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Understanding geodesign process dynamics: towards an analytical framework

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Understanding geodesign process dynamics: towards an analytical framework

Short Abstract

The primary aim of this thesis is to propose a framework for Geodesign Process Analytics (GDPA) based on the use of geodesign workshop log-data gathered by most recent web-based collaborative Planning Support System (PSS). The analysis and mining of PSS log-data enable the coordinator of a geodesign study to gain better insights about the evolution of the design during the process as well as about the process itself and its dynamics. First results show a huge potential for the practical application of GDPA in workshop coordination support, in gaining insights about past geodesign studies, and in understanding participants behaviour in collaborative design processes with the ultimately aim of improve them.

Abstract

Complexity in current spatial planning practice is mainly linked to the multi-dimensional context characterizing its processes. Following latest policies and strategic tools on sustainability, growing number of dimensions and principles should be considered in terms of development and process objectives. Particularly, the involvement of a wide range of actors along with traditional participatory methods make difficult to grasp the dynamics which led to the final decision. Hence, despite guiding principles such as transparency and information-based decision making, there is often insufficient clarity in the process of moving knowledge into action.

Recent advances in collaborative Computer Aided Design (Co-CAD), Building Information Modelling (BIM) and Planning Support Systems (PSS), are nowadays enabling collaboration within increasingly complex workflows in planning and design. Such technologies are currently able to store data about the evolution of the design product, as earlier technology (e.g., CAD, GIS and geo-databases), but also log-data about the interaction of multiple users collaborating in collective design endeavors with the supporting digital platform. As such, log-data can be readily made available to the coordinators to monitor the process, including the temporal sequence of activities and tasks, the users' behavior and productivity, and the evolution of the design in space and time. The opportunity of analyzing this new type of data with digital dashboards may potentially enable to apply a sort of business intelligence perspective in real-time geodesign study coordination and management, and in retrospective or comparative studies, by mining what may be considered geodesign (processes) big-data. To date, early research in this direction was successfully undertaken in several close domains such as industrial design, architecture and construction engineering, but similar attempt in geodesign are still at a very early stage.

Geodesign, as a new method of design practice relying on collaboration and digital technologies, can be thought of both as a verb and as a noun or in other words as a process and as a product of that process. Thus, understanding geodesign and assessing its value require dealing with the complexity of its twofold meaning, as both the quality of the product and of the unfolding of the process should be critically considered. Such an investigation may be useful both for learning from past case studies with the aim of improving future one, and for monitoring ongoing processes dynamically. While the experience and the observation skills of those involved in the coordination of geodesign studies will always be critical, the actual availability of new digital cockpits monitoring the process and its product real-time may potentially add substantial value, especially in fast-pace intensive geodesign workshops. The collaborative PSS Geodesignhub started to offer simple measure about ongoing geodesign workshops. However, a wider and more robust Geodesign Process Analytics (GDPA) is needed to fulfil the potential offered by geodesign process log-data.

The doctoral research aims at defining an operational analytical framework for analysing planning and design processes. The new source of data, that is log-data gathered digitally during geodesign workshops thanks to the functionalities of currently available PSS (e.g., Geodesignhub), were used to operationally test the hypothesis. The methodology applies descriptive and inferential statistics to monitor the process real-time and *ex-post* through e-dashboards in which a variety of indicators is implemented considering the semantics macro-dimensions of log-data which include design, authorship, space, and time.

Early findings suggest a huge potential for making value of available log-data for earning new insights about the collaborative design generation and about the social and behavioral aspects of design process dynamics. Further research is needed to define a robust geodesign process analytics, possibly leading to a better understating of general patterns and behaviours in planning and design processes. Nevertheless, the proposed analytical framework offers the possibility in the short-medium term not only to make past process more transparent, but also to gather new knowledge useful for the design of future collaborative planning and design initiatives through meta-planning.

Acknowledgement

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List of Abbreviations

BI	Business Intelligence
BIM	Building Information Modeling
BPMN	Business Process Model Notation
CAD	Computer-aided design
CM	Change model
DM	Decision model
EM	Evaluation model
GD	Geodesign
GDF	Geodesign framework
GDH	Geodesignhub
GI	Green infrastructure
GIS	Geographic Information System
GDPA	Geodesign Process Analytics
ICT	Information Communication Technology
IGC	International Geodesign Collaboration
IM	Impact model
MCC	Metropolitan City of Cagliari
PM	Process Model
PSS	Planning Support System
RM	Representation Model
R-SDI	Regional Spatial Data Infrastructure
SCI	Sites of Community Importance
SDSU	San Diego State University
SEA	Strategic Environmental Assessment
SMGI	Social Media Geographic Information
UFMG	Universidade Federal de Minas Gerais
VGI	Volunteered Geographic Information

Chapter 1 Introduction

1.1 Background and motivation

Since the early 1990s, the global debate on sustainable development has highlighted the importance of strengthening the decision-making process to ensure, on the one hand, the progressive integration of environmental concerns in spatial planning at different scales, and on the other hand, a wider public participation in the process (United Nations General Assembly, 1992a; World Commission on Environment and Development, 1987). The full implementation of Agenda 21 and the commitment to the Rio Declaration principles (United Nations General Assembly, 1992b) were strongly reaffirmed at the United Nations Summit 2015 by adopting the resolution "Transforming our world: the 2030 Agenda for Sustainable Development" (United Nations General Assembly, 2015). The core of the outcome document consists of 17 goals that are intended to guide global efforts towards a sustainable future over the next decade. Goals 11 and 16, in particular, acknowledge the need for participatory and integrate human settlement planning, and for responsive and inclusive decision-making at all administrative level.

In terms of policy instruments, in Europe the Directive on Strategic Environmental Assessment (SEA - 2001/42/EC) provided renewed impetus for Member States to incorporate environmental considerations into plans and programs, while ensuring transparent and participatory decision-making processes (T. B. Fischer, 2007). Transparency and accountability are key elements in the development process not only as formal mechanisms or instruments of government, but also as leading principles of the policy cycle from decision-making to the implementation phase. (McGee, 2010; Word Bank, 2018) .SEA procedure can, therefore, contribute to an informed and democratic environmental governance aiming at ensuring more sustainable forms of development. Despite difficulties in translating guidelines into practice, public consultation and participation is acknowledged as a defining feature of SEA processes and as an essential element to achieve 2030's sustainability objectives.

Operationally, typical spatial planning situations featuring public participation may involve a variable number of actors in many different types of evaluation and decision phases, and be characterized by a mix of unstructured and structured activities. The approaches to handling these key aspects had varied over time with the evolution of different planning theories and approaches (Khakee, 1998, 1999) affecting the overall planning process, in particular the definition of a set of values and design objectives, the construction of the territorial knowledge and how it influences the creation of design alternatives. Among the eight paradigms or theoretical models synthesized by Khakee (1998), in the rational-comprehensive planning, for example, the decision-making process should be well defined in all its phases, the objectives should be chosen at the political level and the planners should formulate alternative proposals according to an expert approach. Conversely, according to the most recent paradigm of communicative planning, technicians no longer develop models applying purely the scientific method, but they are also required to highlights priorities and requirements of the various social groups involved, and to foster a pluralist discourse between experts and the community aiming at achieving higher level of knowledge. Particularly, in the advocacy planning technicians should be able to reflect the full range of values and interests of all the social groups that make up the local community, and that often are not properly represented in the process. Whereas in transactive and communicative planning, the local community in its various social components participates more actively, albeit with different levels of "social interaction" (Arnstein, 1969; Forester, 1999; Friedmann, 1993), to the more or less structured phases of the process.

Nevertheless, despite recognizing the growing importance of participation in spatial planning, citizens involvement in current SEA practice is still relatively poor and with limited influence on actual decision-making (Chaker et al., 2006; Gauthier et al., 2011). Even in those cases where effective public engagement takes place, there is a lack of information and documentation with respect to timing, means and methods. More generally, several authors have highlighted a series of issues in the application of the SEA procedures in the Member States of the European Union, both at the local and the regional level (Arcidiacono, 2012; COWI, 2009; T. B. Fischer, 2010; Parker, 2007). Specifically, the objectives of transparency most often cannot be sufficiently achieved: it is often difficult to identify the responsibilities within the decision-making processes for what generate negative impacts on the affected communities; the desired relationship between the identification of environmental issues and the development of design alternatives is not always straightforward. The process for moving expert and experiential knowledge to action in spatial planning is complex and often characterized by informal, undefined and/or not well documented activities. Hence the dynamics of the stakeholders' participation and of the entire design process are often poorly understood, limiting greatly transparency and accountability in decision-making.

A possible operational response to the limits encountered so far in the organization of the multidimensional aspects of planning may be linked to the concept of meta-planning (De Bettencourt et al., 1982; Emshoff, 1978; Faludi, 1973). This approach refers to the planning and scheduling of the operational flow of activities, by actors, with methods and tools necessary for implementing the decision-making process. Campagna (2016b) argues that a preliminary design effort can help unpacking the complexity of spatial planning process situations, avoiding imprecisely formulated activities and promoting the integration of customized supporting technologies suitable for each specific activity and task. However, implementing the concept of meta-planning in current planning practices is still limited.

Scholars and practitioners have devoted attention to the development of methods and techniques to facilitate SEA adoption (Geneletti et al., 2007; Lai et al., 2018) and meta-planning implementation (Campagna et al., 2014). Among them Campagna et al. (Campagna, 2016a; Campagna et al., 2018; Campagna & Di Cesare, 2016; Di Cesare et al., 2018) pointed to the potential offered by geodesign – a renewed approach for complex design problem solving – to address many of the issues encountered in SEA application. Contemporary debate on spatial planning showed an increased interest in geodesign concepts and methodology. It is in this context that Steinitz (2012) proposed his geodesign framework (GDF) as a progression of six models and related questions to implement forward-thinking, interdisciplinary, system-thinking design processes. The approach combines environment-oriented planning methods, enabling geospatial technologies, and stakeholder collaborative participation to address the planning problem from an interdisciplinary point of view in order to make informed and evidence-based design choices (Lee et al., 2014a; McElvaney, 2013; Nijhuis et al., 2016). While the Steinitz's framework can be overall considered to be in line with the main approaches in the field of design theories, it promotes a unique process structure for creative problem solving which relies on a set of interrelated models and a variety of support digital technologies to help an interdisciplinary design team collaborate (Foster, 2016). The contribution of digital tools in practice is widely acknowledged (Ervin, 2016).

Current growing interest in geodesign among academic and professionals is closely related to early Planning Support System (PSS) conceptualization by Britton Harris (1989), research aimed at designing reliable integrated information system to help planners implementing digital workflows. However, they had somewhat limited diffusion due to several factors including, to recall few, the limited digital literacy by professionals, the fear of 'black box' effect, or, their somewhat narrow scope (Geertman, 2017; Geertman & Stillwell, 2009). Indeed, most of them focused in supporting very specific tasks of the planning and design process, at the cost of substantial resources investment.

More recently, the Geodesignhub PSS (*Geodesignhub*, n.d.) contributed to address the latter issue for it enabled the implementation of workflows which cover the span of the whole design process from knowledge building (in GIS environment) to design and impact assessment (with the system itself). Geodesignhub is designed to support collaboration and negotiation, and can record log-data about the whole process with regards to design and to the actions of the involved actors, which contribute to generate a final solution. The opportunity of taking full advantage of the geodesign (i.e., planning and design) digital log-data is unprecedented, and it is worth to be investigated further. The research is based on the assumption that a systematic analysis of PSS log-data may contribute to offer a better understanding of the process unfolding and of its results, thus fostering greater transparency and accountability in planning practices.

1.2 Thesis structure, objective and research questions

The previous section has outlined some of the issues relating to complexity in current planning practices examining the role of new technologies in possibly solving them, and it places this doctoral thesis in context. On the above premises, this study attempts to make sense of the log-data recorded by currently available PSS to gain insights into the collaborative (geo)design process. Design dynamics emerges from the interactive actions of different actors along the iterative sequence of activities and tasks and are currently often difficult to grasp. The primary aim is to build a framework for geodesign process analytics by developing a series of indicators to measure and understand those dynamics. The acquired knowledge can be applied to facilitate targeted and effective process improvement initiatives regarding both on-going and/or future situations. The research is guided by the following central question:

- How to fully exploit design information available in current PSS log-data in order to monitor, understand and improve planning and design processes?

The thesis structure follows the 'three papers' format, which generally consists of an introductory chapter, at least three (or more) article-chapters, a conclusion, and a single bibliography. "PhD by publication" (Breimer & Mikhailidis, 1991; Frick, 2019) is already the standard in Sweden and is becoming an increasingly common form of doctoral production in most Europe. As highlighted by Breimer and Mikhailidis (1993) "the advantages of publications-based doctoral system […] are a greater dissemination of knowledge, a fairer examination and a more efficient, productive and appropriate use of candidate time". Organizing the thesis structure by mid-term goals allows to improve the quality of the overall results and to better manage the workload along the three-year doctoral research. Furthermore, in the case the papers have already been accepted for publication, this format contributes to the peer-review process of the overall research.

The nature of the research approach and topic made them suitable to be presented as the three-paper thesis. The structure of the dissertation is in accordance with the guidelines of many European universities (*University of Southampton*, n.d.). It consists of four free standing publications each investigating one fundamental aspect of the main research question. The first three papers represent the core of the thesis, which also include a fourth additional paper on a practical application of the analytical framework. This first introductory Chapter places the papers in the research context more broadly, while the concluding Chapter summarizes findings and next possible steps of the study.

Accordingly, four operative questions were identified to guide the research project:

1. How can geodesign methods and technologies support collaborative and/or participatory planning processes?
2. How does the analysis of PSS log-data help us to understand design dynamics in past and on-going (real-time) geodesign processes?
3. To what extent can the analysis of PSS log-data guide future geodesign processes (i.e., meta-planning)?
4. How useful are geodesign and geodesign process analytics in supporting integrated land use and green infrastructures planning?

1.3 Methodological framework

The use of the structured decision-making workflow of geodesign allows to effectively organize the key aspects of the process: the contribution of the local community within the different phases, and the use of appropriate PSS to support the implementation of specific steps. Public participation can play an important role in the overall process or may occur only at some phases previously defined. Different planning approaches highlight different perspectives on participation and on the role of the planner (Alexander, 1992; Khakee, 1998). In transactive planning citizens are invited to cooperate and share local/experiential knowledge of the territory thus informing the design of technicians (expert knowledge) in a mutual learning process. More recently, communicative planning highlights the importance of interaction and consensus-building by constructing ideal communicative arena within which members of the community are invited to propose change alternatives, negotiate and seek consensus among them in a collaborative decision-making process.

Having a clear framework in mind, such as the geodesign, facilitates the understanding of these different perspectives, opportunities and instruments of public participation in spatial planning and design. In 2012, the concept of geodesign has been formalized by Carl Steinitz in his book "A Framework for Geodesign" (Steinitz, 2012), where he proposes a framework guiding the process definition based on six models (Figure 1).

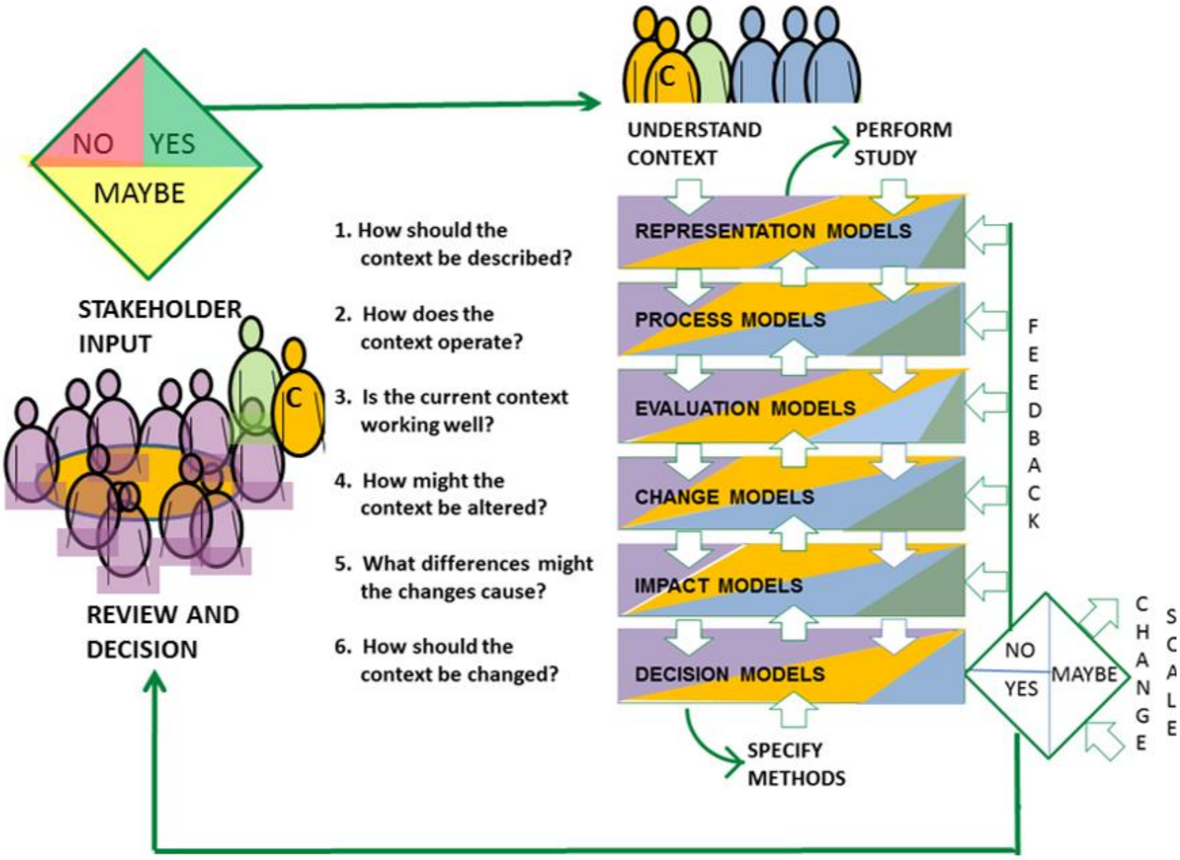

Figure 1. The stakeholders, the geodesign team and the six models of the geodesign framework. | *Source: Carl Steinitz.*

Though they did not use the term, Frank Lloyd Wright, Richard Neutra and Ian McHarg, invoked the idea of geodesign when they respectively talked about organic architecture, design with nature and a geo-based technique to assess the best (or worst) location for a particular land use. On these bases, Steinitz developed his complete methodological framework (geodesign framework – GDF). In particular, the first three models of the GDF (i.e., *representation, process* and *evaluation* models) focus on the knowledge-building process, examining existing conditions in the study area in the evaluation phase. Whereas the last three models of the GDF (i.e., *change, impact* and *decision* models) constitute the *intervention* phase of the process, defining desirable design alternatives and assessing their potential impacts on the territory to reach an informed and negotiated final plan based on consensus. According to Steinitz (2012), this process is not necessarily strictly linear: to perform a complete geodesign process three iterations should be undertaken. The first iteration leads to a clear definition of the objectives underlying the study. In the second iteration the models are considered in reverse order with the aim of clearly defining how the process will be developed (e.g., tasks, roles, methods, tools, etc.) in accordance with the concept of meta-planning. Eventually, the process is fully implemented in the last iteration.

Thinking in terms of environmental impact assessment, within geodesign approach environmental concerns and geographic knowledge of the territory should inform since the beginning the design and an assessment of potential impacts of change (performed in the impact model) should inform negotiation between design alternatives during the decision-making process. The knowledge-building process, whether or not including public participation, is completed within the first three models of the geodesign framework and results in a spatial evaluation of attractiveness, or vulnerability, for a particular resource, location or action based on multiple criteria. The evaluation models should orient the participants in creating design proposals informed by the geographic context in the change model. Geodesign can thus effectively contribute to narrowing the gap between knowledge-building and action, this shift is perhaps the most critical and unclear phase of the process in real world practices. Eventually, alternative future plans for a territory are based on a selection of individual design proposals by groups of stakeholders, which are then involved in a negotiation process to reach consensus on an agreed solution.

Although not strictly necessary, the application of the framework is usually supported by extensive use of digital information technologies, to deal with complex land-based planning and design issues. The geodesign framework encourages the use of spatial analysis techniques and impact simulation processes, in order to evaluate interactively the effects of possible development scenarios, augmenting the real-time interaction in the design process dynamics. Taking advantage of the innovations in the field of sciences (Goodchild, 1992, 2010) and digital technologies (GIS - Geographic Information System) of geographic information, geodesign is gaining momentum in the last decade with the aim to apply a holistic approach - based on geovisualization and geoanalytical techniques - to more traditional practices within collaborative design and spatial planning fields (Lee et al., 2014a; Steiner & Shearer, 2016).

In this context, a research consortium of more than 90 academic institutions worldwide was created in 2018. The International Geodesign Collaboration (IGC) aims to understand how the new planning and design methodology of geodesign can be applied to better address the the global sustainability goals of the United Nations Development Program (United Nations General Assembly, 2015) at various territorial dimensions and in different contexts around the world (Orland & Steinitz, 2019). Each partner involved in the collaboration developed a local planning study applying the geodesign workflow as proposed by Carl Steinitz in his framework (Steinitz, 2012). Participant teams shared several global assumptions and changes, a common working schedule, and specific instructions to achieve collaboration and comparability of project outcomes. Results and findings were finally presented and shared using a standard reporting format at the International Geodesign Collaboration meeting held in Redlands on February 23-25, 2019.

There are many paths and support options to implement the geodesign framework. Current PSS offer increasingly tailored tools to meet the requirements of different planning approaches and different levels of participation (Campagna et al., 2005).

Additionally, recent advances in geo-information tools and information communication technology (ICT) allow PSS not only to support specific design tasks, but also to record information such as time sequence, authorship, semantics and topology, on any design option that contributes to the final design. Latest available technologies, thus, open new possibilities for tracking the evolution of design alternatives under the influence of the acting participants, from their inception toward negotiation and choice of the final plan. Despite in the last decade, information systems' log-data have become an important resource in many fields (e.g., business management, computer science, manufacturing, civil engineering, etc.), their potential use in the design domain remain largely unexploited. Exploring the opportunities currently offered by geodesign (i.e., planning and design) digital log-data represents the focus of the doctoral thesis.

However, in order to taking full advantage of this new data type, a novel ad-hoc analytical approach is required (Figure 2). Collaborative design log-data have a peculiar structure which integrates information relate to both the tasks carried out by participants along the process (i.e., create a diagram; select a diagram) and the outputs of those tasks (i.e., diagrams created, diagrams selected). In his book (2012) Steinitz distinguishes between design as a verb and design as a noun, highlighting the double meaning of the term design: a process, and the product of the process respectively. The analytics tools, therefore, should cover two types of measures: those linked to the actions of the participants which characterize the process (e.g., participants' performance indicators, temporal indicators, indicators of design evolution), and those related to design aspects of the products (e.g., spatial indicators). The former approach to process analysis was partially developed in collaboration with Prof. Piotr Jankowski at the Department of Geography at San Diego State University, USA; whereas the latter analysis and the log-data extraction and preparation were implemented during the research period at the *Laboratório de Geoprocessamento* of the Universidade Federal de Minas Gerais (UFMG) in Brazil under the supervision of Prof. Ana Clara Mourão Moura.

In order to achieve this target, a deductive-inductive approach was adopted which drew upon both literature review, and bottom-up exploratory (log-)data analyses (EDA) to identify potential relations between dimensions and, consequently, define the set of indicators. It should be noted that the specific structure of design log-data required the integration of traditional spatial analysis methods with expertise and contributions from various disciplines such as descriptive and inferential statistics.

Descriptive analysis was used to construct a digital dashboard implementing a sub-set of indicators, related to both the product and the process, that can support the coordinator of the geodesign process in real-time monitoring the ongoing dynamics and make informed decisions as are needed to improve the current process. Inferential statistical techniques were applied to log-data of past geodesign study to elicit and reveal relationships and patterns in participant behaviour and in the evolution of the design, ultimately aiming at better understanding, assessment, design and management of past/future processes.

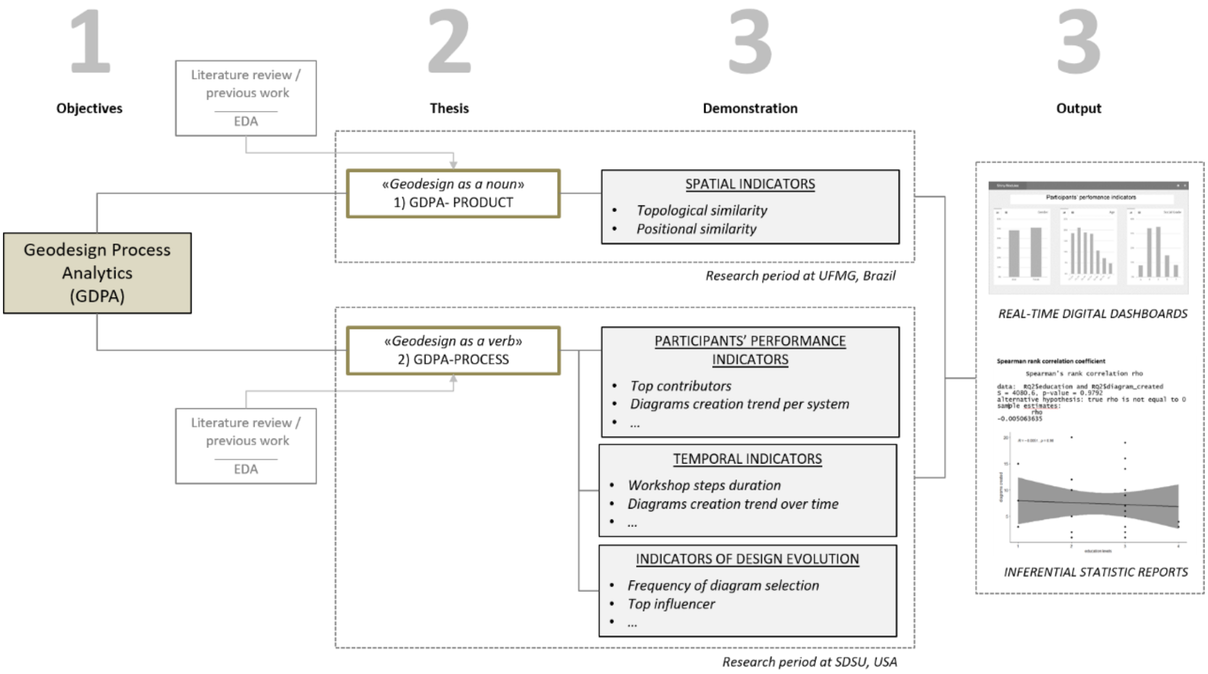

Figure 2. Methodological framework for Geodesign Process Analytics.

1.4 Case study

In order to demonstrate the research assumptions the web-based PSS Geodesignhub (*Geodesignhub*, n.d.) has been used, since i) it allows stakeholders to effectively contribute in the last three models of a geodesign process (i.e., change, impact and decision models), and ii) it records log-data about the whole process with regards to design and to the actions of the involved actors. Geodesignhub software has been developed by Hrishi Ballal, within his doctoral research and under Prof. Carl Steinitz supervision (Ballal, 2015), to support the implementation of geodesign workflows in a native digital form. It can be considered a collaborative PSS (Campagna et al., 2005) designed to support groups of stakeholders in the intervention phase of a planning process, from design inception toward impacts evaluation and choice of the final plan through negotiation.

In a planning and design study with Geodesignhub - usually carried on with a two-day workshop – an ideal number of 30 participants among representatives of local community, each with their own access to the system web-based interface, can draw projects and policies (*diagram)* to improve the existing conditions of up to 10 systems of reference (e.g., agriculture, housing, etc.). An *evaluation map* - a synthetic representation of a suitability map, based on multiple criteria - for each system is previously built on the basis of expert and/or experiential knowledge. The participants divided into stakeholder groups can easily select diagrams to develop a composite design alternatives (*syntheses*) in line with their specific change priorities. Early design proposals are then assessed against their impacts over the existing conditions to frame refined syntheses before starting the negotiation phase. Geodesignhub supports stakeholder coalitions in creating negotiated syntheses towards achieving a consensus thanks to the availability of specific tools for the purpose.

In Geodesignhub the entire process, as briefly described above and more in detail in Chapter 2, is recorded in the database structure and all the output of the participants' actions (e.g., details of all diagrams created in a project; list of diagrams selected in a team/coalition synthesis) are available for download (Figure 3). Geodesignhub stores the spatial and temporal information associated with a diagram, but also thematic attributes (e.g. authorship, system, authors' preferences), and multimedia contents, if available. Furthermore, the design evolution can be traced back by downloading group/coalition syntheses created throughout the entire process, which contains information on the selected diagrams, the change team who created it and the exact timing.

Geodesignhub offers early interactive analytical tools to assess the process during and after its implementation. It deconstructs the digital collaborative process and produces a history for each design that help understand how diagrams are used by the actors as they iterate on a design and negotiate to make changes. These tools offer a first set of measures to analyse the design process. However, there is a need to extend it with a more robust analytical framework that allows explaining how and why actors behave along the evolution of design options toward the final plan.

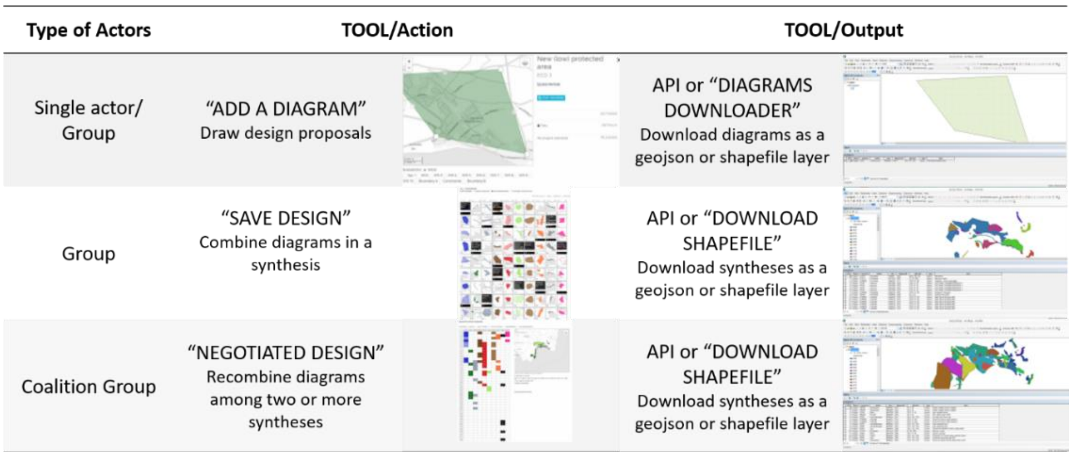

Figure 3. The main actions performed by the participants involved in a geodesign workshop with Geodesignhub and the related output data.

1.4 Outline of dissertation

The structure of the thesis reflects the choice of present the research project as a collection of articles recently published in (or submitted for publication to) international peer-review journals. Chapters from 2 to 4 describe in detail the effort undertaken to improve our understanding of design processes and develop a methodology to analyze geodesign studies by exploiting the data automatically recorded by a web-based collaborative PSS. Chapter 5 proposes the use of geodesign methods and analytics to support the early phases of integrated strategic territorial planning, in order to enrich the relationships between the design of green infrastructure and of the other relevant systems within more comprehensive planning and design applying system thinking. Each chapter is a reprint of a scientific article and answers to an operative research question respectively. Eventually, the last Chapter is devoted to the general conclusions of the dissertation. It summarizes the findings of the four previous sections and, on that basis, responds the main research question.

Chapter 2

This Chapter proposes a critical review of geodesign methods and techniques which can be used to carry out collaborative design in participatory processes. The case study of a geodesign workshop implemented with the collaborative PSS Geodesignhub shows how it is possible to involve teams of members of the community in what is perhaps the most critical phase of a spatial planning process that is putting knowledge into action through the collaborative design of future change alternatives, and their choice based on negotiation. The main steps of the Cagliari geodesign workshop, which will be used in Chapter 4 as case study to demonstrate the research hypotheses, are presented. In addition, a discussion of further potential of the geodesign approach in public participation is discussed with reference to both knowledge creation and community value and preferences accounting.

This first research step is based on the article: Campagna, M.; Carl, S.; Di Cesare, E.A.; Cocco, C.; Hrishikesh, B.; Tess, C. Collaboration in planning: The Geodesign approach. *Rozwój Regionalny i Polityka Regionalna 2016*, 35, 55–72.

Chapter 3

With the above premises, Chapter 3 emphasizes the opportunities offered by collaborative PSS not only for applying a system approach and coordinating involved actors, but also for tracking the evolution of the design options toward the final plan. The availability of process log-data in Geodesignhub opens new paths to the understanding of design dynamics. With the aim of taking full advantage of the new data source, the analytical process towards GDPA is described in detail from log-data extraction and pre-processing methods and tools, to the development of the set of spatial, performance, temporal and design evolution indicators. It is also demonstrated how the proposed measures are suitable to be displayed in a dynamic dashboard making available a real-time process analysis tool to the workshop conductor, thus supporting their core role of facilitating the process. The research assumptions were tested using a geodesign study developed within the IGC project.

This Chapter were previously published as: Cocco, C.; Rezende Freitas, C.; Mourão Moura, A.C.; Campagna, M. Geodesign Process Analytics: Focus on Design as a Process and Its Outcomes. *Sustainability* **2020**, *12*, 119.

Chapter 4

In Chapter 4 the Enhanced Adaptive Structural Theory (EAST2) by Jankowski and Nyerges (2001) was used as theoretical framework to guide the identification of interesting dynamics to be investigated in comparative studies. Unlike the log-data-driven approach, which relies mostly on descriptive statistic in an exploratory way, the theory-driven approach may use inferential statistics to validate theoretical assumptions or construct. The log-data recorded by the by the collaborative PSS Geodesignhub during the Cagliari geodesign case study were analysed with a view to explore the dynamics of participation and interaction among stakeholders involved in a computer-mediated collaborative planning and design process. Results are shown and discussed as a promising contribution towards a novel geodesign analytics approach with a view to future processes improvement.

These findings were previously published as: Cocco, C.; Jankowski, P.; Campagna, M. An Analytic Approach to Understanding Process Dynamics in Geodesign Studies. *Sustainability* 2019, 11, 4999.

Chapter 5

The use of geodesign, and geodesign process analytics were respectively proposed as a holistic and systematic approach and as a user-friendly analytical tool to support integrate and collaborative green infrastructures planning. A case study developed under the umbrella of the IGC, was used to demonstrate how with intensive geodesign workshops it is possible to create spatially explicit design scenarios which take into account the relationships between green infrastructure and other relevant territorial systems and dynamics at once. A set of analyses on the results of the two scales case study is used demonstrate the assumption. Of particular interest is the contribution of the spatial indicators which allow to easily identify possible conflicts of interest. Their implementation in digital dashboard provides an efficient tool for understanding how systems mutually influence each other in rapid real-time design iterations.

Chapter was submitted in the special issue of *Sustainability* "Ecosystem Services, Green Infrastructure and Spatial Planning".

Chapter 2 Collaboration in planning: the geodesign approach

An early version of this chapter has been published as "Campagna, M.; Carl, S.; Di Cesare, E.A.; Cocco, C.; Hrishikesh, B.; Tess, C. Collaboration in planning: The Geodesign approach. Rozwój Regionalny i Polityka Regionalna 2016, 35, 55–72".

2.1 Introduction

Planning literature proposes different paradigms (Khakee, 1998) for interpreting the concept of public participation in spatial planning, ranging from early advocacy planning approaches (Davidoff, 1965) to more recent communicative ones (Innes & Booher, 2010). Different approaches highlight different perspectives on participation, including expression of pluralist community views, preferences, and values, creation of better knowledge, better transparency, and more consensus in decision making.

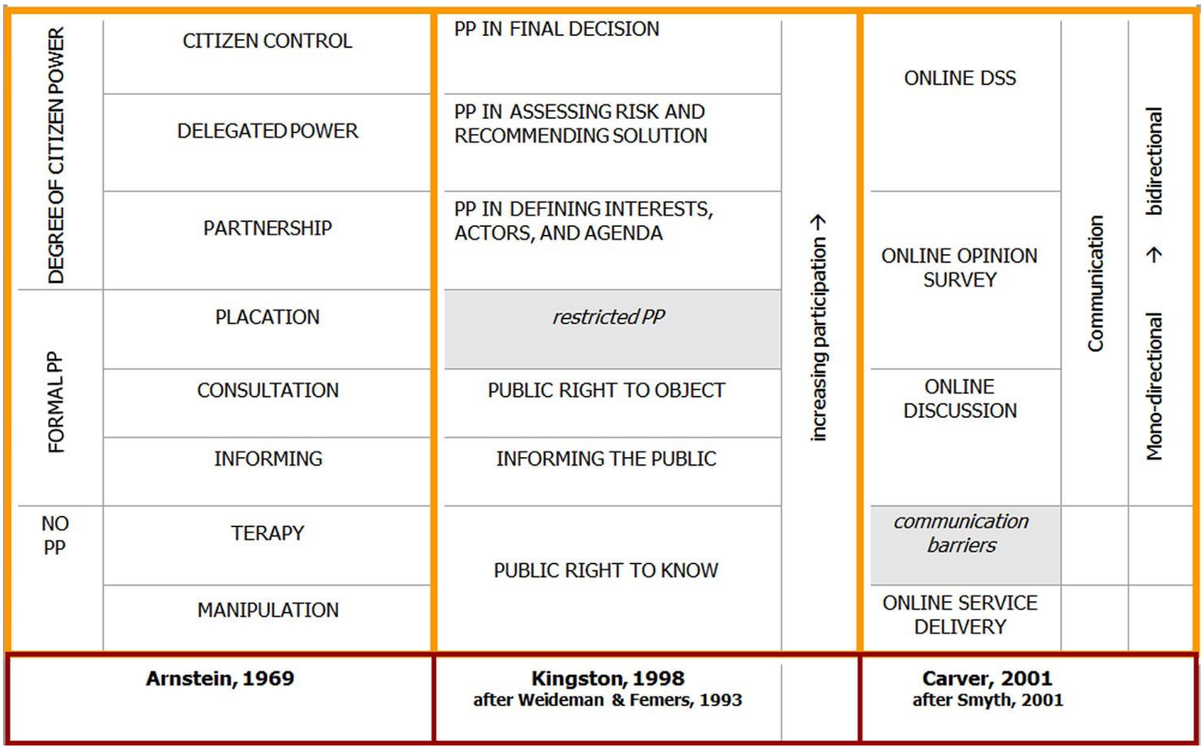

Figure 4. The Arnstein's Ladder of citizen participation revisited in the information age.

