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SEMANTIC WEB TECHNOLOGIES IN A PROCESS-AWARE PLANNING SUPPORT SYSTEM

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PhD Student: Xeni Kechagioglou
Coordinator of the PhD Programme: Prof. Roberto Deidda
Supervisor: Prof. Michele Campagna

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Semantic Web Technologies in a Process-aware Planning Support System

Xeni Kechagioglou

Department of Civil and Environmental Engineering and Architecture

University of Cagliari

Italy

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"Planning and the emerging social sciences are among the more optimistic of […] professions. Their representatives refuse to believe that planning for betterment is impossible, however grave their misgivings about the appropriateness of past and present modes of planning. They have not abandoned the hope that the instruments of perfectability can be perfected."

Rittel & Webber, 1973

"Dilemmas in a General Theory of Planning"

"The actual universe is a thing wide open, but rationalism makes systems, and systems must be closed."

William James, 1922

"Pragmatism: A new name for some old ways of thinking"

"If the future cannot be predicted before it happens, foresight requires an imaginative step that resembles the movement of a mountain climber towards the next hold. […] If innovation is important, we should probably give relatively little weight for trend extrapolations, what-if analyses, and time-series data and instead facilitate creativity and embrace innovation."

Tuomi, 2012

"Foresight in an unpredictable world"

DECLARATION

This dissertation is the result of my own work and includes nothing, which is the outcome of work done in collaboration except where specifically indicated in the text. It has not been previously submitted, in part or whole, to any university or institution for any degree, diploma, or other qualification.

Date: 14 October 2018

Xeni Kechagioglou

BSc Biology, MSc Geoinformatics

ABSTRACT

Indicated by the volume and geographical extent of initiatives for a sustainable future of the planet, there is an increased request for planning to satisfy normative requirements that safeguard sustainability of the adopted plans. However, sustainable planning projects often demonstrate incomplete or oversimplified planning processes. At the same time, a plethora of Planning Support Systems (PSS) exist, heralding the easing of planners' work. Nonetheless, they cannot boast widespread use, which is perplexing to PSS experts.

This PhD sought to explore the two issues for a possible convergence point. To this end, the abductive research strategy was embraced, with existing literature serving as the set of observations. This bottom-up investigative path concluded in recognition of the wicked nature of the planning process and of the fact that design of Information Systems (IS) for planning has been missing this point. The outcome was the suggestion of adopting the Open World Assumption (OWA) in the architecture of a PSS, which translates into using Semantic Web technologies for implementation of its functionalities, as a plausible solution.

The next objective was to design an IS that would test feasibility of the solution, and would ultimately assess worthiness of the OWA approach. Dealing in essence with a wicked problem, emphasis was put on building a suitable approach from step one, a journey that involved ontological and epistemological decisions and which ended up with choosing Pragmatism as the research paradigm and Design Science Research as the methodological framework. Design and implementation of the IS were subsequently arranged around processes taken from two distinct planning cases, namely the Strategic Environmental Assessment (SEA) in Sardinia and the sustainable management of the Maasai Mara rangeland in Kenya, with the first one used for experimenting on knowledge integration and the second one for investigating GIS tool integration.

The outputs of this final phase of the PhD were artifacts - a Knowledge Base concerning a SEA planning procedure and a mapping between a GIS software workflow model and elements of a workflow notation that can be used as intermediary between different GIS software -, meta-artifacts, i.e., the design of two aspects of what could be one integral PSS, as well as knowledge generated during design and implementation. Ultimately, an indication of the approach's research merit has been shown, while work involving more complex processes would help better estimate the potential of the suggested solution.

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Thank you to my friends in Cagliari who have been there for me through some difficult times, while they were also not much better off at the moment I needed them – thank you!

Thank you to my family, first and foremost for showing me how not be afraid of anything.

Thank you to my one and only absolute truth, the pillar of my life, without whom my soul dies. To God.

