4. Discussion, Conclusions and Future Works

This section describes a general overview of the findings reported in the articles that make up the research of this PhD Thesis work. It provides some final conclusions and a summary of the principal contributions to knowledge of each of the publications in relation to the research objectives addressed by this Thesis. In addition, some limitations and future lines of work and research are presented.

4.1 Discussion and Conclusions

This PhD Thesis work presents research on the development of a conceptual and methodological framework for the understanding, analysis, design and use of information systems for the creation and management of volunteered geographic information (VGI). Which we will now refer to as *VGI Systems Analysis and Design Framework*.

This framework structures and develops a set of concepts, principles and guidelines that explain and facilitate the deliberate and methodological production of VGI through the effective design and management of a socio-technical system. The approach and use of the system concept presented in this research, as an integrated set of components with their characteristics and dynamics working towards the same goal, extends the study of VGI achieving a greater knowledge of the processes and complex interactions of the elements involved in obtaining such information. In this way, this Thesis develops and makes available several theoretical and design artefacts with which to work to plan, design and exert directly in the improvement of the factors, elements and their requirements, that facilitate the participation of volunteers and the management of VGI. Therefore, allowing greater control in the production of data, and greater assurance of obtaining the information outcomes and creating the positive impact on the natural, social or economic environment that an organization expects to achieve.

Thanks to the technological changes that have made mapping and geographic reference data available to almost anyone, we know the potential for organizations and society in general that the VGI has as a new source of information. How to get the most value, benefits and innovation out of VGI in extremely diversified fields of application is a task that must be carried out as a whole by many organizations, researchers, governments, and engaged citizen participation, etc. However, the results and proposals of this Thesis are intended to guide and help them in that task. This Thesis exposes an integrated solution based on systems design to make the production and use of VGI to solve problems in our environment easier, more efficient and even more generalized and accessible by any organization.

First, this research describes the components and their processes that support and influence the deliberate production of VGI looking from a systems and holistic perspective. Studies have typically focused more on data and their attributes in relation to specific use cases or problems to be solved using VGI, generating very valuable knowledge within isolated projects, contexts or aspects of VGI. However, this Thesis shifts the focus of VGI to advance in its broader and integrated study. It explains the rationale behind the links of the conditions and human factors of the organizations and the participation of volunteers that are necessary to understand and design the processes that lead to the generation of data and information (Gómez-Barrón *et al.* 2016, 2019a). As well as to define the features of the technology required to implement those processes (Gómez-Barrón *et al.* 2019b).

Next, the study of the factors, links and interactions between the parts involved to generate VGI has led to the need to characterize and formally define VGI systems (VGIS), comprising three main components, i.e., project, participants, and technological infrastructure (Gómez-Barrón *et al.* 2016, 2019b). VGIS are the focus of research with which the framework for their analysis and design is developed, helping to explain explicit goal driven VGI initiatives as systems in an integrated and unifying way, as well as for their practical design. Thus, this Thesis provides researchers and practitioners alike with a set of concepts, models and guidelines that emerge from a holistic study to support the design and development of VGIS for specific situations and goals. The VGIS Analysis and Design Framework identifies, addresses and connects the understanding of relationships that exist in the three main system components. Each component, with its (sub) elements, characteristics, processes and individual factors and requirements, which give rise to the creation and operation of a unique system depending on how they are defined, planned and designed. To connect and make sense of the different actions and functionalities of each component, this framework analyses and introduces several models and criteria around the crowdsourcing concept and process, to understand and work with it in the context

of VGI. It is identified how the design of crowdsourcing as the central process is essential to link and organize the integrated and smoother operation among each system component, so that the system can begin to generate information and results (Gómez-Barrón *et al.* 2016). The proposed framework developed in this Thesis uses and puts at the centre the process of crowdsourcing to make sense of the characteristics and requirements of projects, participants and technologies in an interconnected way, giving a unified context to the interactions and relationships that shape the design and implementation of the entire VGIS. Therefore, the framework makes it easier for the different components of VGIS to be in tune and work more effectively and aligned with each other.

Ultimately, with a perspective oriented to the practice, combined and supported by strong theoretical knowledge, this research gives a different voice to approach VGI initiatives through systems design. The VGIS Analysis and Design Framework introduced is useful for any organization that is looking to organize information and design decisions about their project/participants/technology fit using systems thinking and socio-technical design guidelines. It supports a systematic process for creating totally new VGI initiatives, or introducing changes and improvements, by a) clearly analysing and describing each of the VGIS components, and b) making available guidelines with which to analyse, experiment or create design strategies. In the integration of the concepts, methods and design tools developed in this framework is the key to know what to do and when during the construction of a VGIS.