While the Arnstein's Ladder (Arnstein, 1969) can be still considered a reliable model to describe different degree of participation, ranging from none to full citizen control, most recent studies propose its revised application to the realm of current digital practices in spatial planning (Carver, 2001; Kingston, 1998). As shown in Figure 4, Kingston (1998) and Carver (2001) argue that the highest levels of participation are achieved when citizens are actively involved in designing possible alternatives and in making decisions. However, the latter models did not contribute much to clarifying how public participation intervenes within the different phases of a planning process. Indeed, the contribution of the local community, or the people of the place (Steinitz, 2012) can affect different stages and tasks of the process: local knowledge can be collected to integrate with expert surveys, aimed at the description of the current state of the environment and of the ongoing territorial dynamics; the interests and needs of the citizens can be encoded in risk and/or suitability analyses aimed at guiding the design of future alternatives; or members of the local community can collaborate to propose changes, to assess their impacts and eventually take part to decision-making. Having a clear framework in mind can help everyone to better understand these facets and possibly to better understand the opportunities and functioning of public participation in spatial planning, design, and decision-making.

In the light of the above premise, this paper describes the process of a geodesign workshop held in May 2016 on the future of the Cagliari Metropolitan Area in Italy. The workshop shows how it is possible to involve teams of members of the community in what is perhaps the most critical (and least understood in its dynamics) phase of a spatial planning process, that puts knowledge into action through the design of future change alternatives. After the geodesign framework (Steinitz, 2012), which informed the Cagliari geodesign study, is outlined in Section 2, Section 3 shows how the process unfolded, from data preparation to the creation of a final agreed design solution. Section 4 proposes a final review of the results and issues for further research.

2.2 The Geodesign Methodological Approach

Geodesign (GD) is a novel methodological approach to design and decision-making in urban and regional planning which is deeply rooted in the geographical sciences. While not strictly essential, geodesign usually relies on extensive use of (geographic) digital methods and tools.

In general, geodesign can be defined as a process which integrates analysis, evaluation, design and decision support techniques using enabling technologies for planning built and natural environments. Given the complexity of the issues commonly involved in planning processes, geodesign studies should ideally be carried out by multidisciplinary teams made up of design professionals, experts in the geographical sciences, information communication technology specialists, and, last but not least, members of the local community, who can provide invaluable knowledge and values to inform design and to help create consensus on decisions.

From the perspective of methodology, Steinitz (2012) proposed an operational framework for geodesign (GDF) which starts from detailed representation and analysis of the territorial context aimed at understanding territorial dynamics, in order to highlight opportunities and risks of development, so informing the design of possible future states or courses of actions. The framework also includes assessment of potential impacts of change which should inform negotiation during the decision-making process in a collaborative and interactive manner. All the aspects of participation (e.g., knowledge building, collaboration, expressing values and interests, mediation, negotiation, consensus) which inform different participatory planning models (e.g., advocacy planning, transactive planning, communicative) (Khakee, 1998) may potentially be included. However, a geodesign process is never the same: it should always be tailored to the local context through meta-planning (Campagna, 2016c). Thus, participation may assume many different facets in its application to local processes.

Implementation of geodesign in spatial planning at various scales and within different contextual settings for decision-making has been tested by Steinitz in many case studies (Campagna, Moura, et al., 2016; Nyerges et al., 2016a; Rosanna Rivero et al., 2015a), based on his framework. The GDF is structured in six models: the first three models, constitute the assessment phase, describing the current conditions of the territorial context and their possible evolution without new actions, while the last three models, constitute the intervention phase, which aims to identify how the study area should be altered in order to improve the current conditions if needed.

More specifically the Representation Model (RM) describes the study area in its current state, the Process Model (PM) identifies and analyses the possible evolution of the territorial context with no interventions (i.e., the do-nothing alternative), while the Evaluation Model (EM) assesses the identified processes in order to find possible risks and opportunities for future change. Then, in the assessment phase, a Change Model (CM) is built to design possible alternative future states for the study area, which are then assessed in order to find potential environmental, economic or social impacts through the Impact Model (IM). Eventually consensus among the decision-makers and the other stakeholders on a final choice can be achieved through a negotiation process which is supported by a Decision Model (DM). While the process is not necessarily strictly linear, to perform a complete geodesign, study three iterations should be undertaken, driving the six models from the first to the sixth, or in reverse order. The first iteration aims to identify the case study purpose and this can be considered as a scoping of the study; the second iteration passes through the six steps in reverse order and should clearly define how to carry out the study in terms of methods and tools depending on the needs of the specific planning study, this can be considered as a meta-planning phase. Then, during the third iteration, the study is fully carried out. During a study, the results of the design and the impact analysis can be shared among the stakeholders and visualized in form of maps, charts and graphs (Ervin, 2011) to aid participation. Feedback offers the stakeholders the possibility not only to improve their own designs, but also to collaborate to reach a solution acceptable to all parties.

The application of the geodesign methodological approach seems to be currently highly relevant because of its strong potential to positively affect the way planning processes should be carried out in Europe according to the Directive 2001/42/EC on Strategic Environmental Assessment. Geodesign may contribute to addressing many of its current pitfalls (Campagna & Di Cesare, 2016), including those relating to the involvement of the public in the decision-making process, which are most relevant to this paper.

2.3 The Cagliari workshop

The “Geodesign Workshop on Future Scenarios for the Cagliari Metropolitan Area” took place in May 2016 at the Civil and Environmental Engineering and Architecture Department (DICAAR) of the University of Cagliari (UniCA), Italy, in the form of two intensive planning studio days. The geodesign framework was customized to the local decision-making context in order to develop collaborative sustainable future scenarios for the Cagliari Metropolitan City, recently established by Sardinian Regional Law n. 2/2016. The new metro area is located in the southern coastal part of Sardinia (Italy) and is composed of 17 municipalities. Workshop preparation started in January 2016 with close cooperation in the local coordination team, which included a dozen local experts in architecture, planning and environmental engineering, including the authors of this paper.

During the first phases of the study, the coordination team identified the boundaries of the study area and its relevant territorial context, the primary goals for its future development, and the main ongoing territorial dynamics: the *scoping phase* of the study (i.e., the first iteration through the framework). Second, the methods and the tools to be used in the geodesign models implementation were selected (i.e., second iteration). Next, the representation, process and evaluation models were built (i.e., third iteration). It should be noted that this part of the process was implemented by the geodesign team of experts, but citizen participation could have been part of these phases if the study had been organized differently.

In order to carry out the intervention phase (i.e., CM, IM, DM) of the third iteration of the GDF, an intensive two-day workshop was organized. Thirty-two people, including academics, technical representatives of public authorities, local planning professionals, and students of architecture and civil engineering participated. The group was selected on the basis of the two main objectives of the workshop: to understand and further test the application of the geodesign methodology, and to rapidly identify central issues, options and choices as a basis for further studies and planning. In order to simulate local decision makers, the participants were divided in six teams representing major local stakeholder groups. All of them played a primary role in the design and during the intervention part of the GDF third iteration. The coordination team, who had prepared the early phases of the study, limited its role to coordination at this stage.

The collaborative work was supported by a web-based application called Geodesignhub (*Geodesignhub*, n.d.). Its architecture combines the concepts of Planning Support Systems (PSS) (Harris, 1989) and web 2.0 principles to perform in an integrated and collaborative way the last three models of the GDF. It uses the representation, process and evaluation models, previously prepared with professional GIS desktop application by the coordination team, as input. Geodesignhub represents a promising way to approach the complexity of the participatory design and decision-making processes. A more detailed review of the capabilities of Geodesignhub as compared to other similar planning support tools can be found on the "Sketch Planning Tools for Regional Sustainability" report (Avin, 2016). Indeed, it integrates state of the art technologies into the geodesign workflow, providing - through a user-friendly interface and social networking capabilities - the means to facilitate the collaboration of non-expert participants of various backgrounds and skills, to work intuitively and quickly on design and negotiation.

2.3.1 The Cagliari metro area

Since Italian Law 7 April 2014 n.56 became effective, some Italian cities and their suburbs formed a new local government level, the so called "metropolitan cities". Given its special status of Autonomous Region, the Sardinia Regional Government had to transpose the national principles relating to the establishment and management of these new jurisdictions. Accordingly, the Regional Law 4 February 2016 n.2 created the Cagliari Metropolitan City, defining its functions and responsibilities, as well as its boundary, which includes 17 municipalities around the region's capital. From the spatial government perspective, a metropolitan strategic plan should be adopted as a regulatory and coordination tool for the development of the area. The workshop represented the first design effort to understand central design issues, opportunities and options.

Figure 5. The Cagliari Metropolitan Area

The area is located along the southern coastal edge of Sardinia, Italy (Figure 5), represents an important economic and social attractor for the whole island. In addition, during the last decade the number of tourists visiting the region increased. Thanks to its location on the lower fertile plain of Campidano and facing the gulf called Golfo degli Angeli, the Cagliari Metropolitan City contains highly diverse natural and cultural landscapes and offers a rich variety of agricultural and fishery activities that characterized the important food tradition of the whole region. The area has the highest population density in Sardinia; however, the landscape is not affected by excessive vertical or volumetric occupation. In 2011, the total population was approximately 420.000 people (Census ISTAT 2011). According to the 25-year demographic projections carried out by the coordination team until 2036 (the established time horizon for the study), there will be a growth of about 25.000 inhabitants (i.e., growth rate +0.055). An additional moderate population growth was considered as a result of policies included in the pro-development scenario of this study, resulting in an estimated total of 50.000 new people in a +25-year target.

2.3.2 Pre-workshop phase

The workshop organization was carried out by the local coordination team, with the aim of constructing the knowledge base (i.e., RM, PM, EM) in a consistent format with the Geodesignhub input requirements.

The first step was to specify three main objectives for the Cagliari Metro Area development scenario in a twenty-five-year time horizon:

- Tourism development: intended as the valorization of existing coastal tourism facilities and their improvement in less equipped areas;
- Agrifood: intended as the valorization of the local agricultural areas, promoting sustainable agriculture, and also the implementation of new tourist itineraries connected to agricultural, scenic and cultural assets, traditional production methods, and gastronomic heritage. This objective aims both to extend the tourist offer and to keep the rural territory alive;
- Cagliarifornia: intended as the creation of an ICT industry pole able to create new job opportunities and to attract new population, given the presence in the area of existing industry in this domain.

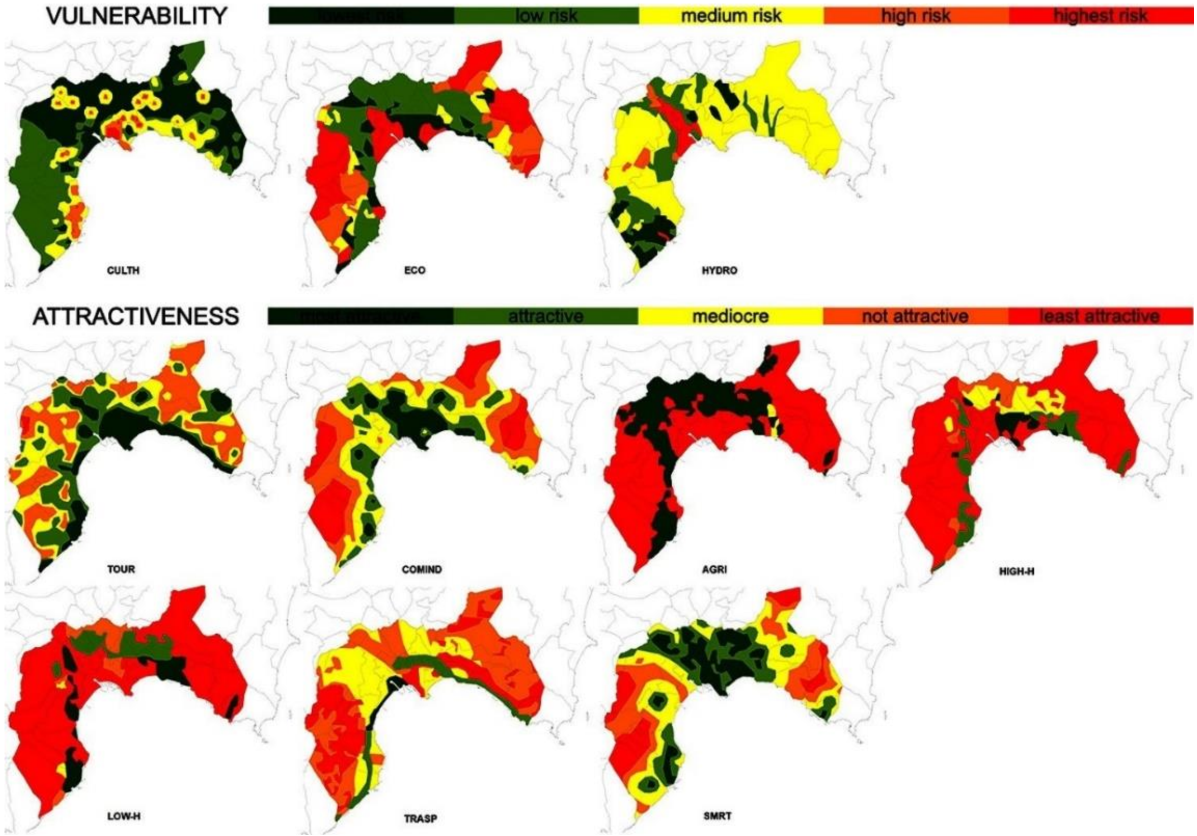

Figure 6. The ten evaluation maps in the geodesign workshop.

In order to describe the main characteristics of the territorial context, ten spatial systems were selected. The choice was based on analysis of the regulatory framework and adapted to the development scenario. Three vulnerability systems were chosen, namely: cultural heritage (CULTH), ecology (ECO), and hydro-geological hazard (HYDRO). In addition, seven attractiveness systems were considered: tourism (TOUR), agrifood (AGRI), transport (TRASP), low-density housing (LOW-H), high-density housing (HIGH-H), commerce and industry (COMIND), and smart services (SMRT). Each system was analyzed starting from the description of its current condition (i.e., RM) and its evolution dynamics (i.e., PM), to the evaluation of the territory in terms of each system (i.e., EM). This gave workshop participants ten evaluation maps (Figure 6) to inform the design. All the EM maps were created by experts through land suitability analyses in a desktop GIS environment, with the aim of identifying the inherent aptitude of the territory. The preparatory phase of the workshop (the first part of the geodesign study process) was carried out using a typical rational comprehensive planning approach (as defined in Khakee, 1998). However, while most of the spatial information used to create the knowledge base was retrieved from the Regional Spatial Data Infrastructure (R-SDI), in this phase the coordination team decided to test the use of passive social media geographic information (Campagna, 2016b, 2014). The TOUR evaluation model was informed by the indirect preferences expressed by social media users to different tourism locations. The use of social media (e.g., Booking, Panoramio, etc.) to account for public values and preferences can be considered a form of input by the community, though involuntary.

The ten EM maps adopted the same color code. The vulnerability maps classified the study area in five vulnerability levels, where red areas indicated those characterized by a very high vulnerability, in which only actions aimed at preserving these sites can be permitted, and the dark green areas are the least vulnerable ones, in which do not present any restriction in use. Likewise, the seven attractiveness maps classified the study area into five levels, but in this case the dark green color identified very highly attractive areas for developing action in that system, and areas depicted in red identified those of very low attractiveness. The ten EM maps were then uploaded in the GDH platform as a common knowledge base to inform the design. The design then became the responsibility of the workshop participants, initiating the participatory part of the study.

In addition, as part of the assessment phase, a cross-system impact matrix was compiled by the local coordination team to identify the positive or negative impacts of each single change action on over the ten systems (Figure 7**Errore. L'origine riferimento non è stata trovata.**). This matrix was also uploaded in the platform, enabling real-time calculation of the performance of each design proposal during the workshop.

System #	SYSTEM CHANGE \ SYSTEM EXISTING CONDITION	1 CULTH	2 ECO	3 HYDRO	4 TOUR	5 COMIND	6 AGRI	7 HIGH-H	8 LOW-H	9 TRASP	10 SMRT
1	CULTH	0	0	0	2	-1	0	-2	-1	-2	-1
2	ECO	0	0	1	0	-1	-1	-2	-1	-1	1
3	HYDRO	-2	1	0	1	1	2	1	1	1	1
4	TOUR	-2	-2	-2	0	2	1	-1	-1	2	0
5	COMIND	-2	-2	-2	-2	0	-1	1	0	-2	-1
6	AGRI	0	-1	-1	2	1	0	-2	-1	-1	0
7	HIGH-H	-2	-1	-2	-1	2	-2	0	-2	-2	1
8	LOW-H	-1	-2	-1	-1	1	-2	-1	0	-1	0
9	TRASP	-2	-2	-2	2	2	1	2	2	0	2
10	SMRT	-1	-1	-1	0	2	-1	2	1	-2	0

IMPACT MODEL	
2	most positive, best
1	positive, good
0	neutral
-1	negative, bad
-2	most negative, worst

Figure 7. Cross-system impact matrix.

2.3.3 The workflow of the Geodesign Workshop

A total of thirty-two participants were selected by the organizers to form a multi-disciplinary team, including scholars, students and local stakeholders from the public and the private sectors. As an introduction to the upcoming workshop, an open lecture given by Carl Steinitz was organized at the University of Cagliari to present the Geodesign concept and framework and their application in a number of previous international case studies.

At the very beginning of the workshop the local coordinator introduced the study area, the main objectives of the development scenarios, and the ten evaluation maps, which were already available as a digital common knowledge base from which to start the design. As emphasized before, the geodesign approach provides a workflow based on applying territorial knowledge to address planning problems from an interdisciplinary point of view, and to make informed and evidence-based designs and decisions.

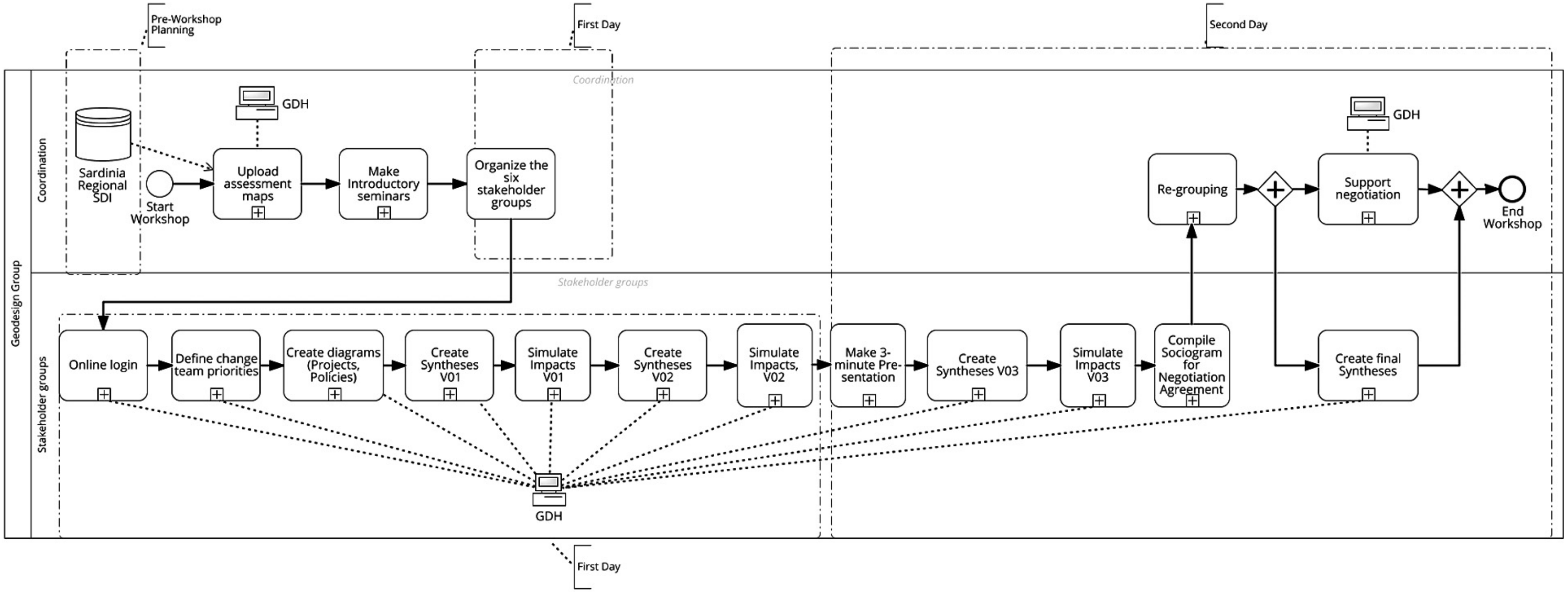

Figure 8. The workshop workflow represented with standard Business Process Model Notation.

The organizing team established the workshop schedule, which concentrated complex design tasks into an intensive and time-constrained workflow agenda (Figure 8). A collaborative PSS is most useful when applied at the beginning of a study of considerable complexity. Given the scale and complexity of the Cagliari metro area and the number of actors involved, the conductor emphasized that in this phase of the planning process speed is more important than accuracy. In the first phase, the participants were arranged in six groups, each one with a different viewpoint to guide their decision-making, (Table 1, Figure 9) and with at least one member of the local staff offering technical support and advice throughout the process.

Table 1. The six stakeholder groups in the Geodesign Workshop.

Groups	
Metropolitan government	METRO
Regional government	RAS
Green NGO	GREEN
Cultural Heritage Conservation	CULTH
Developers	DEV
Tourism Entrepreneurs	TOUR

Each member of each team logged-in and got familiar with the online GDH platform. The first task that needed to be carried out was the definition of each group's change priorities according to their specific role and interests in the decision process (Figure 10). They were asked to prioritize – in rank order – the ten systems, through discussion or by using methods for consensus-building (e.g., Delphi Method).

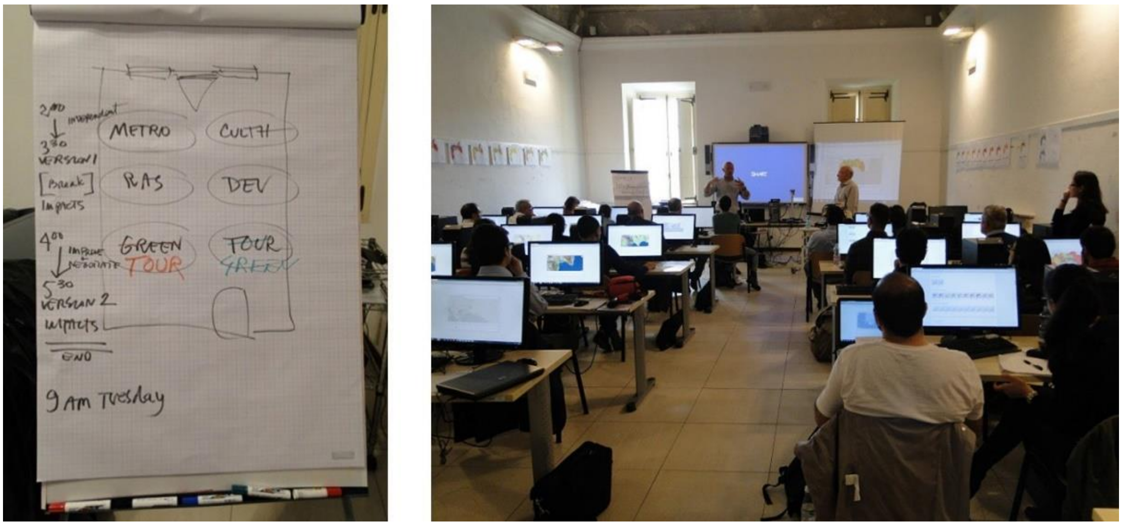

Figure 9. The six teams and their locations in the classroom during the workshop

Figure 10. The different Decision Models for the six groups.

Participants in each team were asked to produce a number of geo-referenced diagrams each one representing a conceptual design proposal related specifically to its system. This marked the beginning of the design part of the study, where participants could exploit the innovative potential of the GDH PSS. GDH enables two types of design interventions: projects and policies (Figure 11). Projects are proposed physical changes in the territory shown by a solid block of color, while policies represent decisions and actions that will not have a physical expression, and are shown by areas of color hatching. The GDH platform includes a sketching tool for drawing lines and polygons, and visualizes changes in the geographic space in real-time, facilitating the assessment of their impacts. Expert and experiential spatial knowledge acquired during the assessment phase of the geodesign framework directly influences the change models by giving guidance to the designers. The EM maps were available as base maps in the software design window, providing a color-coded evaluation of the current development opportunities and risks in the area for each of the ten systems. The proposed projects and policies, referred to as *diagrams*, could be created by an individual stakeholder's initiative or as the result of early negotiations among team members.

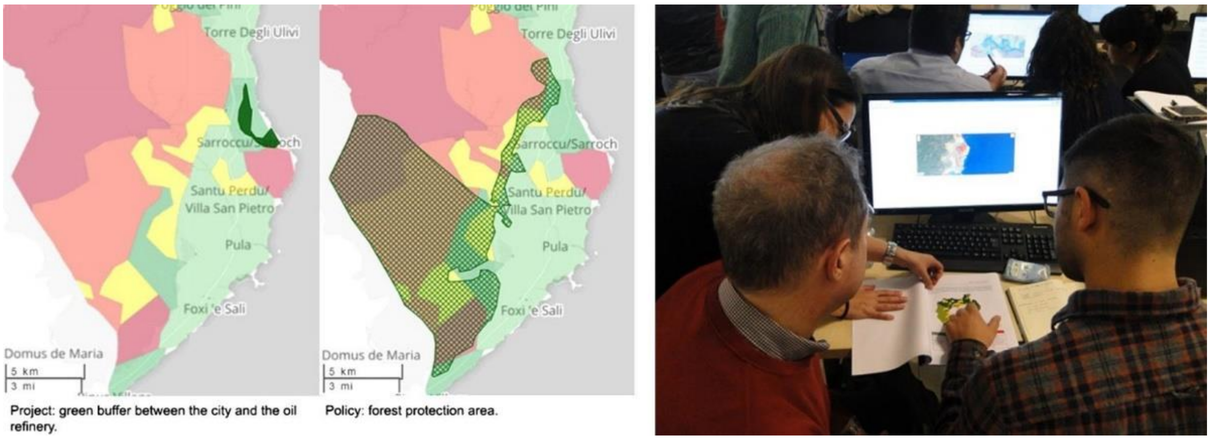

Figure 11. Projects (left) and policies (right) examples overlaying the Evaluation Models of the relevant system as base map.

About 200 diagrams were created in this first stage. They were systematically organized in a matrix by the software, positioned in the column of the related system in chronological order of creation, and shared in real-time among all the participants. At the end of the first morning, each group was asked to select a group of projects and policies (a *synthesis*) in line with their development goals and interests from all the 200 diagrams in order to create their first change scenario. The GDH online platform not only supports rapid syntheses, but it also computes real-time impact assessment providing immediate feedback on scenario performance, creating the opportunity to rapidly revise the choices (Figure 12). More specifically, a series of maps and histograms shows: i) the direct impact of a change in one system both on itself and on the other systems on a three-value scale, from positive (i.e., purple) through neutral (i.e., yellow) to negative (i.e., orange); ii) how the designs perform in light of the target goals; iii) the total cost of implementation. Furthermore, the tool enables dynamic updates to the evaluation maps as the synthesis is assembled, instantly displaying the connections between systems and the changes over the initial conditions.

Steinitz (2012) argues that the first design will never be the best one and that the synthesis process should be repeated at list three times to find an improved alternative: the second synthesis is usually better than the first one, and the third is usually the best. Hence, the possibility to rapidly revise and assess the change models represents one of the central advantages of using digital geodesign technologies to support a dynamic workflow. Accordingly, a second and a third design cycle took place, and the six teams could quickly and easily change their syntheses by modifying or creating new diagrams and adding or removing projects and policies until an agreed solution with acceptable impact performance was found.

Figure 12. Real-time impact assessment visualization.

After each round of syntheses was completed, each team leader made a three-minute presentation to explain the main features of their group design synthesis. It was possible to notice how in the evolution from the first to the third version, the designs were gradually moving in some cases towards more similarity, in others towards highlighting conflicts. At this stage, the built-in tools for effective visual or quantitative comparison of the alternative scenarios facilitated the early stages of the negotiation process (Figure 13). Eventually, not without some vigorous discussions, the teams reached agreement on a final synthesis.

Maps and graphs enabled the participants to analyze more deeply each design version and to find differences and affinities between the groups (Figure 14). This comparative analysis greatly facilitated the efficient utilization of coalition/sociogram techniques (Rosanna Rivero et al., 2015a) with the aim of identifying compatibility or conflicts between the groups. The tool is a matrix where each team could give a value from -2 (disagreement) to +2 (complete agreement) to the other groups according to the compatibility of their designs (Figure 15).

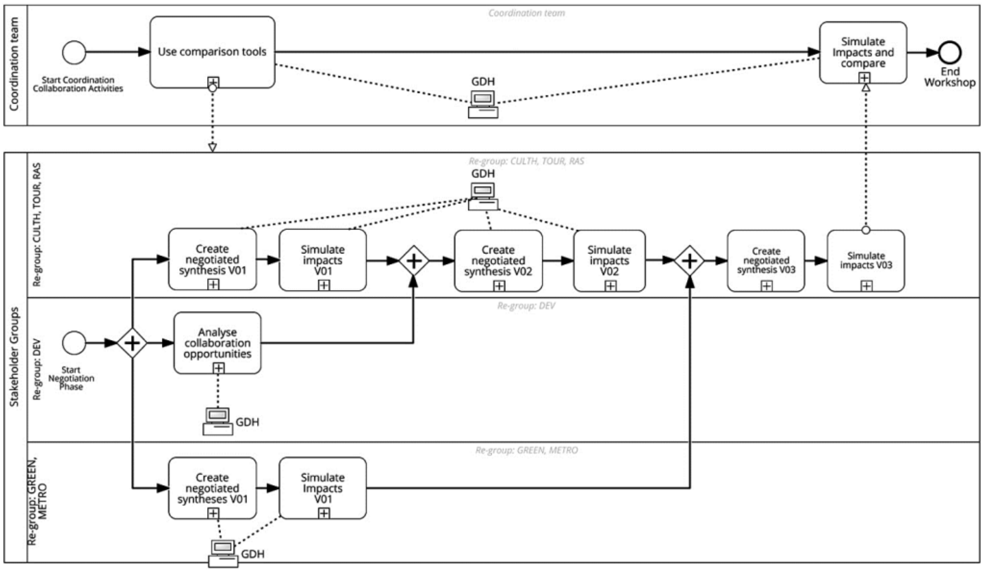

Figure 13. The negotiation phase described with stardard Business Process Model Notation.

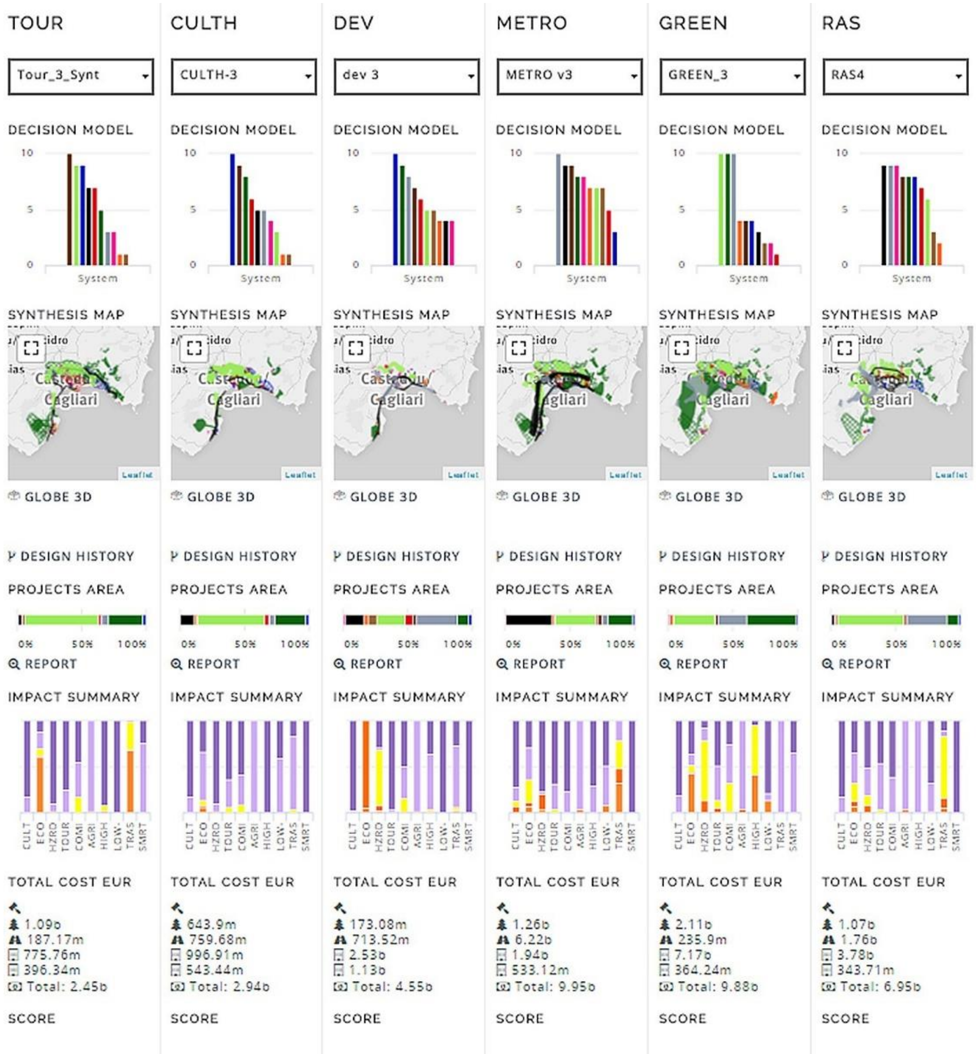

Figure 14. The scenarios comparative tool showing the impacts performance of the six designs.

The results obtained by this approach immediately showed a first coalition that led the stakeholder teams of TOUR, CULTH and RAS to join together in a super-group displaying strong affinity among them. A second less robust alliance was formed between GREEN and METRO. The Developers remained outside the coalition-building process obtaining negative assessments from all the other teams. The two affinity groups started their negotiations, while the Developers, at first, began to think about how they should move forward on this particular situation. They eventually decided to accept compromise and to collaborate with the strongest group. Agreement for Cagliari metro area future development was reached within the coalitions through dialogue and mutual understanding which resulted in the creation of two alternatives and combined solutions. Because of the noticeable convergence towards similarities in the two designs at that point, a third process of negotiation was launched among all the participants aimed at agreeing a single final design. In such a situation, the conductor played an important role in the collaboration/negotiation phase by encouraging mutual understanding, ensuring wider and more efficient communication, and avoiding bottlenecks in the process. At the end of the second day of the workshop, an agreed +25-year change design was created (Figure 16). Then, with the support of GDH visualization tools, it was compared with the frequency map which shows in a single solution all diagrams selected in at least three different alternatives during the third round of syntheses. The two maps present many common diagrams and show the same hotspots of interests.

Figure 15. The Sociogram for Negotiation Agreement.

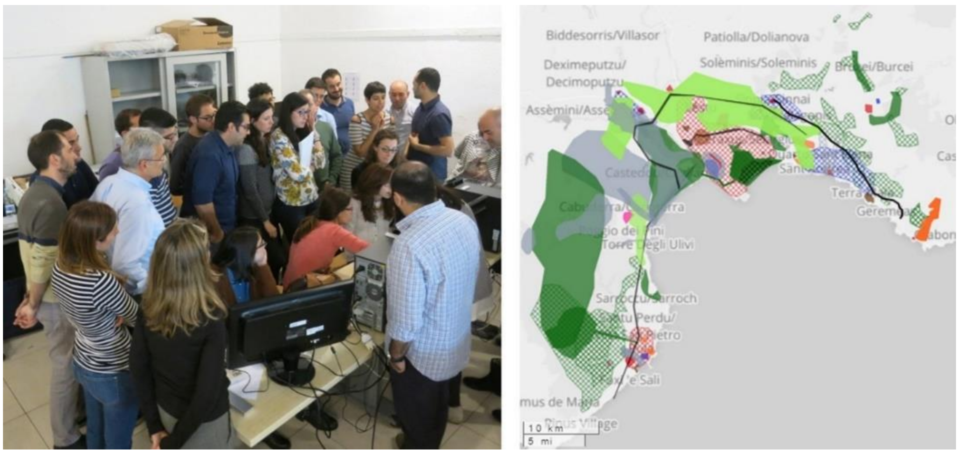

Figure 16. The negotiation process among the stakeholders and the final agreed design.

