o refinamento do quadro teórico a fim de investigar melhor a implantação e uso de Tecnologia de Informação e Comunicação (TIC) por comunidades para fins sociais e ambientais. A segunda contribuição é a expansão da literatura dos Sistemas de Informação (SI) existentes em relação às práticas participativas através da identificação de condições relevantes que podem auxiliar a mobilização das tecnologias de informação e comunicação como ferramentas de empoderamento de comunidades.

PALAVRAS-CHAVE */ Sistema de Informação Geográfica Participativa, comunidades locais, teoria estruturacionista, uso social da tecnologia, consequências sociais da tecnologia.*

RESUMEN

Este trabajo tiene como objetivo entender el uso y las consecuencias de un sistema de Información Geográfica Participativa (SIGP) en una comunidad local mexicana. Fue aplicado un marco multinivel, influenciado principalmente por dos enfoques teóricos – el punto de vista estructuracionista y la formación social de tecnología – y estructurado en tres dimensiones – contexto, proceso y contenido – de acuerdo con la lógica contextualista. Los resultados de nuestro estudio ofrecieron dos contribuciones fundamentales. La primera es el refinamiento del marco teórico con el objetivo de investigar mejor la implementación y el uso de aparatos de Tecnología de la Información y la Comunicación (TIC) por comunidades locales para propósitos sociales y ambientales. La segunda contribución es la ampliación de la literatura de Sistemas de Información (SI) existente sobre prácticas participativas a través de la identificación de condiciones importantes para ayudar a la movilización de las TIC como una herramienta para el empoderamiento de comunidades locales.

PALABRAS CLAVE */ Información Geográfica Participativa, comunidades locales, teoría de la estructuración, usos sociales de la tecnología, consecuencias sociales de la tecnología.*

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INTRODUCTION

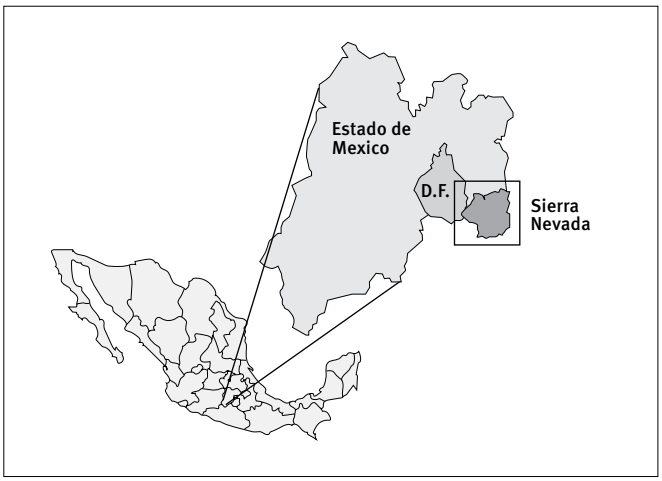
Geographical Information System (GIS) has been increasingly applied to different areas, such as urban and rural spatial planning and natural resources management. Although GIS can also represent a series of manual cartographic overlays, they are more commonly computer-based (Puri, 2007). During the last few decades, the steadily decreasing cost of computer hardware and the availability of user-friendly software has allowed the diffusion of this modern spatial technological artifact to non-governmental and community-based organizations, groups that had previously been excluded from the spatial decision making process (Rambaldi, Kwaku Kyem, McCall, & Weiner, 2006). We call the implementation of a GIS "participatory" (PGIS) when a set of inclusive practices are applied to incorporate participation of local people in all phases of the project, from design and information gathering to map production and decision making.

The purpose of this study is to investigate a particular PGIS – the Sierra Nevada Project (SN project) – implemented in a small Mexican municipality called Tlalmanalco. In that region, for the past 30 years, a series of environmental threats, combined with unequal economic development, have been undermining the connection between the local population and their land. In 1997, after a metropolitan planning authority predicted an ecological crisis for the next decade, a university/community initiative called *Proyecto Sierra Nevada* was established to contain urban sprawl and ecological dangers through local and sustainable development projects (Moctezuma, 2001). One of the challenges found was the need for re-appropriation of the territory by the community, which was addressed with the help of an innovative implementation of PGIS.

Using this case as background, our article aims to analyze the use of a PGIS by a local community and its consequences from a social and sustainable perspective. The meaning of community would merit a separate discussion in itself, as a huge variety of definitions can be found in the literature (e.g., geographic communities, communities of culture, communities of interest, international community, etc.). Our definition of community is in line with Agrawal and Gibson (1999), who shifted the focus from community as a concept associated with small spatial units, homogenous social structures or shared understandings and identities, to a more complex and multidimensional definition wherein multiple and often divergent groups and interests co-exist, interact, negotiate, and struggle to defend different preferences for resources use and distribution. The community targeted by this study is located in Tlalmanalco, a municipality of 45,000 people in Central Mexico, between the Basin of Mexico and the Sierra Nevada Mountains (Figure 1).

Our study was guided by two research questions: (a) what context helps explain the emergence of a PGIS in the Sierra Nevada region? and (b) what are the main social and environmental consequences of the implemented PGIS to local communities?

Figure 1. **Tlalmanalco community is located in Sierra Nevada, Mexico**



Our study brings two main contributions. The first is the refinement of a multilevel conceptual framework structured in three dimensions – context, process and content – conceived to investigate the implementation and use of Information and Communication Technology (ICT) artifacts by local communities, from a social and environmental perspective. The second contribution is the extension of existing IS literature on participatory practices through identification of important conditions for helping ICT to work as a tool for empowering local communities, as presented in the discussion and conclusion section. Our study is one of the few reporting a successful case, which is in itself a reason why both researchers and practitioners might learn from its results.

BACKGROUND

In this section, we first present a brief literature review covering PGIS research over the past 15 years; we then present the conceptual framework used as a guide in the empirical work.