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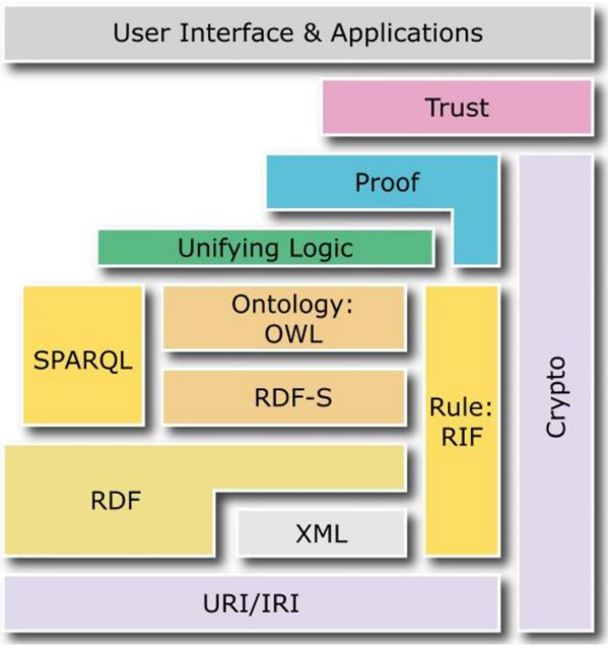
1 INTRODUCTION

1.1 Overview and rationale

Semantic Web technologies came to the foreground at the turn of the 21st century, promising more accurate information discovery on the web, deduction of logically implicit knowledge about any concept of interest, and combination of information from different locations to answer complicated user questions (Berners-Lee, Hendler and Lassila, 2001 [8]). The structure of the web fulfilling these targets would not be that of the well-known network of online documents (aka the "Web of documents") anymore. It would rather resemble a global collection of linked information and would be referred to as the "Web of data" or Web 3.0.

The way Semantic Web technologies (Figure 1.1) work is by rendering the meaning of data machine-processable. Data can stand for anything in this world (and even out of it), be it things, people, services, ideas, etc.; in fact anything that can be identified. Its meaning is naturally understandable by humans, but not so much by computers, and this is where the stack of Semantic Web technologies steps in. What they achieve is an increased cooperation between computers and humans, which has been proven useful through vertical applications, namely studies of how the stack can improve efficiency or upgrade users' experience in areas of interest that include - among others - healthcare and life sciences, e-Government, and social spaces (W3C, 2015 [156]).

Semantic Web technologies are no strangers to Planning Support Systems (PSS), i.e., to Information Systems developed to support urban and regional planning. Formal ontologies, perhaps the most recognisable element of the stack, have been used for enhanced browsing of information concerning, for example, sustainable technologies, spatial decisions or planning projects and policies in portals and wikis. They have also been used to infer unstated knowledge, for categorisation of land areas or planning programmes for example, in land vulnerability or land use classification and in detecting common structure and content in planning schemes, respectively.



Acronyms stand for:
URI - Uniform Resource Identifier
IRI - International Resource Identifier
XML - eXtensible Markup Language
RDF - Resource Description Framework
RDF-S - Resource Description Framework Schema
RIF - Rule Interchange Format
OWL - Web Ontology Language
SPARQL - SPARQL Protocol and RDF Query Language

Figure 1.1 The stack of technologies used for the realisation of the Semantic Web, as created by the World Wide Web Consortium and its partners (Bratt, 2007 [11]). Meanings of acronyms are shown on the right hand side.

One therefore may observe that ontologies in planning have in general been used either in the interest of data analysis, ultimately aiming at more informed spatial decision-making, or in the planning process itself, for evaluating congruence of locally implemented plans with globally defined policies. However, with regard to the application of Semantic Web technologies one step before process enactment, namely in the design of the planning process, a review of existing literature reveals critically little investigation done.

The process of planning presents the difficulty of being complex in nature (Rittel and Webber, 1973 [125]). This is more notable nowadays, considering the broad acknowledgement of planning's participative, dynamic, space-, time- and theme-related context, as well as its cross-domain and governance levels intersecting arrangement. Therefore, seeking the optimisation of its process, particularly while using software tools created with a linear and closed universe of discourse in mind, is not a very realistic goal (Batty, 2007 [5]).

Actually, Planning Support Systems appear quite detached from the fact that their utilisation often forms part of large, interdisciplinary, context-specific, multi-stakeholder, but invariably seamless planning processes (Te Brömmelstroet, 2010 [138]). Evidence comes from the current PSS weak aspects, pointed out in Geertman, Toppen and Stillwell, (2013 [41]): lack of integrity of the underlying models, low transparency of the software's rationale and design, of the information and of the reasoning methods employed, and moderate interactivity and flexibility of the tools.

Such reduced awareness of the overall work environment in which they are expected to become embedded is characteristic of function- and data-based Information System arrangements and results in software and users working in a silo-like fashion (Grambow, Oberhauser and Reichert, 2005 [45]). Rather, to improve quality of support to the global planning process, the latter's identification, modelling and management have been recommended as integral parts of any PSS (Campagna, 2016b [16]), an idea experimentally demonstrated through the operational coupling of Business Process Management suites (BPMS) and Geographical Information System (GIS) software (Campagna, Ivanov and Massa, 2014 [17]).