Furthermore, as the framework is based on a systems perspective that holistically links the aspects involved in the production of VGI, it is useful at any specific point or element within a VGIS design process or research activity. Also, since in open systems the same end state can be reached with different initial conditions or by taking different paths, this framework allows it to be used with flexibility and modularity, thanks to the separation and characterization of its components and its understanding of how they interrelate. Thus, it helps to test different solutions by playing with the different characteristics, processes or design criteria identified for each component. Until finding which solution is the most effective for a shared goal and which best meets the needs of each component.

4.1.1 General Overview of the VGI Systems Analysis and Design Framework

The work done during this PhD Thesis to develop the VGI System Analysis and Design Framework was divided into three fully interconnected research phases. To guide their development, the three main components of a VGIS were used. Each phase of the research has generated as a result the publication of an article with the main findings introduced in Section 3.

As reported in the article "Volunteered Geographic Information System Design: Project and Participation Guidelines" by Gómez-Barrón *et al.* (in Section 3.1), the development of the framework starts with a general characterization of VGIS.

Next, the *VGI System Design: A Methodological Approach and Development Process* is introduced as a methodology that defines a series of design steps (10 steps) and a set of development phases (9 phases). The VGI System Design methodology is based on the understanding that emerges from the initial characterization of VGIS, their components and the main process that guide the different interactions between them, i.e. crowdsourcing. This methodology addresses how to link the actions of the components, explaining how the project, defined by an organization, guides and coordinates the participation of volunteers through a crowdsourcing strategy, and how both determine the technology needed to do so. The organizational and social aspects are considered with special interest, while the establishment of the project and the ways to organize volunteer participation are elaborated in depth. Although the project goals are different, the common characteristics related to the processes they follow are identified. Then, a series of actions that guide the design of these common characteristics facilitates the gradual step-by-step reduction of the gaps that may appear between the project and the personal and social requirements of the volunteers, and with the design of technological solutions that facilitate the production and management of information according to a defined goal.

Then, the article presents an extensive overview of the state of VGI, examining the many dimensions of projects, including objectives, scope, ways in which participants contribute, general characteristics of crowdsourcing tasks and crowdsourced data, as well as general factors motivating participants for contributing according to the design characteristics of a crowdsourcing process. Following the VGI System Design methodology, the findings of the article provide several useful ideas and tools whose main scope are, to a greater extent, the project component of VGIS, addressing the phases for its initiation, planning and design; and the participants component, connecting the first concepts related only to its planning in relation to the general crowdsourcing strategy of a project.

The article contributes as a whole to the first seven methodological design steps and addresses the first four phases for the development of a VGIS. It provides sufficient detail on the applied and theoretical foundations of the guidelines developed. In addition, the four initial development phases are used, incorporating some of the methodological design steps to demonstrate and validate their applicability through the case study of four VGIS.

After that, the development of the VGI System Analysis and Design Framework continues by focusing on how to motivate volunteer participation, in order to develop guidelines and tools that help link an overall crowdsourcing

strategy to the appropriate collaborative environment, and participation and engagement strategies. That is, the eighth step of the VGI System Design methodological approach introduced in the first article. The characteristics of information and participation needed by a project to implement its crowdsourcing strategy must be aligned with the design of participation and engagement strategies that encourage people to contribute and facilitate the achievement of the various types of project goals and objectives. The second article, "Needs, drivers, participants and engagement actions: a framework for motivating contributions to volunteered geographic information systems" by Gómez-Barrón *et al.* (in Section 3.2) reports the guidelines developed in this Thesis for designing these engagement strategies. Hence, its results contribute to the fifth phase within the VGI System Design, picking up where the previous article left off.