Overview of GIS and PGIS research streams

GIS is a computer-based tool for mapping and analyzing spatially referenced data that can facilitate the understanding of spatial aspects of social and economic development (Puri, 2007). In that sense, GIS is not just a "mapping" software, but presents a number of powerful functionalities due to its two main compo-

nents. The software component brings geographical data into the GIS – either from remote sensing sources, ordinary printed or digital maps, or field reports – and converts those data into computer-readable form. A second component is the database incorporated by a GIS that allows the data to be managed and deployed. The categories of data commonly inserted in such maps are, among others: geographic localization, soil types, vegetation and topographic patterns, fauna, water drainage systems, human occupation and land property, degradation areas.

The results from GIS data analysis are disseminated in a number of ways but most commonly in a map form that supports several layers of information (Wastell, 2006). While many forms of mapping systems have been available since the 1960s, Madon and Sahay (1997) emphasize that GIS technology has evolved since the early 1980s. Recent developments of this technology, particularly remote sensing-based GIS, have been widely employed to support the sustainable development of natural areas like tropical forests (Hayes & Rajão, 2011).The studies made about GIS and PGIS over the past 15 years were analyzed and organized in three main streams (Exhibit 1).

Exhibit 1. **Three streams of research on GIS**

Stream	Authors
GIS studies (non-participatory) from the IS literature	Barret et al. (2001); *Hayes and Rajão (2011); Puri (2006); *Rajão and Hayes (2009); Sahay and Robey, 1996; Wastell (2006)
PGIS studies from the IS literature	Aynekulu et al. (2006); Chambers (2006); Nabwire and Nyabenge (2006); Mans (2006); *Puri (2007); *Puri and Sahay (2003); Shrestha (2006); Walsham and Sahay (1999)
PGIS studies from non-IS literature	Aswani and Lauer (2006); Bojorquez-Tapia et al. (2001); *Corbett and Keller (2005); *Dunn (2007); Eisner at al. 2012); *Elwood (2006); *Ghose (2001); *Kyem (2001); *McCall (2003); Peters-Guarin (2012); Sieber (2006)

* Critical views of GIS and PGIS

In the first and second streams, we have included the vast IS literature in order to better understand the processes of implementing GIS artifacts and the consequences of their use (e.g., Barrett Sahay, & Walsham, 2001). While the first stream focuses more on GIS projects taken in a broader sense, the second particularly targets GIS projects that are participatory in nature. In the third stream, we have looked at studies investigating PGIS through other disciplines, such as urban planning, environmental management, geography and others. We have found a huge number of studies and directed our attention to those which offered a link and potential contribution to IS-related issues, particularly those examining the use of PGIS for spatial planning and natural resources management in order to understand how local stakeholders participate in the implementation process as well as the impacts of those participatory projects.

From all these studies, some critical studies have particularly drawn our attention. For instance, Kyem (2001) explores how internal (e.g., the complexity and time-consuming characteristics of the process itself) and external (e.g., dependence on external assistance and technology and training costs) factors influence the degree of local empowerment achieved in PGIS processes. In the same vein, based on the assumption that PGIS can empower disadvantaged groups, Corbett and Keller (2005) propose two working definitions of empowerment – empowerment and empowerment capacity – and a framework to structure the analysis of empowerment. Other authors emphasize elements influencing the degree of "inclusiveness" of the process: on the one hand, there are critical divisions within communities related to gender, age, economic class, etc., which lead to an extensive and difficult to manage range of needs, opinions and interests (McCall, 2003); on the other hand, there is a portion of the population who do not have appropriate training or capabilities to effectively use the information and, thus, might be excluded from the decision making process (Carver, 2003). Pury and Sahay (2003) and Puri (2007) examine the use of PGIS to alleviate the problem of land degradation and recognize indigenous (community-related), technical (technology-related) and scientific knowledge as three important types of knowledge whose mismanagement could lead to important power asymmetries. As we could recognize, knowledge and power are two constructs that cannot be easily separated when a critical perspective is adopted.

One of the main expected benefits of those PGIS projects is making relevant information available to disadvantaged groups in order to enhance their capacity to better manage conflicts with dominant groups and to participate in the resource planning of their territory (Rambaldi et al., 2006). ICT artifacts like GIS tools, when embedded in participatory practices, potentially help local communities to reconnect to their natural resources by improving their planning and negotiating capabilities (Peters-Guarin, McCall, & van Westen, 2012). We argue that this topic, though increasingly important, is still poorly investigated. Notwithstanding a certain number of papers on PGIS projects, more knowledge is clearly needed, from social and environmental perspectives, with respect to the use and consequences of PGIS technology by particular communities and the required conditions to effectively use ICT artifacts as tools for empowering local communities for them to achieve their broader social and environmental goals. In the next section, we propose a framework, based on a review and extension of existing

studies, which will guide our data collection and analysis and thereby help us answering our research questions.

Frameworks for PGIS analysis

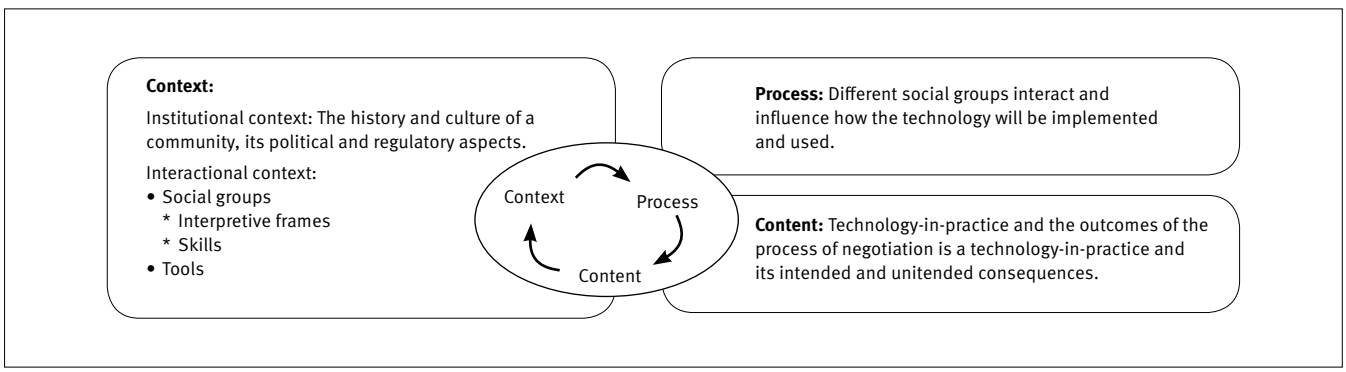
We have identified two distinct frameworks that specifically address PGIS implementation: Sieber (2006) and Corbett and Keller (2005). Although the two can be seen as complementary, we paid particular attention to the second, due to its underlying critical assumptions. Corbett and Keller (2005) propose a distinction between empowerment (the "output" or increase in power) and empowerment capacity (the "process" of change in internal conditions that influences power). They articulate these two definitions within a two-dimensional framework that incorporates two social scales – individual and community – and four catalysts of empowerment, namely: the information contained within a PGIS project (how the documentation, control and use of information contributes to empowerment and changes in empowerment capacity); process (participatory process employed by a PGIS project, i.e., the mechanisms used to include or exclude parts of a community: invitations, demands, coercion, deliberative efforts, etc.); skills acquired by participation in a PGIS project (ability to use new technologies, e.g., learning to operate equipment, to manage files, etc.); and tools (specific equipment) used to develop a PGIS. The analysis of empowerment involves, therefore, "exploring how the different catalysts cause empowerment as well as changes in empowerment capacity at individual and community levels" (Corbett & Keller, 2005, p. 95).