However, in spite of this encouragement for process-based management of the tasks, the problem of the planning process' design is not so readily resolved. In the few PSS solutions that endorse process-awareness, planners are called either to model their own processes and sub-processes from scratch or to execute pre-modelled ones. The former presents the difficulty of complexity, which has been implied as reason for underachievement in sustainable city development projects (Saiu, 2017 [127]). The latter perpetuates the issue of limited interactivity and flexibility and does not render the solution scalable enough to achieve fitness to case context.

This PhD research is using Semantic Web technologies in a Planning Support System, so that the latter can demonstrate affinity to the planning process at hand. As far as process-awareness is concerned, and further to the operational connection of BPMS with other software tools, one could suggest a process-based approach also in the design and development of planning support software, complying with what is indeed one of the fundamental principles of the ISO 9001:2008 standard for computer software (International Organisation for Standardisation, 2015 [68]).

The hypothesis is that a process-aware PSS architecture of the generic use case design of Figure 1.2, based on Semantic Web technologies, would favour integrity and transparency of the process. Modern planning paradigms have tentatively driven the role of planners towards involving design of the planning process, as they require them to become facilitators for the achievement of common objectives by a group of participants (Sager, 2009 [126]). This process needs be overviewed by all experts participating in planning, who, in turn, need to perform their specialised tasks – GIS analysis in this case – in accordance with the process. The motivation for the hypothesis, therefore, is that the inclusion of all these functionalities under a single software system may be expected to favour integrity and transparency of the process, qualities acknowledged as overall benefits of process-awareness (Moliner and Col, 2015 [99]).

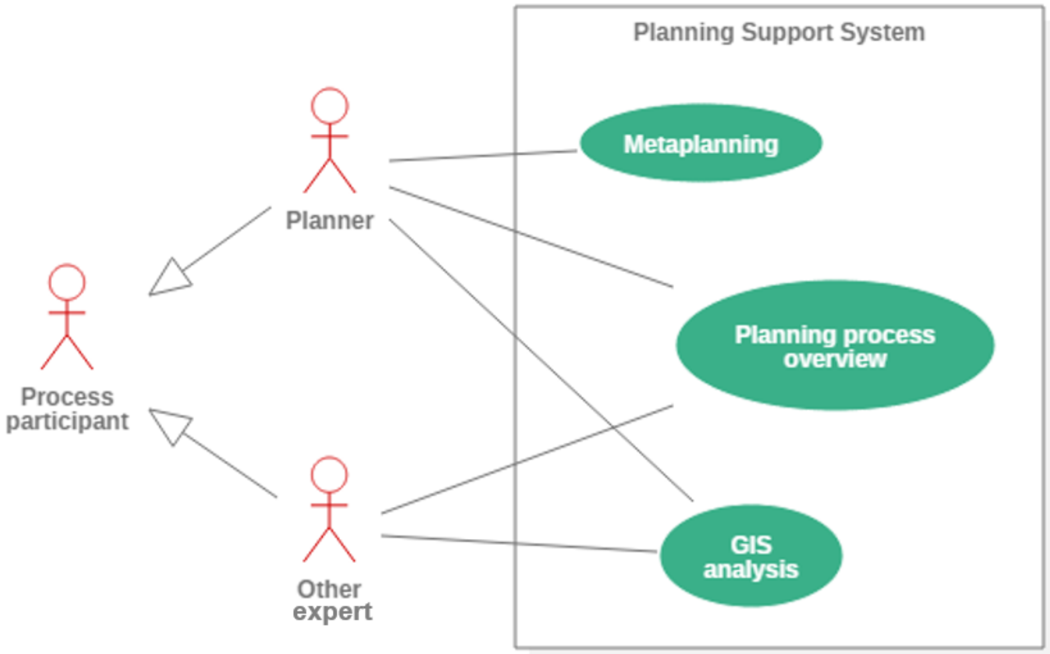


Figure 1.2 PSS use case diagram. For the needs of this project, process participants may be categorised either as planners or as other experts. Planners are responsible for the design of the planning process, aka metaplanning (for a better definition of the term, see section Terminology in the current chapter). Experts are responsible for GIS analysis tasks regarding their area of expertise. All participants need to be aware of the planning process, for transparency of tasks and responsibilities.