These guidelines for participation strategy design are based on the study of human psychology, understanding and placing the fundamental needs of people in the centre to encourage the volunteer's engagement in connection to the purpose, goal, and participation dynamics of a project. This article presents a clear and integrated explanation of the motivational factors, conditions and human needs that drive and facilitate contribution in VGI projects. Then it translates that analysis into practical and structured concepts, models and mechanisms for organizations to address the challenge of motivating participation. To this end, it provides three tools to guide projects in order to more effectively connect their goals and rationale with the needs, characteristics and motivational processes of different types of participants. These instruments form a framework to guide the design of participation and engagement strategies. The tools available for the strategies are based on the development of typologies of core participation drivers and volunteers, and an engagement process that encourages organizations to think in some new ways when designing VGIS. Both at the project definition level, and at the task design level (including their actions and technologies), contributing with this research to existing literature and to practitioners of VGI in relation to how to motivate the participation of volunteers. The design tools developed are grounded in the literature and in the review of current VGI initiatives. Multiple references to existing theoretical and empirical studies on VGI and motivational psychology are used, along with observation of how several existing VGIS are proceeding and have implemented some of the tactics and actions that are part of this framework for motivation. The proposed framework for volunteer engagement offers a structure and a set of tools for participation design that can be further expanded, tested, and implemented in relevant VGIS.

Finally, the development of the VGIS Analysis and Design Framework continues through practical examination of the technological elements, functions, and other aspects of the technology infrastructure that enables a collaborative environment, participation strategies, and data management through

crowdsourcing processes. Thus, the article "Volunteered geographic information systems: Technological design patterns" by Gómez-Barrón *et al.* (in Section 3.3) contributes to the ninth step of the methodology and to the phases (sixth and seventh) of information and communications technologies planning and design, within the VGIS System Design introduced in the first article. Given that participation in VGIS is mediated by information and communications technologies, an important part of the framework is to characterize the general technological components that support the different actions and processes that lead to the generation of data-driven value. Therefore, this article continues with the study of the main components of VGIS, but now with a greater interest in the technical aspects. It describes the typical architectures, functions, technological tools, and the different system procedures for volunteer participation, and data collection, processing, and information management in general.

Through a detailed case study of several VGIS, the actions that participants take within the system to contribute and perform a task are mapped. Using the differences in the dynamics of online-mediated participation initially introduced in the first article and extended in this one, diverse initiatives were selected from crowd-based participation with passive actions and simpler tasks, to cooperation and more active community interaction. This article explores how participants interact with the use of different digital interfaces and other technological tools, and, directly and indirectly, with the actions and processes implemented both automatically by the system and by the project operators. Analysing these interactions, it identifies and explains how the creation and exchange of value lies in the intersection of the community and the offerings of a project through the different system functions implemented using information and geospatial technologies. From the data models that fit the various needs and objectives of the projects, to the collection and processing through different crowdsourcing tasks and the types of contribution they facilitate, to the access and sharing of the data and information generated. But also, describing the set of processes and tools for coordination, communication, participation feedback, social networking, learning, encouraging participation, etc., that these systems use to create different participation engagement strategies based on human factors most in line with the actions of participants and project goals. With the variety of the VGIS analysed, were found differences in the crowdsourcing tasks, their ways of collecting and processing data, their relationship with the type of participation through individual or more collaborative actions, their difficulty and degree of cognitive demand, and even the complexity of the geographical features collected. All this helps to understand and describe which, what kind and how different technological tools are used in VGIS, thus also contributing to their design by providing an organized characterization of the functional components of VGIS.

As a result, the research of projects, participants and technology in an integrated way has enabled the development of the VGIS Analysis and Design Framework proposed in the three publications that make up this Thesis. Helping researchers and professionals with their findings to make sense of and better manage the various challenges of research and system design for the effective production of VGI. Therefore, the described results support the first working hypothesis of this Thesis (**Hypothesis #1**).

Moreover, sustaining the second working hypothesis (**Hypothesis #2**) of this Thesis, in the article "Volunteered Geographic Information System Design: Project and Participation Guidelines" by Gómez-Barrón *et al.*, it was identified that in order to understand the functioning and advance in the design of VGIS it is necessary to address organizational practices and social factors, as they are essential for the success of a project. Both the way to direct participation through the design of crowdsourcing processes, and connecting with the needs and motivations of volunteers —as discussed in the article "Needs, drivers, participants and engagement actions: a framework for motivating contributions to volunteered geographic information systems" by Gómez-Barrón *et al.* — are aspects of human-centred design whose requirements must be linked and properly integrated into the implementation of technological tools. If participant engagement, and the viability, usability and value-creation risks in relation to participant interests, behaviour and needs are not adequately addressed, the technological features and processes will present difficulties to be truly effective. Likewise, the inspection of several VGI initiatives during the whole research, especially the multi-case study conducted in the article "Volunteered geographic information systems: Technological design patterns" by Gómez-Barrón *et al.*, which addresses VGIS from the side of technological platforms and functions they support, confirms that, for their proper functioning, their design needs to introduce a holistic perspective. Organizational, individual, cognitive, social, information, and technology requirements seen in an interdependent way, produce effective socio-technical design solutions, resulting in VGIS that successfully generate information and create value for all involved.