2.4 Conclusions

Over the last two decades or less, the diffusion of the Internet and the Information Communication Technologies (ICT) has opened new possibilities for public participation in many government domains, including spatial planning. Overcoming space and time constraints and digital divides which exist in many countries can pose challenges. Many factors affect the success or failure of digital participation initiatives. Among them, the adoption of suitable methods and tools plays an important enabling role. Geodesign methods and related technologies seem to have broad potential for contributing to collaborative design. The study presented in this paper was developed within an academic research setting and demonstrates the functioning of a geodesign process and its enabling technology. Other studies using the same approach and technology proved to be successful in actual practice. Although limited in complexity, this study is useful to demonstrate and describe the functioning of the geodesign process and its potential.

The collaborative method and technology presented in this paper can support participation especially in some specific working situations such as i) when working through a framework in order to understand it, ii) when there is little time and small data, iii) when starting fast to identify central issues, options and choices, iv) when it takes an experimental design to know what the questions really are, and v) when it takes a design to understand what is really wanted. Conditions i), iii) and iv) particularly apply to the Cagliari metro area workshop. In other situations, especially in ii), extending participation into the knowledge building phase of the project, including the creation of the representation, process and evaluation models can be appropriate. The latter part can be the subject of further research, especially from the perspective of using other social media networking platforms and tools to involve the citizens in volunteering data about the physical environment, about ongoing environmental and social processes, and about community values, preferences and need.

Chapter 3 Geodesign Process Analytics: focus on design as a process and its outcomes

This chapter has been previously published as "Cocco, C.; Rezende Freitas, C.; Mourão Moura, A.C.; Campagna, M. Geodesign Process Analytics: Focus on Design as a Process and Its Outcomes. *Sustainability* **2020**, *12*, 119".

3.1 Introduction

In recent decades, the availability of a variety of advanced digital tools for design has advanced the creative process gradually supplanting the traditional analogue pen-and-paper methods used by individual designers to communicate their ideas. The recent shift towards the development of collaborative design systems has enabled multiple designers and citizens to act together interactively (e.g., collaborative Computer Aided Design—CAD, Building Information Modeling—BIM, Volunteered Geographic Information platforms—VGI) (Arsanjani & Vaz, 2015; Hasby & Roller, 2016) to address the growing complexity of contemporary design challenges. The general trend is now to move farther away from desktop single-user solutions towards web-based interactive multi-user systems (Zissis et al., 2017). Novel technological advances are giving rise to potential new ways of designing and mapping in collaborative environments.

Computer-based support tools in urban and regional planning have moved along this trend thanks to the advances both in Information Communication and Technology (ICT) and in the planning approaches. The increasing complexity of current planning challenges requires "smart" support tools which allow creation and evaluation of design alternatives quickly and efficiently, and at the same time in a more engaging way (Pettit et al., 2018). A subset of these geo-information technologies, known as planning support systems (PSS), has met these challenges by providing support to the whole, or to some part of, complex planning processes and workflows. PSS combine a range of digital technologies to support different aspects of the planning process in an integrated way (Geertman & Stillwell, 2004a; Jankowski & Nyerges, 2001), including "computer-based tools for public participation" and collaboration among stakeholders (Steiner et al., 2012).

The use of digital information technologies and the active engagement of local communities, or *the people of the place* in the design process are two key elements of the geodesign approach (Pettit, Hawken, Ticzon, et al., 2019; Steinitz, 2012). Although traditional public participation has been a challenge in many situations (Loures et al., 2016), geodesign methods have been proven successful in engaging members of the local community in the design phase through genuine collaboration.

In the last decade, the geodesign approach to spatial planning has attracted the interest of the academic community (Albert et al., 2015; Fisher, 2016; Pettit, Hawken, Ticzon, et al., 2019), business companies (Wheeler, 2019) and institutional environments (Patata et al., 2018; Pettit, Hawken, Zarpelon, et al., 2019). Ervin (Ervin, 2011, 2016) identified "15 essential components of an ideal geodesign toolbox" associating to each of them a specific set of digital tools. Among these components, real-time digital dashboards are proposed as a tool for interactively displaying the impacts of design alternatives against desired performance criteria and, thus, offering real-time support to decision-making. These dashboards can be used to rapidly evaluate the achievement of goals or targets, or to identify at a glance potential conflicts or critical situations.

In addition, real-time digital dashboards are useful for monitoring and analysis of the geodesign collaborative process itself. Within the context of the broader geodesign analytical framework, this study focuses on the development of a set of indicators that may be used by the coordinators of geodesign studies to evaluate both the behavior and the performance of the participants involved in the process, and the evolution of the design outcomes through time. Among the objectives of this study are assessment of the achievement of performance and participation levels (e.g., number of times a participant used the sketching tool in a design support system, or to identify leading vs lagging behind participants), along with analysis of spatial relations (e.g., intersection, proximity) among design alternatives proposed by different groups of stakeholders. This is key in identifying areas of disagreement, which may help to reach consensus among stakeholders. It is argued that investigating these aspects can increase the coordinator's understanding of the process, which can, in turn, lead to improved outcomes, as well as inform future process workflows. Moreover, through this approach, it is possible to evaluate existing support tools, as well as to aid the development of new process-oriented PSS (Campagna, 2016c).

In general, traditional data collection methods used to measure design dynamics in collaborative and computer-supported processes are based on traditional data collection tools (e.g., audio/video recording, survey, etc.) (Niccolò Becattini et al., 2018; Jankowski & Nyerges, 2001), and are very demanding in terms of both time and human resources (Niccolo' Becattini et al., 2019; Blessing & Chakrabarti, 2009). However, in the contemporary information age, automated or computer-supported processes leave historical traces behind that exist in several forms, such as event logs (Zhang et al., 2018). Many commonly used design software applications capture and make available information about actions taken automatically by the system or actively by the users(Revit, 2019; SOLIDWORKS, 2016). The recently developed collaborative PSS Geodesignhub (*Geodesignhub*, n.d.) records log-data regarding the actions undertaken by the participants involved in a geodesign study and their products.

Increasingly in the last decade, organizations rely on the availability of log-data to improve and support their business processes in competitive and rapidly changing environments (Van Der Aalst, 2011). Robust process mining techniques have been developed in recent years in several domains ranging from web page contents and usage (Cooley et al., 1997; Nasraoui et al., 2008; Terragni & Hassani, 2018), education and e-learning platforms (Drlik & Munk, 2019; Wong et al., 2019)and software engineering to detect anomalies and errors in systems processes (Pettinato et al., 2019). Despite the growing interest in log-based process analysis, very few, although very promising, studies—have been undertaken to exploit the potentialities of this new data source in the design field (Niccolo' Becattini et al., 2019; Zhang et al., 2018; Zhang & Ashuri, 2018).

Taking advantage of this approach, we propose a methodology to extract knowledge from Geodesignhub log-data in order to monitor and to understand the design dynamics of a study, ultimately aiming at improving collaborative geodesign processes. Both historical and real-time log-data can be analyzed using the set of indicators developed as a part of a more comprehensive framework for a Geodesign Process Analytics (GDPA). In a previous study, we applied inferential statistics techniques for testing a subset of those indicators using log-data of an existing geodesign study (Cocco et al., 2019). Insights gained from ex-post analyses of a large number of collaborative design studies can be used to guide future cases with a view to process, design and coordination improvement.

The objective of the present study is to evaluate whether the analysis of information on the ongoing design dynamics, as recorded in the Geodesignhub log-data and made available in a timely and user-friendly manner through dashboards, can help improve the real-time management of geodesign processes. Several steps are necessary to collect, prepare, and analyze log-data to extract useful information about the current process unfolding. Hence, this paper's structure is organized as follows: in Section 2 the main phases and the characteristics of the log-data of the PSS Geodesignhub are presented; Section 3 is entirely dedicated to the proposed analytical process, from data extraction methods to the detailed description of the indicators, a subset of which was tested with the log-data of the Cagliari case study and presented in Section 4.

3.2 Novel Methods, Tools and Type of Data

3.2.1 Geodesignhub System

The Geodesignhub PSS (Ballal, 2015) was specifically designed to implement the Steinitz's framework (Steinitz, 2012) digitally, enabling dynamic interactive and collaborative design. Its use was tested in a variety of settings (Araújo et al., 2018a; Nyerges et al., 2016a; Pettit, Hawken, Zarpelon, et al., 2019; R. Rivero et al., 2017) and it proved to be particularly useful in the early strategic stages of urban and regional planning. It creates a user-friendly collaborative working environment where in a very short time, multiple stakeholders, with different backgrounds and views, can present their project proposals (i.e., create diagrams representing projects and/or policies), assemble them in integrated complex plan alternatives (i.e., syntheses), and compare them in order to negotiate compromise solutions based on consensus. As such, it enables the rapid development of strategic plans where the design of short-term actions is spatially explicit. This possibility overcomes some of the main pitfalls of strategic planning (Albrechts, 2004; Mintzberg, 1993), including the lack of cross-fertilization and mutual understanding of strategies and short-term actions among stakeholders, the length of the process, and the often vague verbal nature of its outcomes.

In practical terms, Geodesignhub is most often used to support two-day geodesign workshops where the main actors involved in a planning process can interact through the platform. The platform in principle has no limit in terms of number of participants, and workshops with up to about seventy participants have been successful. The typical workshop is divided into three main phases (supported by tools available in Geodesignhub):

1. creation of design proposals in the form of georeferenced project or policy diagrams (using the “sketching and visualization tool”), organized by systems (e.g., agriculture, housing, etc.) each in its own colour;
2. creation of design alternatives (using the “design creation tool” and the “compute detailed impacts tool”), usually by up to six teams, each with its own objectives, who select a set of diagrams and test their performance with an impact assessment interactive dashboard including maps and charts;
3. resolving conflicts and negotiating (using the “comparison tools” and the “negotiation tools”) towards a final common design based on consensus.

The objective of the workshop is twofold: enhancement of understanding of complex planning problems through dialogue and collaboration eventually leading to agreement on a spatial development scheme. The latter will represent those short-term actions (Albrechts, 2004) which constitute the back-bone of the implementation of mid-long term strategies.

A geodesign workshop using Geodesignhub demands a fast-paced iterative workflow and can involve many participants. It is essential for the coordinator to manage the schedule take best advantage of all the participants interacting together (either physical or virtual). In general, and more specifically in workshops with many participants, or in large virtual online workshops, the coordinator’s ability to make sure all the participants are engaged and productive is critical. The availability of a real-time dashboard monitoring of participants’ performance can be of substantial help in aiding the coordinator. The following part of this section describes the main characteristics and data structure of the Geodesignhub log-data, which provides the foundation on which the dashboard monitoring is built.

3.2.2 Geodesignhub Log File

A “log file [is] a computer file that contains a record of all actions that have been done on a computer, a website, etc.” (Press, 2011). Several current information systems and software applications automatically store information about *events* occurring as a result of a user’s action or a running process. Log files represent a valuable source of data to aid understanding of the history of processes. The use of process mining techniques is widely spread in many domains (Van Der Aalst et al., 2012). The logs can use standard or proprietary - and more or less structured - text formats (e.g., common log format, XML, JSON, etc.). Notwithstanding the different formats, log-data always include information relating to each specific activity and task (i.e., event) that occurs within the process workflow. Additional properties are usually recorded, such as the timestamp and information about the user or the device executing the actions.

More recently, the use of log-data has been applied in the design support systems domain on the premise that each command executed by a designer in a working session can be though as an event in the field of process mining, thus an action potentially interesting for analysis (Zhang et al., 2018). Large numbers of commands are often needed to complete a task in computer-aided design software and systems (e.g., CAD, BIM, GIS, PSS, etc.). The number/sequence of commands and the average time taken by a designer to execute a task can be analyzed to understand recurrent patterns in users' performance and design teams' collaboration behaviors. A study to analyze users' productivity performance in the BIM software Autodesk Revit used a log-data database containing information about 25 designers who produced (executed) at the micro-level more than 20,000 design events (/commands) to complete 13 architectural projects at the macro-level (Zhang et al., 2018).

In advanced Planning Support Systems, such as Geodesignhub, information on participants' and teams' actions is closely related to the semantics of the design task at the macro-level, that is to macro-tasks, whose execution originates a meaningful design element (e.g., diagrams created, or diagrams selected in the syntheses). Geodesignhub log-data are, therefore, a collection of diagrams directly resulting from users' actions (i.e., "create, "select"), and thus worthy to be considered as events in process mining. The design elements generated by the software semantically represent individual project and policy, encoded and stored in the system database as polygon spatial features. The data structure of a diagram (Figure 17) differs from traditional geographic information because it combines the traditional spatial components with the temporal dimension (i.e. timestamp, project implementation timing), user information and preferences (i.e. author, system priority weight), as well as the thematic attributes (e.g. type, system they belong to), and in some cases complementary multimedia data (i.e., photo, video, tag). In many ways, it is possible to compare Geodesignhub diagrams to the spatial user generated contents retrieved from social media platforms (Campagna, Floris, et al., 2016). The potential of both new types of data within the design domain is promising, and the analytical framework we are proposing may represent a first effort to fully exploit the possibility offered by the Geodesignhub log-data.

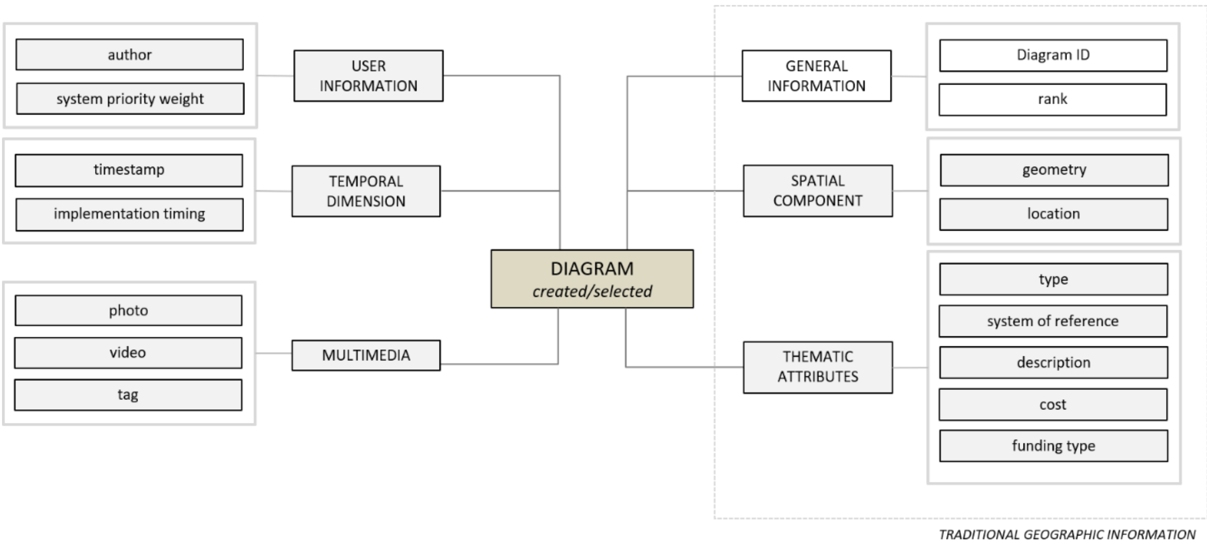

Figure 17. Geodesignhub diagram data structure.

3.3 Analytical Process.

3.3.1 Geodesign Process Analytics

The peculiar data structure of the Geodesignhub log-data provides unparalleled opportunities to analyze geodesign studies. In order to provide the basis for the development of a comprehensive geodesign analytical framework (i.e., Geodesign Process Analytics or GDPA), we focused on the two meanings of the term design, as stated by Steinitz (Steinitz, 2012): design as a verb, highlighting the importance of the *process* itself, and design as a noun, identifying its *product* (Figure 29). Unlike other type of design software, such as CAD or BIM, information on participants' interactions with the Geodesignhub platform is obtained indirectly by looking at the results of their actions.

On the one hand, diagrams are seen as the fundamental products of a geodesign study and analyzed with regard to geometry, the system they belong to (e.g., Agriculture, Housing, etc.), or other characteristics to assess their individual design quality and the spatial relations between them. A set of spatial analysis models, previously proposed by Freitas and Moura (2018), is extended here in order to create spatial indicators useful to identify in real-time possible conflicts of interest among stakeholder teams (i.e., incompatible land-uses).

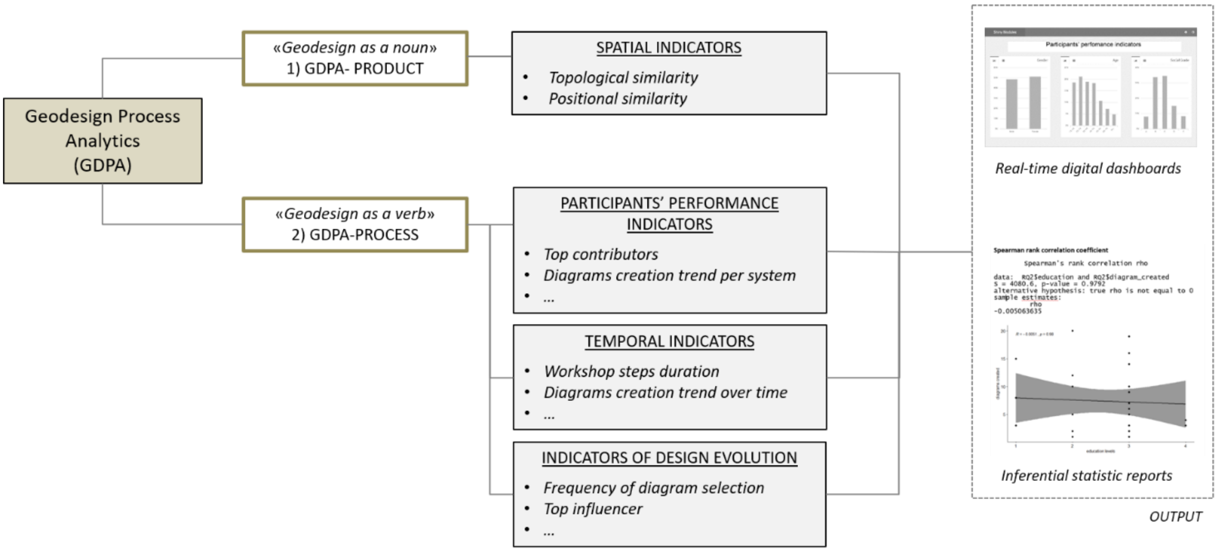

Figure 18. Methodological framework for Geodesign Process Analytics.

On the other hand, diagrams are considered as design events each representing a task carried out by a participant (i.e., create a diagram; select a diagram). The quantity of diagrams created or selected can be used to analyze the productivity of the workshop participants and the evolution of the design alternatives. Temporal information of the diagrams allows evaluation of a participant's behavior and performance over time. The analytical process presented in the following sections aims to extract useful information on the design *product* and *process* from the Geodesignhub log-data. This process includes data collection, preparation, analysis and the use of spatial analysis and statistics techniques to derive useful insights from this information (Figure 19).

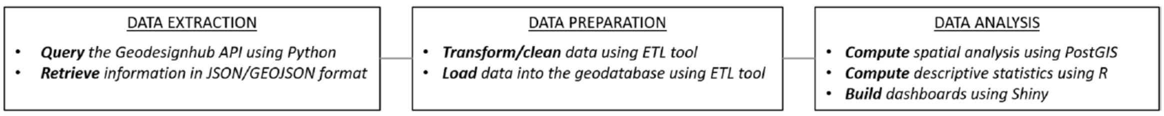

Figure 19**.** The main steps and tools defining the analytical process.

The proposed methodology is only the first step towards developing a complete Geodesign Process Analytics, yet it offers a set of useful indicators and measures to gain insights on the design dynamics and patterns that drive participants' actions and their results in a typical workshop workflow. We argue, in fact, that the new knowledge gained from log-data analysis can help the workshop coordinator i) to evaluate the participants' performance during the ongoing process, and ii) to discover meaningful patterns and trends in post-workshop analyses. Since (geo)design processes are now observable and measurable, ongoing or future processes can be potentially improved on the basis of an empirical understanding of their dynamics. Statistical analytical techniques were applied to the performance, temporal and design evolution indicators proposed in this study. Some of them are more suitable to support the coordinator in real-time in their role of facilitating the process, while others aid post-workshop analysis of the design process itself and in comparisons with other studies. This study focusses on the use of descriptive statistics and interactive dashboards aiming to provide quick and simple real-time updates to the coordinator of the workshop, whose fast pace workflow requires fast-moving attention. Indicators have not been designed to automate decisions but rather as warning systems able to inform the coordinator about potential issues in the process that may require further attention.

3.3.2 Data Extraction

Geodesignhub exposes its log-data via API. Information related to project objects is made available, including: diagrams (e.g., details of all diagrams created in a project); change teams (e.g., list of all diagrams selected in a group synthesis); the project in general (e.g., list of participants that took part in a project); systems (e.g., details of all systems considered in a project). The API is JSON-based and all the requests return GeoJSON files. The Python *urllib2* module was used to query the API and retrieve information useful for analyzing the design process. An excerpt of the GeoJSON file containing details of all diagrams that were created in a project is shown in Figure 31. Spatial and non-spatial components of a GeoJSON object (i.e., FeatureCollection) are stored in the one-row GeoJSON string. In this example, the "diagramid" is the unique identifier assigned by Geodesignhub platform and the "author" information were omitted for privacy. Information on other project objects were similarly retrieved and saved in JSON or GeoJSON formats.

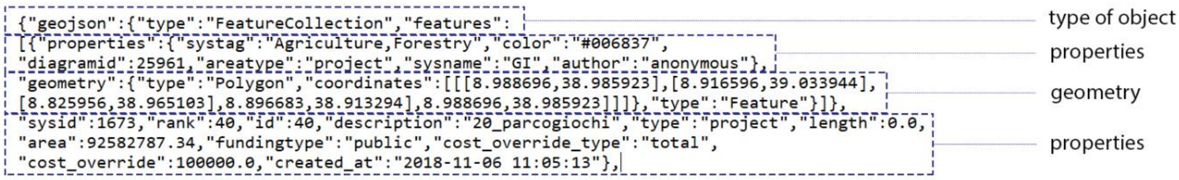

Figure 20. Excerpt of the GeoJSON file containing details of all diagrams created in a project.

In addition, the plug-in Geodesignhub Dashboard is accessible to the non-technical user and allows downloading individual diagrams in the common Shapefile format. API functionality was used here to get a text-based version of the Geodesignhub interface with textual descriptions of diagrams, change teams and users. Groups' syntheses can also be manually downloaded in the "Design History" section. Although Geodesignhub enables export of key data from the platform, manual download can be very time consuming because of the many project and policy diagrams (typically 200 or more).

More recently, the research team of the *Laboratório de Geoprocessamento* of the Universidade Federal de Rio de Janeiro in Brazil developed an open source tool for querying Geodesignhub API and downloading diagrams in Shapefile format. The tool (Geodesign Hub—Vicon SAGA) is integrated in the GIS-based web platform Vicon/SAGA, which provides functionalities for data collection, storage, querying, visualization and exchange in many formats (*Geodesign Hub—Vicon SAGA*, n.d.; Moura et al., 2016). Although programming skills are not required, making downloading much easier and faster, the collected data are lacking several available attributes. Data gaps may affect the analysis and should be addressed. Data access through the API, although requiring more advanced IT skills, remains the preferred option to enable collection of a richer set of log-data.

The methods and tools of data pre-processing described in the next section allowed us to extract complete design process information from raw log-data and organize them into a geodatabase (Beeri et al., 1989), facilitating the analyses. Software and procedures used in this study are not new in the field of data mining, however, the application of these methodologies in the design domain is still substantially unexplored.

3.3.3 Data Preparation

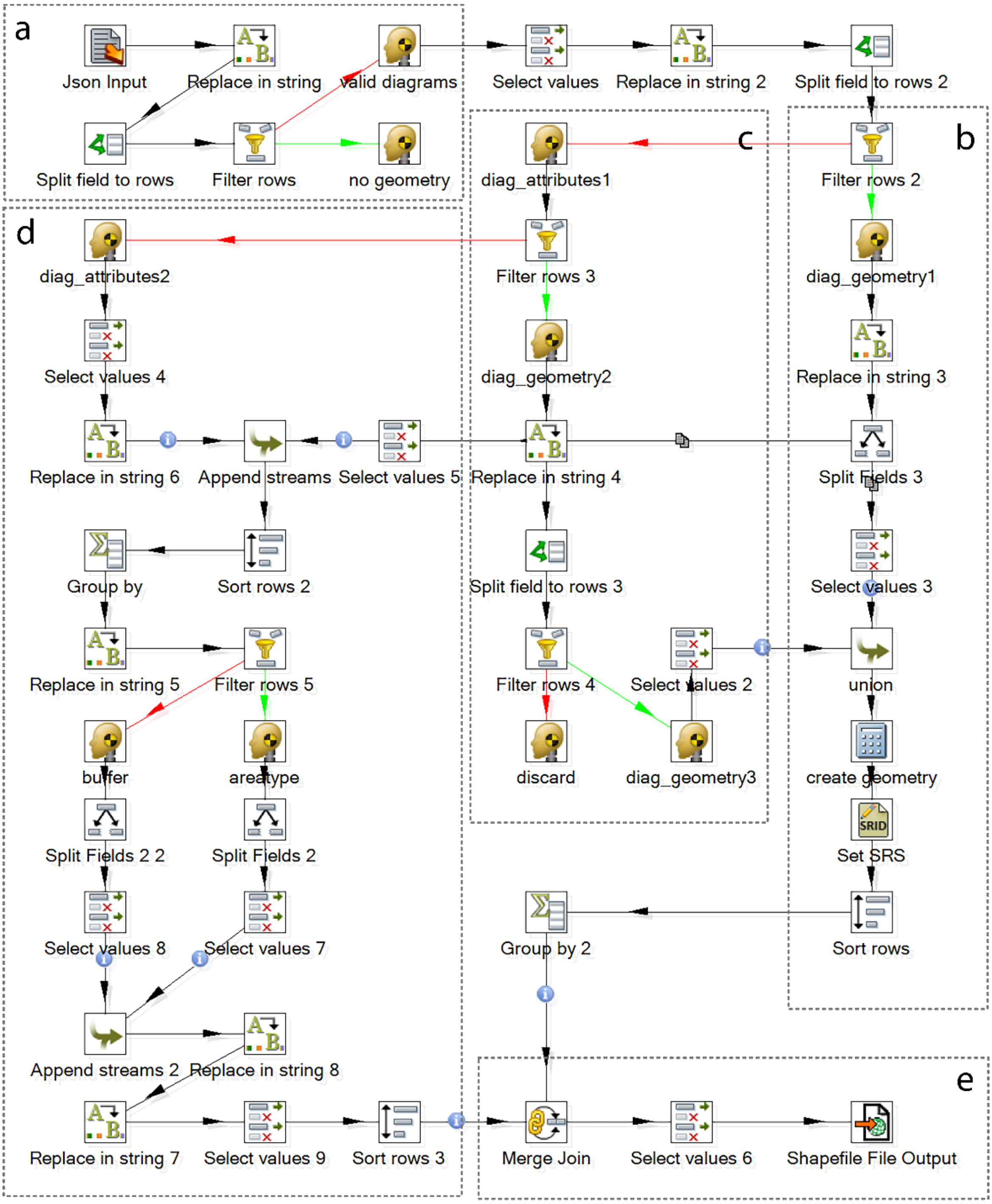

Figure 21. ETL data transformation diagram for cleaning the GeoJSON file of all projects and policies created in a Geodesignhub project and converting it into a shapefile. Main operations of the transformation task include exclusion of empty features (a), conversion of multipart features into

single-part features (b), preprocessing of the spatial component (c) and of the non-spatial attribute (d), joining geometry and properties and store the cleaned data in shapefile format (e).

Data preprocessing aims to offer a structural, reliable, and integrated data source for pattern discovery. This process encompasses a first data cleaning phase that can be implemented using Extract Transform Load (ETL) software. ETL transformation tasks support data optimization for efficient storage and analysis. Performed operations include cleaning, summarization, integration, and aggregation. The spatially-enabled version of Pentaho Data Integration, GeoKettle (version 2.5) provides full control over the entire process through an intuitive graphical user interface. The ETL tool extracts data from a source, transforms it to fit the users' needs, and then loads it into a destination or database. ETL tools were initially developed to be used in the Information Communication Technologies (ICT) field, specifically in the processes of data migration between relational databases. More recently, the rapid diffusion of Business Intelligence tools (BI) has broadened the scope of ETL software by including the fast and automated building of data warehouses for data visualization rather than only storage. Currently, ETL tools expand their functionalities though the inclusion of spatial data and operations capable of competing with existing desktop Geographic Information System (GIS) software. The Geokettle software employed in this study falls within the category of spatial ETL tools.

Figure 21 shows the ETL data transformation diagram for validating (e.g., eliminate empty diagrams), filtering (e.g., selecting only certain attributes/columns) and splitting (e.g., multi-polygon diagram into single-polygon diagrams) a GeoJSON collection of features containing details of all the diagrams created in a Geodesignhub project. The sequence of data transformation activities began with reading the input data, splitting the GeoJSON unformatted single row into features or feature collections, and identifying diagrams with no geometry to be excluded from the analysis (Figure 21a). Features and feature collections were then separated for further pre-processing into their spatial component (Figure 21b, Figure 21c) and into their non-spatial attributes (Figure 21d). A series of transformation steps was applied to pull out useful information from the input data, in particular, multipart diagrams were split into single-part features (Figure 21c) to avoid losing information. Finally, cleaned geometry and properties components were merged and temporarily saved in shapefile format (Figure 21e) to allow a preliminary data exploration and visualization in a GIS environment.

The ETL transformation task described in Figure 21 allows automatic preprocessing of GeoJSON files downloaded from Geodesignhub API. Resulting data were used to create and populate the database following a specific data model (Figure 22.). Although small, the relational database was structured in accordance with a series of normal forms to reduce redundancy of data and prepare a clearer and readable data model (Beeri et al., 1989). Normalization includes organizing data attributes in tables and establishing relationships between those tables. Relations can be of various types as well as different in their representation. For example, a "one-to-many" relationship (1 - 1*) exists between the tables "group" and "sys_priority". A system priority value represents design preferences of a single group, but a group assigns different priority values, as many as the systems considered in a project. Whereas, a "zero-to-many" relationship (0 - *) connects the "group" and the "synthesis" tables. A synthesis could be created by a group or by no group, it could, in fact, be the result of a negotiation process within a coalition. Additionally, a group may have created more than one synthesis.

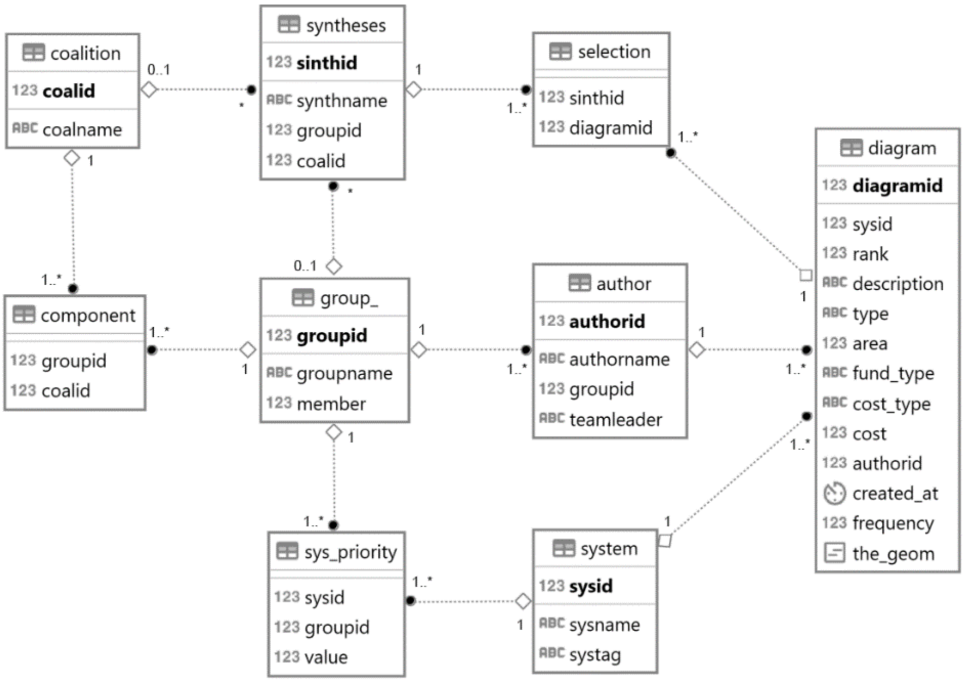

Figure 22. Data model of the log-data geodatabase.

The open source relational database PostegreSQL was used in this study, mainly because of its spatial functions for processing and analysis of geographic objects. The extension PostGIS allows storage and querying of spatial data and supports various geometry types (e.g., POLYGON, MULTI-POLYGON) expressed in Open Geospatial Consortium (OGC) formats (e.g., Well-Known Text – WKT, Well-Known Binary – WKB). Currently, it provides a large set of spatial functions enabling the fast retrieval and processing of geographic information, without the need to use any additional GIS-based analysis tools.

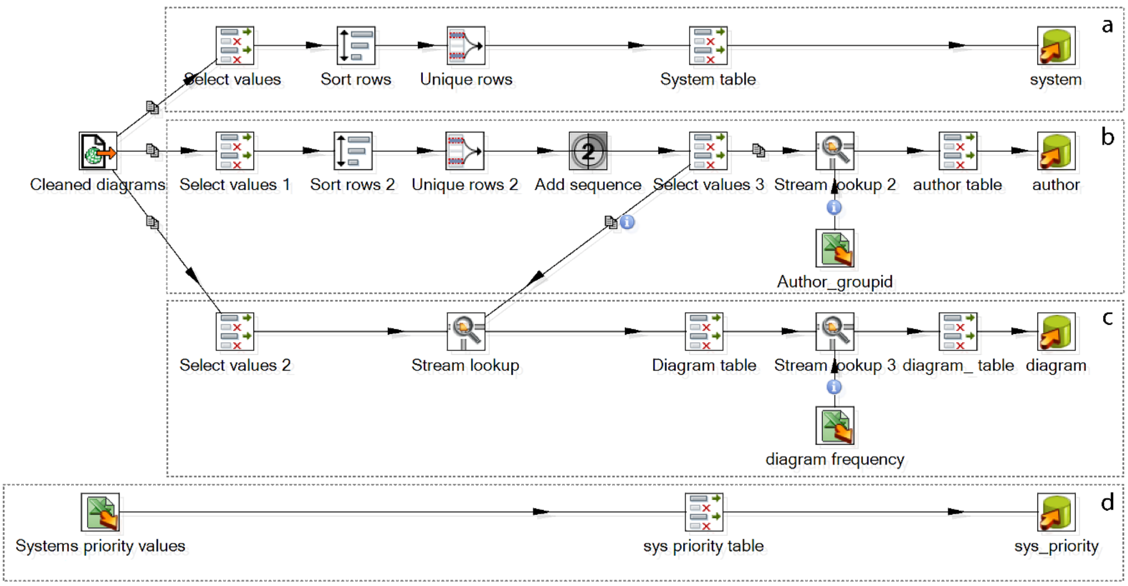

Figure 23. ETL data transformation diagram for loading the cleaned shapefile of all diagrams created in a Geodesignhub project into the geodatabase: "system" (a), "author" (b), "diagram" (c) and "sys_priority" (d) tables were populated.

At this point, the "Load" functions of ETL software were exploited for writing the processed data into the database. The second phase of the data transformation (Figure 23) includes a series of steps for filtering first, and then loading, data attributes into the target tables. Geometries and properties components of all diagrams created in a Geodesign project populated the "system" (Figure 23a), "author" (Figure 23b) and "diagram" (Figure 23c) tables. Additionally, priority weights assigned to the systems by the stakeholder groups can be obtained by Geodesignhub API calls and loaded into the "sys_priority" table (Figure 23d).

The other tables, identified in the data model in Figure 22, were populated with data containing details of all diagrams selected in the group/coalition syntheses created in the project (Figure 24). The input step of the data transformation diagram was a series of shapefiles collected in a File List (a text file listing of the shapefiles contained in the syntheses folder) (Figure 24a). Data was cleaned and loaded in the target tables including "selection" (Figure 24b), "synthesis" (Figure 24c), "group_" (Figure 24d), "coalition" (Figure 24e) and "component" (Figure 24f) tables.

We provided a first set of indicators to analyze participants' performance and design evolution which combines the analytical dimensions made available by the data model. The following section describes in detail the analysis, which was articulated as follows: i) spatial queries were used to investigate the relations among geometric objects (diagrams) present in the spatial dataset, and ii) descriptive statistical analysis was applied to identify the relations between temporal and thematic attributes (e.g. time of creation of a diagram, system name, frequency of selection, etc.). The results of the analyses applied to the Cagliari case study are reported in Section 4.