However, looking deeper into the overview story presented so far, one perhaps may spot a contradiction between the complex nature of the planning process and the quest for operational optimisation that business-like process management is all about. This is where the rationale for using the stack of Web 3.0 technologies in the development of a process-aware PSS partially lies: The Semantic Web is not a closed universe. On the contrary, it takes advantage of extensible conceptual models and does not assume that any information explicitly stated is also complete. The plausible advantage to be gained by use of its technologies is a) consideration of principles of complexity in the configuration of context-based planning processes, and, consequently, b) support with outlining the process for PSS users. Ultimately, benefits would include higher transparency and flexibility, which could in turn promote reusability of the PSS.

The other part of the rationale is that Semantic Web technologies make searching for information more intelligent through the use of logic and inference rules, while they also facilitate translations between models. Both these capabilities may be expected to enhance usability of component-based Information Systems for spatial planning, first by inferring the activities, participants and software parts dictated by the particular context and then by translating process models into different notations for use by different components, all within the goal of supporting process design and implementation.

1.2 Aim and objectives

Research aim

Indicated by the sheer volume and geographical extent of scientific and political initiatives for a sustainable future of the planet, there is an increased request for planning, urban or rural, to satisfy normative requirements that safeguard sustainability of the adopted plans. However, sustainable planning projects often demonstrate incomplete or oversimplified planning processes. At the same time, a plethora of Planning Support Systems exist, heralding the easing of planners' work. Nonetheless, they cannot boast widespread use (e.g., Te Brömmelstroet, 2017 [141]), which is perplexing to PSS experts.

This PhD project seeks to explore the two issues for a possible convergence point. Identifying one, it proposes a design for a process-aware Planning Support System - i.e., a PSS that considers the planning process as a coherent whole, from its layout to its execution - that utilises Semantic Web technologies. It subsequently aims at examining the usability of these technologies, with a view on the Strategic Environmental Assessment in Sardinia and on rangeland management in conservancies of southwestern Kenya.

The research is initially conducted by review of the nature of planning and of planners' difficulty in laying down the path to a final plan that meets all specifications, while, in parallel, it looks into planning support tools' low utilisation and attempts to detect a connection between the two points in question. Determining a conjunction, it is followingly carried out by means of solution design and technical experimentation, in the context of the two distinct cases, following a methodology laid out from scratch to fit the project, from the ontology of the chosen research paradigm to the research plan and the strategies followed.

Research objectives and questions

In accordance with the aim of the PhD project, the following objectives have been formulated, referring to the study of the theoretical background of the two issues under investigation (objectives 1 and 2), the drafting of a plausible solution and the literature review behind it (objectives 3 and 4), methodological and implementation concerns (objectives 5, 6, 7 and 8), and, ultimately, the discussion of the results (objective 9). Research questions have then been defined for each objective, as a means to organise and manage the project.

Objective 1 Review the theoretical background of the planning process.

Question 1. What is the nature of the planning process?

Question 2. With regard to the planning process, what problems have been detected through time?

Question 3. What solutions have been proposed and how well have they performed?

Objective 2 Investigate the problem of PSS' limited use by planners.

Question 1. What has been the rationale behind PSS' development through time?

Question 2. What has PSS' low impact been attributed to?

Question 3. Can any additional aspects of the problem be identified?

Objective 3 Draft a plausible solution

Question 1. What technologies could fit the needs of the problematic aspects of the PSS?

Objective 4 Examine the literature for Semantic Web technologies in the planning process.

Question 1. Which Semantic Web technologies have been used in planning?

Question 2. How have Semantic Web technologies been used for the configuration of processes in other domains?

Objective 5 Pore over methodologies for prototype design and development.

Question 1. Which existing research methodologies are suitable to this PhD project?

Objective 6 Design a prototype PSS.

Question 1. Which languages/notations can be used for the design?

Objective 7 Acquire data pertinent to the implementation of the prototype.

Question 1. How can existing data/models be explored to determine fitness to the purposes of the PhD?

Question 2. If not already existing, how can required data/models be generated?

Objective 8 Implement the prototype.

Question 1. What results do the data/models and the applied methods provide?

Objective 9 Discuss the prototype results.

Question 1. What has been/has not been implemented and why?

Question 2. How could the prototype be evaluated further?

Question 3. What conclusions may be drawn with regard to the PhD project?

1.3 Research methodology

The PhD started with exploration of the nature of the complex planning process and the problem of its incomplete implementation with regard to sustainability frames of reference, as these latter have been defined in milestone conferences and by adopted European and global agendas and directives. Digging through literature, the issue of long (since the 1960s in fact) advertised technology to support planning, the so-called Planning Support Systems, and their bafflingly meagre use in practice emerged in relation to the complexity of sustainable planning processes, as well. Sustainable planning appears underperforming, technology is not helping, and both seem affected by the same world of problems: complexity.