4.1.2 Summary of Contributions

The following summary highlights the most important contributions that, together, make up the *VGI Systems Analysis and Design Framework* previously introduced.

Table 2 summarizes the main contributions of the article "Volunteered geographic information systems: Technological design patterns" by Gómez-Barrón *et al.*, included in Section 3.1.

Table 2. Summary of the main contributions in Section 3.1.

Main Contribution	Description	Research Objectives
VGI System Characterization.	A general analysis and model of what is a socio-technical system for supporting the goal-driven production of VGI. Explanation of what their main components are, and a conceptualization to guide the study of how they work, their role, their attributes, processes and interrelationships to facilitate their understanding and design. VGIS are described as a specific type of information system in which an organization implements a project with specific goals, geoinformation management procedures are based on the process of crowdsourcing whose actions are carried out by a community of participants and the use of a technological infrastructure. (Addressed in conjunction with Section 3.3.)	Objectives #1 and #5
VGI System Design: A Methodological Approach and Development Process.	A proposal for a design methodology and development process for VGIS. Following the analysis of how the components of the system interact and depend on each other to achieve the generation of geoinformation, a theoretical framework is provided with explicit prescriptions to build a VGIS. It consists of ten design actions and nine design and development phases. It describes a roadmap and a set of guidelines focused on recognizing and linking the different organizational, behavioural, social and technological needs and requirements of each of the components of a VGIS for its effective design and operation. The crowdsourcing strategy is central to the design methodology.	Objectives #1 and #5
VGI Project Goals Typology.	A typology with the most representative general goals of the VGI projects, their relationship with more particular objectives and the problem to be solved or geoinformation management process to be improved with the contributions of volunteers. The goal type and its scope guide the project initiation and determines the types of crowdsourced contributions, the crowdsourcing process approach and the participation characteristics. VGI goals are classified into seven different types with several related objectives from generating base maps, to improving government services, to environmental monitoring or tracking human behaviours.	Objectives #1, #2 and #5
Level of Involvement/ Engagement and Related Modes of Organization in VGI.	A model to distinguish the crowdsourced participation characteristics implemented in a VGIS. With different modalities of organization of the volunteers based on contributory, collaborative or participatory processes. Which imply different levels of participants' engagement ranging from passive contributions or basic participation to high levels of active contribution,	Objectives #1, #2, #3 and #5

	and beyond, when proactive participation is needed, even with the possibility of volunteers intervening in setting the direction of the project. This model also introduces the degree of interaction among participants, between participants and the organization, degree of task complexity and interdependence, and of communication, coordination and collective actions required.	
Crowd-based and Community-driven Online Participation Characteristics in VGI.	Conceptual insights about the tendencies and their design decisions that typically follow the general crowdsourcing strategies of VGIS. Explanation of the opposing design approaches of a crowdsourcing strategy based on individuals as a crowd, or driven by an interacting community, as well as their differences in characterization for crowdsourced actions and online participation. These opposing crowdsourcing strategies differ in terms of the type of participation and require different rationale for volunteers to get involved, being a general guideline for the design of the cooperative environment and means to obtain contributions. (Addressed in conjunction with Section 3.3.)	Objectives #1, #2, #3 and #5
Design Criteria of the Central Crowdsourced Processing Unit and Strategy in VGI.	A high-level design model to identify and approach the requirements of a crowdsourcing process in VGIS based on two criteria, which helps to start linking the needs of a project with the appropriate crowdsourcing strategy. It offers criteria to guide design activities by facilitating conceptual thinking and identifying issues such as: participants' dynamics, level of engagement and interaction to contribute, or the level of complexity, cognitive demands and skills needed to perform a task, etc., decisions that affect the participation and project success. The model is offered through a multidimensional visualization tool to facilitate the mapping of a general crowdsourcing process.	Objectives #1, #2, #3 and #5
Interdependent Aspects in VGI Management and Production.	A model to express relationships among concepts for the management of VGI in relation to system components. Description of the many social and technical dimensions and interdependencies of the organization and its project definition, the participation, the crowdsourcing process and crowdsourced contributions (data and content). Each element is linked and listed along with their main aspects needed to be developed when designing a VGIS.	Objectives #1, #2 and #5

Table 3 summarizes the main contributions of the article "Needs, drivers, participants and engagement actions: a framework for motivating contributions to volunteered geographic information systems" by Gómez-Barrón *et al.*, included in Section 3.2.