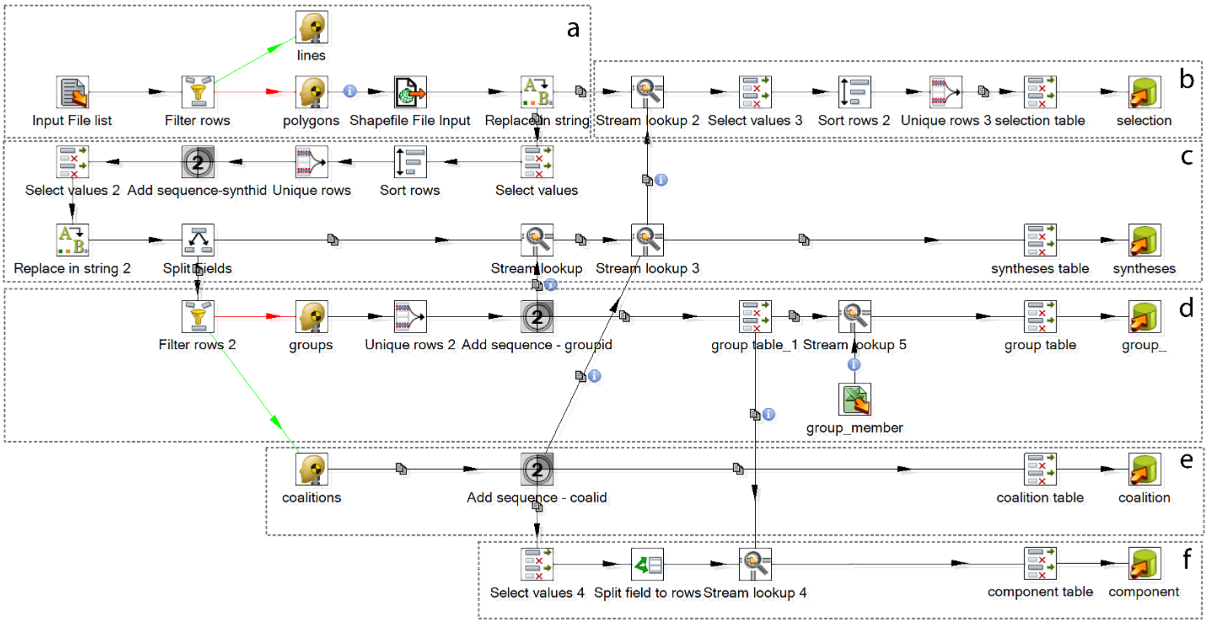

Figure 24. ETL data transformation diagram for cleaning the Shapefiles of all syntheses created in a Geodesignhub project and loading preprocessed data into the geodatabase: "selection" (b), "synthesis" (c), "group_" (d), "coalition" (e) and "component" (f) tables were populated.

3.3.4 Data Analysis

Spatial Indicators

In 2018, Freitas and Moura (2018) exploited the ETL capabilities to manage spatial data and developed effective methods to analyze topological relationships and positional similarity among diagrams (Table 2). Two data transformation diagrams were set up and tested using diagram collections from several geodesign workshops. Understanding spatial relationships (e.g., intersection, proximity) among selected diagrams, and combining them with other attributes (e.g., system name, diagram title), allows identification of possible conflicts of interest or areas of agreement within the teams or among the teams. This, in turn, is likely to stimulate dialogue between workshop participants with a view to fostering consensus on a common design. The following indicators are suitable both to be displayed in a real-time dashboard facilitating dialogue and negotiation and to be used as a basis of comparison with other studies.

Table 2. Spatial indicators.

	Indicator	Coordinator Real-Time Dashboard	Comparative Study	Dynamics Analyzed
1	Topological similarity – topological relationships between two overlapping diagrams (e.g., similar, within, contains)	✓	✓	These measures allow the workshop coordinator to identify possible conflicts of interest or areas of agreement within-teams or between-teams. The dialogue between different stakeholders is thus supported by this real-time information.
2	Positional similarity – spatial relationships between two disjoint diagrams (e.g., close, not close)	✓	✓	

In this paper, we propose the use of PostGIS spatial functionality for querying the log-data database about spatial relationships among diagrams. Spatial databases are able to manipulate spatial data, rather than simply store and organize them. PostGIS, in particular, supports all the standard OGC geospatial operators (e.g., distance, within, intersects, closest, etc.) and it is considered the most efficient open source solution for managing geospatial data (Baralis et al., 2017). Topological and geometrical queries were formulated in SQL to analyze the spatial properties of diagrams. The advantage of using the databases for data analysis (as opposed to ETL tools) is that it eliminates the need to extract the data by creating transformation steps that can be directly performed in the database repository. In addition, data is automatically processed as information and is loaded into the database without the need for further technical intervention.

A first set of spatial functions defines the topological relationships between two overlapping diagrams ($A \cap B \neq \emptyset$) selected by two different change teams (Figure 25). The existing relationships between the spatial objects can be determined by evaluating their possible combinations and calculating the proportion between the intersection area and the diagrams areas. Three topological relations – partially based on the 9-intersection model (Egenhofer & Herring, 1990) – were identified as being of interest for the workshop coordinator:

- If the intersection area is greater than the 80% of the total area of the two diagrams, they are considered “similar” (Figure 25a);
- If the intersection area is greater than the 80% of the area of the first diagram, A is “within” B (Figure 25b);
- If the intersection area is greater than the 80% of the area of the second diagram, A “contains” B (Figure 25c).

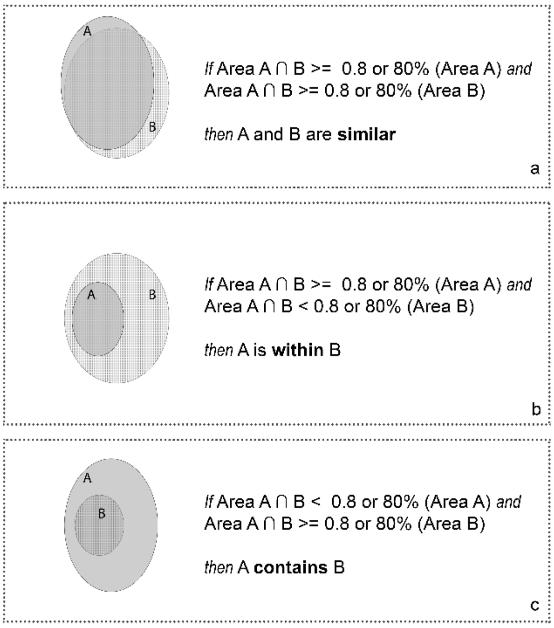

Figure 25**.** Type of topological relations: "similar" (a), "within" (b), "contains" (c).

A second set of spatial functions includes a more elaborate analysis setting to be used in case of a "disjointed" relation between two diagrams ($A \cap B = \emptyset$). The proposed approach relates the concept of proximity (or nearness) between two diagrams to the minimum bounding rectangle of all diagrams created. A bounding box is a rectangular polygon aligned with the coordinate axes that encompass a spatial feature, or group of features, from its minimum and maximum coordinates in the x and y directions. If the distance between two diagrams, based on the length of the segment linking their centroids, is less or equal to 12.5% of the shorter side of the bounding box, the two diagrams are considered to be close. It is worth mentioning that in assessing spatial proximity, the shape of the diagram counts. This approach, which considers the coordinates of the centroids, provides an efficient trade-off between computational time requirements and accuracy of results.

Participants' Performance Indicators

Drawing design proposals in the form of projects and policies is one of the main tasks performed by the participants involved in a Geodesignhub workshop. Diagrams were used as the basis for assessment of participants' performance. The number of diagrams created was combined with thematic attributes (i.e., author, system, type) to construct the first three indicators of the set presented in Table 3. We argue that those indicators can support the workshop coordinator's understanding of participants' performance in real-time, and help detect any related issues in the early stages of the design development process.

The indicator *Top Contributors* (Table 3) identifies leading participants with greatest potential to influence the design and, perhaps more importantly, those lagging behind who may need further attention in performing their work. Also, within the multi-system approach of geodesign, all systems identified as relevant for the development of the study area (e.g., Agriculture, Housing, etc.) will be taken into consideration. The coordinator plays an essential role in identifying systems of major interest and those not sufficiently considered. The real-time assessment of the *Diagram creation by system* efficiently supports this task. Geodesignhub uses two types of diagrams to convey ideas for a change in a system, projects and policies. A *project* envisages a physical change on the study area and its impacts and costs can be measured. In the Geodesignhub computational logic, a *policy* will not have a quantified physical impact on the site. The objectives underlying policies are achieved through private/public incentives or the creation of ad hoc laws, therefore, its impact and cost are not taken into account. The number of diagrams created per type (*Diagram creation by type*) helps to get a preliminary idea of most pressing needs (e.g., new infrastructure or buildings or changes in activity patterns).

A second group of performance indicators is used to evaluate the influence of background information on the number of diagrams created. Cocco et al. (2019) explored the relationship between number of diagrams created and the personal and professional profiles. Inferential statistical techniques were used to perform correlation analysis between the available dimensions: age group, education level (e.g., undergraduate, graduate, PhD), level of experience (e.g., previous experience with Geodesignhub/PSS), professional expertise (e.g., architecture, planning, ecology), role within the area of interest (e.g., practitioner, researcher, student). The number of diagrams created is also indicative of participants' perceived mastery of the built-in sketching tool. However, the tendency of homogeneous categories of participants (in terms of age, expertise, etc.) to reach similar level of performance should be further investigated by using the descriptive indicators proposed here in comparative studies of workshops results, whether or not they are complemented with inferential statistics.

Another aspect to be analyzed in a post-workshop phase is the influence of the role played by system experts and stakeholders) on performance as authors of diagrams. It is expected that stakeholders would create more diagrams if they were not satisfied by the experts' first design proposals. *System experts' performance* can act as an indicator of stakeholders' satisfaction in respect to the experts' first proposals/diagrams.

Table 3. Participants' performance indicators.

	Indicator	Coordinator Real-Time Dashboard	Comparative Study	Dynamics Analyzed (This Indicator Provides Information for the Coordinator as Follows:)
3	Top Contributors – number of diagrams created by each participant	✓		Participants' performance, identifying leading participants with great potential to influence the design, and perhaps more importantly, those lagging behind.
4	Diagram creation by system	✓		Participants' performance, identifying systems of major interest and, perhaps more importantly, those not sufficiently taken into consideration.
5	Diagram creation by type	✓		Participants' performance, identifying which type of diagram they are creating.
6	Diagram creation by age group		✓	
7	Diagram creation by education level		✓	
8	Diagram creation by level of experience		✓	Whether participants' background information (e.g. age, education level, level of experience, professional expertise, role within participant's area of interest) influence their performance, in terms of n° of diagrams created.
9	Diagram creation by professional expertise		✓	
10	Diagram creation by role within participant's area of interest		✓	
11	System experts'		✓	Performance of the system experts, based on

	performance - in relation to number of stakeholder's additional diagrams			their initial diagrams and the number of additional diagrams created by stakeholders.

Temporal Indicators

Time stamps contained in the Geodesignhub log-files provide precise temporal information on two events: "diagram creation" and "synthesis creation". In addition, it is possible to infer temporal information for several different steps in a geodesign workshop workflow (e.g., "Experts Create Diagrams", "Add Diagrams and Create Synthesis 1", "Add Diagrams and Create Synthesis 2", etc.) and establish time intervals between the starting time and the end time of each step. This information was systematically exploited in the set of temporal indicators listed in Table 4.

More specifically, real-time measurement of *Workshop steps duration* was useful to assess whether the workflow is properly following the initial schedule. If delays occur, they should be carefully monitored by the coordinator during the workshop and then analyzed in detail by the project coordination team after the workshop to identify the reasons for delays.

The temporal dimension of diagrams was also used to measure various indicators for evaluating participants' and groups' performance over time. Diagrams can be associated to workflow steps on the basis of their creation time, making it possible to observe variations in the number of diagrams created as the workshop progresses. Participants' performance (individually or in groups) can differ significantly throughout the workshop until a final agreement is reached. This analysis was particularly interesting in regard to *Diagram creation over time by group* of stakeholders/coalitions. Despite the fact that no statistically significant difference has been found so far (Cocco et al., 2019), these dynamics need to be examined in more depth using time series graphs to investigate differences in the *Diagram creation over time*, both between, and within the workshop steps.

The *Average time spent on diagram creation* can help to better understand differences across the steps. We argue average time spent on diagram creation may vary greatly from one step to another. Leaving aside differences in the workshop timetable, there could be other reasons for variations (e.g., influence of the coordinator, difficulties experienced by the participants in using the software, disagreements within the team, difficulty of the subject matter, etc.), which should be considered in comparative studies.

Table 4. Temporal indicators.

	Indicator	Coordinator Real-Time Dashboard	Comparative Study	Dynamics Analyzed (This Indicator Provides Information for the Coordinator as Follows:)
12	Workshop steps duration – time interval between the starting time and the end time of a step	✓	✓	Whether the workflow is properly following the initial schedule.
13	Diagram creation over time – number of diagrams created in each workshop step	✓	✓	Participants' performance over time, by evaluating whether there are any significant differences between the number of diagrams created across the workshop steps.
14	Diagram creation over time by group – number of diagrams created in each workshop step by each stakeholder	✓	✓	Groups' performance over time, by evaluating whether there are any significant differences between the number of diagrams created across the

	group/negotiation coalition			workshop steps by the stakeholder teams/negotiation coalition.
15	Average time spent on diagram creation – average time between diagrams creation across workshop steps		✓	Participants' performance over time, by evaluating the average time between diagrams creation and if there are any significant differences across the workshop steps.

Indicators of Design Evolution

Log-data have previously been used to measure the productivity of participants based on the number of diagrams created and assessed over time. Similarly, in this section we relate the number of diagrams selected in the groups'/coalitions' syntheses to different thematic attributes (i.e., author, stakeholder group, system, system priority weight) to develop a better understanding of design evolution dynamics. The first set of indicators proposed in Table 5 should both help the coordinator to have a clearer insight into the intermediate results of the design process, and enable a comprehensive analysis of the results.

The *Frequency of diagram selection* in all the groups'/negotiation coalitions' syntheses is a useful indicator of each diagram's success. The diagrams with the highest frequency of use in the syntheses were identified. The shape of the curve in the frequency distribution graph shows the extent of agreement among groups and provides a first indication of the degree of disagreement that must be addressed in order to achieve consensus among the stakeholders. This metric was also applied at the level of individual participants to identify leading individuals having greater influence in the design. The *Top Contributors* can be compared to the *Top Influencers* to identify for each participant potential relationships between the number of diagrams created and their success.

The evolution of the syntheses, measured by the number of diagrams selected, provides an indication of the groups' performance over time, especially if compared with the analysis of how many diagrams were selected per system. Differences across the syntheses can be associated with possible changes in *Groups' views* as the process develops. Significant differences across the group's syntheses in the number of selected diagrams aggregated by system in relation to its priority weight are likely to indicate that the group has modified its views.

Lastly, the role played by the diagram authors can also be tested. The number of diagrams selected in the syntheses is classified by author type, either system experts or stakeholder teams. The hypothesis according to which the *Diagram selection frequency* changes based on the *role* played by author has been tested in a previous study (Cocco et al., 2019). Preliminary results showed that the chance of diagrams created by expert groups to be selected in the subsequent syntheses was greater than those created by the non-expert stakeholders in the other steps.

Table 5. Indicators of design evolution.

	Indicator	Coordinator Real-Time Dashboard	Comparative Study	Dynamics Analyzed (This Indicator Provides for:)
16	Frequency of diagram selection – number of times each diagram was selected in all the groups'/negotiation coalitions' syntheses sorted in ascending order		✓	Evaluating the distribution of selection frequency of diagrams among all group/coalition syntheses.
17	Top influencers - number of times diagrams were selected in the	✓	✓	Assessing the success of diagrams and, in turn, identifying leading

	syntheses aggregated by author and sorted in ascending order			participants with great influence in the design.
18	Diagram selection over time by group - number of diagrams selected in each synthesis by each stakeholder group/coalition	✓	✓	Evaluating groups' performance over time, by understanding whether there are any significant differences between the number of diagrams selected across the syntheses by the stakeholder teams/coalition.
19	Diagram selection over time by group and system - number of diagrams selected in each synthesis by each stakeholder group/coalition per system	✓	✓	Evaluating groups' performance over time, by understanding whether there are any significant differences between the number of diagrams selected in each system across the syntheses by the stakeholder teams/coalition.
20	Group's Views – number of diagrams selected by each group in each synthesis per system in relation to the group's priority weighting		✓	Evaluating groups' performance over time, by understanding to what extent the selection of diagrams mirrors the priority weighting assigned to the systems and, thus, stakeholders' initial values and views.
21	Diagram selection frequency by role – number of times diagrams were selected per role played by the author		✓	Evaluating the performance of the system experts, by understanding whether their proposals - presented in a first set of diagrams – were selected more often than those created by the non-expert stakeholders.

The participants' performance, and the temporal and design evolution indicators described above, and related set of measures, were implemented in R, an open source software environment for statistical computing and graphics. R can be used to analyze data from many different sources including PostgreSQL. The log-data geodatabase was connected, and data access operations were performed using the R driver PostgreSQL. The indicators suitable for display in the coordinator's real-time dashboards were tested on the Cagliari geodesign workshop log-data. The results are presented in the following section. The R extension Shiny was used for data visualization in interactive dashboards. Dashboards are visual indicators of information based on performance metrics that have been previously defined as relevant. Shiny enables users to rapidly build complex web applications using the R language without web development. It cannot be considered a direct substitute to more complex Business Intelligence (BI) platforms, yet it ensures an interactive data experience of sufficient quality for use in this study.

3.4 Case study

3.4.1 The Metropolitan City of Cagliari

Among the various geodesign workshops developed by the authors encompassing a range of conditions (i.e., academic environment, real planning problems) and territorial scales (e.g., neighborhood, metropolitan area, etc.), the geodesign study of the Metropolitan City of Cagliari held in October 2018 was chosen for testing the effectiveness of real-time indicators. The interactive dashboard is investigated as assistance for the workshop coordinator, helping monitor developments in the design process, especially in cases where their multiple roles of guidance, coordination and control of activities are extremely complicated (e.g., multi-session workshop, many participants, majority of non-expert participants, etc.).

The Cagliari workshop took place at the University of Cagliari within the Spatial Planning Course of the Civil Engineering MSc program, investigated a study area of 80x80 km including the whole Metropolitan City of Cagliari (MCC), and involved 56 students with little or no earlier background in spatial planning and design. The geodesign workflow was divided into five three-hour sessions and coordinated by a team of experts (i.e., a professor and two assistants). It required an intense organizational effort and substantial monitoring work between sessions to assess the evolution of the process, maintain its efficiency and efficacy, and assess student performance. It was necessary, as in many dynamic situations to devise remedial targeted actions to address problems of both participation and subject matter.

The design of scenarios for future sustainable development of MCC has been the focus of two earlier geodesign studies in 2010 and 2016 (Albert et al., 2015; Campagna, Steinitz, et al., 2016), of one week and two days respectively. The choice of the area is very timely since the Metropolitan Government recently began (2018) their Territorial Strategic Plan, the development framework for future physical planning.

The 2018 study is part of the International Geodesign Collaboration (IGC) project (Orland & Steinitz, 2019), and therefore followed the requirements established by the Collaboration. The IGC is based on two future planning horizons of 2035 and 2050, and three different design approaches: Non-Adopters (NA) continue with business-as-usual until the final study date; Late Adopters (LA) follow a business-as-usual scenario during the first time stage (2020-2035) and consider adopting technological innovations in design proposals for the second period (2035-2050); Early Adopters (EA) include innovations within project and policies in both time periods. IGC standards include nine systems to be analysed, including blue infrastructure (BI), green infrastructure (GI), grey infrastructure (TRANS), energy (EN), agriculture (AG), low-density housing (LDH), mixed high-density (MIX) housing, institutional uses (INST) and industry-and-commerce (IND) land uses. Based on the specific conditions of the study area, History and Cultural Heritage (CULTH) was added to become the tenth of the systems. In the first phase the students played the role of experts and were assigned to one of the systems (e.g. transport planners or engineers, agronomists, etc.). In this stage they worked individually to produce a first set of diagrams, and become familiar with the Geodesignhub software. In the second phase they were grouped into six scenario-driven change teams (EA35, EA50, LA35, LA50, NA35, NA50) and were asked to select appropriate combinations of diagrams to create a design representing their development goals and interests which was then evaluated. After three rounds of designs, each of the six groups produced a plan for the MCC. The final stage of the workshop identified shared strategies amongst the six change teams, grouped them into coalitions, (NA35+NA50; LA35+LA50; EA35+EA50) and instigated a negotiation process in order to reach consensus on a single integrated development strategy for the MCC 2020–2050.

3.4.2 Results

Precisely by the negotiation phase, the spatial indicators can provide a great support to focus the dialogue more sharply on solving the potential conflicts of interest between stakeholder groups. Table 6 shows in detail the topological relations between the overlapping diagrams of the latest synthesis of the group EA50 and EA35 respectively, which was exactly the starting point for their negotiation process. The construction of new "High-density 3D printed houses" proposed by the Early Adopter 50 group is "within" an area devoted by the group Early Adopter 35 to "Smart farming and precision agriculture with drones", which appear to be not compatible (Figure 26). The immediate identification of areas of conflict, as well as, of agreement (e.g., "Precision agriculture with drones" "intersect" "Smart farming with drones") facilitates the negotiation process.

Similarly, the positional similarity analysis (Table 7) highlighted the relations of proximity between disjointed diagrams. Two diagrams identified as close and that foresee potentially conflicting projects (e.g., a new project for a “Floating wind farm” is close to an area devoted to the “Protection of underwater ancient relict”, Figure 26b) require greater attention during the negotiation process than two incompatible, but not close, diagrams (e.g., “High-density 3D-printed housing” is not close to “Green corridor”).

Table 6. Excerpt from the output generated by the SQL query to measure the *Topology Similarity* between the diagrams selected in the last synthesis of the group EA50 and EA35 respectively.

Title	Diagram A (EA50)	% (A∩B/A)	Relation	% (A∩B/B)	Diagram B (EA35)	Title
High-density 3D-printed housing	MIX 21	100	within	0.64	AG 43	Precision agriculture with drones
Smart farming with drones	AG 34	47.88	intersects	57.29	AG 43	Precision agriculture with drones
Poetto beach – solar sidewalk	EI 19	1.59	contains	100	TRANS 6	*Viale Poetto* – solar road

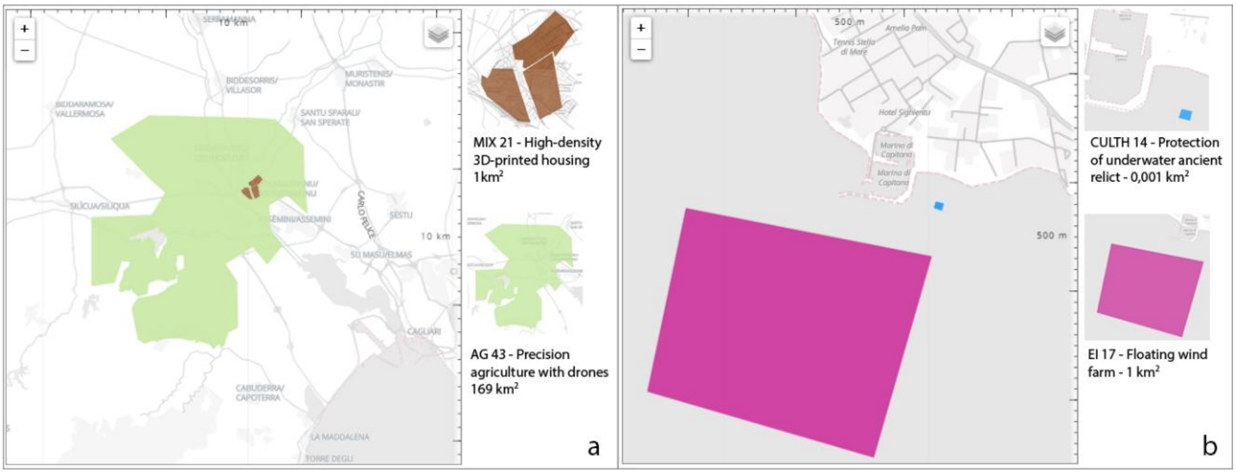

Figure 26. Topological relation between two diagrams: MIX 21 “is within” AG 43 (a); proximity relation between two diagrams: CULTH 14 and EI 17 are close (b). Spatial indicators allow immediate identification of potential areas of conflicts.

Table 7. Excerpt from the output generated by the SQL query to measure the *Positional Similarity* between the diagrams selected in the last syntheses of the group EA50 and EA35 respectively.

Title	Diagram A (EA50)	Relation	Diagram B (EA35)	Title
Floating wind farm	EI 17	close	CULTH 14	Protection of underwater ancient relict
Zoo with different ecosystems	CULTH 10	close	IND 25	Automatic car factory
High-density 3D-printed housing	MIX 21	not close	GI 5	Green corridor

PostGIS spatial functions return results of spatial indicators in tabular form (e.g., Table 6 and Table 7), however it is possible to visualize the analyzed diagrams in Geodesignhub (Figure 26) using the "diagramid" unique identifier.

Among the other indicators listed in Section 3 and suitable to be displayed in a real-time dashboard, in this case study we only focus on the indicators of participants' performance and design evolution. Despite at the time of the workshop the measures were not available, it is however possible to assess ex-post their potentialities (Figure 27).

More specifically, the histogram in Figure 27a provides immediate information on the number of diagrams created by students. This measure helps the coordinator better target the support towards those who risk to lag behind and are most in need of assistance directly during the ongoing design process. Moreover, comparing the *Top 10 Contributors* with the *Top 10 Influencers* (Figure 27b) it is possible to observe the relationship between the number of diagrams created by a participant and their selection frequency, measured as the number of times diagrams were selected in the syntheses by the groups. It is worth noting that 4 participants out of the top 10 influencers (author ID 55, 43, 50 and 46) were not among the first contributors (respectively 7, 7, 6, 7 diagrams created that were selected 37, 29, 27, 26 times), with a 1:4.4 ratio between diagrams created and selection frequency (top 4 participants had a 1:2.5 ratio).

The *Diagram creation by system* is generally clearly observable in the Geodesignhub user interface. Diagrams are systematically organized in a matrix by the software and positioned in the column of the related system in chronological order of creation. However, when large numbers of diagrams are created - around 350 in the Cagliari workshop – monitoring the trend is not as straightforward as in the case of workshops involving limited number of participants. The bar graph in Figure 27c allows the coordinator to identify at a glance the most popular systems and those requiring additional attention. Their role is further facilitated by the red threshold line that defines the minimum goal that participants had to reach in phase 1. At least 3 diagrams had to be created by each student playing the role of system expert.

Similarly, the *Diagram creation by type* (Figure 27e) may provide early indications on the type of intervention participants considered more appropriate for communicating their visions and needs. For example, designing blue infrastructure (BI) interventions to manage water resources may be a very difficult task for non-expert participants, who tended to make greater use of policies than in the other systems. Policies provides an efficient way to express design intentions (e.g., introducing water quality laws; incentives to use precision agriculture technologies) without defining the projects that would best support these policies (e.g., install a water quality monitoring system; install a capillary communication network in the agricultural areas).

In addition, while evaluating groups' performance over time (Figure 27d), the line graph reveals continuing positive trends for most of the stakeholder teams. The number of diagrams selected by each group is generally increasing from synthesis 1 to synthesis 3. However, the group LA35 showed a different trend reducing from 64 to 46 diagrams in syntheses 2 and 3 respectively. The *Diagram selection over time by group* acts as an early warning system providing useful information to the coordinator that can immediately investigate the possible causes of an unexpected behavior.

In this respect, it is essential to have information on the breakdown of the diagrams in the ten systems selected in the three syntheses (Figure 27f). The graph shows the increasing interest, or disinterest, of the group EA35 in the systems. Interestingly the number of low-density housing (LDH) diagrams increased significantly in the last synthesis, whereas the number of interventions in mixed high-density housing dropped from 7 in the second synthesis to 2 in the third synthesis. These outcomes reflect a change in the housing development model of the EA35 group: from building mid-rise and high-rise residential communities with retail/commercial businesses to single family housing development.

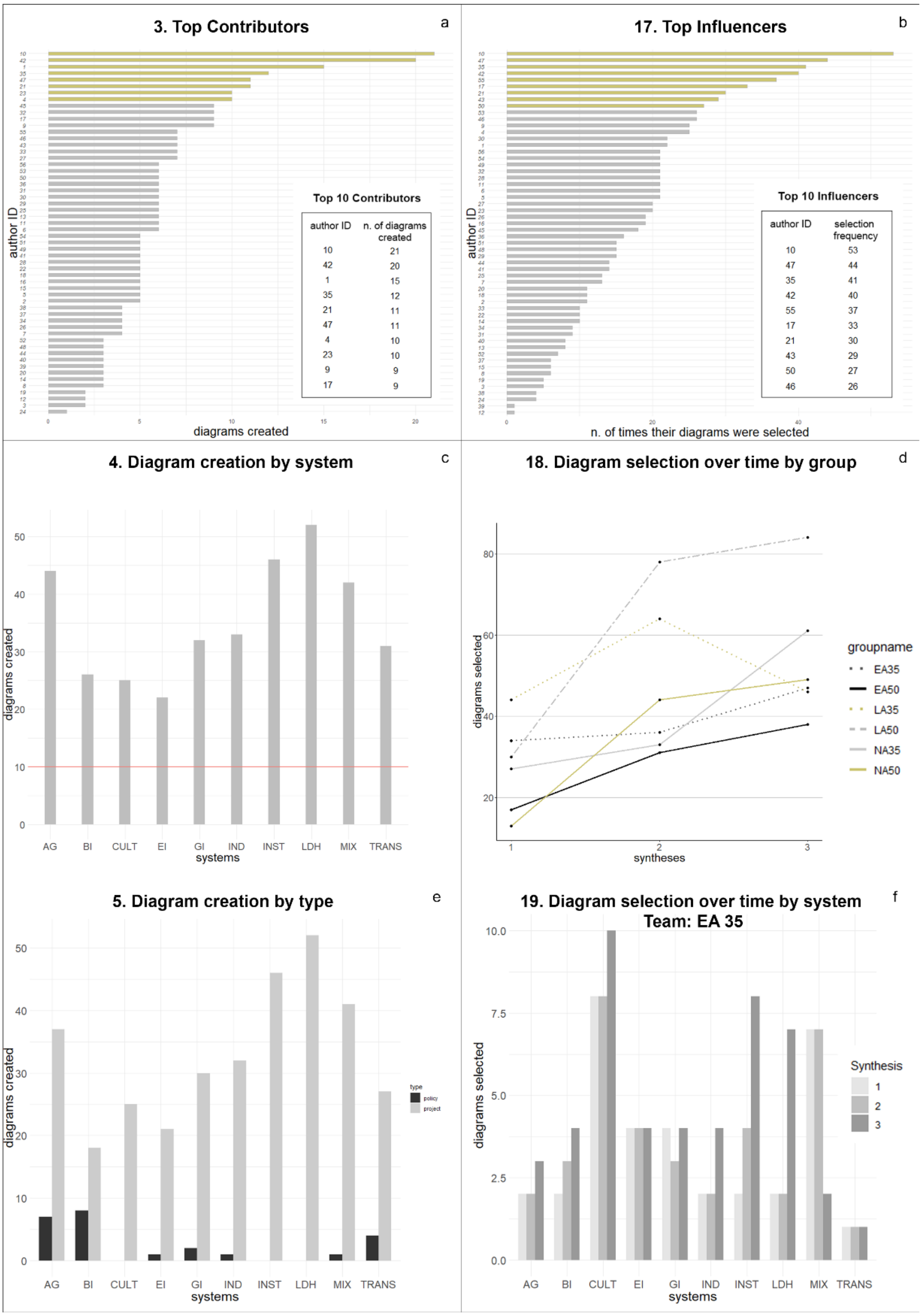

Figure 27. Indicators applied in the monitoring of the participants' performance and design evolution in the Cagliari geodesign study. The sub-set of indicators includes: Top Contributors (a), Top Influencers (b), Diagram creation by system (c), Diagram selection over time by group (d), Diagram creation by type (e), and Diagram selection over time by system (f).

3.5 Discussion

In this case, even more than in others, the tasks that are necessary for the correct geodesign workshop development were included in a well-structured workflow. In particular for its academic and educational nature, the coordinator should have constantly had a clear vision of the participants' performance and of the design evolution. This required ex-post evaluation work after each session by the coordination team in order to better target support during coming session. The implementation of the indicators described in the previous section (Figure 27) may provide important complementary support aimed at improving the monitoring in real-time.

For example, the information obtained through *Top Contributors* and *Top Influencers* analysis may not only be used for monitoring the participants' or students' performance, but also to analyze whether those who have great potential to influence the design are also those who really influence the design, or in other words, to make an assessment of performance in terms of quantity vs quality. As can be seen by comparing Figure 27a with Figure 27b there is not a direct relationship between the number of diagrams created by a participant and their selection frequency.

In addition, it is particularly useful to break down the number of diagrams created by system and by type thus offering detailed insights into the participants' performance. Arguing the fact that all the systems need to be taken into consideration when designing future development alternatives, the *Diagram creation by system* and *Diagram creation by type* (Figure 27c and Figure 27e) facilitate the identification and timely execution of "corrective" measures to ensure a balanced distribution (in terms of number and type) of initial proposals, whether they were created by experts or by stakeholders.

Similarly, the *Diagram selection over time by system* helps in identifying that all systems were taken into account in the syntheses creation. Again, the relation between diagrams created and diagram selected broken down by system is not strictly linear (e.g., Figure 27f shows they the cultural heritage diagrams were the most numerous in all syntheses created by the group EA35; however cultural heritage is among the less considered systems – in terms of created diagrams - as shown in Figure 27c), and thus both indicators should be analyzed.

Another interesting aspect that is not clearly observable in the Geodesignhub user interface is the *Diagram selection over time by group* that provides a detailed pictures of the groups' performance and highlights possible differences in behavior (e.g., the opposite trend recorded for group EA35 in Figure 27d).

Summarizing, the chart reports are an effective way to visualize ongoing dynamics in a live dashboard and may ensure the effective coordination of the assistance efforts during the workshop. The overall results show the appropriateness of the first set of indicators proposed to analyze the design log-data made available for the first time by recent PSS, as Geodesignhub. Such an investigation may be useful both for monitoring ongoing processes, and for learning from past case studies with the aim of improving future one. First, while the experience and the observation skills of those involved in the coordination of geodesign studies will always be relevant and needed, the availability of digital dashboard monitoring the process (*design as a verb*) and its product (*design as a noun*) real-time may potential add great value, especially in fast-pace intensive geodesign workshops with high number of participants. Second, by identifying recurrent behaviours and pattern which appear to be more or less effective for the process to succeed, better processes could be designed and managed in the future avoiding bottlenecks and facilitating the emergence of positive dynamics.

Lastly, the opportunity of analysing this new type of data with digital dashboards may potentially enable the application of a a new business intelligence perspective in real-time geodesign study management, and in retrospective or comparative studies by mining, what may be considered geodesign (processes) big-data.

3.6 Conclusion

The use of process mining techniques to discover, monitor and improve processes dynamics is gaining acceptance in many fields including collaborative design. Planning processes are becoming increasingly complex as a result of the multi-dimensional context (i.e., multi-actor, multi-objective, multi-criteria, multi-scale processes) characterizing current practices. The new generation of advanced planning support technology is able to handle complex design workflows and to record detailed information about the history of processes and make it readily available for analysis.

This research develops an analytical framework to exploit information about collaborative geodesign processes recorded in the Geodesignhub log-data aiming at supporting the workshop coordinator in their role of guidance by getting real-time feedback on ongoing dynamics. As an early step towards a comprehensive Geodesign Process Analytics, this paper describes in detail the proposed analytical process: data extraction, preprocessing and analysis.

As highlighted in earlier sections, collaborative design log-data have a peculiar structure which integrates information relate to both the tasks carried out by participants along the process (i.e., create a diagram; select a diagram) and the outputs of those tasks (i.e., diagrams created, diagrams selected). The analytics tools, therefore, should cover two types of measures: those linked to the actions of the participants which characterize the process, and those related to design aspects of the products. The acquired knowledge can be applied to facilitate targeted and effective process improvement initiatives regarding on-going and future situations.

To this end, the indicators proposed for the analysis of a typical workshop dynamics provide knowledge about i) spatial relations among design proposals by different groups of stakeholders, ii) participants' performance, iii) actual compliance of the process with the workshop schedule, iv) design evolution over time. The usefulness of the analytical framework has been demonstrated *ex-post* by applying a sub-set of representative indicators to gain insights on the geodesign study in real-world use-cases developed within the International Geodesign Collaboration project and involving postgraduate students in designing the future of the Metropolitan City of Cagliari, Italy.

While the set of the indicators has not been tested yet live during a geodesign workshop, the simulation of the application of a real-time dashboard implementing the indicators demonstrates their potential value in offering contextual advice to the geodesign workshop coordinator. The application of so called "descriptive" analytics does not, in fact, lead to any automated decisions based on the results of the analysis, but rather to better-informed real-time/proactive coordination actions and decisions. The objective is, therefore, to develop an analytical tool to support the coordination and management of running geodesign workshops and, subsequently, to facilitate the identification of recurrent behaviors and rules in the post-workshop analysis. In both cases, the improvement of current/future processes is the focus of the application of the proposed analytics.

In the light of the results of this research, the proposed analytical process could be integrated in the PSS architecture. The recently developed plugin "Geodesign Analytics" in Geodesignhub can be regarded as a first step towards the integration of process analysis tool within a PSS. The tool provides basic analysis including a timeline of when different groups saved their syntheses, a visual representation of how many diagrams were added and subtracted as the design develops. The capabilities offered by current web-based analytic apps should be fully exploited to carry out exploratory log-data analysis directly downloading design information from the cloud-based design platform. Design logs are rich data sources that offer many advantages in comparison with more traditional data gathering techniques and coding systems. The opportunity of obtaining value from this data is unprecedented, and it is worth to be investigated further as it may contribute to offer a better understanding of the process unfolding, and of its results.

Chapter 4 An Analytic Approach to Understanding Process Dynamics in Geodesign Studies

This chapter has been previously published as "Cocco, C.; Jankowski, P.; Campagna, M. An Analytic Approach to Understanding Process Dynamics in Geodesign Studies. *Sustainability* **2019**, *11*, 4999".