Having no prior knowledge of the domain, this initial exploratory phase lasted a little over a year and a half of my three-year PhD scholarship. It was ultimately rounded off by statement of a hypothesis as to where – a small part of - the problem of inadequacy of sustainable-planning support may lie: in the architecture of the software. The developed hypothesis served as a tentative theoretical explanation regarding the "why" of PSS inefficiency in a complex world, in a sort of "elephant in the room" recognition.

Due both to the fair obviousness of the "elephant" and to my interest in investigating practical solutions, I delved into experimenting with techniques which I had encountered during my studies of geoinformatics, namely Semantic Web techniques. To this end, I developed examples based on the two cases at hand – the Strategic Environmental Assessment in Sardinia and the rangeland management case in Kenya -, ran measurements on data and performed tests, in order to explore technical feasibility of a model PSS, which I designed for the purposes of the PhD. Eventually, I tweaked its elements and observed their behaviour, to elicit indications as to up to what degree solutions might be attainable.

1.4 Expected outcomes

The outcomes expected from this PhD project fall into four categories, representing the four purposes of the endeavor, i.e., a) have both a theoretical and a practical contribution to the field of spatial planning, b) pave further research, c) broaden the author's knowledge of the subjects dealt with, and d) strengthen the author's research skills.

Regarding the theoretical and practical contributions, the first output is a study of planning and its process, as well as of Planning Support Systems' well-known issue of limited use, with emphasis on the nature of puzzles they are invited to solve. This is not innovative in itself, but aims at summarising existing knowledge. Subsequently, the formulation of a hypothesis that views the problematic point of conjunction between the two subjects from the aspect of pertinence of the software design to the planning theory is expected to add value to the study. Last, the design of a prototype PSS that considers the arrangement of the planning process as a context-based job will make the project relevant to the planning practice and contribute to the field.

Looking into possibilities for future research, experimentation carried out and outcomes achieved can eventually contribute to setting up in-action research and development, examining up-close how planning is practiced and concurrently assisting and influencing it with the technical solutions provided by Semantic Web technologies. Potentially, building on such in-depth study from within real-life planning situations, further investigation into correlations and causalities may be carried out, which may establish (or not) a solid relation between planners' difficulty in laying out and handling the complex process of their work and the architecture of their software.

This being a PhD, and thus aiming at strengthening the student's research skills, a number of publications, conference presentations and specialised training would provide invaluable feedback and are also expected to strengthen credibility of the project. Last, but not least, the project will hopefully enhance the researcher's expertise in the areas of interest, namely in planning, Semantic Web technologies and software design and implementation.

1.5 Terminology

The following terms are encountered throughout the thesis, so acquiring an initial idea of their intended meaning will make reading easier.

Open world / open system: A universe of discourse where neither a unique, universal structure nor a definite endpoint to its phenomena or its knowledge exists (Geyer, 2003 [43]). In the text, the term is used as synonym to "complex system".

Simple world / simple system: A universe of discourse that is not complex. The terms simple, linear, deterministic, Newtonian, and closed world or system are used interchangeably.

Metaplanning: A term coined by DeBettencourt *et al.* (1982 [29]) to signify the design of the planning process according to its context. Its importance for achieving transparency and manageability is maintained by Campagna (2016b [16]). The concept is also encountered as a methodology developed by Hoffman (2006 [57]) in the field of project management, although written as two separate words: Meta Planning. The meaning in both cases is similar, favouring early project planning that involves the entire team of participants. Limitations arise from the fact that planning is not a linear, pre-calculated process, while metaplanning tends to address it as a business process, with the consequent pitfall of attempting to optimise it.

Process / sub-process / procedure / workflow: These are terms encountered often and with diverse meanings in literature, so it is important to establish the way they are being used in this thesis. The following figure (Figure 1.3) depicts the spatial planning process as consisting of sub-processes, procedures, and workflows, without, however, forming a strict hierarchy, although each one of them may possibly possess a number of different abstraction levels if modelled. Further argumentation with regard to the terms is provided in Planning process disambiguation.

Ontology: An ontology is a worldview and the term has obvious philosophical origins. In this thesis, ontologies are used twice, with a different connotation for each use. First, in the chapter Research Layout: Paradigm and Plan, an ontology is presented that defines what is considered real and existing in the universe of discourse. The second use is as models for knowledge representation in the implementation of the designed Information System.