Table 3. Summary of the main contributions in Section 3.2.

Main Contribution	Description	Research Objectives
VGI project goals in relation to the human needs	A basic conceptual guide that helps relate human needs based on Maslow's extended work to the VGI project goal typology developed previously. A starting point for, depending on the characteristics of the project, recognizing general needs and understanding in which area a project can benefit, add value and contribute to improving the lives of participants, and properly connect with them.	Objectives #2 and #3
A Framework for Participation and Engagement Strategies in VGI	A human-centred design framework for building participation and engagement strategies for VGIS. A set of design guidelines and tools for joint use to increase participation and enhance community engagement, which connects the needs and several frameworks of human motivation, psychology and behaviour with the particular characteristics and context of VGIS. It offers a guide for understanding how organizations can motivate volunteers. It provides three main components of participation, *Core Drivers*, *Participants Types*, and an *Engagement Process*, that lead to the design of specific strategies according to the characteristics of the VGI projects and tasks.	Objectives #3 and #5
Core Drivers of VGI	A framework of core drivers that facilitates volunteer participation and engagement in VGIS. Design decision guidelines, both at the level of the project's rationale and approach, as well as at the level of participants' actions and task design, encouraging and reinforcing their activity. It explains, classifies and gathers under the core drivers, diverse external and internal motivational factors and supporting conditions in relation to the practical use of human needs, motivation and behavioural principles. And according to the characteristics of the VGIS, its operation and the social and geographical or environmental aspects with which they interact. It translates volunteers' needs that incentivize their motivation into a tool for VGIS design providing nine interconnected drivers to build different participation environments.	Objectives #3 and #5
Participant Types of VGI	A typology of participants that explains the different volunteers and their connection with what motivates them to be part of a VGI project and complete tasks. A tool to understand why volunteers participate, the different archetypal behaviours, their interests, needs and motivations, in order to build VGIS that support them. It explains eight different types of participants in connection with the *core drivers*, helping to design actions to attract volunteers and increase their engagement since they can be	Objectives #3 and #5

	targeted to the typical characteristics of the volunteer in which a project is interested.	
Engagement Process in VGI	Guidelines and roadmap on how to motivate participation with a set of organized actions to develop along different moments or dynamics of the participant-system interaction. Rich insights on human behaviour applied to VGIS design actions to raise awareness of the project and demonstrate its value to participants. Address the effort and skills to participate by focusing on ways to reduce task effort, simplify actions and increase participants' competencies to initiate, facilitate and enhance their contributions. Motivate further contributions by recognizing progress over time through feedback and retention mechanisms that continually support and encourage participation. Within the "Enrol" "Grow" and "Retain" main phases based on participants' path of experience, they are explained a total of eight actions. They can be combined to design different engagement tactics to increase participation in relation to VGI projects, participant types and task characteristics.	Objectives #3, #4 and #5

Table 4 summarizes the main contributions of the article "Volunteered geographic information systems: Technological design patterns" by Gómez-Barrón *et al.*, included in Section 3.3.

Table 4. Summary of the main contributions in Section 3.3.

Main Contribution	Description	Research Objectives
VGIS formal definition and complete characterization	The concept and definition of VGIS is formally introduced, proposing a clearer and better explained term in the line with the concepts of work system and information system developed by Alter (2008). VGIS as a conceptual model, which relates in a more complete and precise way its main components, the online participation of the crowdsourcing process, and how it affects the different configurations of its general design under the technological perspective.	Objectives #1, #4 and #5
VGIS general architecture	A conceptual architecture of the VGIS consisting of three layers based on the VGIS definition and the explanation of its general system actions. An architectural framework to understand, plan and design a VGIS according to the configuration and size of its layers, which varied directly with participation dynamics, crowdsourcing task design, data processing strategy and information outputs. Across all VGIS, three layers are in operation: *Community*, *Information Technology,* and *Information/Data* layers, serving as a tool to guide the design over the actions,	Objectives #1, #4 and #5