Although we find Corbett and Keller's (2005) model highly valuable, it lacks a clearer and more concrete frame to guide empirical work that encompasses multiple levels of analysis. In line with Burton-Jones and Gallivan (2007), we apply the term multilevel to a type of framework that entails more than one level of conceptualization and analysis. The relevance of studies at the community/societal level is rising, opening opportunities for IS research to address the relationship between ICT and people in broader contexts than just organizational settings. Frameworks that incorporate several levels of analysis – individual, group, community, society – are welcome.

Pozzebon, Diniz, and Jayo (2009) have presented a conceptual framework that seems particularly useful for research, involving complex and multilevel interactions between individuals, groups, organizations and networks at the community/societal level, struggling to implement and utilize ICT innovations for change and developmental purposes. This framework is influenced by three theoretical perspectives: social shaping of technology, structurationist view of technology and contextualism.The social shaping of technology pays special attention to the diversity of actors' interpretations of the meaning and content of technology and emphasizes the identification of opportunities where decisions and actions regarding technology management and change may be undertaken (Wilson & Howcroft, 2005). Three of the concepts of Pozzebon et al. (2009) theoretical framework come from this perspective: (1) relevant social groups; (2) interpretive frames; and (3) negotiation. The fourth, (4) technology-in-practice, comes from the second theoretical influence, the structurationist view of technology, which represents a well-established IS research stream influenced by Giddens' structuration theory (Jones & Karsten, 2008). Finally, the third theoretical influence comes from the contextualist approach, which was first introduced by Pettigrew (1985, 1990). Arguing that much research on organizational change was non-processual and non-contextual in character, Pettigrew has emphasized three dimensions: context, process and content, and claimed that these three dimensions are equally important and should be considered in concert.

We propose a theoretical scheme to analyze the use and consequences of PGIS in local communities (Figure 2). It combines the two frameworks previously described – Pozzebon et al. (2009), further elaborated in Pozzebon and Diniz (2012), and Corbett and Keller (2005). A detailed definition of three dimensions and their main concepts are provided below.

Figure 2. **Framework for participatory GIS analysis in communities**



The context refers to the social setting where the technological artifact is being implemented and used, helping to define the boundaries of the investigation. It has two levels: institutional and interactional. As pointed out by Haynes and Rajão (2011) and Barrett et al. (2001), in order for ICT-related projects to contribute to social and environmental changes, it is important to take into consideration the historical, cultural, political and regulatory aspects, i.e., the institutional context. The second level, the interactional context, includes identification of different social groups interacting in a given social and cultural setting and the identification of interpretive frames for each social group. Subgroups, alliances or coalitions among social groups form political social spaces that shape the choices arising from implementation and use of any kind of technology (Rajão & Heynes, 2009), including a GIS. In addition, people within a social group are likely to share a set of assumptions, beliefs and expectations about a given subject of interest (for instance, the expected benefits of the implementation of a new technology like GIS). This leads to the concept of interpretive frames: mental models that shape people's interpretations, influencing their actions and decisions (Giddens, 1984). Although individually held, those frames are articulated with value preferences and sectional interests that are shared across groups (Gallivan, 1995). The extent to which frames from different groups are congruent or conflicting will determine the likelihood of a successful implementation and use of GIS (Lin & Silva, 2005). The interactional level also encompasses skills and tools (Corbett & Keller, 2005). Skills would denote social groups abilities in general terms, both regarding use of the technology as well as the social changes they would like to promote (e.g., the ability of community members to use GIS or the ability to organize themselves in social movements). Tools ought to be regarded not only as specific artifacts but also as resources (material and financial) and methodologies implemented.

The second dimension is process. It refers to understanding how social groups (and their frames) influence the negotiation process taking place around the implementation and use of a given technological artifact. The implementation of a new technology in a community or region can be seen as an opportunity, or risk, to effect change in information flow, resource allocation and attribution of responsibility. For this reason, by implementing a GIS, people can reproduce, transform, adapt and even reinvent their community practices.

The implemented GIS is seen as the outcome of social processes of interaction between social groups. This leads to the third dimension, content, which refers to the resulting socio-technical characteristics of the technological artifact being implemented, as used by social groups. We pay particular attention to the resulting consequences, both intended and unintended (Haynes & Rajao, 2011), of the technologies-in-practice. The concept of technology-in-practice emphasizes the different ways by which a given technology can be implemented and used in different contexts by different social groups (Orlikowski, 2000). The focus is on the enactment of technology, where people's choices in the implementation and use of a given technology produce a certain number of consequences, intended or unintended.

METHODS

For the purpose of this investigation, we applied an in-depth single case study (Stake, 2000), the case selected being the SN project. The rationale supporting this choice is that this case study represents a remarkable experience in terms of GIS appropriation by a local community located in a developing region. Not only is Sierra Nevada an example of successful implementation and use of GIS for social and environmental purposes, but it is notable for having been achieved by communitarian organization in an effective bottom-up and participatory approach as well.