Formal: In the field of Artificial Intelligence or Information Systems or any other field that is using ontologies for technological purposes, the term “formal” or “formalised” means structured and machine understandable. Ontologies drawn on paper are not formal. Ontologies that have been written in a suitable language and in this way can be readily used by computers are formal. In literature for spatial planning the term “formal” is sometimes used for an ontology – or any other type of model in fact - , meaning that the model has been discussed, accepted, and is now public and official. This meaning is nowhere implied in this thesis.

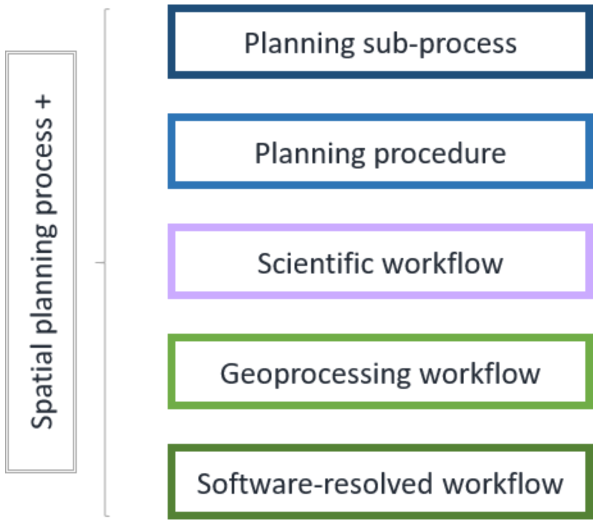


Figure 1.3 List (not necessarily a hierarchy!) of process abstraction terminology for this study. The spatial planning process comprises all parts on the right hand side, but its complex nature entails that its whole is more than the sum of its parts (Lee, 1973 [80]). This particularity is denoted by the + symbol.

1.6 Outline of the thesis

This is a quick overview of the content of the thesis in the chapters that follow.

Chapter 2 includes the literature review that regards the planning process and Planning Support Systems, considering the aspects of sustainability and complexity. It is the first step taken towards understanding the problem and forming an idea as to the probable causes of it.

Chapter 3 defines the ontological and epistemological positions embraced in this study. It then illustrates the selected methodology, by describing the research model used. Finally, it presents the research plan and the corresponding strategies for data collection and analysis.

Chapter 4 presents the data used for each part of the research plan. Followingly, it describes the methods employed for the design and the implementation of the final output, in accordance with the strategies indicated in chapter 3. These include the two cases of planning used for the purposes of the PhD, as well as the experiments performed.

Chapter 5 follows the path to the implementation of the prototype. It includes diagrams that represent the design of the Planning Support System, as well as the artifacts created for the implementation of the system's functionality.

Chapter 6 summarises the work done and the main outcomes, discusses impact and limitations, and concludes with research ideas for the future.

1.7 Conclusion

This introduction aimed at presenting the zest of the theoretical research that drove the rest of the PhD. This overviewed exploratory research that reveals likely points of question and identifies a possible new viewpoint at them is unfolded in detail in the second chapter of the thesis. The introduction also gives away the rough story behind the methodology followed, a quick idea of the meaning of certain recurring terms, and a short outline of the document structure. Most importantly, it sets out the research aim, objectives, questions, and expected outcomes, intending to revisit them later on, in the final two chapters of the manuscript.

To sum up, this work is focusing on the study of technology to support comprehensiveness and flexibility in integrative planning processes, and as such, it aspires at making a contribution in the coordination of actions towards sustainability and resilience. The question posed is whether currently available Planning Support Systems (PSS) are ready to tackle complex planning processes. Recognising that the majority of these tools befit an operational, and as such principally linear, systems approach, this work attempts to build a foundation for the introduction of semantic models and reasoning.

2 THEORETICAL FOUNDATIONS

2.1 Introduction

This chapter aims at laying the foundations regarding this PhD. It therefore presents the information in the same way as it was used by the author of the thesis in order to form an idea of the issues dealt with and come to a verdict as to what may have been missed in research to the day. This serves as a prompt for the formation of a hypothesis about a plausible solution.

This first part of the PhD follows the abductive research strategy. Abduction is inference of an explanatory hypothesis (Peirce, 1903 p.231 [113]), based on information that the researcher acknowledges of being merely sufficient to form some conclusion, but in no way is it exhaustive of the issues concerned. Abduction is known for being effective in developing explanations in the form of hypotheses for phenomena or problems that are some kind of unchartered territory to the researcher. It is therefore suitable to this part of the thesis, first because the field of study is indeed quite unknown to the author.

