# Transdisciplinar Meta-design for Geomatics Applications

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## ABSTRACT

Transdisciplinar collaboration is essential to approach the most important socio-environmental problems of our time. The transdisciplinar problem is not only the consensus building over common conceptual principles but also on how our reference frameworks organize and are sustained by the contributions of disciplinary and specialized knowledge built through their integration.

The paper emphasizes the lessons learned through our line of research called Geomatics and Society, enabling us to advance transdisciplinar methodologies by establishing links between research and social claimants (government, private sector, NGOs, and civil society). As a result, complex interactions are represented, organized and geared towards the needs or problems expressed by actors involved in the search for possible solutions. The themes undertaken by our teams include territorial and land management, ecosystem services, environmental risks and vulnerabilities, competitiveness, health, education, public safety, migration, water and energy.

To deal with such complex problems, a meta-design was developed, with a territorial systemic, analytical and transdisciplinar approach, in which not only scientific knowledge (explicit and formal) is considered valuable, but also the **profound** experience of the society is recognized as a product of creativity and tacit knowledge, acquired and progressively adapted to changes in its environment.

We introduce **"the territory"** as a key and novel feature of the above framework thus enabling, through Geomatics solutions, the intersection of maps and knowledge from diverse specialists and social plaintiffs. This transdisciplinar meta-design is relevant to the understanding of the way social and natural phenomena auto-organize in a changing world.

**Keywords**: Trans-disciplinary design; meta modeling; complex systems; geomatics applications; territory; emergent knowledge network; social claimants.

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## 1. INTRODUCTION

In the 90's, UNESCO organized a series of symposia to stimulate knowledge integration through transdisciplinar approaches. "The Symposium made it clear that it was not enough. Gathering is a requirement, proximity is a necessity, even establishing a daily physical or virtual exchange is crucial. But a substantial factor, the most important factor, is the kind of interaction among the elements of the gathering. And, as is the case for human beings, the decisive 'ingredient' is their mental and personal disposition to trust, share, negotiate and collaborate "(UNESCO, 1998).

Transdisciplinar research deals essentially with the need of a meta-framework of concepts and methods in order to integrate a wide range of disciplinary perspectives into the study and practice of emerging complex socio-ecological systems (Toledo, 2014).

It is by considering the theoretical and empirical aspects of trans-discipline, that we can make progress in elucidating the concepts used in the formulation and construction of complex solutions in Geomatics, making explicit the processes involved in the generation and integration of knowledge. (Paras, 2008).

**Background.**
In 1999, CentroGeo in Mexico City initiated its activities as a Public Research Center of CONACYT*. Due to a very tight budget, the academic and consulting skills of its few researchers were a key factor in pursuing innovative projects and obtaining funding. In dealing with specific problems posed by society, it was possible to build relationships with the claimants who sought support and help to address their problems in terms of territorial management, ecosystem services, environmental risks and vulnerabilities, competitiveness, health, education, public security, elections, migration, among others. (Reyes, Paras, 2012).

## 2. A SCIENTIFIC MANAGEMENT MODEL FOR GEOMATICS AND SOCIETY

The Scientific Management Model -SMM- (Reyes, Paras. 2010) was instrumental as a guide for the institutional organization of CentroGeo, with four main foundations:

– A scientific project and a strategy to compete at the international level,

– Human networking,
– Heterarchical groups,
– Method to approach knowledge production and innovation in Geomatics.

The introduction of society´s demands within the SMM gave rise to a line of research called Geomatics and Society, enabling us to design and develop methodologies that establish links between research, education and social claimants (government, private sector, NGOs, and civil society). The SMM was coherent with the claims of Science Mode 2 (Gibbons, 1994; Nowotny, 2001) for the role of scientific management in the context of a social contract among science and society.

As a result, complex interactions related to the needs or problems expressed by main actors have been represented and modeled in a transdisciplinar way and geared towards a purpose and possible solutions (applications).

## 3. THEORETICAL AND CONCEPTUAL FRAMEWORKS:

There are several reasons that lead to the construction or development of a theory, be it formal or informal. In most cases, a theory is constructed to model an aspect of reality, a certain view of observed reality. Holland (1998) claims that without a theory we walk blindly on unexplored and marshy terrains.