Data collection

The field work took place in 2006 in Tlalmanalco (Mexico). However, it is important to note that contact with two of the SN project's leaders, Pedro and Elena, had begun some years before and continued following our stay in Mexico, in the form of telephone calls and meetings in locations outside Mexico. The case study was based on three main sources of data: interviews, participant observation and documents. This triangulation enabled us to reduce the risks of inaccurate interpretations (Denzin & Lincoln, 2003) or problems with validity of the data (Glesne, 1999).

Concerning the first source of data, it was composed by field notes from participant observation. During one week, the first author participated intensively in informal discussions and formal meetings involving the SN team and the Tlalmanalco community (including both citizens and governmental representatives). These interactions gave the researcher the opportunity to gain a better understanding of the conceptual framework three elements: context, process and content. For instance, on one of those occasions, the researcher participated in a walk in one of the environmentally damaged areas of Tlalmanalco, together with some of the SN team members, and the students engaged with

the group "*Los guardianes de los volcanes*", in order to enter data in GIS regarding recent deforestation or polluted margins of rivers.

The second source of data was semi-structured and non-structured interviews. The respondents were selected according to one of the concepts described in the theoretical framework: social groups. Among the various social groups interacting in Tlalmanalco, four took part in the PGIS implementation and are recognized as particularly relevant: Sierra Nevada Team (SN team), researchers from Autonomy University of Mexico (UAM), Sierra Nevada (province) and Tlalmanalco (municipality) governmental authorities, and Tlalmanalco community organizations. One of our respondents (Pedro) is part of two social groups: SN team and UAM researchers. Exhibit 2 presents a summary of the interviewees.

Exhibit 2. **Data collection – summary of interviews**

Type	Respondents	Role	Social group
Individual interviews (total = 6 semi-structured interviews)	Pedro (2 interviews)	Leader of SN team (general project coordinator) and UAM professor and researcher	SN Team UAM researchers
	Elena (1)	Leader of SN team (project coordinator)	SN Team
	Gisela (1)	GIS designer and operator	SN Team
	Delia (1)	Coordination of community movements; GIS data entry	SN Team
	Rebeca (1)	Community communication and GIS trainning	SN Team
Collective interviews (total = 2 non-structured interviews)	8 Students + 1 coordinator (1)	Members of the social group "Los guardianes de los volcanes"	Tlalmanalco community organizations
	3 Municipal authorities (1)	Members of the group "Los regidores" (the aldermen)	Governmental organizations

A total of six individual semi-structured and two collective non-structured interviews were carried out. The semi-structured interviews were conducted twice with the general coordinator of the SN team (Pedro), once with the co-coordinator (Elena), and once with other three other members (Gisela, Delia and Rebeca). The two non-structured interviews were carried out collectively (with 9 and 3 people participating, respectively), involving two other social groups: *Los guardianes de los volcanes* (a group of students engaged in a community project for environmental monitoring) and the *Regidores* (aldermen in local government). Although focus groups are also collective interviews, we cannot consider our strategy a focus group because in our collective interview we follow the semi-structured interview guideline in a more linear way than what is expected in a focus-group. All these interviews were based on a protocol created from the multilevel framework, were tape-recorded, and were transcribed verbatim.

Finally, and no less importantly, we had access to numerous documents, articles, doctoral dissertations and PowerPoint presentations, some provided by the SN team and others found on the Internet and in newspapers.

Data Analysis

The analysis of the empirical data comprised three phases, following Miles and Huberman (1994): (a) data condensation, (b) data presentation and elaboration, and (c) verification of conclusions. We used NVivo® software to organize the set of data collected and assigned labels to the units of meaning according to the coding procedure, using the multilevel framework. We also wrote analytic memos to record our ideas, reflections, and emerging results. The use of deductive/inductive analysis enabled us to refine the framework through an iterative approach, leaving room for emergence of topics or dimensions which had not been initially considered (Patton, 2002; Berg, 2001). The process of categorizing empirical data was built based on the concepts proposed by the framework – social-groups, frames, skills, tools, etc. To the extent that analysis evolved, new labels (categories) emerged, refining the codification process (an illustration of the coding process is available upon request).

RESULTS

In this section we present the data analysis results. In order to answer the two research questions, we have structured this section according to the three dimensions of our theoretical framework: context, process and content.

The context of SN project: institutional and interactional

The SN project was officially created in 1997 in Tlalmanalco, a municipality of 45,000 people in Central Mexico between the Basin of Mexico and the Sierra Nevada Mountains. The project is

the result of a fruitful partnership between the university (UAM) and 12 municipalities, including Tlalmanalco, where the SN team was located. The entire region where Tlalmanalco is located is considered one of the world's most densely populated and critically threatened regions, primarily because it is situated directly in the ecological footprint of Mexico City megalopolis. The external threats to the local environment started long ago but had reached a peak by the 1990s. The sense of localness was also disrupted as uncontrolled sprawl from the metropolis threatens to transform Tlalmanalco from a predominantly rural area into a bedroom community (Moctezuma, 2001).

In 1997, soil, water and atmospheric contamination, coupled with urban sprawl in the region, were leading the entire region to an ecological crisis. Political authorities seemed powerless to face those challenges. That same year, with UAM professor Pedro as general coordinator, and his wife, Elena, as co-coordinator, SN project was established with the objective of supporting local initiatives by applying academic research and inclusive techniques so as to transform the Sierra Nevada region into a green belt of micro-projects that would contain the encroaching city and halt environmental destruction of the region. SN team members identified three dimensions to those regional challenges: a) promoting consensus-building around key social and environmental issues; b) mobilizing local communities in a process of collaborative planning, social organization, capacity-building and reconnecting the local population with their natural environment; and c) putting together a multi-stakeholder process of bottom-up vision-building, collaborative planning and implementation. To deal with these challenges, the SN project tried to salvage local traditions of community participation and introduce a broader, more participatory process at the regional level involving various local organizations. One of the means to facilitate this process was to provide the community with "geographic literacy".