	processes and technologies that correspond to each layer and how they will interact.	
VGIS Functional Components	A model with the technological components of VGIS that carry out different functions to manage the processes of participation and information generation. It explains in detail and linked to the main components and architecture of VGIS, the different procedures and technological elements (e.g. web maps) that a system implements and provides for modelling, collecting, processing and accessing data, as well as for the participants' contribution and interactions, and the engagement processes. It guides the understanding of the most relevant actions for the generation and manipulation of data and information, especially in connection to the crowdsourcing process. The functional components are proposed as elements of the technological infrastructure required for the design and development of VGIS.	Objectives #1, #3, #4 and #5
Typology of Tasks in VGIS	A typology of geo-crowdsourcing tasks that explains the different processes for data collection that are implemented in the VGIS according to the participants' core actions and the participant-technology interactions needed to make a contribution. It explains the differences of the tasks in relation to the crowdsourcing process, the data model, the relationships between the variable or attribute of data, its geometric object, its source, the mechanisms and information and geospatial technologies needed for its collection, etc. It describes the types of contribution (data and content) that could be obtained with a given task, helping to select or design the different tasks that are appropriate for the information objectives of a VGI project.	Objectives #1, #2, #3, #4 and #5

In conclusion, the body of knowledge and framework resulting from this PhD Thesis work offers a logical structure and groups concepts, design methods and tools to explore VGIS. It provides clear and functional definitions of their components, aspects and processes. It contributes to advance in the construction of a common language of VGIS as a foundation for analysis and practice, to formulate and exchange design experiences and strategies, as well as to understand success stories and implementation decisions on whether or not to use certain elements or criteria in different contexts or fields of application.

New initiatives have a guide to design VGIS introducing different aspects to consider and work from scratch, but also, this framework facilitates the modelling of design decisions made by other successful initiatives. VGI initiatives have an organized set of criteria, processes and typical configurations for a much faster and more agile experimentation in the design process, facilitating the generation

of solutions suitable for a type of project and objectives, or to give way to innovative solutions. Consequently, initiative launch times can be accelerated by gaining time in design and development, which is often critical for some projects that need to solve urgent social or research problems, respond quickly to a crisis, or have a small window of opportunity to make a greater impact. Also, the time to market of the commercial applications is reduced. Similarly, the concepts and models proposed in this framework help the modular development as the different components of the system can be compartmentalized. The use of design guidelines develop for the specific components and processes allows to create a certain independence in the testing, change or refinement in an organized and isolated way, without the need to affect or work with the whole set, accelerating the process of continuous improvement and scalability of a VGIS.

Ultimately, the VGIS Analysis and Design Framework describes the components involved, explains their general functioning, and frames their study and current knowledge. But at the same time, it lays the groundwork for the improvement, expansion and construction of new knowledge. Being a valuable structure and reference for the development, proposal and dissemination of good practices, principles, processes and new design methodologies and tools.

The use of VGIS that enable the power of the crowds and participatory communities, of data and of geography to be harnessed, presents enormous potential to continue creating value and positive impact on places, their people, and their economies. The characteristics of the VGI with a collaborative and participatory approach, being able to generate large amounts of data, scalable and accessible in real time, with a finer grain resolution than many conventional sources of information, and with an understanding of the world mediated by the contributions of the communities who build it, is a value that must continue to be created. VGIS help facilitate innovative solutions that are "out there" in the collaboration of a geographically distributed population full of thinking, creative and expert minds in their environment and daily experiences. Networks of citizens who can reach more places, faster, and build unified collective knowledge and value that continuously adds, merges and stacks on top of the previous, so that new and better solutions emerge over time. The concepts, insights, models, guidelines, strategies and tools developed in this Thesis advance in this perspective seeking to help in the construction of new solutions based on VGIS.

4.1.3 Limitations

In addition to the research limitations mentioned in each of the articles in Section 3, the following issues are included.

Because of the scope of this Thesis and the methods used, this research focuses on a high-level perspective of VGIS. First, it works on identifying and describing their structure. Then, it identifies the patterns of characteristics and functioning