Geographers, physicists, biologists, sociologists, economists and anthropologists have developed concepts to approach spatial-temporal phenomena. This is a crucial knowledge and information for spatial analysis and modeling of the geographic space or territory. (Paras,2008). New research questions point to the importance of developing theoretical and methodological frameworks to formalize "the integration of knowledge" of various sciences and/or disciplines. This is the case for proposals that address the link between cybernetics and Geomatics, such as Cybercartography (Taylor, 2004) and Geo-cybernetics (Reyes et al, 2006). These conceptual frameworks helped explain how the empirical research developed during almost two decades at CentroGeo addressed the various problems proposed by social plaintiffs. (Reyes; Paras, 2010; 2012).

### A. Cybercartography

Wiener's (1954) cybernetic proposal has provided a key framework that facilitates the development of Geomatics solutions in methodological and transdisciplinar terms.

Cybercartography establishes a communication with the society through diverse cartographic, linguistic, mathematical, statistical and even visual resources. (Taylor et al, 2004). In projects at CentroGeo, virtual maps, geo-text, videos, photographs, space maps, satellite images, computer simulations, graphics, sound and diagrams were used to convey relevant information and knowledge to social claimants and users.

In fact, **Cybercartography** poses a paradigm shift for cartography by explicitly incorporating cybernetic concepts according to three main axes: modeling, communications and knowledge-based processes (Reyes, 2004).

### B. Geocybernetics:

Similar to Cybercartography, Geocybernetics also has its own body of knowledge and its own theoretical framework. The term "Geocybernetics" was proposed (Reyes et al 2006, 7-20) to encompass several avenues of research that explicitly incorporate the science of cybernetics, general systems theory, modeling and complexity theory as theoretical building blocks.

"This new conceptual framework leads to the inclusion of preexisting paradigms, combining quantitative and qualitative methods under the cybernetic, complex, and chaotic vision stemming from the structure, functioning and behavior of living and social systems interacting in space-time." (Lopez et al, 2014, 18).

Following Reyes model and applying it further to Geocybernetics, the research group finds that cybernetics principles work at new levels of abstraction, expanding the concept of control by the functions of organizing principles through **territorial knowledge, modeling and communication.**

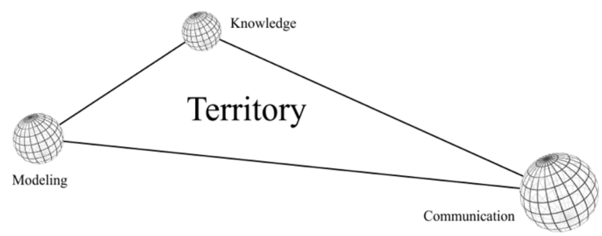



Fig. 1. Organizing principles in Geocybernetics. Adapted from Reyes, 2005, p.78.

This "knowledge-based approach to geographic information sciences and Geomatics" has been very effective for the interaction between science and society and has resulted in novel scientific findings and outcomes (Reyes, Paras, 2012, 9).

### C. Territory:

The territory is a concept and level of our reality that has played an extremely important role in the research prototypes developed at CentroGeo. It points precisely to that space of social interaction with nature and the world we have built. It provides us with elements for its deliberation and the models that articulate the planning proposals. (Paras, 2008).

The concept of open system proposed by Bertalanffy (1968), helped explain its emergence when considering the intricate network of interactions (local and/or global) of social and natural processes that are present in space-time, generating a dynamic interlaced behavior of global and self-organized interdependence. "It is important to consider the territory from a spatial-temporal, scientific perspective that leads us to an evolutionary regionalization that explains the story of the natural manner in which living beings describe how they maintain their livelihood in a dynamic environment by performing their activities in space-time" (Kauffman, 2000, 104). (Lopez et al, 2014, 19).

## 4. THE TRANSDISCIPLINAR META-DESIGN

The complexity of social systems makes it inherently difficult to model, control or predict them. Transdisciplinar teams, with members looking from different angles and expertise, are required to develop appropriate solutions for the problems they denote.

In the light of the formalization of knowledge over Cybercartography and Geocybernetics research and practice (Taylor et al, 2005 and 2014; Reyes et al 2006; Reyes and Paras, 2012; Lopez et al, 2014), we represent a transdisciplinar framework (fig. 2), highlighting its main building blocks, their integration and the organization of knowledge models, at different levels towards a purpose, through the key role played by a meta-design.