> We had different workshops in which we started working with maps. With this kind of imaginative drawing, how your community draws your municipality, draws up your natural resources management, does transect to understand the logic in the natural resources management, there emerges a regional mirror of which everybody draws a part [...]. Our activity was doing these geographic literacy activities. (Pedro)

In addition to the institutional context, the interactional aspect helps elucidate the interactions of social groups. As previously described, we identify four social groups (SN team, UAM researchers, governmental authorities and community organizations), each with different interpretive frameworks, skills and tools. Exhibit 3 summarizes our analysis of the aforementioned three concepts.

Exhibit 3. **Interactional context of SN PGIS Project**

Social Group	Interpretative frames	Skills	Tools (resources and methodologies)
Community organizations	GIS is seen as a tool for improving local development; a tool for providing maps for political and ecological change.	They provide deep local and historical knowledge of their territory.	They do not posses particulat tools.
UAM researchers	GIS is seen as a source of knowledge for synthesizing local and technical information.	They provide technical and scientific knowledge.	They provide technical resources like aerial and satellite photos, official maps, etc.
Governmental authorities	GIS is seen as a tool to support political decisions and policy making.	They provide legal knowledge; they lack skills for an appropriate management of natural and social resources.	They provide financial resources and opportunities for contracts.
SN team	GIS is a tool for empowering local community members, for leveraging their skills and to guarantee the sustainability of the project.	They promote synergies amoung the other groups; they develop skills to operate the technology; they develop skills to estabilish external partnerships and to reach the market.	They master and refine inclusive-participatory methodology; they obtain a license to use GIS and other devices like GPS.

The first social group is the local community – more precisely a number of community organizations, a combination of formal and informal sub-groups and coalitions that have, to different degrees, been involved in the SN project. The members of the community provide contextualized indigenous knowledge about the past and current history of their land. They see GIS technology as a

tool to address the region's ecological problems. By participating in the SN project, local community members expect to improve their welfare and promote the sustainable development of their city. For instance, "Los Guardianes de los Volcanes" is a group of about 35 students from different municipalities around Tlalmanalco that actively participate in the SN project by gathering data and monitoring ecological sites. One of the members says:

> We want to make this a better region to live in.... our rivers are contaminated (student).

Other community groups look forward to having access to information necessary to improve their knowledge and ownership of their land. For example, the "ejidatarios" (traditionally responsible for public community lands) and rural producers have participated actively in data gathering for the municipal atlases because they wanted to see the exact boundaries of their lands incorporated into a map. Until the beginning of the SN project, the official maps describing the boundaries of the community-owned lands (termed *ejidos*) were treated as privileged documents in the possession of elected leaders. "Ordinary" people in the locality could not gain access to them, and nobody really knew where the communal lands were anymore.

The UAM researchers represent the second relevant social group to the project, mainly because of the legitimacy they bring: working together with SN team and the community, they are essential to endowing it with credibility and quality in the eyes of governmental authorities and the media. The partnership with UAM allowed the SN project to obtain significant governmental contracts. In turn, university professors gain access to rich local knowledge, which contributes to their academic interests.

> To do good research, they [UAM researchers] need local guides, then they can have access to all the information that local people have, which you can't get from a satellite. (Elena).

Therefore, UAM researchers perceive the GIS as source of knowledge that combines and synthesizes local and technical information. The products of the SN project (e.g., GIS maps and atlas) are used to complement their teaching and research activities. Correspondingly, UAM researchers provide technical resources (e.g., aerial photos) and scientific knowledge related to topography, ecology, geography, botany, etc.

The assumptions and expectations concerning the SN project held by the third social group, the governmental authorities, are related to the potential use of PGIS maps as a tool to support their political decisions, with particular regard to natural resource planning. At the municipal level, the local authorities trust the GIS maps generated by the SN team and believe that this tool will help them resolve impasses over certain territory being claimed by a neighbouring municipality. Through use of GIS maps, they are able to prove that the area belongs to them.

> We trust the (GIS); mapping the territory, we will know exactly the territory of our municipality (Regidores, municipal authorities).

Concerning their skills, on the one hand, governmental authorities provide the legal knowledge – about regulations, laws and governmental requirements –required to produce GIS maps. On the other hand, they lack skills for appropriate management of natural and social resources.

> We gathered enough data to argue and tell – you know, this land is ours – with a clear support of SN team at a technical level. Without this support, we could not finish our plan. (Regidores, municipal authorities)

The governmental authorities provide the SN project with financial resources to support certain activities (e.g., research activities) and with access to new important contracts (such contracts for drawing up natural resources plans).

Last but not least, the fourth social group is the *SN* team, whose members share a common vision of the GIS: because their main goal is to empower the community members, they see GIS as a tool to enhance community competences, to catalyze their emancipation and to guarantee the project goals' sustainability. Thus, the SN team has developed the ability to create a synergy between the community and the other social groups – mainly UAM researchers and governmental authorities – who are interested in the GIS for different reasons. They have also succeeded in establishing partnerships with external stakeholders in order to reach the market and to strengthen the project. For example, looking for a flexible way to introduce information and produce maps, they initiated contact with an important North American GIS vendor and, in 1999, they have purchased their first copy of the basic software, Arq-View, for a trial run. The process evolved quite rapidly thereafter.