that each component has and the system as a whole, including their interdependencies and processes that work transversally and are typically present. In this way, a global but more "static" image of VGIS is obtained about their functional architecture, configuration, and explaining the conditions, factors and variables that intervene in its functioning and integrated design. However, apart from the structure dimension and the pattern dimension giving an overall VGIS design, a third dimension focused on the processes that follow each of the components, their sub elements, actions and functions at a detailed lower level was not fully explored. Therefore, starting from the system structure and patterns introduced, further study of VGIS is needed using process thinking to characterize and model in more detail the differences in the actions and logical sequences that occur within each component and their internal parts and functions. The analysis of the different types of data flows, data pipelines, processes, automated algorithms, etc., used to control and coordinate the different procedures within the system components were not addressed. They could be studied and classified in order to introduce different typologies of processes that guide the low-level design of VGIS in connection to strategies and architectures presented in this Thesis. For instance, the different feedback mechanisms and dynamic triggers to encourage participation, the processes to improve participant performance, task allocation or data quality, etc. that would be built within the participant engagement, data collection and data processing VGIS functional components. Further research is also needed on the different strategies and types of data processing in relation to the type of contributions, crowdsourced tasks and data collection mechanisms that have been identified in this research.

Moreover, product/service management strategies aligned with the crowdsourcing and participation strategies, including for instance service-oriented architectures or modular programming, for the development, deployment and maintenance of the technology infrastructure of VGIS were not addressed. The same case with general strategies related to monitoring and control of project and system performance. Thus, missing the development or introduction of, for instance, key performance indicators, quality metrics, usability metrics, participation analytics, engagement metrics or system logs analysis, as part of a VGIS performance management strategy that needs to be align with the crowdsourcing, participation and engagement, and product/service management strategies. All the latter corresponding to the tenth design step, and to the eighth and ninth phases within the VGIS System Design methodology introduced in the first article, which remain to be developed.

4.2 Future Works

Although almost eighty VGI initiatives were inspected during all the research work for the development of the VGIS Analysis and Design Framework and its initial validation, more empirical research is needed to continue its practical validation, calibration and improvement. For instance, through quantitative analyses with a greater amount of data on particular factors or design criteria of interest. Or by using the framework or some of its guidelines in the design and development of several new VGIS. So far it has only been partially used to brainstorm some VGIS design strategies proposals, and as part of teaching material in workshops about VGI. Also, by using the several themes resulting from the qualitative research of this Thesis to generate some hypotheses for testing through quantitative methods. Thus, researchers interested in expanding particular aspects of VGIS can translate the concepts and models from the qualitative themes into quantitative variables.

Moreover, it is possible to continue this research with comparative methods with a broad set of successful VGI initiatives. This in order to determine if some aspects of VGIS design are more important than others, or which are indispensable and must always be present, regardless of the type of project or crowdsourcing strategy, for a system to achieve a certain level of success. For instance, using the engagement framework proposed in Section 3.3 to carry out a qualitative comparative analysis of the different engagement components and actions designed by several VGIS as drivers and supporting conditions to motivate participation. The latter with the objective to identify which of those components and their configurations or combinations in different types of VGI projects and the systems they implement, are associated with or create the sufficient or necessary conditions to facilitate the engagement of participants.

Furthermore, with the potential of VGIS to organizations for creating new sources of geographic data and content through online communities, a future work that emerges and benefits from the VGIS Analysis and Design Framework is the practical development of modular software components to easily design and implement on-demand VGIS.

As this Thesis presents insights a cross several kinds of VGIS with diverse goals, crowdsourcing processes and participation aspects, two types of developments are considered for future works:

1. **VGIS web platforms as digital marketplaces** where organizations and citizens can connect to create new kinds of data-driven value. Thus, any organization has the possibility to design online campaigns to publish several on-demand geographic crowdsourcing tasks (as the typology of tasks in VGIS). With distributed volunteers as "function calls" in software, being able to cooperate and get value from the selection of the

different crowdsourcing campaigns of their interest offered by several organizations in a centralized digital platform.

Therefore, a future line of work to apply and improve in practice the results and proposals of this Thesis is the development of a multi-sided online platform for fast and easily design on-demand VGIS for organizations to generate information from precise people, locations, places and time, and to improve their products, services and understanding of their users, customers or citizens. This platform can provide the technological and participation engagement tools to design campaigns that help to connect different volunteers' needs to the right project and crowdsourcing task design. It can integrate the technology to design and support different modes of participant organization and interaction, data and content creation requirements, and skills that different crowdsourcing tasks may need. Also, backed on the understanding and use of the core drivers that motivate and sustain participation in VGIS, this platform can provide organizations with the tools to identify participant types and create different engagement strategies to better attract and incentivize them, thus improving matching and collaboration between data creators and the organization, and facilitating a hub for value creation and exchange.