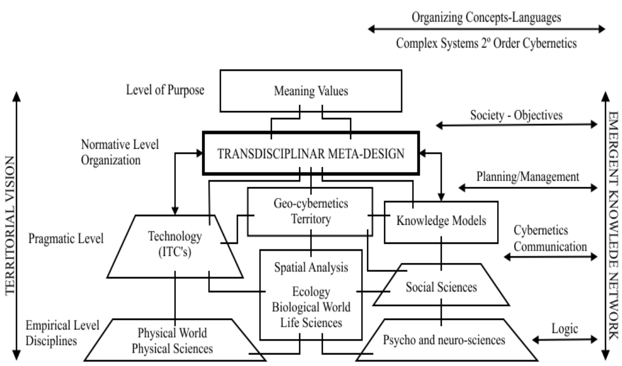



Fig. 2. Transdisciplinar meta-design framework. Adapted from Jantsch, 1975 p.232 and Paras, M. 2008, p.66.

From a top down approach, we distinguish the conducting axes to the design an implementation of a Geomatics Prototype:

At a **normative level,** the **Social claimant proposes** the problem and social needs, establishing the approach to the solution and the main drivers of the TMD, which derive from planning, design, management and politics. It is in these models, concerning the human action, that society and scientists make explicit their knowledge relating the possibilities as well as the territorial constraints of the solution. The organizational languages are those of specialists, acting as bridges concerning the pertaining knowledge and territorial models.

The next level is called **pragmatic or managing framework**. It is the level that comprises socio-environmental systems with their multiple territorial interactions, including relations with the systems of nature and technology. Here the vertical coordination between disciplines suggests a correspondence with the development of specified scientific-technological capacities required by the TDM to construct and model the physical and social spaces. At this level we emphasize the potential of Geocybernetics. In fact, territorial modeling provides conceptual bridges enabling integration of knowledge among disciplines. The language of organization is that of cybernetics, incorporating the processes of control, feedback, modeling and communication.

An **empirical level** corresponds to the sciences/disciplines that study the physic/biological systems in which life develops, allowing us to know what exists using spatiotemporal analysis and quantitative models.

**Methodology:**
To deal with complex problems we need a working methodology or a strategy that takes into account cognitive, methodological and procedural aspects leading to a solution.

After some years of research, we came to the understanding of the formal processes that bring about the development of the meta-design, an organizing knowledge-model and what has been defined as the **emergent knowledge network (EKN)**. (Lopez, 2011, 20; Lopez et al, 2014, 21).

In this regard, the **Reyes Method** is a pragmatic guide that consists of taking to a workspace the conceptual models of all the participating agents, from which a common knowledge base is constructed, synthesizing the knowledge and the geographical vision of the social emergent network. (Lopez et al, 2014, 20-21).

**The methodology implemented has the following stages:**
Social stakeholders are convened to participate in a collaborative teamwork for learning, discussion, consensus and scenario building. The key is to consider tacit and explicit knowledge from the social actors compromised in the problem at hand and in the possible solution. The spatial approach and geo-technology used to represent and communicate their knowledge and information act as a bridge between the scientific framework put forward and the policy and decision tools that have to be mobilized.

A. **Social claimant** -main stakeholders identification-
A solution is successful when it meets the needs of the social claimant in a comprehensive and consistent way and the requirements analysis has been well defined.

This type of analysis should be conducted by a team of specialists who are responsible of establishing the links with key stakeholders and identify the needs, the spatial/temporal characteristics and the institutional or cultural context -organizational, administrative, social and cultural- that have to be taken into account at this stage of the project design.

B. **Conversations: game rules**.
The conversations between the actors of society take place through a **heterarquical** group. Some individuals play a key role in the modeling at different stages of the interaction process; we identify them as **"knowledge managers"** whose function is to interconnect knowledge frameworks for Geomatics solutions. In some cases they are researchers and in others well qualified professionals with an understanding of the impact of geo-spatial knowledge on specific and societal problems. (Reyes and Paras, 2010).

Reyes establishes the following rules to achieve convergence in the construction of models and possible solutions to the stated problem:

- Each of the specialists and societal actors/claimants has a knowledge model.
- The dialogue or conversation among them should be focused on the territory, on a conceptual level as opposed to a technical one.
- The specialists and the actors must cooperate and have empathy while exchanging knowledge and information.

The challenge for the social agents involved is to be able to negotiate and build consensus regarding group goals and methods of achieving them, going beyond individual interests (Lopez, 2011, pp. 124-129).

C. **Qualitative and requirements analysis**:
This analysis consists of a detailed qualitative study of the organization and the potential users' needs in order to design a solution that meets those needs. The strategies, key concepts and functional models with which the institutions/organizations operate must be identified. The final results should be made explicit for the beneficiaries and main social claimant. (Lopez, 2011, pp. 119-123).