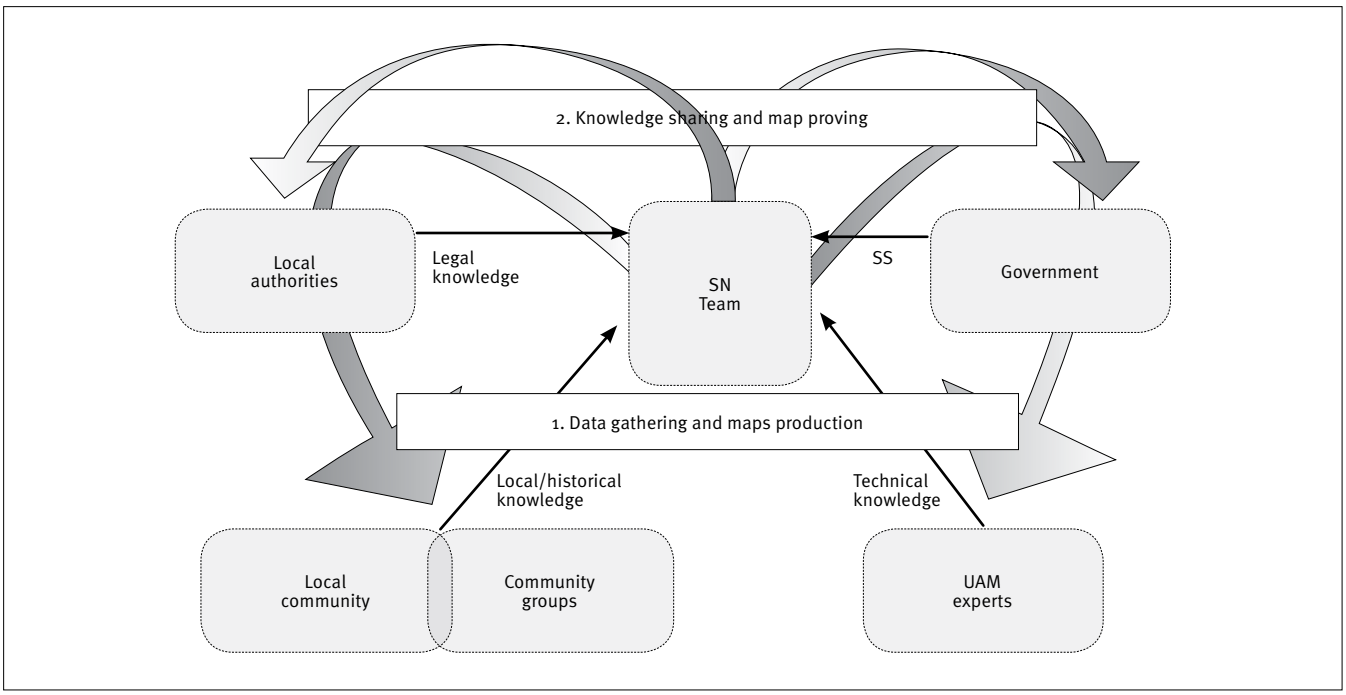
> We began working with people from Arc-View firm and they were very excited about our project. They said they had never seen such intensive use of their software (Elena).

It is important to mention that although the interpretive frames, i.e., the assumptions, beliefs and expectations of the four social groups were neither similar nor convergent, but more importantly, they were not conflicting or divergent, at least not during the implementation of the PGIS. It is quite acceptable that before or even in some moment during the project some small divergences occurred. Because our interviews were retrospective we could not grasp the evolution of frames over time.

The process of implementing a PGIS

The SN project implementation is characterized by two key phases: (1) data gathering and map production, and (2) knowledge sharing and map providing. Figure 3 represents these two phases, the social groups involved and the type of interaction in terms of knowledge and resource sharing.

Figure 3. **Process of SN project**



First phase of process: data gathering and map production- In this first phase, we outline the presence of three different types of knowledge: (a) Local (indigenous) and historical knowledge, provided by community members; (b) Technical and scientific knowledge, provided by university researchers; (c) Legal knowledge, provided by governmental authorities, along with financial resources. These different types of knowledge usually do not come together mainly because the social groups that hold them frequently do not sit down together. In addition, as outlined in the previous section, the interests and expectations of those different groups regarding the GIS implementation were not necessarily convergent. So, how to make those distinct groups converge?

Although we could not grasp all the process that lead to a consensus among those different groups, we are aware that a number of conflicts, tensions and divergences marked the beginning of the project. For instance, the "*ejidatarios*" were very suspicious at first, they were afraid that the GIS could affect the allocation of the communal portions of land. Likewise, the municipal authorities were also suspicious regarding Pedro's political agenda, in the beginning of the project. Our retrospective data do not allow us to enter in the detailed processes of resistance, but we do know that they existed. However, it seems that the consensus-building process put in place by the SN team was able to make those people, with different perceptions and expectations, sit together and converge their interests around the GIS.

> [...] Women, rural producers, people from different ages and economic situations, a huge heterogeneity and a huge synergy. One could find: a poor rural producer with in-depth knowledge of the local flora engaged in discussion with an elegant urban devotee of gardens; a rural woman talking with a representative from a cultural centre; intellectuals conversing with people who live off handmade production (Pedro)

Second phase of process: knowledge sharing and map providing - In the second phase, knowledge, maps and atlases are made accessible for a number of purposes. For example, the community has access, at no cost, to a publication called Municipal atlases of natural resources encompassing the six municipalities of the Sierra Nevada region. These atlases contain rich information about opportunities and challenges related to natural resource management and community-owned lands. Similarly, universities integrate the atlases into their teaching material and academic programs, and governmental entities use them to support public policies and environmental planning. Therefore, due to their maps and atlases richness, the SN project became a privileged recipient of new governmental contracts, increasing the power to influence public polices:

> Having a GIS technology places us in the market with a high value. And it's allowed us to carry out a number of important interventions in terms of environmental government policy for our region. (Elena).

Moreover, the SN team has created a local documentation center providing: free maps for local farmers seeking to learn the precise boundaries of their lands or where erosion or deforestation is most serious; information (for a small fee)for tourists wishing to locate a waterfall in relation to the road, or a place to observe a profusion of butterflies, or alternative bike paths around a volcano; and maps for students, teachers, local producers, associations, cooperatives, community groups, eco-tourists, mountaineers, and municipal, regional and (more recently) national authorities that have joined other academic and political bodies. This strategy – free access to a new type of knowledge that did not exist before and that mesh, blend different kind of expertise –contributes to the community empowerment and is one of the SN project main achievements.

The consequences of technologies "in practice"

We note that the GIS-in-practice produced a number of intended and unintended consequences (Figure 4). This "practice" view is important because we are not outlining the final technical features of the technology put in place but, rather, the social uses of the technology as mobilized by different social groups.

Intended consequences - Among the targeted goals of SN project, perhaps the most important one was achieved: community awareness and empowerment. One of the challenges initially identified by the SN project was the loss of connection between the local population and their land. Elena, SN project co-coordinator, remembers the results of a survey carried out at the beginning of the project concerning what local young people felt their future would be like.