2. **Add-ins/plug-ins for GIS desktop software** so that geospatial data analysts can design and publish on-demand, semi-automated geographic crowdsourcing tasks as part of organizations geographic analysis workflows where volunteers collect data as input to their in-house GIS. But also, to create, schedule and publish geographic crowdsourcing tasks as a process in automated geoprocessing workflows or data pipelines within GIS software. With these kind of plug-ins, using the database schema of a geographic layer (e.g. points, lines, polygons and its attributes), different crowdsourced tasks can be visually and quickly designed for completing missing data, data tagging, spatial querying for geometric/attribute data collection (e.g. find and report damage street lighting within a 1km. buffer of a location), thematic data validation in n random control points, and models output validation (e.g. land cover and use classification algorithms, or continuous surface data validation like suitability models for a specific activity in an area), among other crowd-powered data analysis within a GIS.

In order to build the proposed application clients, two generic and main VGIS modules can be designed and developed in the future, enabling several of the concepts, models, design criteria and guidelines introduced in the framework:

1. ***Crowdsourcing Campaign Plan:*** this tool provides a user interface with a set of predefined guides (i.e. project templates) that assist managers in the design and setup of a crowdsourcing process with

different VGIS task types and their core actions, interactions and data requirements. The crowdsourcing setup assistant steps use the definition of a data model and schema, the modes of organize online social participation (e.g. contributory, collaborative, or by co-creation/participatory processes), and the required VGIS functional components and tools for information management, communication and work coordination that a project (campaign) requires.

2. ***Engagement Strategy Plan:*** this tool incorporates a predefined participant classification based on the core drivers behind volunteers' motivation, to recommend campaign managers different configurations (i.e. participation templates) to set up an engagement process targeting diverse VGI participant types. Also, introducing applied motivational tactics and incentive mechanisms (e.g. human needs and intrinsic and extrinsic motivations, progress, sense of achievement and other forms of feedback, reward systems and gamification, etc.) and the future development of automatic system triggers and rules.

In order for the two VGIS modules to work, they will need the development of some submodules that can be available using, for example, application programming interfaces to expose their logic. Ideally, their design should be open, interoperable and easy to connect and use in any existing VGIS development. For instance, it will be necessary to develop the following submodules with some basic features for VGIS design:

- ***Crowdsourcing Publisher:*** crowdsourcing campaign manager, task designer, data and information management and quality control techniques, etc. related with crowdsourcing processes.
- ***Participation Analytics Engine:*** tracking of tasks completed and their characteristics, contributions, achievements and progress, campaign and tasks matching algorithms, etc.
- ***Engagement Engine:*** core drivers base, participant types base, engagement processes, and gamification engine (mechanics and dynamics) based on participants types, etc.

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Annex A. Additional Results

List of other articles made by author related to the research objectives of this Thesis, with additional results that contributed in some extent with the development of this research:

- Gómez-Barrón, J.-P., Manso-Callejo, M.-Á., Alcarria, R., & Pérez-Gómez, R. (2014). **A mobile crowdsourcing platform for urban infrastructure maintenance**. *Proceedings of 8th International Conference on Innovative Mobile and Internet Services in Ubiquitous Computing, IMIS 2014* (pp. 358–363). Birmingham, UK: IEEE. http://doi.org/10.1109/IMIS.2014.49
- Gómez-Barrón, J.-P., Manso-Callejo, M.-A., Alcarria, R. & Gómez-Pérez, R. (2015). **Volunteering assistance to online geocoding services through a distributed knowledge solution**. *Paper presented at the RICH-VGI: enRICHment of volunteered geographic information (VGI): Techniques, practices and current state of knowledge, Workshop* at *18th AGILE Conference on Geographic Information Science*. Lisbon, Portugal.
- Gómez-Barrón, J.-P., Manso-Callejo, M.-Á., & Alcarria, R. (2017). "Diseño de Estrategias de Crowdsourcing en Sistemas de Información Geográfica Voluntaria" —English: **Crowdsourcing Strategies Design in Volunteered Geographic Information Systems.** *Proceedings of 1st Congress in Geomatics Engineering - CIGeo* (pp. 60–68). Valencia: Universitat Politècnica València. http://doi.org/10.4995/CIGeo2017.2017.6629
- Gómez-Barrón, J.-P., Alcarria, R. & Manso-Callejo, M.-Á. (2019). **Designing a Volunteered Geographic Information System for Road Data Validation**. *Proceedings*, 19(1), 7; https://doi.org/10.3390/proceedings2019019007