Second, it is a fact that during studying the subject for the purposes of this PhD, a surprising fact was revealed regarding the nature of the problem and a tentative explanation, perhaps somewhat far-fetched at the beginning, popped into mind. Reasoning with observations is not devoid of logic, but it is "*the logic of discovery*" that matters in this case - a discovery that the researcher is called to validate as worthy of further investigation and this is dealt with in the second part of the PhD - rather than the logic of proof, which might be relevant in a later stage (Levin-Rozalis, 2010 [85]).

Like induction, abduction is a bottom-up approach and in this context it has been used to form a theory that might possibly explain a certain gap in the world of spatial planning, based, however, on a sample of literature regarding planning, rather than a set of field observations. In this chapter, the problematic situation is first stated, through a historical account of the process of planning and of the use of Planning Support Systems. Through this review, the nature of the problem is identified, a possible explanation is outlined and an approach to a solution suggested.

2.2 The problematic situation in planning

The current political agenda for planning

The New Urban Agenda, adopted at the Habitat III conference (UN General Assembly, 2016 [148]), reflected a request for improved living conditions of humans inside their environment now and in the future. The Agenda can be interpreted simply as a call for better urban planning, nearly coinciding in time with the Basque Declaration (ICLEI Europe, 2016 [63]) and complementing analogous worldwide or European efforts of the likes of the United Nations' Agenda 21 (1992 [150]) and the European Parliament and Council's Directive 2001/42/EC (2001 [34]), respectively.

All initiatives concur in sustainable policies, development and management being the targets of 'better planning'. The most recent ones also introduce the term 'resilience', catching on the observed increase of occurrence of climate change-related events that were previously considered extreme or unlikely (IPCC, 2014), as well as emergence of population shifts and urbanisation (UN General Assembly, 2016 [148]; ICLEI Europe, 2016 [63]). They further agree upon integrating environmental information into decision-making to achieve these targets and they recognize that this entails inclusion of cross-sectoral, cross-administrative level, and even geographically transboundary sets of actors. In turn, actors that have an interest in planning come in an array of profiles, often overlapping, from government to domain experts, to society/economy/environment/technology professionals, business stakeholders, community groups, and individual citizens.

Planning and the operational approach

Accords for sustainability and resilience signed over the past couple of decades did not introduce revolutionary novelties to the theory of planning (Campbell, 2016 [18]). In fact, they confirmed the realisation that social, economic and environmental systems form interconnected networks rather than isolated units, where everything is related to everything else and nothing may be ignored when planning a human intervention.

Recognition of the matter culminated globally during the UN Sustainable Development Summit in 2015, where the 17 announced Sustainable Goals and their associated targets that spanned across social, economic and environmental systems were characterized *"integrated and indivisible"* (UN General Assembly, 2015 [147]).

Professional awareness of the fact that interventions in open and interacting systems have a sequence of far-reaching repercussions, however, had already emerged in the 1950s – at least in the UK and the USA (McLaughlin, 1969 [95]; Rittel and Webber, 1973 [125]) - and it proved a turning point for planning.

During the industrial age (roughly from the 18th century until perhaps a few decades ago), professionalism in general, and evidently in the craft of planning as well, was pervaded by a notion of efficiency which promoted an "install and operate cheaply" attitude (Rittel and Webber, 1973 [125]) as equivalent to perfection. The trend went in hand with relatively uncomplicated achievement of consensus, since the technically expert was essentially the sole responsible person for solving (planning) problems. The world thus saw rapid urbanisation and invasive methods of control, in a largely successful attempt to increase cost-effectiveness.

The approach, however, did not bring similar success in providing *"a decent livelihood and tolerable conditions for a majority of the inhabitants"* (Beatrice Webb in "*My Apprenticeship*", 1926 cited in Hall, 1989 [51]) and any remedial or otherwise action that followed seemed to target similar issues in a rather disconnected, symptom-treating fashion. A paragon was the City Functional movement (1916-1939 in the U.S.A.), which dissociated zoning from urban planning in practice, ruling the former obligatory, while retaining the latter nonmandatory, at least in the U.S. (Hall, 1989 [51]).

What followed in the 1950s was a challenge to the established tradition, stemming from the revelation that social and environmental systems are interconnected rather than isolated units, where everything is related to everything else in a cause-effect chain and nothing may be ignored when planning a human intervention (Wagner, 1960, p.4-7 [158]). The growing public awareness of the fact that interventions in interacting systems of the likes of society and environment have a sequence of far-reaching repercussions, triggered a rush to review goals and values on a (inter)national level (McLaughlin, 1969, p.15 [95], Rittel and Webber, 1973 [125]).