4.1 Introduction

Despite claims that spatial planning is in the public interest, the idea that location-based decision problems can only be effectively addressed if approached from a "unitary public welfare" perspective should be rethought (Moroni, 2004), if not downright rejected (Rittel & Webber, 1973). As the most recent theoretical approach to planning transitioned from the rational-comprehensive paradigm to advocacy and communicative planning (Khakee, 1998), specific interests of individual social groups are given more attention. The pluralistic approach to planning has brought to the attention of technicians and decision makers a broader range of values and conflicting interests (Davidoff, 1965; Healey, 1998). Problems currently facing communities cannot therefore be easily defined and are intrinsically complex (Innes & Booher, 2010; Rittel & Webber, 1973). The plurality of goals makes it difficult to identify a measurable set of objectives and consequently to pursue an approach purely based on goal optimization constrained by resource availability (Faludi, 1973). On these premises, Rittel (1972) proposed what he termed the "second generation" of systems approach to deal with complexities in "wicked" problems. The approach emphasizes the need for planners and stakeholders to engage in a dialogic process whereby all participants can interactively share knowledge, while attempting to more clearly define the problem and propose alternative solutions. However, we "cannot understand and formulate the problem without having solved it" (Rittel, 1972, p. 393). The process, thus, involves several rounds of problem definition and solution generation.

The iterative planning process shaped by the geodesign framework (GDF), as presented by Steinitz in his book (Steinitz, 2012), fulfills the principles of the second generation systems' approach advocated by Rittel (Rittel, 1972). Geodesign workflows are articulated in three iterations within which non-linear sequences of tasks alternate between analysis, design, and decision to finally reach a mutually agreed solution. The GDF can efficiently tackle the multiple dimensions of spatial decision problems through a collaborative and/or participatory process based on extensive dialogue among people representing diverse areas of competence, political agendas, and social interests. The increasingly extensive use of digital information technology can not only effectively support the analytic-deliberative planning workflow (Jankowski & Nyerges, 2001), but also facilitate the understanding of the collaborative geodesign process dynamics by offering the opportunity to collect information on the evolution of design and on participants' actions (Pettit, Hawken, Zarpelon, et al., 2019).

In fact, after the transactive planning paradigm emerged in the 1970s, evaluation methods started focusing not only on the effectiveness of the results, but also on the quality of the process (Friedmann, 1973; Healey, 1993; Khakee, 1998). The necessary shift from "substantive" to "procedural" theory has been extensively examined by Faludi (Faludi, 1973) according to whom one of the objectives of a planning theory is "meta-planning". "Since planning, like learning, is an information process, it is observable and within limits, capable of manipulation and thus itself the object of planning" (Faludi, 1973, p. 51). Procedural planning theory is generally applicable and should help planners in understanding and managing the process. Decision problems always require some degree of process design to better orchestrate the workflow across sequential activities involving specific participants, methods, tools, and data. However, implementing the concept of meta-planning in current planning practices is still limited. The process is often perceived as a 'black box' with a non-transparent, unstructured, and unclear workflow, and several difficulties arise in describing and understanding design and decision dynamics (Pettit, Hawken, Zarpelon, et al., 2019).

In an effort to improve our understanding of design processes, this study proposes a methodology to analyze geodesign studies by exploiting the data automatically recorded by a web-based collaborative planning support system (PSS) and uncover patterns in participants' behavior and design evolution. Despite the yet unresolved implementation gap in practice, PSS and underpinning technology are developing rapidly providing unparalleled opportunities for planning practitioners and researchers (Geertman, 2017). Information and communication technology (ICT) tools and geo-information technologies (e.g., data visualization, sketching tools, interactive web mapping and services) not only support key planning tasks (Pettit et al., 2018), but also for the first time allow the automated collection of structured quantitative data about the cognitive acts of computer aid users. The acquired knowledge may provide useful guidelines for improving future planning processes and existing digital tools under a meta-planning perspective, and also be instrumental in developing new process-oriented supporting technology (Campagna, 2016d). To date, research on urban and regional planning process dynamics has relied mainly on traditional data gathering techniques (i.e., video recording, direct observation, survey), time-consuming coding systems and, therefore, on interpreted data and a limited number of analyzed dimensions/variables (Jankowski & Nyerges, 2001).

Among recent digital information technologies, a novel collaborative PSS called Geodesignhub (Ballal, 2015) stores information about the whole planning process in the form of log-data, documenting both the design versions and the actions of involved participants. This new type of data allows for design and decision dynamics to be quantitatively understood.

Borrowing from computational social science (Conte et al., 2012), the study is guided by the following research questions:

1. How does the analysis of log-data help us understand past and current (real-time) geodesign processes?
2. To what extent can the analysis of log-data guide future geodesign processes?

The analysis of information systems' log-data in order to understand process dynamics and user behavior has been practiced in several disciplines including business management, computer science, human–computer interaction, manufacturing, and civil engineering. Process data mining techniques are increasingly applied to extract process-related information from log files recorded by enterprise information systems to improve workflows and business processes within different types of organizations (Van Der Aalst, 2011). Web mining algorithms are widely used to analyze web log files for discovering useful knowledge to efficiently organize multimedia content and enhance user experience (Cooley et al., 1997; Nasraoui et al., 2008). Recent applications of log-data mining include detection and prediction of system failure and attack, and crime investigation (Iqbal et al., 2019). In the domain of design, building information modeling (BIM) log-data have been used to capture designers' interactions (Zhang & Ashuri, 2018), and quantitative information about designers' human–computer interaction behavior has been obtained by processing log files from an information system supporting collaborative design processes in packaging and products' industrial design (Niccolo' Becattini et al., 2019). The approach similar to the one presented in this paper has been proven to be effective in previous studies that led to the construction of innovative analytical tools as well as targeted and effective process improvements. For instance, Zhang et al. (2018) developed a systematic approach to monitor and measure the productivity of the design process and the recurrent design sequential patterns from BIM log-data. Carrera et al. (Carrera et al., 2015) analyzed social networking log-data to understand dynamic information flow within social media platforms, which may be useful in various disciplines such as viral marketing and opinion mining. Campagna (2016d) highlighted the importance of citizens' engagements in urban planning and proposed a set of innovative methods for extracting useful experiential knowledge, perceptions, interests, needs, and behaviors from social networking platform logs. Arguably, Social Media Geographic Information (SMGI) analytics integrated with more traditional data sources may potentially improve decision-making and planning processes. Identifying citizens' needs was also the ultimate objective of the study proposed by Ghodousi et al. (2016) to enhance dialogue between citizens and the government. Data collected through a municipal phone-based request/response system were analyzed to prioritize urban needs using different clustering algorithms and assessed for citizen satisfaction. A qualitative approach was adopted by Ashtari and de Lange (2019) who used traditional data collection techniques. Their analytical framework investigates play dynamics and mechanics in digital games as a participatory urban planning tool capable of improving civic skills of citizens.

Despite recent studies, process data mining techniques remain largely unexploited in the design domain. Likewise, this current study aims to investigate the potential of log-data analytics in geodesign processes. The paper is structured as follows. In Section 2, the key aspects of the geodesign approach and a conceptual model for the analysis of the Geodesignhub log-data are described in detail. The enhanced adaptive structuration theory framework is presented in Section 3 as a means of studying process dynamics and organizing data from cases studies. Four hypotheses are derived from the theoretical framework and subsequently tested, in Section 4, with data from the Cagliari geodesign workshop. The results are presented and discussed in Section 5.

4.2 Geodesign

4.2.1 The Methodological Approach

Geodesign is an emerging approach to spatial planning and decision-making, which in the last decades has attracted the attention of a rapidly growing community of scholars and practitioners worldwide. The term was first established on the fertile ground set by multi-disciplinary discussions on the relationships between design and Geographic Information Science that took place during a few specialist meetings in California in the early 2000s (Wilson, 2015). Geodesign quickly became a subject of research and academic curricula and offered an opportunity for innovation in the planning practice. In 2018, the International Geodesign Collaboration was created as a (mostly) academic network involving scholars and researches worldwide, and in the first year of its activity produced 56 standardized geodesign studies addressing locally complex global challenges we face today in addressing sustainability issues (Orland & Steinitz, 2019).

While geodesign finds its roots in a long tradition of thought at the intersection of architecture, landscape architecture, and environmental planning (Miller, 2012; Steinitz, 2012) its innovation—in comparison to more traditional planning and design approaches—is the advanced use of information and communication technology. The use of digital methods eases the application of systems thinking and dynamically relates the creation of design proposals to a multi-scale computational representation of the environment, making the relationships between design and its geographical context more explicit. Thanks to the use of technology, real-time impact assessment is enabled, and the interactive collaboration and negotiation among the process participants facilitated. Hence, geodesign momentum is partially due to the current maturity of geo-information technologies, which after a few decades of evolution are now enabling the implementation of user-friendly, interactive, dynamic PSS (Geertman & Stillwell, 2004a). In order to bridge the gap between PSS research and practice (Vonk et al., 2005), Campagna (2016c) proposed that PSS design should derive from the design of planning process, or meta-planning. In the realm of geodesign, Steinitz (2012) provided a robust and flexible framework, which can be used to organize planning and design processes. It entails the interactive creation of six models (i.e., representation, process, evaluation, change, impact, and decision models), the first three of which create the necessary information and knowledge to support the creation of design alternatives (i.e., change model), assessment of their impacts, and eventually decision-making. Among the recent PSS, Geodesignhub (GDH) system design was informed by the Steinitz framework (Ballal, 2015), creating a novel way of supporting the planning and design process (Campagna, Steinitz, et al., 2016). It is an open-source web-based collaborative platform, which supports geodesign workflows addressing the implementation of the last three models of the Steinitz framework (i.e., change, impact, and decision), while professional Geographic Information Systems (GIS) software can be used to provide the input data generated by the implementation of the first three models (i.e., representation, process, and evaluation). Thanks to its user-friendly interface, Geodesignhub supports multi-user input and dynamic output processing, facilitating real-time design interaction and collaboration.

4.2.2 The Geodesignhub Platform

Geodesignhub (*Geodesignhub*, n.d.) is a web-based geodesign platform, where the users (i.e., participants involved in the process) access through individual accounts a shared and collaborative design virtual working space. While the actual workflow is flexible, the platform offers user-friendly mapping tools to iteratively: (i) propose and share projects and policies (i.e., diagrams); (ii) select diagrams to create integrated planning alternatives (i.e., syntheses); (iii) negotiate to elicit a final design based on consensus. In Geodesignhub, project and policies are arranged by systems (e.g., green, grey or blue infrastructures, housing, industry, commerce or the like, depending on the study area). For each system, an evaluation map, previously created with GIS, is mashed-up to the base maps of the geographic interface in order to inform location choices. After the first round of the diagram creation phase is completed, the users present their project and policy proposals, which can be selected to create syntheses (i.e., complex integrated design alternatives) in the following phase. Further diagrams can be added to the matrix at any stage of the process as needed. In the second phase, teams of stakeholders can select diagrams to create syntheses, and revise subsequent versions with the support of qualitative geographical impact assessment tools. After each team of stakeholders completes a synthesized version of their design, it can be compared with the syntheses created by other teams. Tools supporting negotiation are available to support the work of team coalitions, until a final version is agreed upon by all the teams. The diagram in Figure 28 presents the overall workflow.

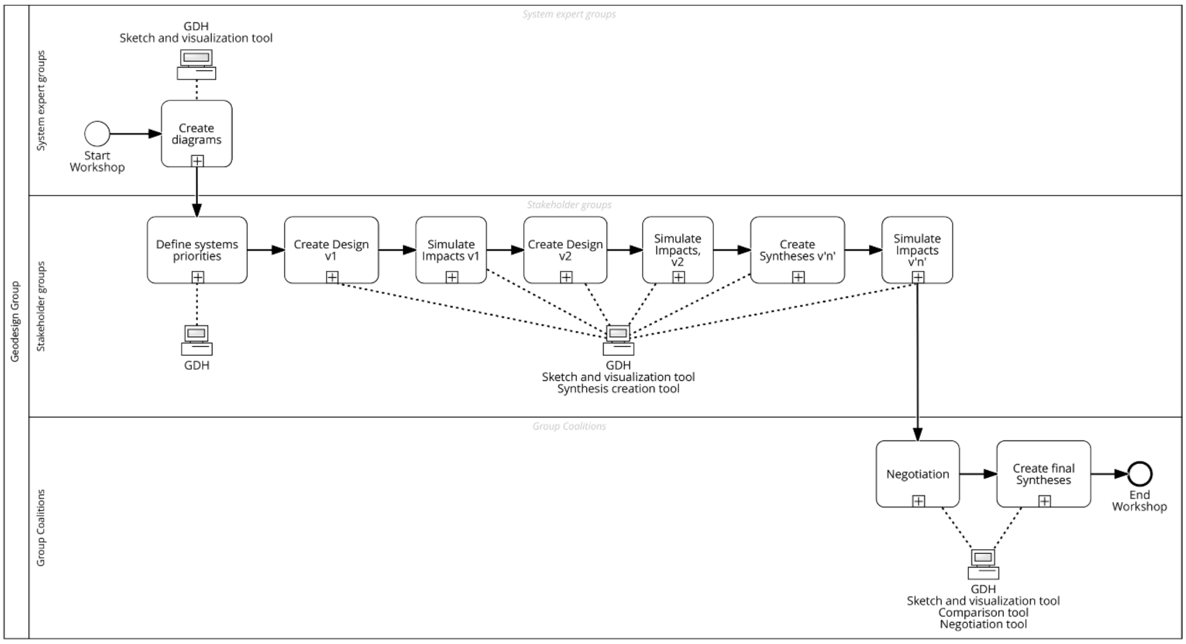

Figure 28. The workflow of a typical geodesign workshop supported by Geodesignhub (GDH) platform and represented in standard Business Process Model and Notation (BPMN).

While Geodesignhub may flexibly support a variety of planning and design processes, it has been widely used to support intensive geodesign workshops where groups of stakeholders with different views, needs, and objectives are guided to rapidly create design scenarios based on negotiation

(Araújo et al., 2018a; Nyerges et al., 2016a; Pettit, Hawken, Zarpelon, et al., 2019; Rosanna Rivero et al., 2015a). Users are guided through different steps of the workshop workflow by one or more facilitators responsible for effectively coordinating the process in order to keep the time required for each activity to a reasonable duration and promote cross-fertilization of ideas and consensus building. Diagrams and syntheses created along the process are automatically stored on the platform server and are accessible anytime for download or through the application programming interface (API). Thanks to the real-time storage of the design and process log-data, the possibility to analyze and monitor the geodesign process has emerged. Geodesignhub already offers a simple e-dashboard with process indicators to assess the workshop process during and/or after its implementation. It produces a detailed history for each design that helps understand how diagrams are used by the participants. This tool offers a basic set of metrics to analyze the process. However, there is a need to extend it with a more robust analytical framework in order to explain participants' behavior and choices during the design process.

4.2.3 Geodesign Process Analytics

In geodesign, the availability of log-data about the design process recorded in real-time by PSS such as Geodesignhub, enables the project facilitator to analyze both the results of the design process, and the process itself. Looking at the data structure of a geodesign workshop's log-data it is possible to identify the two main dimensions of analysis Figure 29: the product (i.e., geodesign as a noun) and the process (i.e., geodesign as a verb) (Steinitz, 2012). Hence, there is the potential to elicit explicit knowledge about how a design evolved from early proposals to the final plan, and why it evolved in a certain way, including insights on the influence of each participant. Our assumption is that from the design process's log-data, we can not only calculate measures to better understand the individual process at hand, but also gain insight into more general process dynamics. In regard to process understanding, calculating process performance measures can help workshop facilitators to manage the workflow in a more effective manner, making their actions more responsive to the casual unfolding of behavioral dynamics. Indeed, such measures (indicators) could be used in post-workshop de-briefings, or even during a workshop to prevent possible behavioral bottleneck situations with the help of e-dashboards. In regard to process dynamics, by analyzing log-data it might be possible to better understand collaborative design process dynamics and use this insight to better prepare future processes following a meta-planning approach (Campagna, 2016d).

Data representing the product of a geodesign workshop are structured as a geographic dataset (e.g., a shapefile). This means that simple and advanced spatial analysis techniques can be used to study similarities and conflicts among different design versions (as in Freitas & Moura, 2018) as well as variation in the design evolution dynamics. In addition, spatial and thematic attributes of individual diagrams and their syntheses relate to each other, as well as to the participants and teams who created, modified, and selected them along the steps of the process. The diagram in Figure 29 represents the data model of Geodesignhub log-data at a conceptual level.

In terms of conceptual data model, the product of design consists of several objects, or feature classes, including diagrams, syntheses, and systems priority weights. For each class one or more type of attributes are recorded, where S represents spatial attributes (e.g., location, geometry, area, etc.), T represents time attributes (e.g., project starting time, duration, time of creation), and Att represents thematic attributes (e.g., name of the project, type of system, cost, etc.). As such, spatial and temporal analyses as well as thematic queries can be performed with GIS software. To explore the spatial relationships among designs, Freitas and Moura (2018) proposed a number of topology relationships and tested them with the use of extract transform load (ETL) tools to automatically analyze project diagrams in terms of geometrical or locational similarity.

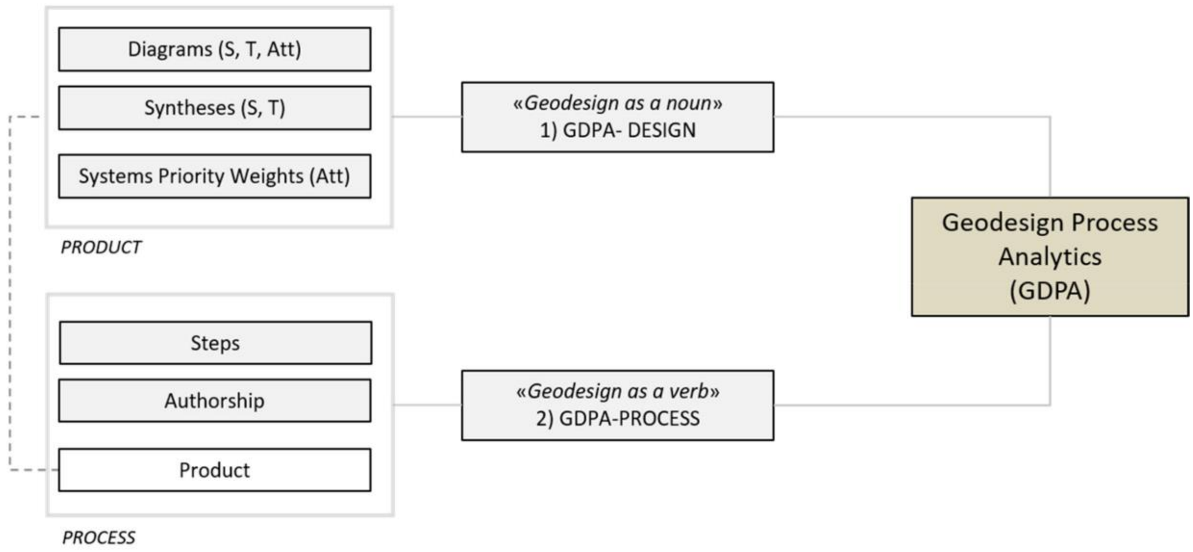

Figure 29. Conceptual data model of Geodesignhub log-data.

Process data describe the participants in terms of authorship of design data objects, sequence (i.e., step), and their product. The latter makes the relations between process and product explicit, offering further ground for analysis. In an earlier study, Cocco and Campagna (2018) started developing geodesign process analytics (GDPA), a framework for monitoring and analyzing geodesign processes, and used descriptive statistics to analyze the productivity of the workshop participants and the evolution of team syntheses along the geodesign workshop iterations, supplying real-time evidence of the workshop process dynamics. Nevertheless, a question of whether it is possible to elicit from geodesign workflow data more general and complete design rules is still an open issue. In the next section, a set of operational questions and statistical hypotheses is articulated by following the conceptual map of enhanced analytical structured framework (Nyerges & Jankowski, 1997) to guide an explanatory analysis of the log-data. This is followed by deploying standardized inferential statistical techniques to test the reliability of findings.

4.3 GDPA for Studying Process Dynamics

4.3.1 Enhanced Analytical Structured Framework

The assessment approach called enhanced adaptive structuration theory (EAST) (Nyerges & Jankowski, 1997) was formulated to guide and evaluate the use of geographic information systems by groups in complex decision situations involving conflicting objectives and solution trade-offs. The revised version of the framework (EAST2) offers 25 qualitative aspects of decision situation assessment that can help to understand the circumstances surrounding the use of geospatial methods and to assess their outcomes Figure 30. EAST2 was initially formulated and tested in collaborative group decision-making in environmental planning (Jankowski & Nyerges, 2001; Nyerges & Jankowski, 2009), but the framework can be applied in various subject domains and at various levels of granularity. It offers an opportunity to choose the level of detail at which the assessment is to be made. The analytical framework includes aspects organized along the three main construct categories. The convening constructs describe the context of the decision situation comprised of social-institutional influence, participant influence, and technological influence. Process constructs describe how the convening aspects influence the technologically-supported process of decision-making and its emergent dynamics. Outcome constructs focus on task and social outcomes of the decision-making process. In this study, EAST2 is applied to assess collaborative planning and design intended as a spatially explicit decision-making process.

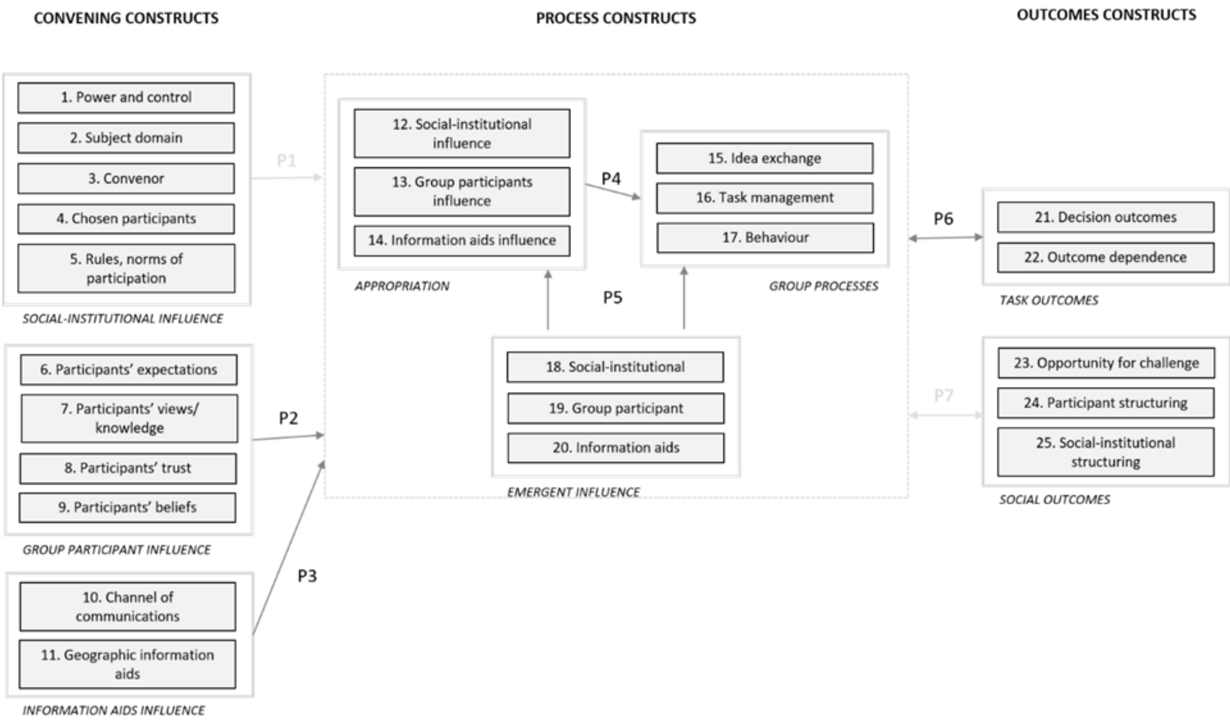

Figure 30. Conceptual map of the enhanced adaptive structuration theory (EAST2).

4.3.2 Decision Situation Assessment for a Geodesign Study

In this study, EAST2 is proposed as a conceptual framework for studying group participation and problem-solving dynamics of the design process in geodesign use cases. We analyzed a typical geodesign workshop using 25 aspects of EAST2. Yet, with the particular workshop workflow examined herein some of the aspects were not applicable or non-measurable. Thus, only 6 out of 25 aspects of EAST2 were used in the analysis. More aspects could have been be used if a mixed data (qualitative–quantitative) study design was adopted. This study, however, exclusively focused on the quantitative characteristics of the geodesign process in the Cagliari workshop. A different subset of 25 EAST2 aspects might have been found relevant in a different study situation. In this case, we found six constructs to be sufficient to test the reliability of the overall method.

In any event, the workflow of a geodesign study developed in a workshop format can be broken down into eight steps. Each step identifies a set of associated actions characterized by specific sub-objectives, group composition, and digital supporting tools. A geodesign process assessment can be performed at different levels of details. Some EAST2 aspects were examined for the entire geodesign process (i.e., social-institutional aspects), others at the level of a single geodesign step (i.e., geographic information aids).

The steps are presented in the columns of Table 8, individually or merged in cases where they are repeated, while the aspects are given in the rows. In this way we can effectively organize the available information and identify the process dynamics that should be investigated. We, therefore, performed the decision situation assessment for those aspects that could be measured (Table 8; aspects 5, 7, 11, 16) or calculated (Table 8; aspect 14 "Appropriation of information aids influence", aspect 19 "Emergence of group participant influence") and we linked them together to "map" different relationships.

Table 8. Decision situation assessment: geodesign workshop steps by EAST2 aspects.

	Step/Group of Steps					
	1	2	3, 4	5	6	7, 8
	Create Diagrams	**Define System Priority Weights**	**Add Diagrams and Create Design v1, v2**	**Make Three Min Presentation**	**Add Diagrams and Create Design v3**	**Create Negotiated Design v1, v2**
Aspect 5 Rules and norm of participation	participants are grouped in system expert teams	participants are grouped in stakeholder teams				teams are grouped into coalitions
Aspect 7 Participants' views/knowledge	background information (age, education level, academic/working area of concentration, previous experience with Geodesignhub (GDH)planning support system (PSS)					
		systems' priority weights stand for stakeholders' values and their worldviews	selection of diagrams mirror stakeholders' values and their worldviews		selection of diagrams mirror stakeholders' values and their worldviews	
Aspect 11 Geographic information aids	"sketching and visualization tool"	"set priority weights tool"	"sketching and visualization tool"; "design creation tool"	"comparison tool"	"sketching and visualization tool"; "design creation tool"	"sketching and visualization tool"; "comparison tools"; "negotiation tools"
Aspect 16 Task management	system teams create diagrams	stakeholder teams assign priority weights (from 1 to 10)	stakeholder teams create additional diagrams and save a collection of diagrams in a design alternative	stakeholder teams shortly present their designs in a large screen	stakeholder teams create additional diagrams and save a selection of diagrams in a design alternative	group coalitions compare their design and strive to reach a consensus through negotiation

The first set of operational-level research questions underpinning the study of the geodesign process dynamics were then formulated. Each question asks about a relationship between a subject aspect and an object aspect:

1. Do different participation strategies/group compositions (aspect 5) influence the number of times a diagram has been selected in the synthesis (aspect 16)?
2. Does the background information (aspect 7) influence the appropriation of the "sketching and visualization tool" (aspects 11 and 14)?
3. Does the appropriation of the "sketching and visualization tool" (aspects 11 and 14) change between the teams across the steps (aspect 16)?
4. Do any group processes (aspect 16—e.g., public 3-min presentation) affect the emergence of new participants' views (aspects 7 and 19)?

4.3.3 Hypotheses

Based on practical experiences gained from organizing and running geodesign workshops worldwide and on anticipated findings from preliminary analyses, we drew a series of hypotheses relating to the four questions formulated in the previous section.

1. In regard to the first question, we hypothesized that the diagrams created by the expert groups in step 1 would have a greater chance of getting selected in the subsequent designs than those

created by the non-expert stakeholders (step 3, 4, and 6). This hypothesis was based on the following observations: (i) the groups of experts created close to 100 diagrams at the very beginning of the process (system teams created at least 10 diagrams in their own system column), which constituted the first set of diagrams available to be selected in the syntheses; (ii) the experts enjoyed greater confidence than the non-expert stakeholders due to their technical knowledge and familiarity with geographical data representations and interfaces.

2. The second question aims at gaining insight into the influence of participants' background information (e.g., age, education level, previous experience with GDH/PSS, academic/working area of concentration, main activity within the area of concentration), on the use of the "sketching and visualization tool" in GDH. Age was expected to be negatively correlated with the propensity to use digital supporting tools, whereas participants who achieved higher education and have already experienced the use of planning and decision support systems would demonstrate greater ease of using the "sketching and visualization tool". We also expected to find differences in the use of the tool associated with training and main professional activity (e.g., practice, research, student). Architects and planners are expected to have robust visual-spatial thinking skills and greater familiarity with tools for digital sketching and design. In this analysis, the appropriation of the tool was in fact associated with the perceived usefulness and measured by the use frequency, following the rational: if the tool is useful, they use it to create diagrams.
3. In question three, we intended to analyze the actual appropriation of the "sketching and visualization tool" within the activities and thus determine whether there were any significant differences between the number of diagrams created across the steps by the stakeholder teams. We argue that, despite facilitators' instructions, the diagrams creation trend can differ significantly between groups mainly due to the composition of group members and the role represented/played. In fact, the length of time allowed for each activity is defined by facilitator, which can thereby affect the appropriation of the tool. The creation of the first syntheses (step 3) is usually a quick task, in which each team is asked to select diagrams mainly from those created by the expert group in step 1. Whereas in the second and third round of syntheses (steps 4 and 6) they are encouraged to add additional diagrams to better accommodate their interests.
4. The last question focuses on the priority weights assigned to the systems by each of the stakeholder teams at the beginning of the process (decision model, step 2) and reflects the values and worldviews of the participants. We hypothesized that the groups changed their views along the process and, specifically, that the mean of priority values associated with the diagrams selected before the three min presentation would be significantly higher than the mean of the priority values associated with the diagrams selected after the three min presentation. This could mean that the groups selected a greater number of diagrams from the systems, which they identified as medium or low priority prior to the diagram synthesis steps in the geodesign process. We posit that the three min presentation of the syntheses, although based on a group-specific set of priorities, may be complementary but important part of the learning process within each team and for all participants. We intended, therefore, to compare the groups' designs to discover trends (if any) in diagram selection and relationships among systems with different priority weights. In carrying out this comparison, the groups' values and views were measured for each design as the mean of the priority values (from 1 to 10) associated with the territorial systems, to which the selected diagrams relate.

4.4 Analysis

4.4.1 Cagliari Geodesign Workshop

To test the hypotheses and gain insight into geodesign process dynamics, we used the log-data from a geodesign workshop conducted in 2016 at the University of Cagliari, Italy, with 29 participants formed into six teams each representing a stakeholder group involved in a realistic land use planning process (Campagna, Steinitz, et al., 2016). The objective of the workshop was to collaboratively develop future change alternatives for the Cagliari Metropolitan City, recently established by a regional law. The choice of the study area was motivated by real challenges facing the Metropolitan Government in coordinating the planning effort of a geographically wide area including 17 municipalities, each of which traditionally planned only within their own boundaries. The same area was the subject of a geodesign study held in 2009 at the University of Cagliari and involving 30 international students in an intensive planning workshop characterized by a mix of analog and digital techniques (Albert et al., 2015). Despite its academic nature, the study involved a local coordination team (comprising 10 experts in architecture, planning, and environmental engineering) who spent three months part-time implementing the preparatory phase of the geodesign process (i.e., knowledge building, GDH project set-up). The workshop was developed following six interrelated models of the geodesign framework and using Geodesignhub, that proved to be useful in facilitating collaboration among public and administration representatives in other geodesign studies (Pettit, Hawken, Zarpelon, et al., 2019).

Some of the participants were invited because of their institutional or academic role while others decided to participate driven by interest in the planning problem at hand. They included academics, technical representatives of public authorities, local planning professionals, and students of architecture and civil engineering at the University of Cagliari, equally divided into six groups (one group had only four participants whereas the other five groups had five participants each) according to their expertise and knowledge. Even though the participating sample was not representative of all real decision-maker and stakeholder groups for the study area, the participants were all somehow related to the study area (they lived or worked in the area). The participants were guided through eight steps of a standard geodesign workshop that had the format of a two-day intensive planning session in a multimedia laboratory equipped with 30 PC stations (29 participants, 1 facilitator) and a public display screen. Specifically, the "Add diagrams and create a design version" step was repeated between three and four times to find an improved alternative within each stakeholder group (metropolitan government—METRO; regional government—RAS; green and non-governmental organization (NGO)—GREEN; cultural heritage conservation—CULTH; developers—DEV; tourism entrepreneurs—TOUR), and to reach a consensus on a final solution agreed upon after two consecutive rounds of negotiations within group coalitions in the "Create a negotiated Design version" step.

The quality of the preparation process and the group composition of participants led the authors to choose this specific case study from a small set of documented case studies to test the hypotheses.

Data Collection

Within this research setting, log-data about the product and the process were collected using both the API tool and the direct download function of Geodesignhub. In accordance with the logical data model in Figure 31, the shapefiles were processed using ETL software (GeoKettle) and organized in a geodatabase (PostgreSQL, Figure 31). In addition to the data storage functions of Geodesignhub, traditional data collection techniques (e.g., survey) were used.

A post-workshop survey was designed to gather feedback on the general experience of participants, but not to collect structured background data. Instead, information on the personal and professional characteristics (age group, background, etc.) of the participants was inferred from public sources (e.g., Chamber of Engineers online database, University of Cagliari website) and added to the study database. In total, 214 diagrams were created during the workshop by 29 participants resulting in a number of variables available for analysis and hypothesis testing.

The use of GDH log-data is proposed here as a complement to established data collection strategies (e.g., video recording, survey, interview), that have been widely used to analyze design processes. Study setting (e.g., laboratory, field) and envisaged data collection techniques have a direct effect on the whole research strategy. Traditional tools for data collection (i.e., audio and video recordings) combined with standard processing methods (i.e., protocol analysis) have proved to be highly time-consuming and resource-demanding, especially when applied to analyzing complex decision-making processes (Niccolo' Becattini et al., 2019). Nevertheless, this study should be considered as an early research effort whose findings will need to be corroborated by analyzing more extensive data sets from other geodesign workshops including mixed-data collection techniques.

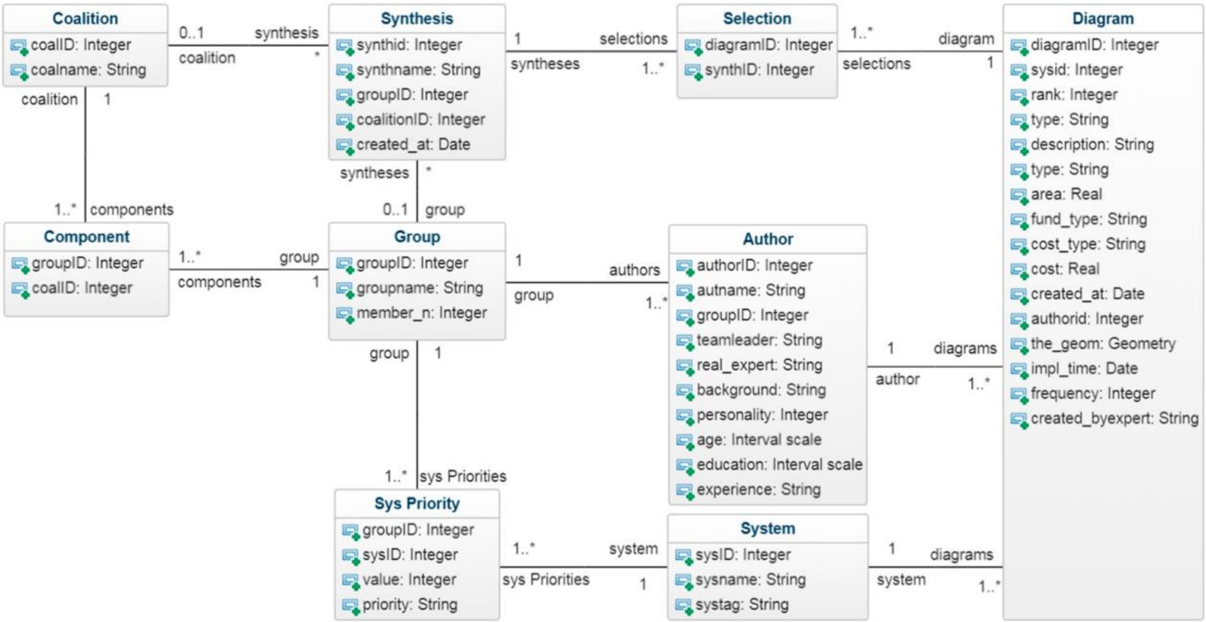

Figure 31. Logical data model of the Cagliari geodesign workshop log-data geodatabase.

4.4.2 Hypotheses Testing

Hypothesis testing with the Cagliari workshop sample data was carried out to evaluate the hypotheses formulated in the previous section. The analytical procedure sought to statistically demonstrate the effect, relationship, or difference between two or more groups as previously stated, thus disproving the null hypothesis according to which the observed or assumed dynamic was due to a chance factor. At first, each hypothesis was specified in terms of variables corresponding to the Cagliari workshop data model. An appropriate statistical test was then identified based on the specified variables and the sampling distribution. In order to decide which method was more appropriate to use, we verified the assumptions underlying the traditional (parametric) tests and concluded that in all cases those conditions were partially or fully violated. Therefore, non-parametric tests were used to analyze the Cagliari workshop log-data. The results of the tests performed with the statistical software R are presented and interpreted in the following two sections.