D. **EKN formation**: **emergent knowledge network.**
*A knowledge network emerges (EKN)* from the communication and conversations of scientists and non-scientists building a common language in the process. At the normative and managing levels, a conceptual language is required in order to achieve structural coupling between the different concepts of the participants' -tacit or explicit-models (Heylighen, 2003) considering the territory (Lopez et al, 2014, 22-25).

E. **Management/organizational model**.
The EKN functions as a knowledge manager framework from a top-down view. The modeling is introduced at the design process, of the creative action with purpose. The domain of its knowledge emerges in the "space of interaction" of the disciplines that converge in the TDM.

In our modeling process, it is at the territorial level that we can identify and ponder the problems we address and the potentialities of the solutions, because it reveals the variety and complexity of the context, the spatial functionality and the various processes that generate them. (Paras, 2008; 2016).

The Emergent Knowledge Network must reflect the holistic view of the territorial landscape (Lopez, 2011, 163-174), and should serve to trigger the construction of a heterarchical network of concepts that organize, coordinate and integrate quantitative models -mathematical, physical, and statistical or heuristic- that are required in the solution. It is important to point out that these solutions are systems open to the integration of social knowledge on a permanent basis, so that they evolve in conjunction with the social systems where they are inserted.

Due to the spatial/temporal dynamics of territorial processes, the EKN must have the ability to reconfigure itself, depending on its adaptation to the environment being modeled. The territory has a double function:

- To help make explicit the participants' models, when they establish conversations;
- As a catalyst to the convergence and consensus towards a common knowledge base between the different models.

F. **Operational framework:**
Currently, geo-information technology and ITC´s are applied to develop tasks such as monitoring and geospatial patterns recognition of social and natural processes in real time. Spatiotemporal language has been developed between different groups of observers and stakeholders through geo-technology in the WEB. Its social meaning will be built as they share the values of territorial capital and the information and knowledge constructed through the conversations in the social networks.

## 5. TRANSDISCIPLINAR GEOMATICS PROTOTYPES

In this segment we illustrate, as an example, the Transdisciplinar design methodology followed for one of (more than 60) Geomatics applications developed at CentroGeo.

In 1995, the United Nations Environment Program (UNEP) launched an environmental assessment project called GEO (Global Environmental Outlook): products which include a series of periodic reports on environmental perspectives at the global, regional, national and city level.

In this context, the GEO Cities project was set up in 2001 as an environmental priority for the Latin American and Caribbean region (initially for 8 cities). It consisted in carrying out environmental reviews of the impact of urban growth, which are valuable inputs for environmental decision-making and, in general, for public environmental policy processes, including the phases of social consensus and communication.

**Project: Geo Ciudad de México.**
**Executing agency:** CentroGeo
Our main **social claimant** for the project was UNEP-Latin America. Other end point users were the Mexico City authorities (City Major and the Environmental Secretariat).

The review should focus on environmental assessment process of participatory character with specialists from the academia, government and social organizations; developing new conceptual and methodological frameworks and assessment indicators that could lead to public policy recommendations.

**Qualitative and requirements analysis:**
A range of diagnoses had been made on the urban and environmental problems of the Metropolitan Area of Mexico City (ZMCM). In order to extend the participatory character common to all UNEP GEO projects, the initial process included specialist workshops and subsequent direct consultations with experts and public officials.

**Main recipients:**
It is worth mentioning that GEO Mexico City was not exclusively aimed at governmental interlocutors. In fact, the emphasis on the main problems affecting the public, on public policies and on the evolution of the environmental agenda, clearly indicated that the target groups were also the social agents, academicians, groups and citizens interested in the environmental problem of the city.

**The emergent knowledge network**
The description of the urban-environmental problems of the ZMCM in spatial terms is an essential factor to support public policies and decisions with information and knowledge. The spatial dimension contributes to the incorporation of a territorial vision in the public policy, which compensates the traditional sectorial and disciplinary bias and the limitation to the political-administrative limits.

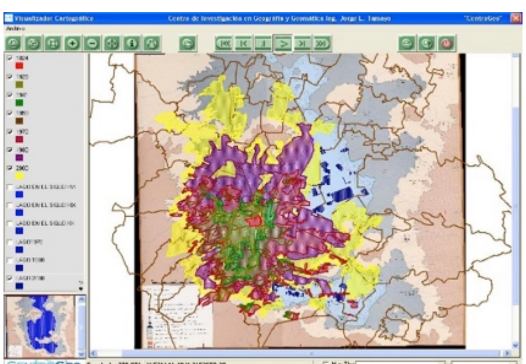
**Meta-design** for a territorial vision of the urban-environmental system comprising the metropolitan region of Mexico City.