> A typical response was: 'My future is in Mexico City. Here is nowhere'. This is part of our challenge... part of the work we are trying to do is to help people re-appropriate their space because, in the urbanization process, people gradually lose the connection with the forests, with the earth around them and their vital space becomes their house, their yard, and the street in front of it and they don't think about anything else. They don't feel responsible for more than this [limited space]. (Elena)

Seeking to promote a progressive change in this perception, the SN project is succeeding in making local people remain on their land instead of abandoning the region. The participatory process served as a tool to promote local community awareness concerning their rights, and people began to realize gains from the use of the maps produced with the SN team. Overall, this process empowered their actions.

> They recovered this sense of belonging and empowerment to control their own communal plans. (Pedro)

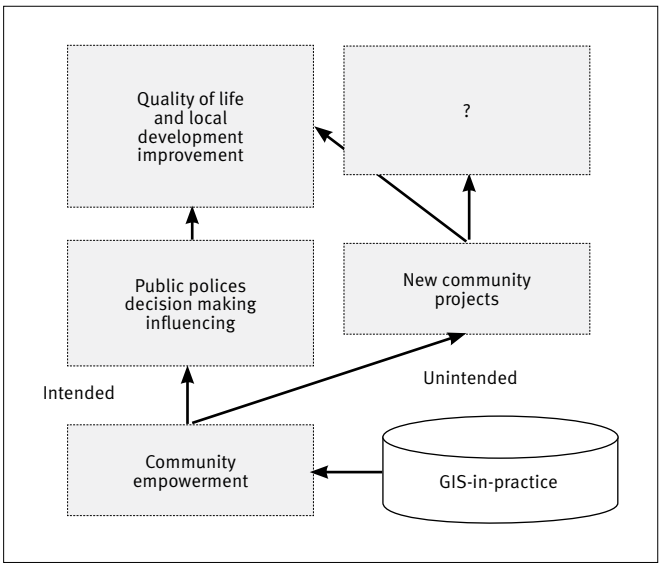
It is with this outlook that *ejidatarios* now use the municipal atlases developed to defend their rights.

> With the information contained in these atlases they can now defend their lands (Delia).

This empowerment came mainly from the capacity-building process: being trained to use the tools, local people increased their possibilities of participation in the regional decision-making process. The main consequence of that empowerment is a new influence on environmental and territorial policies. The increasing use of GIS maps by municipalities and other governmental institutions is allowing the Tlalmanalco community, through the SN project, to exert a significant influence on regional environmental and territorial policies. Their unique expertise vis-à-vis the kind of GIS maps they produce has had important consequences. GIS maps are exercising strong influence on governmental plans and policy making, which is referred to as "bottom-up" law enforcement by the SN team.

Finally, in addition to increasing local community participation in their territory's policy making, the SN project has helped to improve the quality of life and local development. For instance, some outputs of the SN project are used in the coordination of a number of municipal prevention programs involving solid waste management. In addition, geographical information produced was the main input for the elaboration and publication of documents used to develop new economic activities. This is the case with the "Ruta de los Volcanes Sagrados" document used with a tourism project aimed at promoting enjoyable ecological activities, such as horseback riding or waterfall baths.

Figure 4. **Intended and unintended consequences of GIS-in-practice**



Unintended consequences - The SN project is resulting in a number of achievements in line with the SN team initial goals. However, one of the strengths of the technology-in-practice view is that it helps to recognize unintended consequences that any implementation of technological artifacts may produce. In the case of our investigation, we outline two unexpected positive consequences. A clear illustration of an unintended consequence is the production of spillovers for new communitarian projects. The revenue generated by the production of rich GIS maps has turned out to be higher than expected, thereby allowing the SN team to finance additional, and sometimes unprofitable, SN sub-projects, as well as community projects, such as "Pueblos originales de la región de los volcanes" (native people from the volcanic region), concerned with water improvement in the region:

> I am a member of this social organization... and I have seen the impact of the technology outside the project. It is really motivating to be able to have access to this type of information... We are establishing a council for water management and this information is essential for us in our project. (Delia)

DISCUSSION AND CONCLUSIONS

Here we discuss our results concerning the two research questions guiding our study: what context helps explain the emergence of a PGIS in the Sierra Nevada region and what are the main social and environmental consequences of the implemented PGIS to local communities?

The problems faced by Tlalmanalco in the Sierra Nevada region are similar to those many other Mexican municipalities are facing: they often suffer from poor administrative infrastructure. This lack of skills and resources hinders the development of a more strategic vision and capacity to deal with social and environmental problems in an integrated manner. In line with Rajão and Hayes (2009), we corroborate the assertion that the PGIS process that emerged in Tlalmanalco was shaped by an institutional context where all information that could influence political decisions affecting local people lives were concentrated in the hands of regional government. Local people were not empowered to dialogue and negotiate their needs and rights with regional government due to the lack of relevant information and knowledge. So, what might be put in place to change such a context? The lack of a strong institutional frame helps explain the possibility of emergence of an ICT-related, bottom-up and participatory initiative – a community-university partnership committed to local traditions – as a response to the incapacity of the political realm to face mounting social and environmental problems.