Hypothesis 1

In this study, we were interested in investigating different aspects of a geodesign process starting from the validation of the first hypothesis, according to which the success rate of a diagram was greater when it was created by an expert team rather than by a non-expert stakeholder group. The dependent variable was, therefore, the frequency of use of each diagram (discrete variable; greater than zero; attribute "frequency"; table "diagram", Figure 31). The explanatory variable in all group/coalition syntheses indicated whether the diagram was created by an expert or by a non-expert stakeholder (nominal variable; two possible values: yes/no; attribute "created_by_expert"; table "diagram"). Differences in the frequency means between the two sets of diagrams were assessed using the Wilcoxon rank-sum test (Wilcoxon, 1945). The sampling distribution dictated a non-parametric alternative to the unpaired two-samples t-test to compare the two sets.

Hypothesis 2

The second hypothesis states that participants' background information influenced the use of the "sketching and visualization tool" in Geodesignhub. The relationships between the frequency of diagrams created by each participant (discrete variable; equal or greater than zero; attribute "diagram_created"; table "author", Figure 31) and the personal and professional characteristics of the participants were assessed. Age group, education level, and previous experience with GDH/PSS were classified using four-level (education level, previous experience with GDH/PSS) and five-level (age group) Likert scales. Academic/working area of concentration and main activity within the area of concentration were the three-class nominal variables. The non-parametric Kendall's tau test (Kendall, 1955) was used to perform correlation analysis with the three ordinal explanatory variables, whereas the Kruskal–Wallis test was applied to test differences between the groups. The latter is a non-parametric alternative to a one-way ANOVA test for comparing means in a situation where there are more than two groups (Kruskal & Wallis, 1952).

Hypothesis 3

We also analyzed the frequency of using the "sketching and visualization tool" in Geodesignhub over time in order to determine whether the hypothesis 3 (there were statistically significant differences between the mean frequencies of diagrams created across the steps by the six groups) is true. Diagrams were divided between each step, in accordance with temporal information, available in the column ''created_at" in the table "diagram" (Figure 31). The stakeholder groups that differed in the appropriation of the "sketching and visualization tool" were explored using the Kruskal–Wallis test. The analysis was first carried out at the group level and then repeated for teams grouped in coalitions. In fact, at the beginning of step 7 a sociogram was used with the aim of identifying compatibility or conflicts between the groups (T. Nyerges et al., 2016, p. 22). The results obtained with this approach immediately identified the stakeholder teams of TOUR, CULTH, and RAS who joined in a coalition displaying strong affinity among them. A second, less robust alliance was formed between GREEN and METRO. The developers remained outside the coalition-building process obtaining negative assessments from all other teams.

Hypothesis 4

Finally, the hypothesis 4 envisages differences in groups' views between design versions separated by the three min presentation. All groups' versions (design 1, 2, 3 and, when present, design 4) were considered in the analysis. Using the database model, the relationship between the tables "selection", "diagram", and "system priority" was clearly expressed (Figure 32). Each "selection" relates to a single "diagram" while each "diagram" can be selected in many designs ("one-to-many" relationship). Likewise, each "system priority" relates to many "diagrams" and each "diagram" can be associated to different system priority weights—one for each stakeholder group ("many-to-many" relationship). The attributes of the three tables were joined to obtain an output table containing the identifier (ID) of the design version, in which the single diagram was selected, and the priority value associated with the system to which the diagram relates. Once again, the Kruskal–Wallis statistic was applied to test the alternative hypothesis.

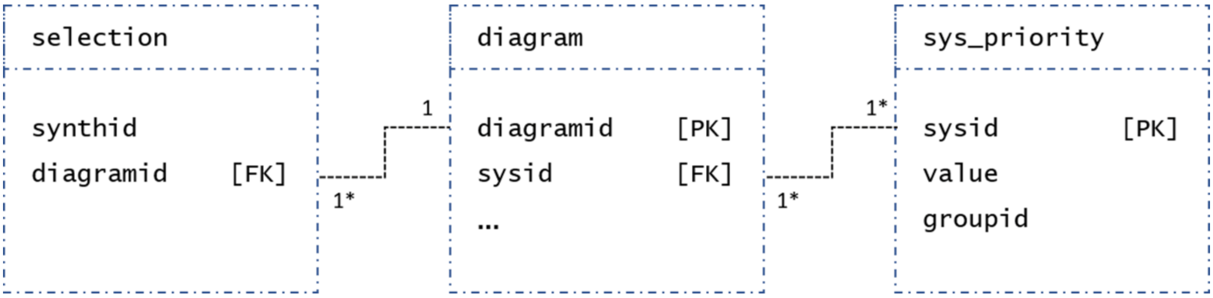

Figure 32. Excerpt of the Cagliari workshop data model showing in detail the relationship between the tables "selection", "diagram", and "system priority". A "one-to-many" (1*–1) relationship connects the "selection" and "diagram" tables. A "many-to-many" (1*–1*) relationship connects "diagram" and "sys_priority" tables.

4.5 Results

Following the analysis of variables organized in a geodatabase, it was possible to test the four research hypotheses using data collected during the Cagliari workshop. This section examines research findings and provides a detailed interpretation of the results reconnecting to the four operational-level research questions stated in Section 4.4.2.

4.5.1 Group Composition Influence

Figure 33 displays the density plot of all diagrams selected in all group/coalition syntheses (Figure 33a), and the box plot (Figure 33b) of the frequency of diagram selection divided in the two groups of the variable "created_byexpert" (Table 9). The data do not follow normal distribution Figure 33a): many diagrams were selected only a few times (0–5), few diagrams were selected many times (15–22). Figure 33b shows that the diagrams created by experts had a mean value of 7 with a standard deviation of 5 due to three extreme outliers/diagrams selected more than 20 times. Conversely, the diagrams created by non-experts had a mean of 3 and standard deviation of 2.8. The results of the Wilcoxon rank-sum test confirmed our initial hypothesis: there was a significant difference between the two groups (p-value < 0.001).

The test result was instrumental in answering the first research question: "Do different participation strategies/group compositions (aspect 5) influence the number of times a diagram has been selected in the synthesis (aspect 16)?". The success of a diagram is mainly linked to the step in which it was created. The diagrams created at the beginning of the workshop were selected more frequently than those designed in later stages. Other than the step duration time, the steps of the geodesign process differed due to group composition: experts (step 1) or non-expert stakeholders (steps 3, 4, and 6). Consequently, it is reasonable to conclude that both the duration time and group composition influenced the success of a diagram.

One possible reason for this might be the intensive and time-constrained workflow agenda of a geodesign workshop. The time available for creating additional diagrams after step 1 "Create diagrams" was very limited. Furthermore, the interface of Geodesignhub does not effectively help to identify newly-created diagrams. Diagrams are systematically organized in a matrix by the software and positioned in the column of the related system in a chronological order of creation. The new diagrams can be found only at the very bottom of the column.

Further analysis is needed to measure the confidence level in experts rather than in non-expert stakeholders. The test should be repeated with data samples from other case studies reporting on geodesign workshops. For example, Pettit et al. (2019) observed the opposite trend in the Sidney geodesign workshop indicating the use of diagrams created in the latter steps of the workshop, which could be tested using the proposed methodology.

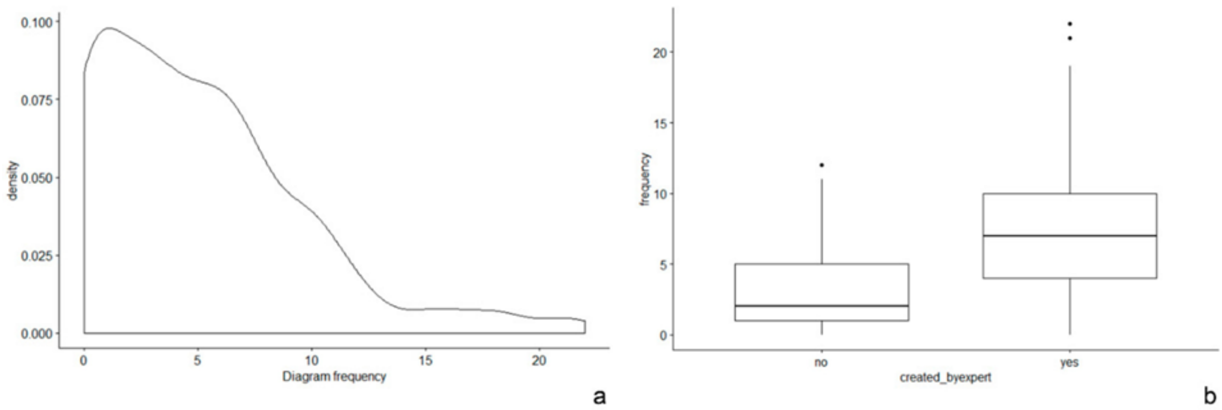

Figure 33. (**a**) Density plot of all diagrams selected in the group/coalition syntheses; (**b**) box plot of the of diagrams selection in the groups of the variable "created_byexpert".

Table 9**.** Summary statistics by groups of the explanatory variable "created_byexpert".

Attribute "Created_Byexpert"	**Count**	**Mean (Frequency of Selection)**	**SD**
yes	113	3.02	2.80
no	101	7.62	5.07

4.5.2 Background Information Influence

Regarding the second hypothesis, there was weak negative correlation between the number of diagrams created by each participant and their personal and professional characteristics: age (Figure 34a), education level (Figure 34b), and previous experience with GDH/PSS (Figure 34c). The Kendall's rank correlation coefficients are respectively −0.089, −0.025, and −0.015. The correlation coefficients were statistically non-significant (p-value > 0.05 for all tests).

The other two nominal explanatory variables (academic/working area of concentration and main activity within the area of concentration) were analyzed with the one-way analysis of variance. The Kruskal–Wallis test found no significant difference in the median frequency of diagrams created between the three groups in both cases (i.e., $p > 0.05$).

Considering the results of the test, participants' background did not influence the frequency of "sketching and visualization tool" use. Consequently, we have to reject our initial hypothesis for the second research question: "Does the background information (aspect 7) influence the appropriation of the "sketching and visualization tool" (aspects 11 and 14)?". Due to the academic purpose of the Cagliari geodesign workshop and the homogeneity of participants—mainly between 26–35 years old (Table 10), postgraduate students (Table 11), and researchers (Table 12) in planning-related fields (Table 13)—this result of the study might not hold in other cases with more diverse participant samples. It is, however, important to point out that given the participants' previous experience with GDH/PSS (Table 14), the group composition was quite diversified (none = 1, low = 11, medium = 6, high = 11). In this case study, the number of diagrams created by participants was not correlated with participants' experience with planning and decision support systems. This early outcome seems to support a claim that the Geodesignhub platform is user-friendly and can be effectively used by users of various backgrounds. This last assertion and the corresponding hypothesis should be further verified with different cases studies, possibly providing larger and more diverse samples of participants working on realistic design and planning problems.

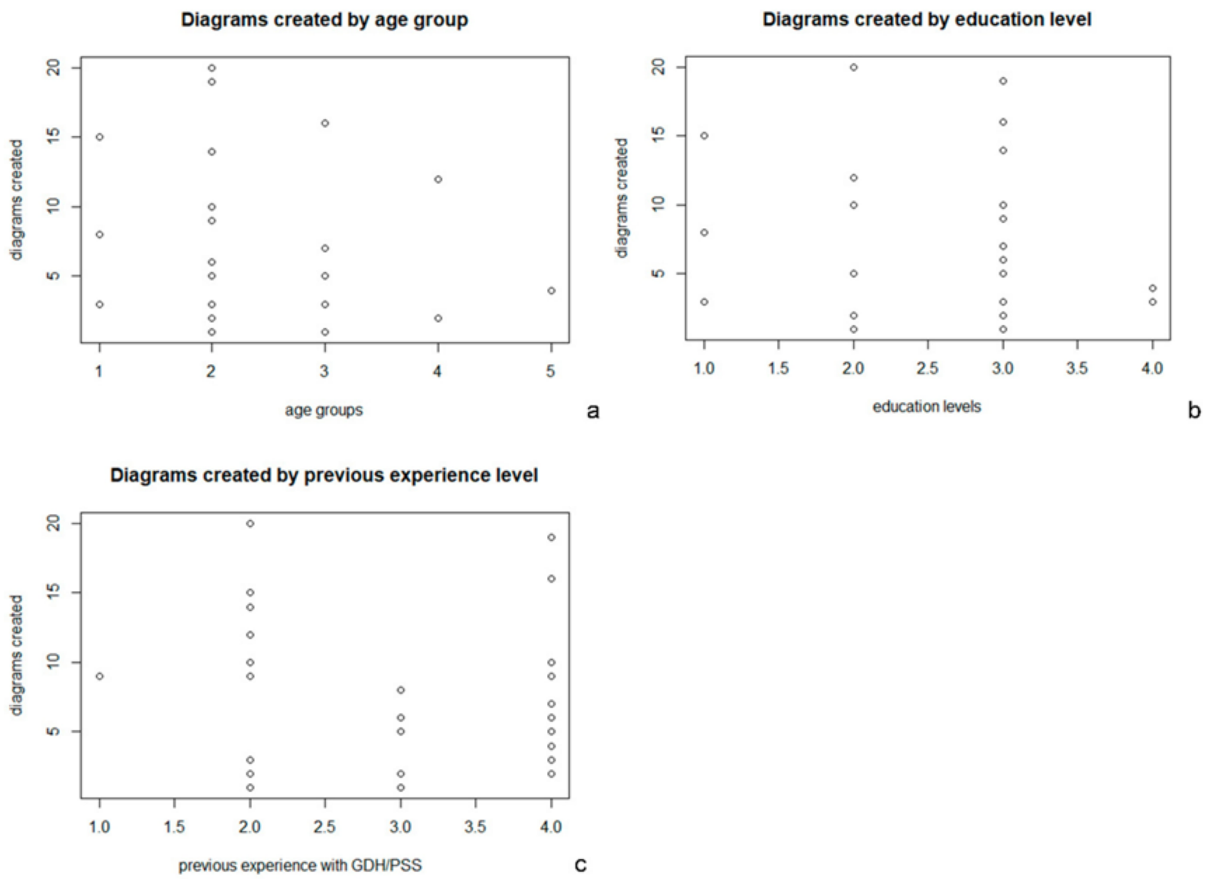

Figure 34. Scatter plots of diagrams created by age group (**a**), education level (**b**), and previous experience with GDH/PSS (**c**).

Table 10. Summary statistics by groups of the explanatory variable "age_group".

Attribute "Age_Group"	Count	Mean (Diagrams Created)	SD
≤25	4	7.25	5.68
26–35	17	7.94	5.55
37–45	5	6.4	5.81
46–60	2	7	7.07
>60	1	4	NaN

Table 11. Summary statistics by groups of the explanatory variable "education".

Attribute "Education"	Count	Mean (Diagrams Created)	SD
undergraduate	4	7.25	5.68
graduate	7	7.43	6.97
postgraduate	16	7.88	4.99
PhD	2	3.5	0.707

Table 12. Summary statistics by groups of the explanatory variable "main_activity".

Attribute "Main_Activity"	Count	Mean (Diagrams Created)	SD
practice	5	9.4	7.33
research	18	7.33	4.96
student	6	5.83	5.08

Table 13. Summary statistics by groups of the explanatory variable "background".

Attribute "Background"	Count	Mean (Diagrams Created)	SD
architecture, engineering	9	8.44	6.64
other	3	7.33	3.79
planning	17	6.82	5.00

Table 14. Summary statistics by groups of the explanatory variable "previous_experience".

Attribute "Previous_Experience"	Count	Mean (Diagrams Created)	SD
none	1	9	NaN
low	11	8.36	6.39
medium	6	4.5	2.59
high	11	7.82	5.38

4.5.3 "Sketching and Visualization Tool" Appropriation

The number of diagrams created was also considered as a dependent variable in assessing the aspects related to the third research question: "Does the appropriation of the "sketching and visualization tool" (aspects 11 and 14) change between the teams across the steps (aspect 16)?". Figure 35a displays a box plot of the diagrams created by each group in the five steps where the tool was used. The stakeholder groups TOUR (tourism entrepreneurs) and RAS (regional government) created, on average, more diagrams than the other groups. However, no significant differences emerged from the result of the Kruskal–Wallis test ($p > 0.05$). The same analysis was repeated for the teams grouped in three coalitions (Figure 35b). In this case too, the differences were non-significant ($p > 0.05$).

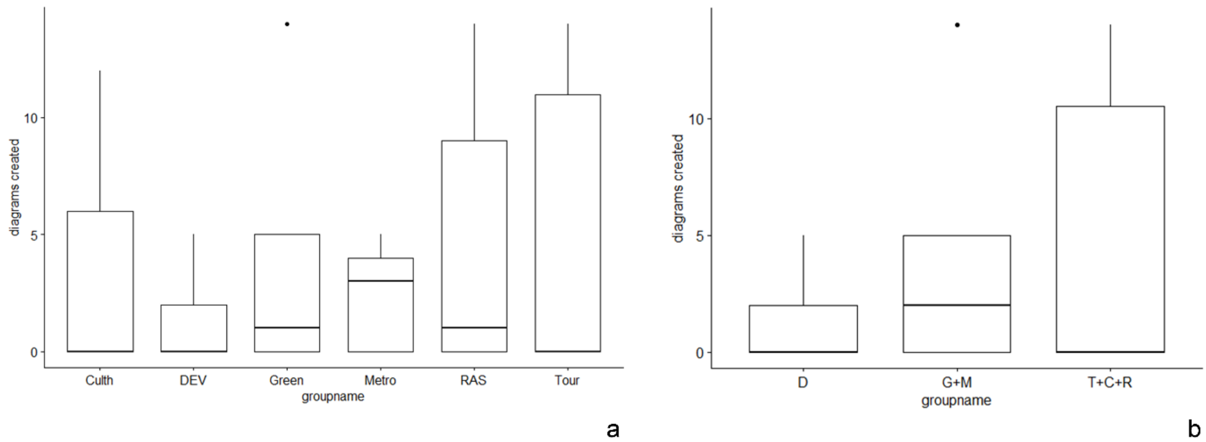

Figure 35. Box plots of the frequency of diagrams created by group (**a**) and by coalition (**b**). Abbreviations: metropolitan government—METRO; regional government—RAS; green and non-governmental organization (NGO)—GREEN; cultural heritage conservation—CULTH; developers—DEV; tourism entrepreneurs—TOUR.

Given the results, we can conclude that the hypothesis formulated in Section 4.3.3 cannot be accepted: there is no statistically significant difference between the mean frequency of diagrams creation and the mean use of the "sketching and visualization tool" between the groups and across the steps. The same results can be observed when grouping the teams into coalitions. However, the statistical power of the data sample was low due to its small size and low diversity. We expect to see significant differences in larger and more diverse samples.

4.5.4 Group Processes Influence

Finally, the box plots in Figure 36 show for each stakeholder team the priority values associated with the diagrams selected in the groups' design versions produced during the workshop. The differences in the means of priority weights associated with group design versions, tested with the Kruskal–Wallis test, were statistically non-significant at the $p = 0.05$ level in all cases except the group METRO, which reached the significance at the $p = 0.1$ level. In this instance, the mean of the priority values associated with the selected diagrams differed significantly between the versions. In particular, Figure 37 shows an increase for systems of initially lower priority (value ≤6), especially between the second and the third synthesis, and a decrease in the diagram priority for systems of initially high priority (value ≥9). The results of analytical procedure were particularly useful in responding to the fourth research question: "Do any group processes (aspect 16—e.g., public three min presentation) affect the emergence of new participants' views (aspects 7 and 19)?" The observed trend, albeit in a single group, may justify the emergence of new groups' views and should be further investigated. Our hypothesis can in fact be accepted only in the case of the METRO group. The Cagliari Metropolitan Government has proportionally a much greater number of professionals working in the areas of planning and design than their corresponding number among the Cagliari workshop participants. These professionals are likely experienced in participating in public meetings, delivering presentations, and thus potentially more sensitive to the cross-fertilization of ideas.

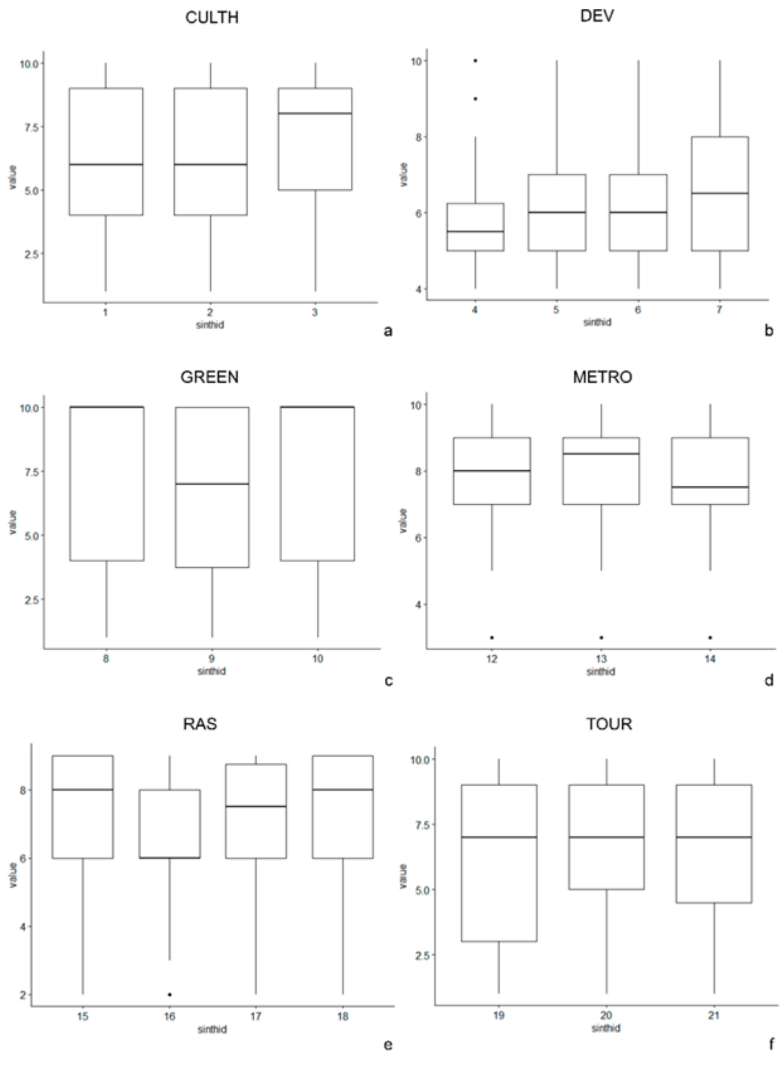

Figure 36. Box plots of the priority values associated to the diagrams selected in the three/four design versions created by each stakeholder group.

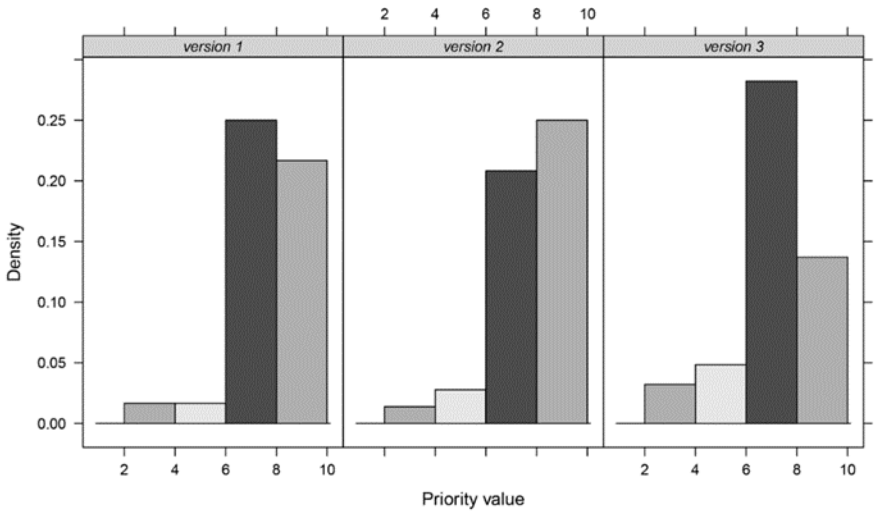

Figure 37. Density histograms of the priority values associated with the diagrams selected in the three versions created by the group METRO.

4.6 Discussion and Conclusions

The main goal of this research was to introduce a new set of metrics to study geodesign process dynamics and, consequently, contribute to developing an efficient analytics strategy within the GDPA framework. The employed log-data management workflow made it possible to obtain empirical and quantifiable feedback on the design process dynamics, while the analytical procedure of statistically testing the significance of possible causal effects and/or relationships between variables ensured the reliability and reproducibility of test results.

Limitations of the Cagliari workshop dataset (small and homogenous sample of participants) and of a single case study did not allow for testing of a more comprehensive set of hypotheses, than presented in this paper. However, the proposed methodology leverages log-data analytic capabilities to gain a meaningful and nuanced understanding of complex collaborative planning processes. The key actions (e.g., add a diagram, save a synthesis) of the participants involved in a Geodesignhub project, along with their main characteristics (e.g., background information, group composition), were recorded in structured log-data, processed and analyzed providing insights into diagram selection patterns (hypotheses 1 and 4) and technology-use dynamics (hypotheses 2 and 3). With reference to the analyzed case study, it was observed that (1) the success of a diagram seems to be influenced by the time when it was created during the process and the group composition at a given process step. Conversely, (2) the occupational, expertise, and skill characteristics of participants do not seem to influence the usage of "sketching and visualization tool". The frequency of using the tool is measured by the number of diagrams created by the participant and (3) does not change significantly across the steps between the six groups. Furthermore, (4) new group views can be generated throughout the process of collaborative design development.

The overall results of hypothesis testing show the appropriateness of the metrics chosen to analyze the log-data made available for the first time by a PSS (i.e., Geodesignhub). The potential of this new type of data within the design domain is promising and has only been partially explored in this study. Preliminary results provide evidence that the analysis of log-data can help understand past geodesign processes. The insights into the process dynamics gained from this study can serve as a basis for comparison among different past case studies in a post-workshop analysis. The validity and applicability of the proposed methodology needs to be further assessed by applying the metrics to a wider number of sample datasets. This in turn, could help to generalize findings and possibly to identify recurrent patterns in participants' behaviors and design evolution, which may eventually contribute to a more informed implementation of the concept of meta-planning. In this respect, describing and explaining the workflows of geodesign case studies can help improve future processes, enhance existing technologies as well as develop ad-hoc supporting digital tools. We argue, in fact, that the management of future planning processes could be significantly improved by better understanding of its internal dynamics and dependencies.

In a similar vein, the work presented here—as part of the comprehensive framework of GDPA—can be extended to ensure real-time information on workshop process dynamics, which in turn can lead to the development of automated and integrated real-time monitoring systems to support the workshop facilitators in effectively orchestrating the geodesign workflow.

In addition to the main research questions, we have been particularly interested in assessing the applicability of EAST2 as a planning framework to help understand geodesign processes. Projecting the conceptual framework of EAST2 theory onto the geodesign workshop workflow allowed us to identify significant aspects for understanding the process. The questions and hypothesis formulated in Section 4.3.3 act as the organizing framework for the log-data analysis. Although it is currently not possible to measure all the identified dynamics by merely exploiting the information collected in the log-data, the results achieved so far demonstrate the potential of EAST2 in guiding the analysis of past geodesign workshops. Ultimately, the study confirms the effectiveness of the framework in characterizing aspects and relations relevant for a broad class of collaborative decision-making processes including the geodesign process.

Chapter 5 Integrating Green-infrastructures design in Strategic Spatial Planning with Geodesign

This chapter has been submitted in the special issue of *Sustainability* "Ecosystem Services, Green Infrastructure and Spatial Planning".

5.1 Introduction

Over the last decades Green Infrastructure (GI) has stimulated growing interest in research policy-making and planning (Slätmo et al., 2019). Since the concept was first introduced in the second half of the 1990's in contrast with the one of "grey infrastructure", it has been recognised as one important element for contributing to sustainability of development (Wang & Banzhaf, 2018). Green infrastructure can be defined as a strategically planned network of high quality natural and semi-natural areas, either in terrestrial, freshwater and marine zones, which contribute to enhancing environmental protection and biodiversity preservation, while delivering multiple valuable ecosystem goods and services (Naumann et al., 2011). The importance of GI lies in its capacity to provide a wide range of benefits, such as environmental benefits (e.g., protection against soil erosion, provision of clean water, rainwater retention), biodiversity benefits (e.g., ecological corridors, landscape permeability), social benefits (e.g., food production, diversification of local economy, human wellbeing, additional tourism opportunities) and climate change mitigation and adaptation benefits (e.g., carbon storage and sequestration, strengthening ecosystems resilience, flood alleviation).

As GI can be found both in natural and green artificial areas and it may take different forms, the following main typologies of green infrastructure elements can be distinguished at various scales: core areas of high biodiversity value, restoration zones such as reforestation areas, ecosystem service zones oriented to provide a range of ecosystem service benefits, green urban and peri-urban areas such as urban parks and green roofs, and natural and artificial connectivity features to assist species movement (Mazza et al., 2011). Connectivity and multi-functionality are considered key characteristics for the GI to remain resilient to change (Muñoz-Criado & Domenech, 2014; Slätmo et al., 2019). The first characteristic is related to the need of biotic functional groups to have not only high quality living and restoration space (i.e., core areas), but also to be able to move across patches in order to support genetic diversity (Olds et al., 2012). The second characteristic concerns the ability of a GI to perform several functions in the same spatial area related to the provision of a variety of Ecosystem Services (ESs), serving a range of functions for both nature and society.

Due to its multi-sectorial nature, GI requires a holistic and cross-sectorial approach to spatial planning in order to both stimulating possible synergies and coordinating initiatives, and to avoid the consequent risk of conflicts between objectives related to different goals (Slätmo et al., 2019). Munoz-Criado et al. (Muñoz-Criado & Domenech, 2014) recognize the central role of GI in guiding the early stage of the planning process across the different levels (i.e., regional, municipal and project scale) and proposed a reform of the legal framework of landscape and urban planning at the Autonomous Region of Valencia by identifying a unique GI as an ecological-based tool to overcome fragmentation and to interconnect all the different policies concerning landscape protection. Over the last decades a wide range of GI projects have been carried out on local, regional, national and trans-boundary levels, highlighting that projects defined in different scale should be closely interconnected and coordinated in order to maximize the GI benefits.

Green infrastructure can be reinforced through strategic initiatives oriented to maintaining, restoring and connecting existing, as well as creating new, areas and features. Nowadays there is not a single globally recognized working framework for supporting GI design, however in literature it is possible to find some different approaches trying to integrate GI in decision-making processes concerning spatial planning and design. Lanzas et al. (Lanzas et al., 2019) define an operational GI planning framework to reconcile the need of biodiversity maintenance and the need of maximizing benefits deriving from ESs both for humans and for natural conservation, by using a systematic planning approach. Cannas et al. (Cannas et al., 2018) propose a methodology to support planners in spatially identifying multifunctional GI through (i) the combination and mapping of four values, specifically calculated, representing four main functions of a GI (i.e., biodiversity conservation, supply for ecosystem services, recreation and cultural heritage), and (ii) the identification of the most suitable land parcels to be included in ecological corridors on the basis of their connectivity. Liquete et al. (Liquete et al., 2015) propose a methodology, useful at different spatial scales, to design green infrastructure networks at landscape level based on the delivery of multiple ecosystem services, essential habitats and connectivity.

At the institutional level, the European Union recognize the contribution of GI in achieving some of the EU's key policy objectives, such as protecting and restoring natural capital and combat the impacts of climate change (Green Infrastructure (Gi)—Enhancing Europe's Natural Capital, 2013). The EU Biodiversity Strategy, adopted by the European Commission in 2011, sets out 6 targets and 20 actions with the aim of putting an end to the loss of biodiversity by 2020. In particular, target 2 explicitly refers to GI and requires that "*ecosystems and their services are maintained and enhanced by establishing green infrastructure and restoring at least 15% of degraded ecosystems*" (Our Life Insurance, Our Natural Capital: An Eu Biodiversity Strategy To 2020, 2011). The EU Biodiversity Strategy also included a commitment for the Commission to develop an EU-wide Strategy on GI, later adopted on May 2013, which identifies some urgent issues to be addressed in order to encourage GI projects and investments to protect and improve natural capital. The need for GI to become a standard part of spatial planning and territorial development is recognized, together with the need for consistent and available data concerning ecosystems and the development of innovative approaches. In this regard, a significant role in the definition of a strategically planned EU-level GI is Natura 2000, which is the main instrument for biodiversity maintenance within the European Union. Specifically, it is an ecological network extended for over 700.000 km^2 on terrestrial areas and for over 500.000 km^2 on marine areas (*Natura 2000 Barometer*, n.d.) established by Directive 92/43/CEE (Habitats Directive), which identifies a series of regions where long-term conservation of natural habitats and flora and fauna species need to be ensured. The Natura 2000 network includes over 27.000 sites, classified as: Sites of Community Importance (SCI) - subsequently designated as Special Areas of Conservation (SAC) pursuant to the Habitats Directive - and of Special Protection Areas (SPA) in accordance with 2009/147/CE (Birds Directive). Natura 2000 sites should be not only preserved, by avoiding the development of deleterious activities within their boundaries, but they should also properly interconnect to allow the genetic renovation of the species populations (Mazza et al., 2011). Within this context green infrastructure contributes to the full implementation of both the Birds and Habitats Directive.

To date, despite several GI design best practices can be found in Europe (*Green Infrastructure—Environment—European Commission*, n.d.), a more integrated approach to their design within the spatial planning practice would be desirable.; This would require to inform design taking into account the tight relationship between GI and the other natural (e.g., blue infrastructure, agriculture) and artificial systems (e.g., grey infrastructure, commerce, housing) according to comprehensive approach at least in the early phases of strategic territorial planning. According to this line of thought, several geodesign case studies have been recently carried out (Nyerges et al., 2016b; Pettit, Hawken, Zarpelon, et al., 2019; R. Rivero et al., 2017) which, within their broader scope, somehow included the synergic design of GI as well as of the other systems stemming from local development priorities applying system thinking, so ensuring a contextual territorial coordination of future development scenarios.

With a similar approach, this paper presents the Metropolitan City of Cagliari (MCC) case study. The objective is to present an operative example focusing on applying system thinking to planning and design, and to demonstrate how the geodesign approach, and more specifically geodesign workshops can facilitate the integration of GI design within early phases of regional strategic planning. To this end, in section 2, a brief discussion on the geodesign approach is given as methodology background, and the Cagliari case study is presented, including the description of the study area, the design process, and the general results of the study. In the second part of the paper, in section 3 a detailed focus to the GI system modelling is given in order to clarify how knowledge about GI can be structured to inform integrated design. Lastly, section 4 focuses on the analysis of the results of the geodesign study in order to clarify the relationships between the GI and the other systems along the design process. The conclusions summarize the overall results and propose issues for further research.

5.2 The geodesign approach to spatial planning and design

Geodesign applies system thinking (Meadows, 2008) to spatial planning and design (Gu et al., 2018), that is seeking to understand the big picture in territorial transformations dynamics in relation to short- and long-term consequences. It would be reductive to think green infrastructure performance is only due to the correct design of its inner parts. From a system thinking perspective it would be rather more correct to assume GI performance is affected by the complex functioning of the surrounding environment. If this is true, green infrastructure planning and design should be handled applying a system approach and designing GI and other interacting subsystems in a single design endeavor.

The landscape architecture and planning tradition was since long aware of this principle, however until recently, traditional analogue methods had some limitations inherent to the supporting media. With the introduction of computation in geography, and with most recent advances in digital (geographic) technologies, it is for the first time currently possible to build user-friendly multiscale interactive computation environments to support collaborative planning and design (Lee et al., 2014b). This is what characterize geodesign as opposite to traditional landscape architecture and planning methods, that is offering concepts and methods, and at the same time, their enabling technologies supporting the creation of design proposals with real-time dynamic impact simulations informed by geographic contexts.

In the last decades, the shift from hand-drawing, to Computer Aided Design (CAD), to Geographic Information Systems (GIS), enabled the creation of Planning Support Systems (PSS) (R. Rivero et al., 2017) which can offer real-time computational feed-back in terms of visualization, simulation, and impact assessment. Some available PSS are structured to help designers to better understand the effects of a design choice in one system not only within it-self, but within all the other interacting systems, supporting system thinking. From the larger to the smaller design scale, Building Information Modelling (BIM), GIS and PSS nowadays enable all that to an unprecedented level. However, until recently even more advanced PSS somehow failed to address important parts of the planning and design workflow, resulting in an implementation gap which limited their widespread diffusion (*Bottlenecks Blocking Widespread Usage of Planning Support Systems—Guido Vonk, Stan Geertman, Paul Schot, 2005*, n.d.). Among the issues to be address for improving PSS diffusion Geertman and Stillwell (Geertman & Stillwell, 2004b) argued their design should be more tightly related to the contextual planning and design process, in order to better meet the users' needs. On the same line, Campagna (Campagna, 2016d) argued the need for more process orientation in PSS design. Geodesign methods, and in particular the Steinitz's framework for geodesign (Steinitz, 2012), may help in this respect for it supply a guide for the organization of the full planning and design process in a way that is adaptable to contextual local conditions.

The Steinitz' framework for geodesign (Steinitz, 2012) entails the creation of six models. The *representation* model provides the description of the study area in its historical evolution until the present, and it is based on available data. The *process* model simulates the evolution of the system under the assumption of no action (i.e., do-nothing design alternative) and it is based on modelling and forecasting. The *evaluation* model may express the values of the experts, of the decision-makers and/or of the stakeholders involved in planning and design, and it is based on their assessment of the output of the process model. While the development of the representation and especially of the process models is often carried on by system experts, the evaluation model is the base for action (i.e., linking the analysis to the design of different planning and design alternatives) and it may require, to a variable degree depending on the local context, the expression of values by a wider number of stakeholders, granted the guidance of experts. The process of implementing the models is not strictly linear though, and several iteration loops may be required during their construction. The *change* model uses the evaluation model as input to orient actions, locational choices and avoidance of risks of hazard in the creation of design alternatives. In this sense, the construction of the evaluation model is a critical step in the application of the geodesign framework for it bridges the gap between knowledge (i.e., analysis) and action (i.e., design and decision-making). Once design alternatives are created, their performance can be assessed with the *impact* model. Lastly, the *decision* model makes the decision-making context explicit, defining who act in which step of the workflow, and on the base of what power-relationships and values.