In order to incorporate this vision, we developed methodologies that provided robust models and tools for the analysis of the interactions between urban development and the environment. The meta-design is a conceptual management model (top-down approach) structuring the EKN for geo-spatial knowledge and information. The approach guides the integration of tacit and explicit knowledge, and makes explicit cognitive and procedural aspects leading to a solution, which resulted in an interactive digital document (UNEP-CentroGeo, 2003).


**Organization and Content**

The content of this cybernetic document is organized in six modules, related through links that allow the reader to navigate transversally throughout the text. For example, the module on the built environment (3rd module) finds its logic in the module on spatial functionality (4th module); and is connected by links that allow moving from the description to the explanation. Other important links are located between the module on the ecological history of the basin (2nd) and the environmental quality of life (5th).

The way the City has expanded is determined, in part, by the conditions of the physical-geographical landscape of the basin on which its growth has occurred. Similarly, the dynamics of population and urban agents, the systems of roads and transport, have defined the modalities of occupation of the territory, and consequently, the functionality of Mexico City.




Simulation: Mexico City growth in different periods, vs. the shrinking of the lacustrine region of the Basin.

**Functionality of the Cybernetic Document**

a) It is supported by a meta-model that defines the organization of second level models, information, graphics, photos, texts and a cartographic visualizer, with some flexibility to make consultations.

b) It incorporates a collection of photographs and maps related to the topics covered. It also contains a range of analytical maps -like the spatial dispersion of atmospheric pollutants-, developed by various institutions.

c) Its technological platform offers a variety of options for its management, including navigation through thematic links of the different modules that make up the structure of the report.

d) It offers options for the user to make friendly and versatile map overlays that support and enrich their queries from the available map library. This option facilitates the performance of analysis exercises that help to balance the basic characteristics of some subjects, such as the spatial distribution of urban density compared to the spatial distribution of risks, air pollution, access to drinking water, or green areas.

e) This tool facilitates the spatial visualization of the spatial distribution of the environmental quality of life, by areas of the metropolis and by segments and social strata of its population, of great utility for the design and implementation of public policies.

f) The format in which the information is presented responds to UNEP's concern about the links between human actions and their environmental performance. In this sense, we can see an advance in the flexibilities for the urban environmental systemic interpretation of Mexico City, which represented, at the time, a substantial improvement over the possibilities offered by a traditional linear assessment methodology.

This research prototype has served as the basis for the TMD instrumented in several of the Masters' degree thesis in Geomatics at CentroGeo. Some of the models developed deal with the integration and sustainable management of urban water resources in Mexico. This transdisciplinar path has also been put forward by the United Nations University Institute for Integrated Management of Material Fluxes and of Resources.

Their aim is stated as a nexus methodology required for making linkages between the traditional top down sectorial approach and the multi-stakeholder approach that must include selective stakeholders, in order to develop and implement Integrated Watershed Resources Management. (UNU-FLORES, 2014).

## 6. CONCLUSIONS

The vulnerability of terrestrial ecosystems introduces ethical dimensions never before raised, originated by human interventions in the environment. Only a transdisciplinar view can account for the relationship between causal values and their effects on the broad systems that make up the biosphere.

The potential of novel technologies and the emergence of disciplines represent an interesting challenge for scientific management -theoretical and practical frameworks- that integrates knowledge and information. In this task the transdisciplinar experience in the formulation of a meta-design in Geomatics has led to explore innovative processes, with the expectation that their applications allow decision-makers to tackle complex territorial problems, in order to meet the society´s demands. (Paras, 2013).

Technology remains a pillar in the development of Geomatics and has also supported it as a means to build bridges between its scientific proposals and society. However, geo-technology alone cannot solve the deep questions of society. These issues can be anticipated through theoretical and conceptual frameworks developed by researchers in conversations with social actors.

Transdisciplinarity theory and practice is imperative in making possible the transition to an emerging, systemic science capable of emphasizing its collective and integrative properties, such as self-organization, co-emergence and co-evolution. It recognizes, therefore, the legitimacy and the need for other complementary perspectives and territorial views in the generation of knowledge. It therefore requires, as a necessary condition, the participation of other creative agents who carry out a process of socialization of knowledge, in its generation and in the use of its results.

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