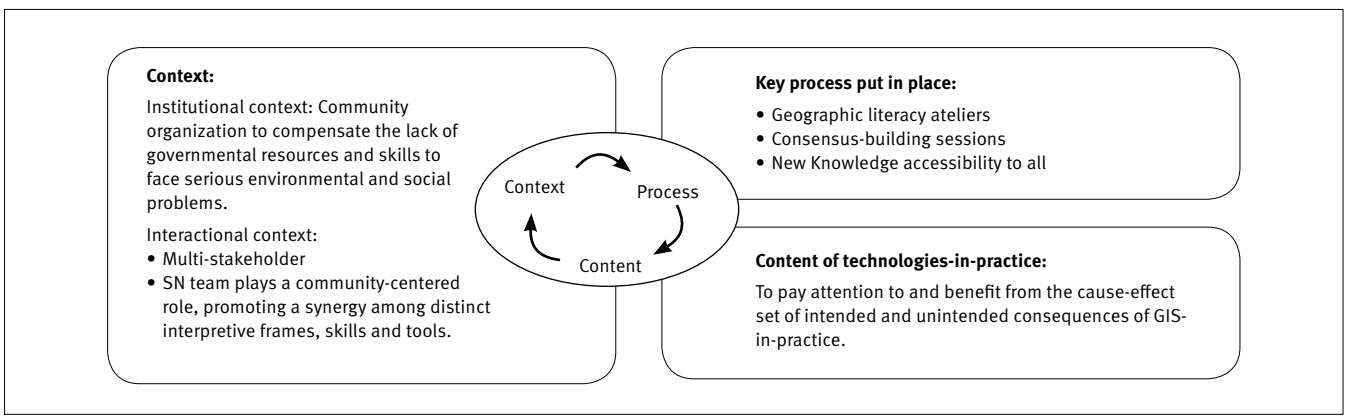
Although the institutional context helps to explain the emergence of the SN project, it is not sufficient to a better understanding of the project's success. Here, we outline the importance of understanding the interactional context, where two elements emerged as relevant: the multi-stakeholder character of the interactions and the role played by the SN team. Several authors insist on the importance and challenge of integrating indigenous knowledge into PGIS projects (Aswani & Lauer, 2006; Eisner, Jelacic, Cuomo, Kim, Hinkel, & Del Alba, 2012). IS researchers have targeted not just indigenous knowledge, but the ability to effectively involve different social groups in order to combine different types of knowledge (e.g., Puri, 2007 and Sahay & Puri, 2003). Local community members were empowered by access to scientific and legal knowledge and university members were empowered by access to precious local, indigenous knowledge.

Our results complement Corbett and Keller's (2005) framework, by indicating how the multi-stakeholder approach and the community-centered role of the SN team have put in place two key processes – geography literacy ateliers and consensus-building sessions – that allowed the combination of distinct types of knowledge (legal, technical and local). This in turn affected the empowerment capacity of different social groups, and particular of local community and university members, by changing their ability to influence and negotiate. The SN team's emphasis on competence building (e.g., the geographical literacy program) resulted not only in community empowerment, but also in changes in the community's capacity for empowerment: community members developed not only tools to help them protect their rights (e.g., GIS maps) but also the capacity to deploy those tools, increasing their ability to engage in dialogue with governmental institutions in terms of managing social and natural resources in the region.

These findings are also in line with IS authors who stress the need to take into account macro, institutional factors, like educational process and administrative infrastructure (Walsham & Sahay, 1999) and micro, situated factors, like existing local power asymmetries (Puri & Sahay, 2003). In addition, our study has corroborated previous studies showing that combinations of different types of knowledge are likely to create a new type of hybrid knowledge that brings invaluable results when incorporated into map production (Puri, 2007). More importantly, in the case of the SN project, the SN team was able to create spaces and occasions for a high accessibility for everyone to this new kind of knowledge, a source of empowerment to all stakeholders, but particularly to the local community.

Another particularity of our results is the analysis of the outcomes not just in terms of pre-established goals but also with attention to unintended consequences. However, while unintended consequences are often seen as potentially negative (Hayes & Rajão, 2011), our case shows that the opposite is also possible. A summary of our contributions is presented in Figure 5: the guiding framework is enriched by the data analysis of the particular case study and provides concrete clues to create the conditions for effective empowerment of local community through implementation of a technological artifact like a GIS.

Figure 5. **An actionable framework for participatory GIS**



This study provides a number of contributions for research and for practice. The refined conceptual framework might support researchers and practitioners in dealing with projects where local communities try to implement ICT artifacts for social and environmental purposes. We claim that, in addition to the institutional context, the interactional context – the different social groups with their interpretive frames, skills and tools – should be identified and understood. In order to make this multi-stakeholder arrangement work, the project team has an important role to play in order to create a synergy among different types of knowledge and promote a convergence among distinct interests. For that, three key processes were identified – geographic literacy ateliers, consensus-building sessions and a knowledge free-access platform – and in this vein we contribute to existing literature. Finally, we direct attention to intended and unintended consequences of technologies-in-practice, changing the focus from the technical features of technologies to their effective use.

This research has also a number of limitations. The first and more important is the absence of "negative elements", such as resistance, conflicts and tensions among the different social groups. There are a number of reasons that help to explain why those "negative elements", or simply a more critical view, do not appear in this piece of research. The field work was carried out in 2006, a moment when the Sierra Nevada Project was living a very successful phase. One of us – the one who has carried

out data collection – arrived in Tlalmanalco in a period when virtually all stakeholders were proud and satisfied with the results of the Sierra Nevada, even those more resistant in the beginning of the process. Overall, the four social groups identified were proud of the reconnaissance that the local project achieved not only locally but regionally. Therefore, is not surprising that they had a tendency to highlight – in the interviews – harmony and convergence instead of conflicts and divergence (which for sure took place in the past). As mentioned in the results presentation, we do have field notes indicating that, in the beginning of the project, there were conflicts and resistance. For instance, in the first years of the project, the governmental authorities did not see with trust the fact that the community and the university were working in creating maps – an activity that until then was in charge of government-related agencies. Likewise, Pedro has told us stories of the beginning of the meetings, where very heterogeneous people were put together, and the trust could not be built easily or quickly. Yet, the consensus-building processes put in place seem to have worked very well. The second limitation is that our retrospective interviews could not grasp the details and micro-processes that characterized the participatory process over time. Although our two research questions are not related to a fine-grained processual narrative, we wish to further explore the dynamics of the participatory process in the next phases of this research.

Finally, we would like to comment on our research design. From a conventional standpoint, our research could be considered limited in terms of the "generalization" of the results, once they are based on a single case study located in Mexican territory. However, the assumptions guiding the empirical work are founded on robust theoretical traditions like constructivism, structuration theory and contextualism. We do argue, cautiously, for the theoretical "transferability" of our results to other contexts, instead of arguing for its "generalization", as we do prefer to use the terms "authenticity" and "plausibility" of our results instead of talking about validity and reliability (Pozzebon, 2004). Our analysis follows a constructivist logic which offers a means to advance theoretical and practical arguments without any pretention of making universalizing claims.

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