In the last five years, since its availability to the public, the PSS Geodesignhub faced a growing interest by the geodesign community for it was designed to support the second part of the Steinitz' framework, that is the iterative implementation of the change, impact and decision models. Despite its short life, Geodesignhub was widely used to support geodesign workshops worldwide and its usage have been widely documented in literature (Araújo et al., 2018b; Campagna, Carl, et al., 2016; Ernst et al., 2017; Lanfranchi & Fonzino, 2018; Nyerges et al., 2016b; Patata et al., 2018; Rosanna Rivero et al., 2015b).

In the light of the above premises, in the next paragraph, the MCC case study is introduced, and in section 3 a detailed discussion on the creation of the evaluation model for the GI system is given.

5.2.1 The IGC and the Cagliari Case study

The International Geodesign Collaboration (IGC) is a recent global research initiative involving almost one-hundred partners from five continents(Orland & Steinitz, 2019). In early 2018, a group of scholars active in geodesign coordinated a major research project, which, in one year only, produced fifty-six studies following common guidelines. The main research objective was to earn insights in a systematic and comparable way on how global territorial dynamics affect local regions and cities around the world, and to explore how technology innovations with regards to different interrelated territorial systems may help to address current sustainability challenges. Before the local studies started, IGC working groups developed preliminary studies to define sets of i) Global Assumptions; ii) System Innovations; and iii) common working and reporting rules (*Home | International Geodesign Collaboration*, n.d.), so that at the end of the geodesign studies the results could be easily compared. The results were presented at the first IGC meetings in Redlands California, hosted by the leading GIS industry ESRI.

Among other common working rules, a set of nine systems structuring the study was agreed beforehand by the coordination team. They included green, blue, energy and grey infrastructures, low- and mix high-density housing, industry and commerce, agriculture, institutional services. A tenth system was left to be defined locally by the study teams on the base of the contextual conditions.

Most of the IGC studies were undertaken following the format of intensive geodesign workshops, and the majority relied in extensive use of supporting digital technologies such as GIS and PSS. According to the IGC common rules for comparability, the study areas were squared, with variable size spanning from 0,5 to 160 Km. The case study of the Metropolitan City of Cagliari in Sardinia (Italy) reported in this paper was carried on at two nested scales: 1) a square 80 by 80 km including all the MCC; 2) a square 20 by 20 km focusing on the South-Eastern edge of the MCC, with a shift of the design scale (Figure 38). As tenth system for the MCC case study, historical and cultural heritage was chosen as the area is rich in resources.

The common IGC workflow for the study entailed the development of three alternative development scenarios (Orland & Steinitz, 2019) by different design teams considering three time stages, namely year 2020, 2035, and 2050. The design teams had to design according to different assumptions with regards to the timing of introduction of technology innovations in their design. Accordingly, three main scenarios were to be created: 1) Early Adopter (EA) introducing technology innovation as early as in 2035; Late Adopter (LA) introducing innovation after 2035; and Non-Adopters (NA) not considering technology innovation at either of the time stages.

While the IGC study teams were free to use the digital (or analogue) design workflow they deemed appropriate on the base of locally available data and skills, many of the study followed the Steinitz's framework to inform their workflow for the design process. In our study, thanks to the availability of large scale geographic information on the Sardinian Regional geoportal, the process was fully digitally supported, relying on ESRI ArcGIS software for the development of the representation, process and evaluation models (and for the representation of the results at a later stage), and on the web-based Geodesignhub collaborative PSS for implementing the change, impact and decision models during two intensive geodesign workshops (i.e., one for each design scale) held in temporal sequence.

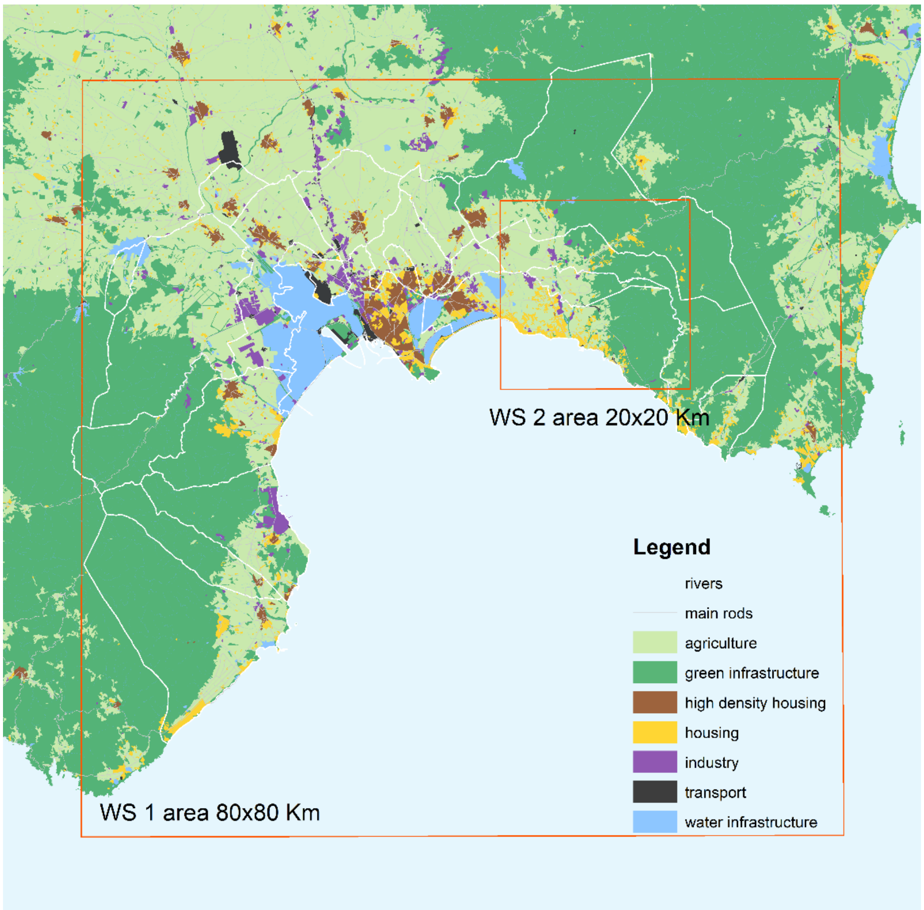

Figure 38. The Metropolitan City of Cagliari geodesign study areas.

Overall the workshop workflow in both cases included the following main steps:

1. Creation of the representation, process and evaluation models by the study coordination team with GIS software. In this step the evaluation maps were produced for the ten systems to be used as input to inform design in the following phases;
2. Set-up of the Geodesignhub PSS by the coordination team, including the creation of a matrix recording impact scores among systems, as input for the impact model
3. Creation of project and policy *diagrams* by the study participants. The participants in this phase acted as system experts and were asked to produce diagrams representing projects and policies considering technology innovations at each of the given time stages. The result of this phase was in both workshops the creation of a matrix of diagrams arranged by system, to be shared by the participants in the following phase;

4. Creation of integrated comprehensive design alternatives, or *syntheses*, by design teams according to the IGC scenarios (i.e., EA, LA, and NA). The syntheses were composed using the shared project and policies matrix;
5. Final negotiation among design teams to reach consensus on the final design for each given IGC scenario.

In general, in both cases the workshop was a first experience in applying system thinking to address the MCC development challenges for the participants, who were civil and environmental engineering students with little or no spatial planning and design (and GIS) experiences. The scenario-driven design alternatives produced during the two workshops are shown in Figure 39 and Figure 40.

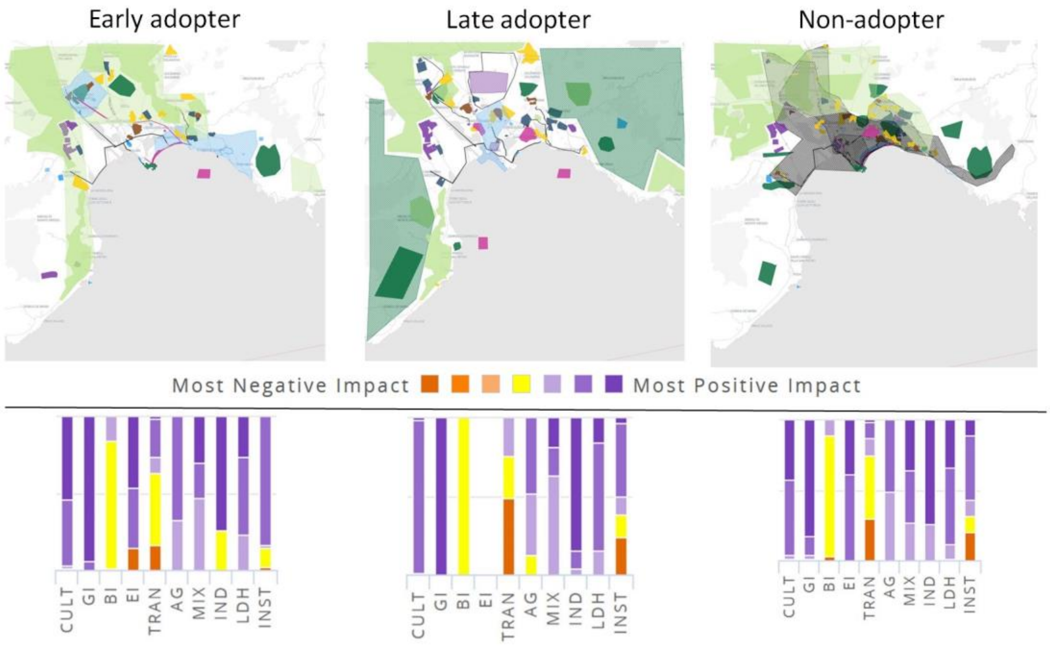

Figure 39. Final syntheses of the IGC MCC geodesign workshop 2018 (area 80x80 km).

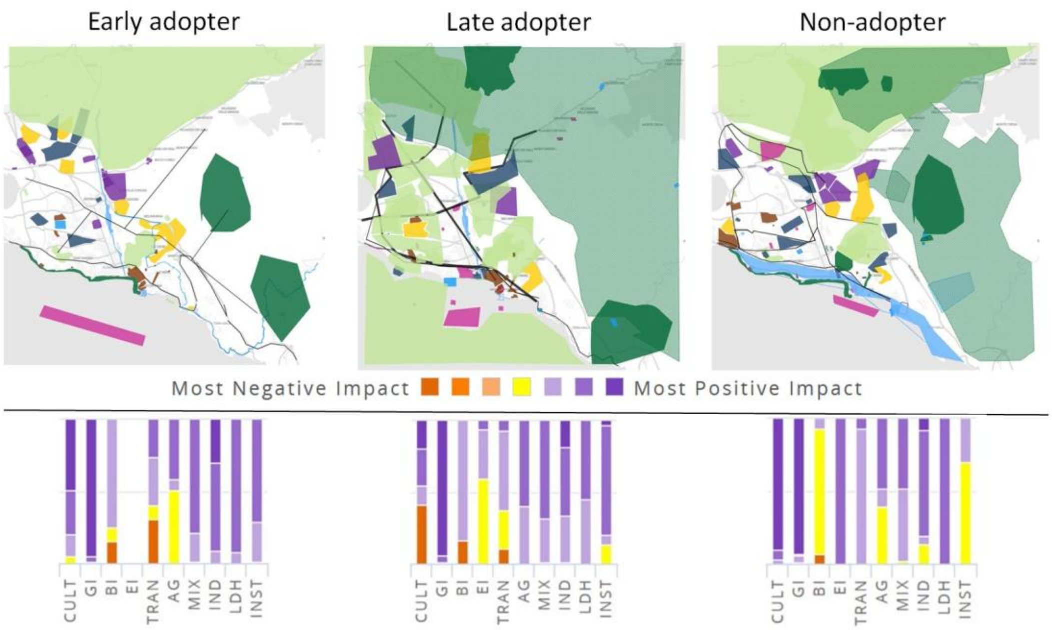

Figure 40. Final syntheses of the IGC South-East MCC geodesign workshop 2018 (area 20x20 km).

The geodesign approach, in the very limited time of the intensive workshops (i.e., 15 hours each), enable them to grasp the complexity of studying comprehensive strategic planning alternatives dealing with the interaction of ten systems at once. As shown in Figure 39 and Figure 40, the impacts model of the final syntheses were overall positive, as substantially was the impact on the GI system in all the alternatives. In the light of these general results, in the following sections a closer focus is given on the GI system modelling and design within the MCC study in order to highlight the adopted level of detail in the analysis and in the design.

5.3 The green infrastructure system in the Metropolitan City of Cagliari

The Metropolitan City of Cagliari, recently established with Regional Law n. 2/2016, is located in Southern Sardinia (Italy) and includes 17 municipalities. The area is located on the fertile plain of Campidano and overlooks the Gulf of Cagliari to the South. The area is surrounded to the East and to the West by mountains.

The MCC has currently a total population of 430,798 inhabitants distributed over an area of 1,248.71 km², with a density of 345 inhabitants per km². The population distribution is uneven as it is more concentrated around the regional capital, Cagliari and its neighboring municipalities belt, Quartu Sant'Elena, Selargius, Quartucciu and Monserrato. The territory is characterized by the presence of heterogeneous areas of naturalistic interest, since the geomorphology, lithology, pedology, land cover and landscape are extremely variable.

Table 15. List of Natura 2000 sites in the Metropolitan City of Cagliari

Site name	Site code	Type	Area [ha]
Stagno di Cagliari, Saline di Macchiareddu, Laguna di S. Gilla	ITB042207	SAC	8.567
Costa di Cagliari	ITB040021	SAC	2,623.851
Bruncu de Su Monte Moru - Geremeas (Mari Pintau)	ITB040051	SAC	139.000
Monte dei Sette Fratelli e Sarrabus	ITB041106	SAC	9,295.794
Canale su Longuvresu	ITB042207	SAC	8.567
Riu S. Barzolu	ITB042241	SAC	281.341
Torre del Poetto	ITB042242	SAC	9.371
Tra Forte Village e Perla Marina	ITB042231	SAC	0.320
Monte Sant'Elia, Cala Mosca e Cala Fighera	ITB042243	SAC	27.448
Foresta di Monte Arcosu	ITB041105	SAC	30,369.312
Stagno di Molentargius e territori limitrofi	ITB040022	SAC	1,275.232
Capo di Pula	ITB042216	SAC	1,576.379
Stagno di Cagliari	ITB044003	SPA	3,756.385
Foresta di Monte Arcosu	ITB044009	SPA	3,132.074
Monte dei Sette Fratelli	ITB043055	SPA	40,473.932
Saline di Molentargius	ITB044002	SPA	1,307.155

In particular, the MCC includes sixteen Natura 2000 sites: twelve SACs, and four SPAs both in marine and terrestrial zones (Table 15) covering an area of 52.000 hectares of SACs (31.000 ha of which fall exclusively within the territory of the local authority) and 49.000 hectares of SPAs (18.000 ha of which fall exclusively within the territory of the local authority). Despite the presence of a quite number of core areas characterized by a rich biodiversity, the sites, often located in or near densely populated urban areas, are not always adequately connected to each other. Within this context, one of the main priorities for the creation of a metropolitan level GI is to enhance connectivity among protected areas and counter habitat fragmentation.

As noted by Slätmo et al (Slätmo et al., 2019)”the land uses that conflict most in terms of habitat fragmentation with GI preservation and development are transport and energy infrastructures and agriculture. This may be considered an issue of interest also in the study area, and it was considered in defining the input of the impact matrix in Geodesignhub. In addition (Slätmo et al., 2019), low-intensity use of land for built up areas, commonly referred to as ‘urban sprawl’ is also an important factor of habitat fragmentation. In addition, “denser urban structure and land cover changes in urban areas are often at the expense of green areas and the ecosystem services they preserve.”(Slätmo et al., 2019)

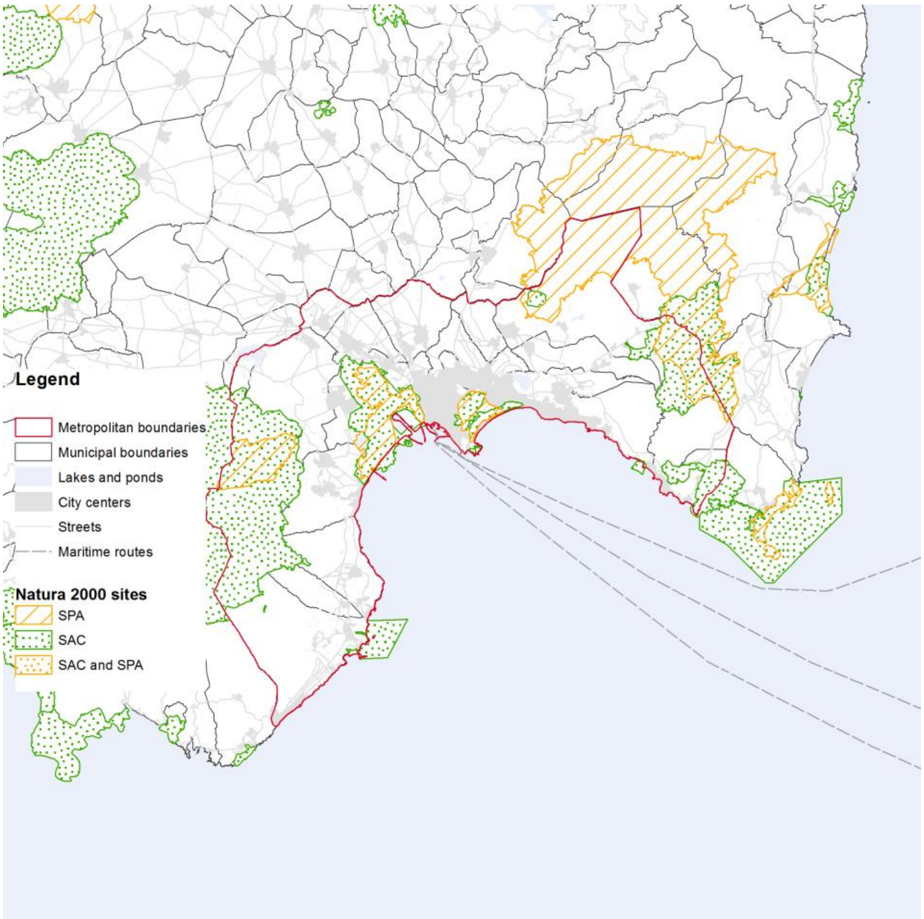

Figure 41. The Metropolitan City of Cagliari and the Natura 2000 sites

3.1 Green-Infrastructure Evaluation Model

In the knowledge building phase of the study, an evaluation model was prepared for each system by the study coordination team. The construction of the evaluation model is a critical step in the geodesign workflow. On the one hand, the output of the evaluation model (i.e., an evaluation map for each system) needs to include several criteria in order to suggest suitable location choices for an action in the system, as well as, to identify areas were changes are not needed or unfeasible. On the other hand, in doing so the evaluation model needs to be transparent to the user, which may otherwise not accept the recommendations represented in the evaluation maps, due to the possible occurrence of the well-known black-box effect. In addition, the number of criteria, and their spatial patterns, used to identify more or less suitable areas may vary in space. The degree of uncertainty involved in the preparation of the evaluation maps, may vary accordingly, sometimes to a substantial degree. Therefore, a step by step modelling process, to be documented in detail, may help to avoid the black-box effect, and to better deal with uncertainties, while making s based on the recommendations. Formalizing the evaluation model for each system, may help in dealing with complexity, and in making the model transparent, hence more reliable, to the users. Below, the evaluation model for the GI system is described in detail.

The modelling starts with short but comprehensive verbal description of the system (i.e., the rationale row in Table 16). The specification of categories of possible actions may help to make the description more operable.

It should be noted that as evaluation map legend, the classification applied in the Georgia Coastal Region geodesign study (R. Rivero et al., 2017) based on Carl Steinitz's adaptation of the G. Angus Hills work (Harvard University. Department of Landscape Architecture. Research Office, 1969) was used. The description of each class is given in the row "classification" in Table 16. This classification was widely adopted by the authors, as well as, by other geodesign experts and proven to be reliable. Nevertheless, a carefully modelling stands crucial in order to reduce uncertainties in the final evaluation maps.

For each class of the evaluation map legend, a list of spatial criteria to identify them is given first in natural language (in row "description", Table 16), then as list of spatial data layers (row "data", Table 16). As a complement to increase transparency, the row "operators" (Table 16) specify the conditions applied to spatial data layers through GIS functions (e.g., query, geoprocessing, and so forth). Table 16 presents the modelling table used for the GI system in the MCC workshop, and it is proposed here with the aim to illustrate the rationale of the creation of the evaluation map. In general terms, the model itself is indeed context-dependent and may vary substantially in different study areas, at different scale, and with the objectives and scope of the design.

Table 16. Modeling table of the green infrastructure evaluation model.

Rationale	**GREEN: Green Infrastructures** The Green Infrastructure system focuses on protection and connection of high quality natural and semi-natural areas located in urban, suburban and rural areas, in order both to protect biodiversity and enhance nature's ability to deliver multiple valuable ecosystem goods and services. Sardinia includes 125 Natura 2000 Sites of Community Interest and Special Protection Zones, which are part of Natura 2000, a network of core areas instituted by EU Directive 92/43/EEC (Habitat Directive) and EU Directive 2009/147/EC (Birds Directive), with the aim to ensure the long-term survival of the local most valuable and threatened species and habitats, listed under the body of the Directives. In the Metropolitan City of Cagliari, Natura 2000 sites are situated near densely populated areas and they are not always adequately connected to each other.	
	Possible actions on landscape (regional/metropolitan scale): • New Protected areas • Ecological corridors • Green Infrastructure for storm water management • Creek Restoration & Naturescaping • Multi-functional farming • Wildlife overpass • BeehivesOther • Other	**Possible actions on settlements (urban scale)**: • Green roofs and walls • Green streets • Rain gardens • Urban agriculture • Urban forest • Wildflower verge • Other
	Possible integrated actions • Green belt • Other	

	Existing	Not appropriate	Capable	Suitable	Feasible
Classification (Courtesy of Carl Steinitz)	is where the system is "**existing**" already and **in a healthy state**, meaning that it is feasible to remain….a constraint in terms of information but not a total Constraint.	is lowest priority for change… "not appropriate" or not capable of supporting the system, meaning don't put it there, e.g. too wet or steep or….unless you provide change to the basic area conditions e.g. fill in the ocean for new land, regrade the mountain, etc.. (all very risky projects). This is also a constraint in terms of information.	is low but higher priority …."capable", meaning that you can place it here IF you also provide the technology and market to make it feasible, e.g. water and sewers, access roads for mechanical harvesting, etc., and the market comes…	is higher priority…."suitable", meaning that the area is capable of supporting the project and it already has the appropriate technologies to support the activity taking place e.g. septic tank soil or sewers, access roads for mechanical harvesting, etc. BUT there may not yet be a market for the change.	is the highest priority for change…."feasible", meaning that it is suitable AND there is a demand or market to provide the new land use change, e.g. that someone wants to buy the product or new house (and at a profit) OR that the government wants to protect and improve an historical landscape.
Description	This class includes: • Core areas of high biodiversity value which act as hubs for GI (i.e. Natura 2000 sites) • Natural features containing healthy functioning ecosystems, acting as wildlife corridors or stepping stones	This class includes: • Urbanized areas (due to the design scale)	This class includes: • Artificial areas that, if sustainably managed, enhance ecosystem services or assist wildlife movement	This class includes: • Natural and artificial areas that, if sustainably managed, could help to improve the general ecological quality and permeability of the landscape to biodiversity	This class includes: • Not protected natural and semi-natural areas • Buffer zones around natural protected areas and natural features that help to reconnect existing natural areas

Data	Layers • Natura 2000 sites (Sites of Community Interest and Special Protection Zones) • Corine Land Cover 2008 (CLC)	Layers • Corine Land Cover 2008	Layers • Corine Land Cover 2008	Layers • Corine Land Cover 2008	Layers • Natura 2000 sites • Corine Land Cover 2008
Operators	• Natura 2000 sites • CLC 1.4: Artificial, non-agricultural vegetated areas • CLC 4: Wetlands • CLC 5: Water bodies	• CLC 1.1: Urban fabric • CLC 1.2: Industrial, commercial and transport units • CLC 1.3: Mine, dump and construction sites	• CLC 2.1: Arable land • CLC 2.2: Permanent crops	• CLC 2.3: Pastures • CLC 2.4: Heterogeneous agricultural areas	• CLC 3: Forest and semi natural areas • Natura 2000 buffer (2000 m) • CLC 4 buffer (500 m) • CLC 5 buffer (500 m)
Notes					

The modelling table should be, and it usually is, distributed to the workshop participants to familiarize with the model. In addition, the modelling experts for each system should be present during the workshop in order to give the participants appropriate recommendations in case of needed. Unlike more traditional suitability maps (Hopkins, 1977; Malczewski, 2004), which are usually built for a given well-defined land use (e.g., a given type of crops for agriculture, or a given type of building typology for lower density housing, and so forth), depending on the system and on the scale, the model underlying an evaluation map should represent the level of suitability, or, on the contrary, the lack of necessity or feasibility at various locations, of more or less complex sets of development actions (i.e., conservation or development projects or land-use changes). As such, the results should be considered as general recommendation and not in a regulatory way. The importance of understanding the model and its level of uncertainty, which may vary locally depending on the class, is fundamental in order to make informative recommendations for locational choices of design actions during the geodesign workshop.

In our study, the modelling exercise was made even more complicate for it concerned both the regional and the urban scale at once. However, it should be noted that the scope of the workshop was exploratory in nature, and undertaken in educational context. As such, the level of the uncertainty was considered acceptable for the working context. The main objectives of the workshops were understanding the influence in the use of advanced design technologies for the change actions, and educating early career students in architecture and civil and environmental engineering in geodesign methods and techniques for spatial planning and design. Analyzing the results of the design exercise, and the learning curve of the participants observed during the workshops, both objectives could be considered reached. Nevertheless, it should be noted that in a real world geodesign study, such level of uncertainty might not be considered acceptable, and one model for each scale would be recommendable.

Figure 42 shows the GI evaluation map obtained by geoprocessing implementation of the modelling table (Table 16). It should be noted that the modelling workflow is not strictly linear. Several iterations were carried on by the study team before the results presented here were considered appropriate in terms of model and level of details for this study.

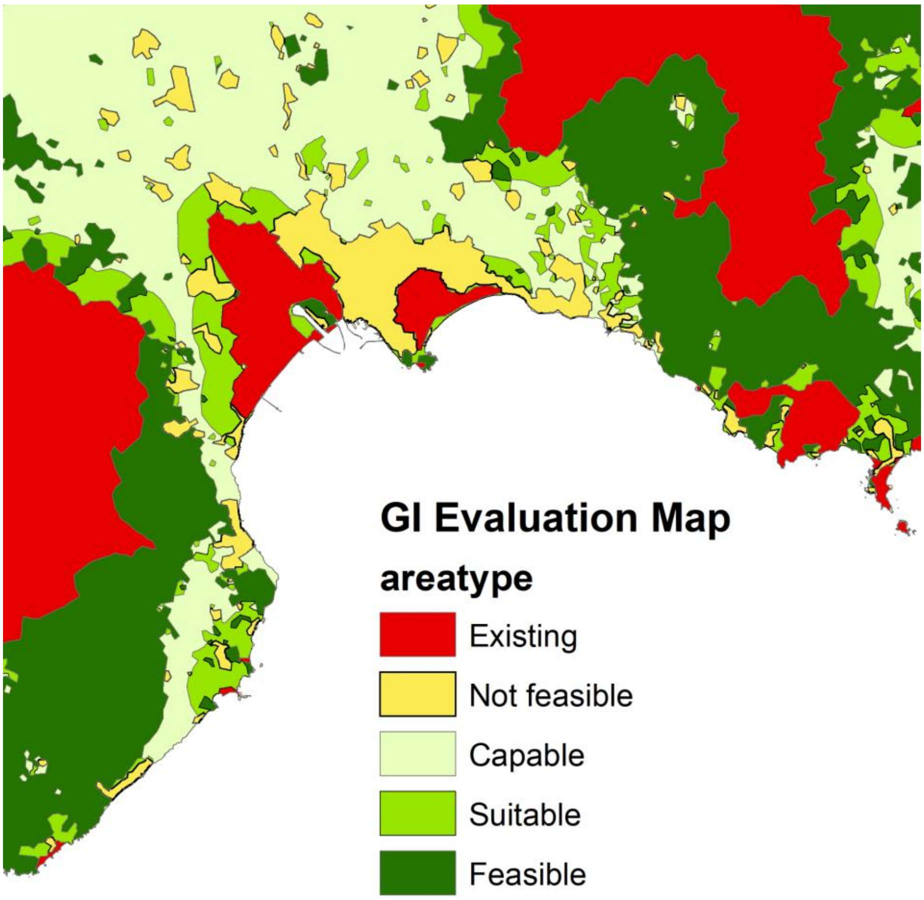

Figure 42. GI evaluation map.

5.4 Analysis of the GI design results

The geodesign study was carried on in the context of two studio courses involving a large number of engineering graduate students (master's degree) and architecture undergraduate students respectively. Five three-hour sessions were fully dedicated to the collaborative development of design alternatives for each of the two planning scales. While the design in the workshops were carried on by students with little or no previous knowledge, the analysis of the design they produced collaboratively provided interesting results, contributing to demonstrate that the overall geodesign workflow effective in supporting the integrated design of GI with other systems. A detailed analysis of the green infrastructure design results was carried out in a de-briefing phase (Figure 43). During the step 2 of the workshop on the smaller design scale (i.e., larger area) the students grouped in ten system expert teams produced 353 diagrams with a mean of 35 proposals in each system. In the system green infrastructure 2 policies and 30 projects were created representing the 9% of the diagram matrix (Figure 43a). Among them 18 were selected in the final designs as result from the negotiation process between teams grouped by development scenario: NA35+NA50 (Figure 43b), LA35+LA50 (Figure 43c), EA35+EA50 (Figure 43d). All the design teams included further GI management down the mountain areas on the East and on the West.

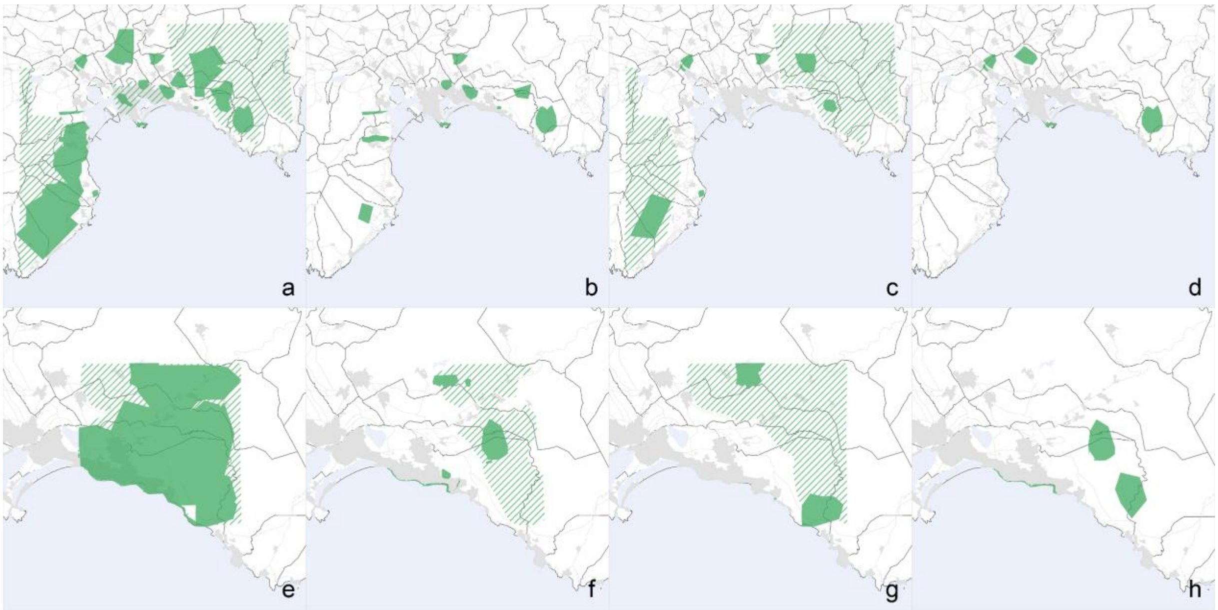

Figure 43. The GI diagrams created during the first workshop on the smaller design scale (a) and selected in the final syntheses: NA35+NA50 (b), LA35+LA50 (c), EA35+EA50 (d); and the GI diagrams created during the first workshop on the smaller design scale (e) and selected in the final syntheses: NA35+NA50 (f), LA35+LA50 (g), EA35+EA50 (h).

Focusing more on individual projects, the EA team proposed a project representing an extended green park, connecting two existing core areas, one in the coastal and one in the inland zone. The park has been designed both to create new habitats and to allow movement of animals between existing areas of high biodiversity value (Figure 44a). Other diagrams, both located in the Northern part of the MCC near urban centers, represent respectively new residential areas designed with a modular system of green facades in order to contribute to the reduction of urban heat island effect and new public gardens (Figure 44b) with the aim to stabilize the concentration of CO2.

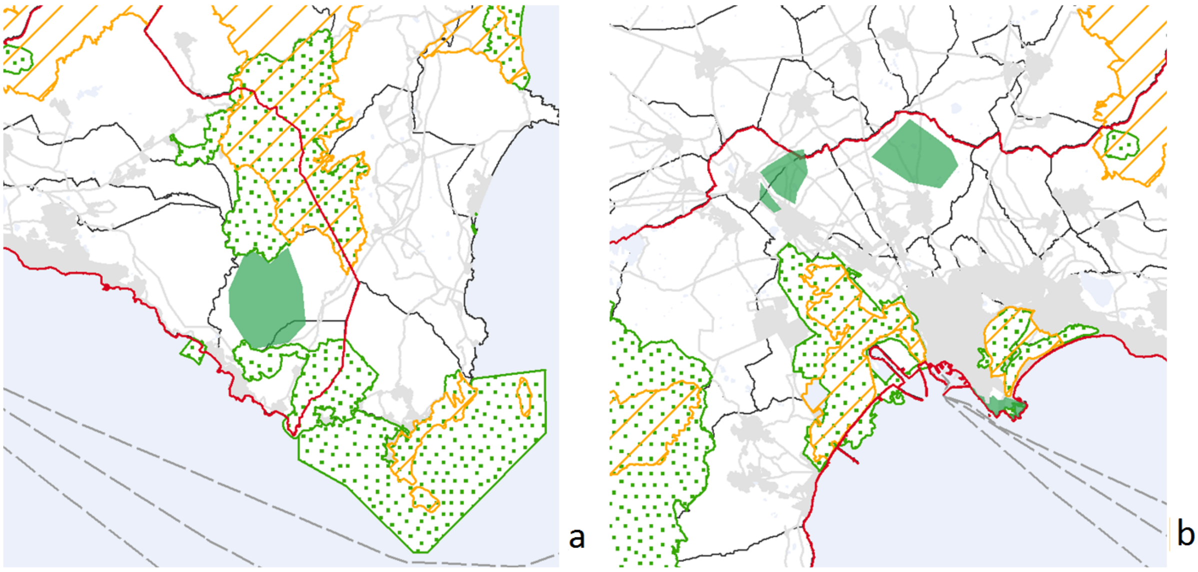

Figure 44. Example of integrated GI projects proposed in the MCC geodesign workshop 1.

The LA team proposed two wide area policies, one in the East and one in the West side of the MCC, both proposing multifunctional green areas (Figure 45a, Figure 45b). Inside these areas they planned reforestation zones and green parks. Moreover, near densely populated areas they planned residential areas with green roofs and walls (Figure 45c).

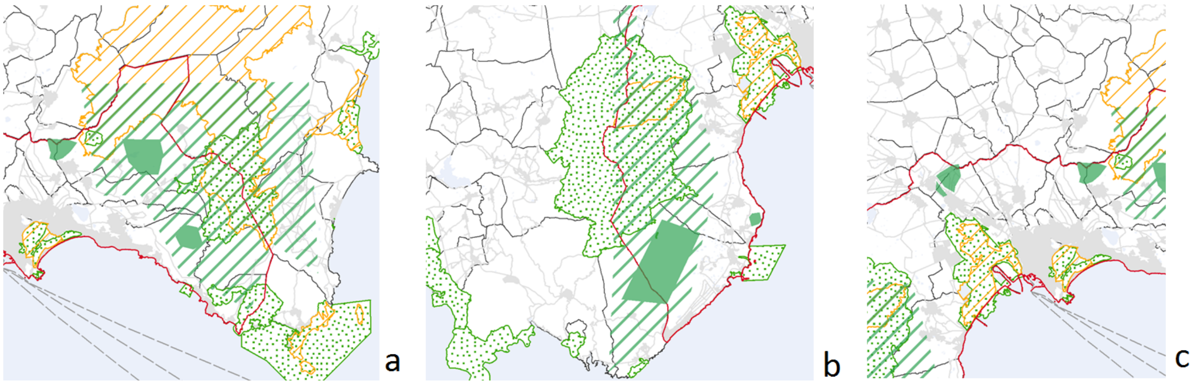

Figure 45. Example of GI projects proposed in the MCC geodesign workshop 1.

The NA team proposed smaller and spatially widespread projects, most of which represent ecological corridors connecting existing green areas, which support the restoration and enable wild animal populations to move more freely (Figure 46a, Figure 46b).

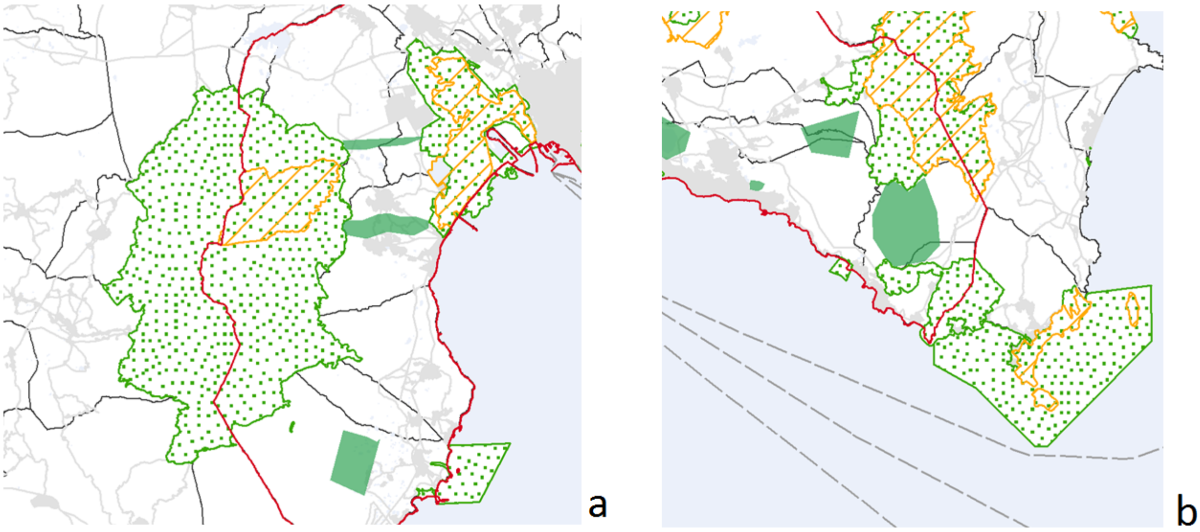

Figure 46. Example of GI projects proposed in the MCC geodesign workshop 1.

The PSS Geodesignhub facilitates the green infrastructure design at different scales and in relation to the other systems, rather than focusing on single-level sectoral planning. Running two geodesign workshops in sequence allowed to experiment the change of scale in the design of future alternatives for the MCC. The architecture students who attended the second workshop in the sequence had to comply with the design earlier developed by the engineering students in the first workshop. Geodesignhub enabled the shift from the metropolitan level to the local level providing the projects and policies from the first workshop as input in the larger scale study. The GI design of the South-Eastern edge of the MCC was, thus, informed by the whole metropolitan strategic strategy developed in the first workshop. The architecture students designed 356 diagrams including 12 policies and 21 projects in the GI system (e). It is worth noting that the GI diagrams included in the final syntheses (NA35+NA50, Figure 43f; LA35+LA50, Figure 43g; EA35+EA50, Figure 43h) spatially coincide in part with the small-scale GI proposals with an area of overlapping of 20%, 100% and 5% respectively.

The EA team proposed two main types of intervention. The first consists of two extended green parks near a Natura 2000 site, which improve the general ecological quality of the landscape and enable nature conservation and human recreation (Figure 47a). The second project is located in the

Southern area along the coast and consists of a flora coastline protection green infrastructure (Figure 47b), which protects coastline and residential areas from sea level rise resulting from climate change, while creating new habitats for marine fauna species.

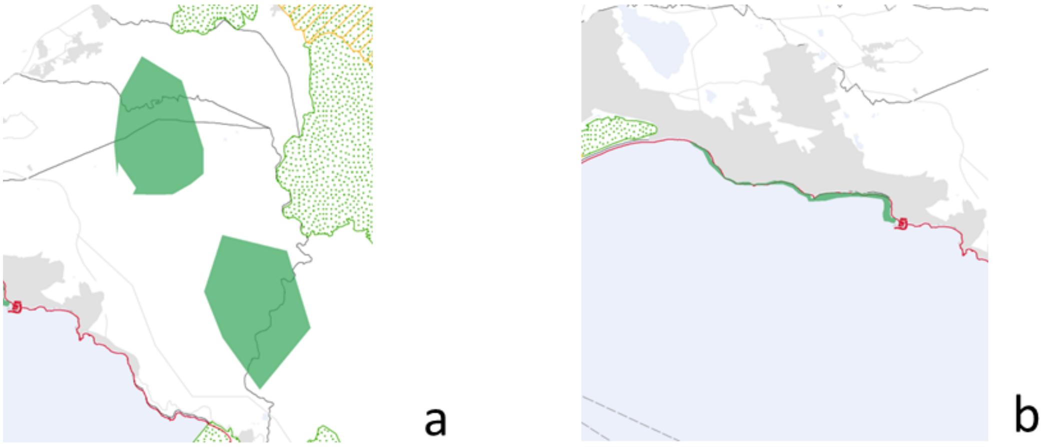

Figure 47. Example of GI projects proposed in the MCC geodesign workshop 2.

The LA team proposed a big policy in the Eastern rural area, next to a Natura 2000 site, which offers an attractive outdoor area, near the residential one, for recreation (e.g., trekking, horse riding, picnic areas) and wildlife (Figure 48a). The second project is a biodiversity-rich park, which falls under the wide area policy mentioned above and it is located in the Northern edge, planned to help to absorb CO_2 emissions and improve air quality (Figure 48b).

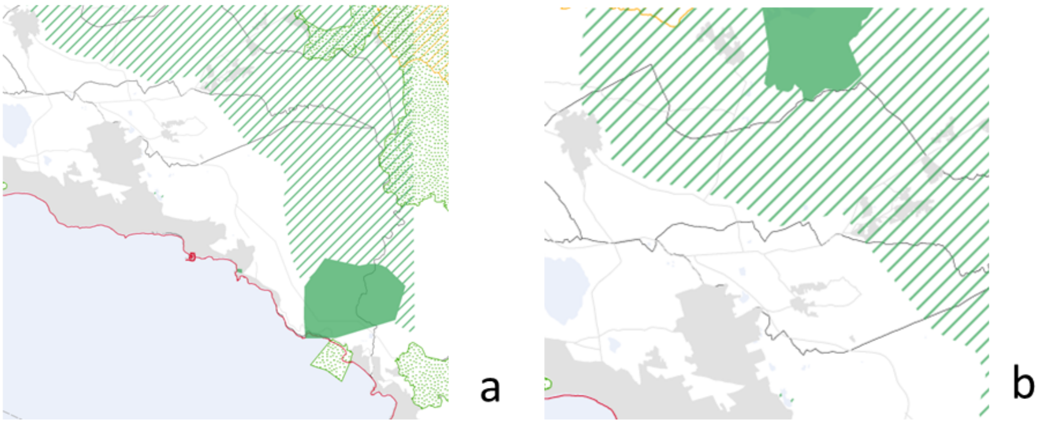

Figure 48. Example of GI projects proposed in the MCC geodesign workshop 2.

The NA team proposes a big policy in the Easter zone, planned to support multiple land uses in the same spatial area: human recreation and food production (e.g., wildlife-friendly agriculture and farming, which enable the permeability of the landscape to biodiversity) (Figure 49a). The second project is the flora coastline protection green infrastructure (Figure 49b) with the aim to protect from sea level rise.

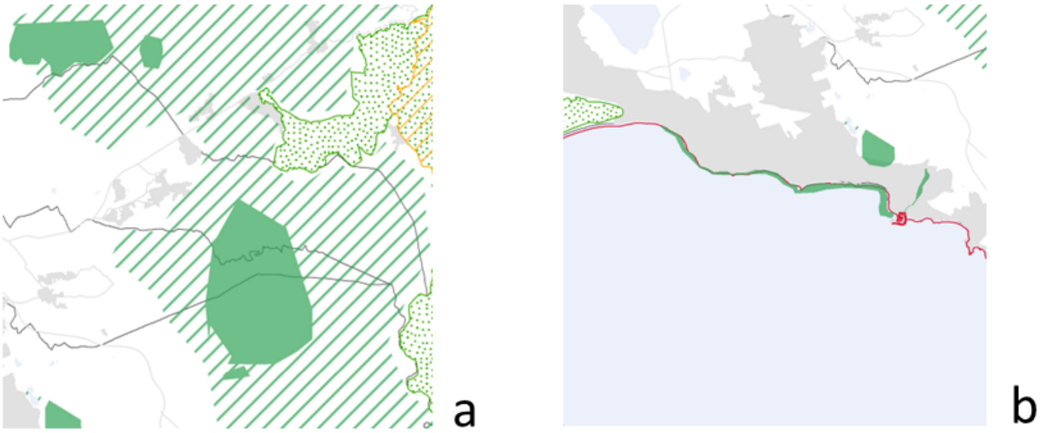

Figure 49. Example of GI projects proposed in the MCC geodesign workshop 2.

5.5 Discussion

The PSS Geodesignhub, which was designed to implement the second part of the framework for geodesign (Steinitz, 2012), encourages the users in applying system thinking. The cross-system approach is supported by the possibility to compute the impacts of projects hence to evaluate the cumulative performance of design proposals in relation to both the systems the projects belong to, and to the other systems. Geodesignhub overlays diagrams with the evaluation maps and checks their intersections to compute impacts. The relationships between systems are computed thanks to values imputed in the impact matrix beforehand. With reference to the example shown in Figure 50, the two diagrams GI 2 and GI 3 represent the implementation of green corridors on the Eastern and Western edges respectively (Figure 50a). Their impacts on the system Green Infrastructure are positive, meaning that the existing natural resources are in need of protection (Figure 50b). Conversely, the cross-system analysis (Figure 50c) displays negative impacts in the system Commerce and Industry. The area in orange is, in fact, also highly attractive for locating commercial or industrial facilities, thus possible conflicts among different land-uses may occur in the area. The establishment of a green corridor would considerably restrict the possibility in the area for commercial and/or industrial development. Hence the spatial overlay analysis allows to automatically identify possible conflicts of interest, and provides an efficient tool for understanding how systems mutually influence each other in rapid real-time design iterations. Such kind of assessment can be repeated real-time many times during the design providing for an efficient trial and error aid when studying multi-system locational coherence.

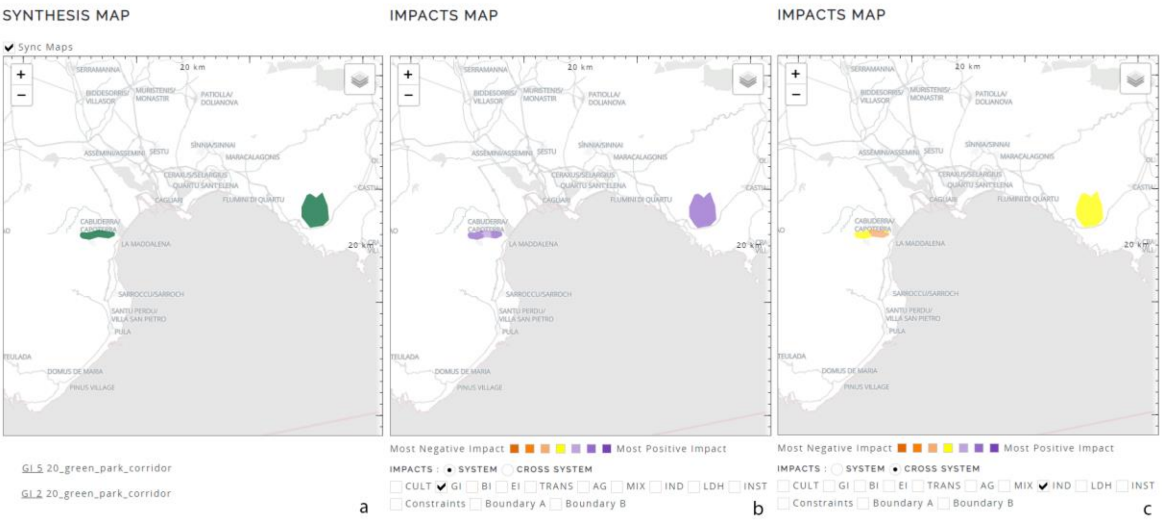

Figure 50. The tool “Compute Detailed Impact” in Geodesignhub.

The “Display Overlaps” function identifies overlapping features in a selection of diagrams by a single design team. Once again, the goal is to represent conflict in design, within a single synthesis. Figure 51a shows the overlapping projects of the final synthesis of the group Early Adopter 2050. Some of the projects may coexists (e.g., GI 27 “New botanic garden” and LDH 44 “Nursing homes with robotic assistants”), while others include potentially conflicting land-uses (e.g., INST 26 “Expansion of the harbor capacity” and CULT 14 “Protection of underwater ancient relict”). Likewise, the function “Combined Analysis” displays overlapping projects in two or more syntheses (Figure 51b). Mismatching dark colors identifies conflicts between teams while consistent colors confirm agreement on a certain land use.

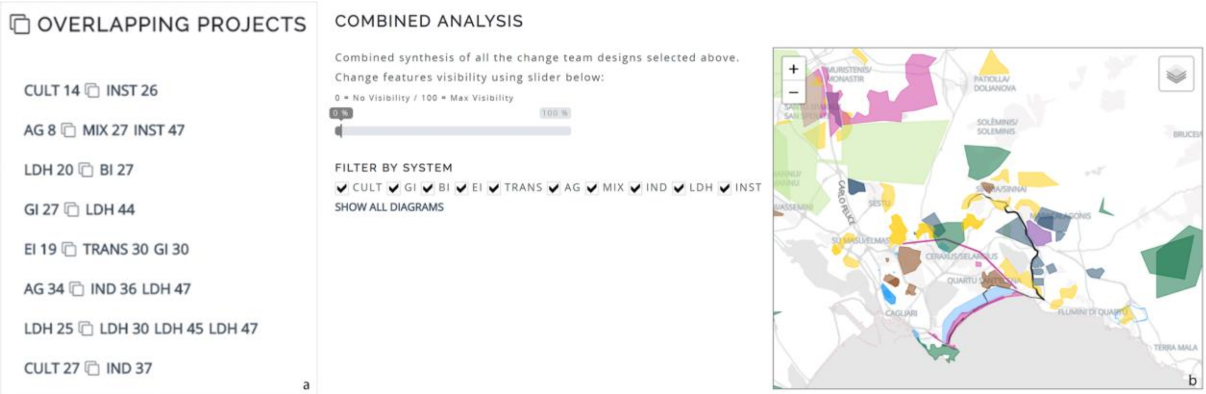

Figure 51. The “Display Overlaps” (a) and “Combined Analysis” (b) tools in Geodesignhub.

In addition to the available built-in tools in Geodesignhub, the Geodesign Process Analytics (GDPA) approach (Cocco et al., 2019) can be used to process Geodesignhub log-data to monitor and real-time display in a e-dashboard the process dynamics, including the spatial overlaps between projects, the temporal sequence of activities and tasks, the user behavior and productivity, and the evolution of the design in space and along time. The set of indicators proposed in these analytics support the application of systems thinking during the rapid design iterations of a typical geodesign workshop (Nyerges et al., 2016a; Pettit, Hawken, Zarpelon, et al., 2019), highlighting in real-time the relationships between GI projects and those of the other systems. Making projects synergies or conflicts more explicit it encourages systems thinking and help design teams in reaching consensus on common proposals. Following on previous studies (Freitas & Moura, 2018) GDPA exploit the spatial functions of the PostgreSQL database to automatically identify topological relations between diagrams. If the overlapping area represents more than or is equal to 80% of the total area of the two diagrams, they are considered similar. Other types of relations can be identified: diagram A “contains” diagram B when the area of intersection represents more than or is equal to 80% of the total area of the second diagram; diagram A is “within” diagram B when the area of intersection represents more or is equal to 80% of the total area of the first diagram; diagram A “intersects” diagram B when the area of intersection is less than 80% of the area of both diagrams.

Table 17 shows the results of the application of the Freitas` and Moura’s method (Freitas & Moura, 2018), that is not only that there is an overlap but also the type of relation that characterize the overlapping diagrams in the final synthesis of the group Early Adopter 2050 (EA50). The same indicator can be used to bring out spatial relations between diagrams of two different syntheses. Analyzing the relation between two overlapping diagrams, their titles and related systems, it is possible to disclose potential conflicts resulting from incompatible land-uses, which were earlier identified only graphically in the map in Figure 51b.

Table 17. Excerpt from the output generated by the ETL transformation to measure the *Topology Similarity* between the diagrams selected in the last synthesis of the group EA50.

Title	Diagram A	% (A∩B/A)	Relation	% (A∩B/B)	Diagram B	Title
Protection of underwater ancient relict	CULT 14	93.80	within	1.56	INST 26	Expansion of the harbor capacity
New botanic garden	GI 27	47.88	intersects	57.29	LDH 44	Nursing homes with robotic assistants
Drone laser scanning for precision agriculture	AG 34	1.50	contains	99.98	IND 36	Hydrogen fuel cell power plant

Table 18. Excerpt of the output generated by the ETL transformation to measure the Topology Similarity between the diagrams selected in the last synthesis of the group EA50 and EA35 respectively.

Title	Diagram A (EA50)	% (A∩B/A)	Relation	% (A∩B/B)	Diagram B (EA35)	Title
High-density 3D-printed housing	MIX 21	100	within	0.64	AG 43	Precision agriculture with drones
Smart farming with drones	AG 34	47.88	intersects	57.29	AG 34	Precision agriculture with drones
Poetto beach – solar sidewalk	EI 19	1.59	contains	100	TRANS 6	Viale Poetto – solar road

The implementation of the participants' performance and design evolution indicators in a digital dashboard provides an efficient tool to identify systems of major interest and those not sufficiently considered in the design from the perspective of a comprehensive plan design. Among the first set of indicators proposed, the "Diagram creation by system" (Figure 52a) shows the total number of diagrams created during the workshop. While, the indicator "Diagram selection by system in a synthesis version" offer the possibility to measure how many diagrams were selected in a group synthesis among those initially proposed (Figure 52b). The drop-down menus allow to select the team and synthesis version and display the histogram accordingly. It should be noticed that the number of diagrams created/selected can act as a rapid alert system for the workshop coordinator, but is not in itself a measure able to assess whether all the systems were properly taken into consideration. Local challenges in some systems could be addressed with few diagrams, conversely, the peculiar characteristics of some other could require a greater number of diagrams to face up the changes taking place or envisioned. Nevertheless, it provides useful information for the workshop coordinator when compared to other measures. To better evaluate these design dynamics the number of diagrams selected can be assessed with regards to expected targets. There may be a target associated with some of the systems (e.g., for this study area, 4000 hectares of new green infrastructures were required).

Histograms in Figure 52c shows in the left bar the target to be achieved and in the right bar the amount of area the change team devoted to that land use. This comparative analysis can support the workshop coordinator to best focus their assistance to design teams where an increasing/reducing in complexity (i.e., number of diagrams selected) is required to achieve the objectives and their targets. Furthermore, typically at the beginning of a geodesign study participants are asked to formulate a minimum number of design proposals in each of the systems (e.g., for this study area, a minimum of ten diagrams had to be created in each system). In order to ensure that this task has been accomplished a reference line was applied to the "Diagram creation by system" showing the target value (Figure 52a).

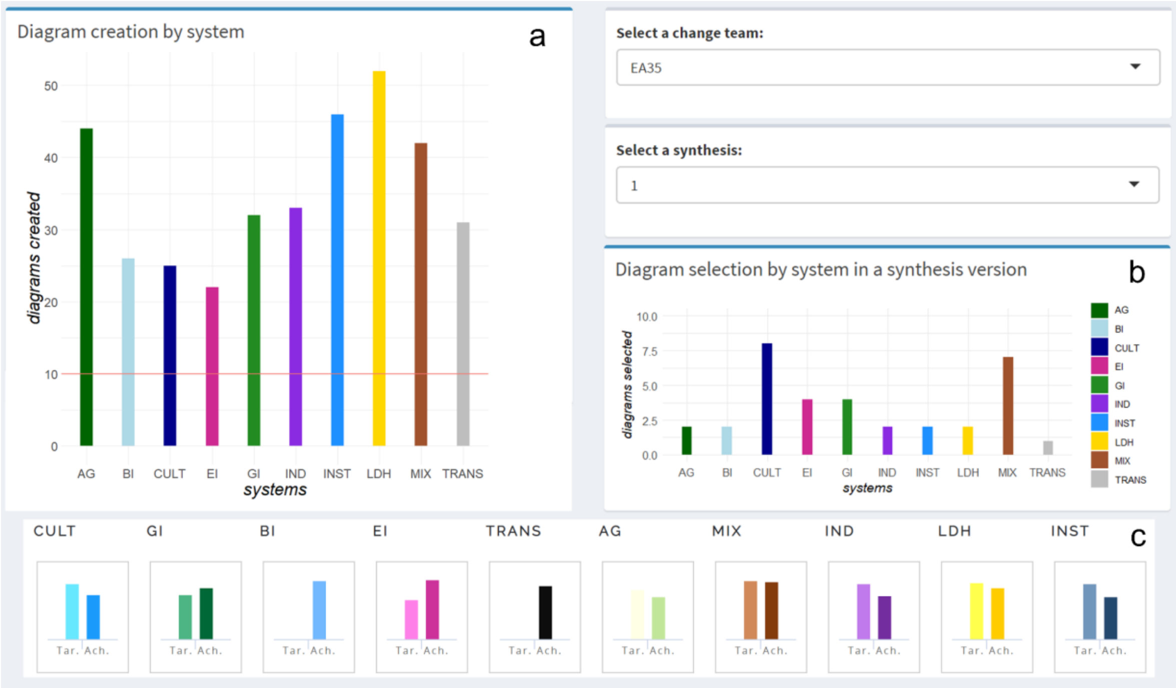

Figure 52. Excerpt from the Geodesign Process analytics dashboard used to analyze the log data of the MCC case study. The figure shows the "Diagram creation by system" (a), the "Diagram selection by system in a synthesis version" (b) and the histograms with the target objectives (in hectares) to be achieved (left bar) and already achieved (right bar) by the change team in the selected synthesis.

5.6 Conclusions

The main underlying assumption of this paper is that the design of GI should not be a sector design act, but GI should be considered as one of the main pillars in comprehensive regional strategic planning. Nevertheless, in current practices this is not often the case. This may be due to the fact that the importance of GI -in the current meaning of the term - in contributing to sustainable development has been widely recognized only recently. Hence, GI planning and management often may result as a sector endeavor, and an integration with more comprehensive spatial planning and policy-making is far from be common practice. Possible hindering factors may be institutional, as the recent concept may require time to be structurally introduced in planning systems with long traditions, but also methodological, for it may require innovation through reliable methods and tools to handle the systemic relationships between GI and the other territorial development system and dynamics. In order to address the latter issue, a geodesign study developed within the IGC is presented in order to propose a practical example of how applying system thinking through geodesign methods and tools may help to tightly couple the design of GI with other important territorial systems and dynamics.

The geodesign workflow applied in this study was implemented in two design workshops on the MCC. The results contribute to demonstrate how it is operationally possible to include GI in spatially-explicit strategic territorial planning. While this level of design may require a shift in scale to further develop the design in implementation plans, it is very likely to contribute to grow the awareness of decision-makers and stakeholders about the importance of GI, and of its relationships with other systems since the early phases of spatial planning, in order to avoid possible conflicts at a later stage.

The study presented in this paper was developed for research purposes and in educational settings, and further testing in real-world planning studies may be required in the future to further confirm the robustness of this approach in the real practice. However, while it may be considered only a first example towards more integrated GI planning, we hope the method, techniques and tools presented in this paper may provide a useful aid to planners towards reaching this aim.

Chapter 6 General Conclusions

In this Chapter the findings stemming from the four operative research questions are summarized. The results will be used to answer the central research question and to outline possible future developments stemming out from this doctoral research.

It is important to emphasize that the study did not focus so much on the application of the geodesign method and therefore on the quality of the outputs deriving from specific case studies, but rather on the evaluation of the workshop processes by taking advantage of the log files generated by the modern web-based platforms used for the management of the collaborative workflow (e.g., Geodesignhub). The analysis of the log-data stored during geodesign processes has proved useful in measuring some key dimensions of the design dynamics whose identification may, in turn, lead to recommendations for the methodology and its application. The findings reported in the following paragraphs are relevant and place the research within the broader context of process engineering.

6.1 Operative question 1

How can geodesign methods and technologies support collaborative and/or participatory planning processes?

The first research issue analyzed in this study stems from the ever-increasing demand to promote collaboration and participation initiatives in spatial planning practices. The adoption of sustainability principles in current European regulatory framework - governing spatial planning and environmental protection - aims at achieving more inclusive, democratic, evidence-based and transparent decision making. Although it is recognized as a determining factor with respect to the quality of the process, participation is currently proposed in a disaggregated variety of approaches and applications far from a systematization. The involvement of a wide range of actors, along with traditional collaborative and participatory methods (e.g., hearings and public meetings) may turn to be either complex or unclear.

Chapter 2 highlighted the key role of novel design methodologies and digital techniques in coordinating involved actors and avoiding informal or ill-defined steps. While, the geodesign approach facilitates a systematic and holistic view of the multiple issues and actors involved, the use of digital technologies and PSS supports planning experts and stakeholders in the implementation of the different design tasks.

The six-model operational framework of geodesign allows to manage effectively all aspects of participation within the different phases of a planning process. In particular, the clear definition of the methodology to be used in carrying out local geodesign studies (i.e., second iteration though the framework/meta-planning phase) results in a more efficient process thanks to clear choices of targeted methods and tools.

The use of currently available web-based digital applications innovatively supports the collaborative work. Their architecture combines the concepts of PSS and web 2.0 principles to implement in an integrated and participatory way the geodesign framework models. Among them, Geodesignhub represents a promising tool to approach the multi-dimensional context characterizing spatial problems, since it supports a collaborative and workshop-oriented planning and design process. Chapter 2 traced the main steps of the Cagliari Metropolitan City geodesign study that used the GDF and the PSS Geodesignhub to undertake the first design effort to develop a metropolitan strategic plan for the area. The results obtained by this case study demonstrate the potentials of geodesign methods and tools in contributing both to manage the complexity of planning workflows and to implement a transparent, collaborative and/or participatory decision-making process. The usefulness of geodesign as a new model of design practice is considered as a prerequisite for this research that proposes a specific assessment of the method application procedure.

6.2 Operative question 2

How does the analysis of PSS log-data help us to understand design dynamics in past and on-going (real-time) geodesign processes?

The application of digital information technologies promises unprecedented opportunities not only for facilitating collaborative design, but also for recording the dynamic of the planning process and contributing to address some of the most urgent issues of implementing the SEA Directive principles (e.g., transparency, identification of responsibilities, etc.). Chapter 3 describes the development of an analytical framework to exploit design information available in current planning support tools (i.e., Geodesignhub) log-data. Early research based on similar premises was successfully undertaken in several close domains such as industrial design, architecture and construction engineering, however, still little use (and value) has been made of log-data in the design domain.

The necessary steps and tools to collect, prepare, and analyze log-data were successfully tested and described in detail in this Chapter offering a novel and effective data processing workflow. Spatial, performance, temporal and design evolution indicators were designed to analyze quantitatively and in a systematic manner the geodesign process dynamics for the first time. The proposed analytics can be implemented using descriptive statistics and displayed in a dynamic dashboard, this way offering to the workshop conductor a real-time process analysis tool. Additionally, they can be used in a debriefing phase by applying the indicators to past geodesign processes. While the indicators have not yet been tested in a real-time case study, an *ex-post* implementation of the geodesign analytics has been explored using the log-data recorded in the Cagliari geodesign study. The workshop was carried out within the IGC project in 2018 and involved a group of over fifty engineering students of the University of Cagliari.

On the basis of the experimental findings reported in this Chapter, it possible to confirm that the use of currently digital tools compared to traditional ways of recording or tracking the process workflow (i.e., video recordings, surveys) makes available for analysis a greater number of aspects and dimensions, thus contributing to grasp many facets of the complex design dynamics in a systematic fashion. Beside the value of the single indicator, which in general should be contextualized by the coordinator in the face of the process dynamics at hand, visualizing the indicators in an e-dashboard (Figure 53) represents a valuable tool for design process log-data mining. GDPA framework provides sort of design process intelligence solution, looking at how business process intelligence is proficiently applied in other industries.

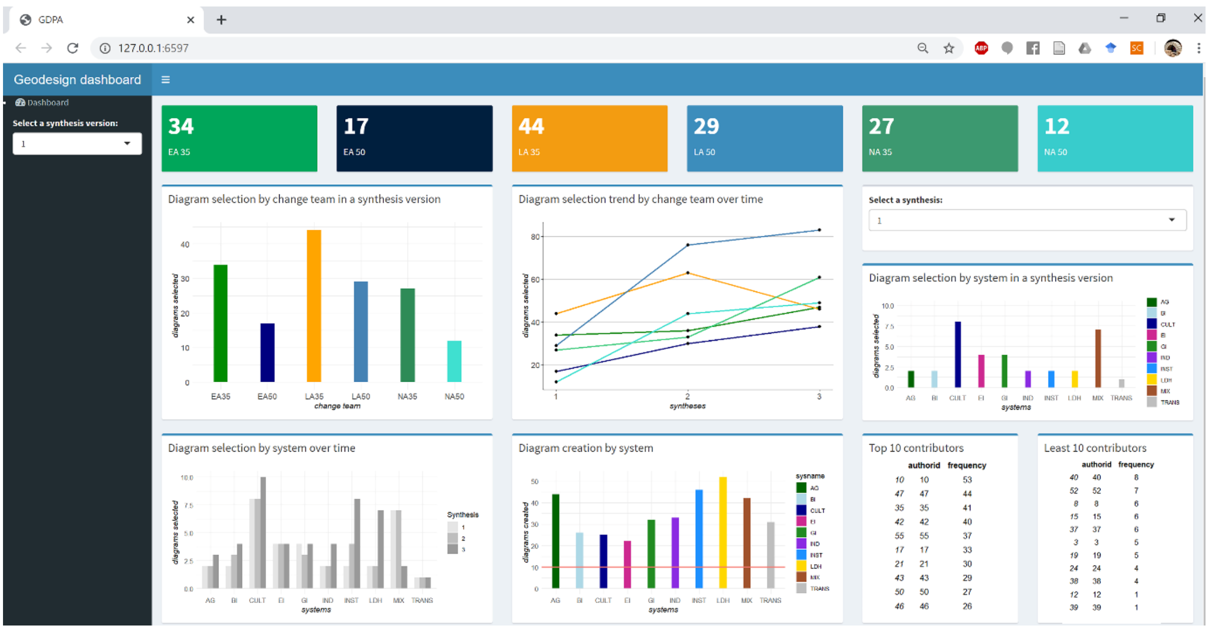

Figure 53. Geodesign Process analytics: example of e-dashboard.

6.3 Operative question 3

To what extent can the analysis of PSS log-data guide future geodesign processes (i.e., meta-planning)?

Chapter 4 continued to explore the potential of currently available PSS log-data using EAST2 as a theoretical framework to guide a more robust analysis based on inferential statistical techniques, which may lead to the detection of recurrent patterns in the behavior of involved actors. The proposed approach made it possible to measure statistically different aspects of a past geodesign process. A series of hypotheses were formulated and tested to explore the dynamics of participation and interaction among stakeholders involved in a computer-mediated collaborative planning and design process. Diagram selection patterns and technology-use dynamics were investigated.

The 'ways of designing' may differ among groups and individuals, and with varying scale and size of the area. Therefore, breaking down the digital workflow and using quantitative measures to identify recurrent patterns in participants' behaviors and design evolution may help better design and manage future geodesign processes, as required by the meta-planning approach. The acquired knowledge can be used to better design supporting technologies with the aim of trigger, promote or prevent observed reactions and behaviors.

The use of the conceptual map (i.e., concepts and relationships) of the EAST2 theory to structure the analysis of the log-data allowed to place the proposed methodology for geodesign analytics in a broader scientific context related to "decision situation assessment"(Nyerges & Jankowski, 2009).

6.4 Operative question 4

How useful are geodesign and geodesign process analytics in supporting integrated land use and green infrastructures planning?

In Chapter 5, the research focused on the use of geodesign technology and process analytics to support the early phases of integrated strategic territorial planning, in order to enrich the relationships between the design of green infrastructure and of the other relevant systems within more comprehensive planning and design applying system thinking.

In the last decades green infrastructure planning, design, and management have been widely recognized as a way to contribute to reach higher levels of sustainability of development. However, often GI are considered in a sectoral way, while their design should be more integrated within comprehensive planning and design. This Chapter provided a systematic and quantitative demonstration of how geodesign techniques and PSS log-data analysis can be successfully used to integrate the green infrastructure design within broader in scope strategic territorial planning. The use of spatial and statistical analysis allowed to measure quantitatively several aspects of the design process highlighting the fundamental relationship between GI and other systems thus helping to avoid possible conflicts at a later stage. It is also argued geodesign intensive workshops (usually lasting two days) can in a very short time contribute to raising the awareness among the participants to collaborative design of the importance of green infrastructure in strategic territorial planning.

6.4 Central question

How to fully exploit design information available in current PSS log-data in order to monitor, understand and improve planning and design processes?

A major challenge in collaborative geodesign, and in spatial planning in general, is not only to reach consensus towards a final plan, but also to make the process transparent to all the users, including those who participate to the design process but also those who eventually will have to implement the plan or will be affected by the plan implementation. Transparency of the process is of utmost importance both to understand how to react in case of unexpected issues during the plan implementation, but also to acquire better knowledge of the dynamics underlying the process which may serve as experience for the future. Understanding how the process dynamics affect the design outcome is a sensitive issue.

Digital supporting technologies are currently able to store both data about the design product, as earlier technology (e.g., CAD, GIS), but also log-data about the actions of multiple users with the collaborative platform. As such, PSS log-data represents a valuable source of information which can help us better understand the unfolding of the decision process clarifying i) how design alternatives are produced and ii) the design dynamics that characterized the interaction among individuals and groups involved in the planning process.

The combined inductive and deductive methodology adopted in this research helped taking full advantage of both underlying theories and empirical data in a complementary way. The use of spatial and statistical analysis allowed to measure quantitatively several aspects of the design process revealing dynamics previously unknown or not sufficiently analyzed.

The overall results show the appropriateness of the first set of indicators proposed to analyze the design log-data made available for the first time by such PSS, as Geodesignhub. Such an investigation may be useful both for learning from past case studies with the aim of improving future one, and for monitoring ongoing processes. First, by identifying recurrent behaviours and pattern which appear to be more or less effective for the process to succeed, better processes could be designed and managed in the future avoiding bottlenecks and facilitating the emergence of positive dynamics. Second, while the experience and the observation skills of those involved in the coordination of geodesign studies will always be relevant and needed, the availability of digital dashboard monitoring the process (*design as a verb*) and its product (*design as a noun*) real-time may potential add great value, especially in fast-pace intensive geodesign workshops with high number of participants.

Lastly, the opportunity of analysing real-time this new type of data with digital dashboards may potentially enable to apply a new business intelligence perspective in geodesign study management, and in retrospective or comparative studies by mining, what may be considered geodesign (processes) big data. The often-misused business adage "If you can't measure it, you can't manage it" could be transposed to the design domain as measurement made processes more transparent and manageable.

6.5 Future Developments

While the development of a full-fledged geodesign analytical framework is still in progress, this research aims at sharing the structure of the framework and the first results of its application, aiming at demonstrating its feasibility and stimulating interest for further investigation. Two important direction for future researches were identified focusing on technical and methodological aspects respectively.

As regards the former aspect, while the proposed analytical methodology innovatively exploited the API capabilities offered by Geodesignhub for data extraction, its application relied on desktop software for data preparation and analysis. Thus, so far, the analytics were exclusively implemented in a post-workshop debriefing situation. Future research should first focus on testing the indicators live during a geodesign workshop. For this reason, we envisage to integrate the analytical process into the PSS architecture. Complementing the API capabilities, currently available online data analytics and visualization tools (e.g., Plotly, Tableau, etc.) should be used to carry out exploratory log-data analysis directly retrieving design information from the cloud-based design platform (i.e., Geodesignhub) and to display the results in a real-time dynamic e-dashboard.

Another direction for future development, more focused on research strategy, would be to use PSS log-data in complementary manner to more traditional tools for data collection (e.g., video recording, survey, interview, etc.). Log files are capable of describing some of the dynamics taking place in the planning process, but it is still difficult to distinguish what is happening during the steps when the participants do not interact with the system. Particularly during the negotiation phase, video/audio recording of the verbal communication among stakeholders may help to better understand the subsequent actions within the design platform. However, traditional tools for data collection combined with standard processing methods (i.e., protocol analysis) have proved to be highly time-consuming and resource-demanding. In this light, log-data analysis could become useful to drive the identification of the more relevant parts of the process to be subsequently analyzed with standard approaches.

Two case studies focusing on the same area (i.e., the Cagliari Metropolitan City) were selected for applying the methodology. The first one was chosen for it involved academic, but also public, representatives in a realistic land use planning process, whereas the second one well represents an extremely complex planning situation (e.g., multi-session workshop, high number of participants, majority of non-expert participants, etc.). However, the validity and applicability of the geodesign process analytics need to be further assessed by applying the methodology to a wider number of case studies under different conditions (i.e., academic environment, real planning problems) and at different territorial scale (e.g., neighborhood, metropolitan area, etc.).

Finally, the indicators proposed in this study should be regarded as a first set of quantitative measures of the design dynamics and subsequently enriched with other measures capable of grasp more and more facets of a collaborative and computer-supported geodesign process that are by their very nature unique and specific to the situation at hand. The geodesign framework and the supporting digital technologies have been applied in many different case studies and each time adapted to fit the specific planning context. We should therefore take these aspects into account when developing a complete geodesign process analytics, focusing on the analysis of those design dynamics that appear in a recurrent way in geodesign studies developed in a workshop format.

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