And so, if once the job of the planner had been all about finding solutions to well-defined, comprehensible problems of near universal acceptance, professionals now found themselves confronted with the task of solving problems of policy and planning in a society marked by pluralism of ideas, values, and opinions as to concepts like "welfare", by curiosity on what the causes are and which effects they have, and by a wish to avoid unintended consequences.

The movement had effects in the scientific and professional domains, which responded to the challenge by endorsing a general systems theory and the linear system analysts' approach of thinking ahead about outputs of actions and of not using strictly factual problem descriptions. A systems approach and its associated operations research, as established by the pioneer of management science, West Churchman, does not break away from the pursuit of cost-effectiveness, while, simultaneously, it urges reaching out to other systems to acquire a more holistic view of the problem.

The planning system analyst, therefore, in pursuit of system optimisation or, in other words, money-, space- and time-efficiency, sought to understand the natural process of change, its reasons and how to interfere, the interactions between social, physical and biological systems, and, finally, how to foresee and guide change (McLaughlin, 1969, p.24 [95]), assuming that system properties are tractable all the way (Harris and Batty, 1993 [52]).

Revisiting planning problems, however, Rittel and Webber (1973 [125]) concluded that such an approach in a highly pluralistic, polysystem world was controversial, if not unfit. When territorial planning embraced systems once considered outside its field of play in order to comply with the espousal of the novel world ethos, planning experts realised that revised foci and thinking ahead of probable impacts across networked systems had transformed problem locating, problem defining, and practical solution devising into intractable problems. Planning had turned into a hydra (Figure 2.1) and the assumptions of tractability and linearity in the cause-and-effect chain, typical of simple systems, appeared as naïve simplifications, incongruous with the systems' reality.

Pursue of the systems standpoint was thus early recognized as a potentially "frustrating and fruitless game" (Wagner, 1960, p.7 [158]), continuing "ad infinitum" (McLaughlin, 1969, p.37 [95]). Its positivist principles, however, were broadly accepted as the best possible compromise, and optimism regarding its prospects in guiding planning for change was prevailing at the time of Rittel and Webber's article (1973 [125]).

In contrast, its critics observed that the approach's double aspiration of analysis for finding the root causes and at the same time synthesis for a holistic overview may work in linear, closed, Newtonian universes, but is impossible in problems that assume an open world: that of interlocked polysystems (e.g., McGregor, 1980 [94]). The effect of the systems approach was therefore twofold: On one hand, it resulted in less clear problem and intervention foci. On the other hand, awareness of chain-like consequences in networked systems was further stimulated. Or, as West Churchman himself concluded, the systems approach upheld and fostered confusion as well as enlightenment (1968 cited/interpreted in Van 't Hof, 2013 [151]).

Figure 2.1: The Lernaean Hydra is a serpentine monster of the Greek mythology, possessing several heads. For every head severed, Hydra had the ability to grow back two new ones. In one of the analogies to planning, for every solution found, several new problems emerge and have to be dealt with. The scene depicts Hercules and Theseus combatting Hydra; Greek postage stamp, created by G.Velissaridis & P.Gravvalos, printed by Aspioti-ELKA, March 1970.

Acknowledging a world of open systems, however, is simply another way of saying that planning is not a linear, but a complex process. Complexity was first pointed out by Rittel and Webber (1973 [125]), who identified 10 properties of planning problems that cancel claims of linearity. Indicatively, in Table 2.1 the properties are contrasted to the four major characteristics of linear systems, namely *determinism*, *order*, *reductionism*, and *predictability*, as these have been given by Geyer (2003 [43]). Several studies have since confirmed it, both through advancements in theory (de Roo, 2010 [26]) and through social, policy-making, and spatial planning studies on local, national and international levels (Boelens and de Roo, 2016 [9]; Andersson, Törnberg and Törnberg, 2014 [2]; Mitleton-Kelly, 2015 [98]; Huys and van Gils, 2010 [62]).

<table>
<tr><th colspan="3">Rittel and Webber’s significant points of planning problems and Geyer’s characteristics they contradict</th><th>Definition of Geyer’s characteristics of linear systems</th></tr>
<tr><td>1</td><td>No definitive or exhaustive initial formulation of the problem</td><td>determinism</td><td rowspan="2">Order:
given causes lead to known effects at all times and places</td></tr>
<tr><td>2</td><td>No stopping rule</td><td>determinism</td></tr>
<tr><td>3</td><td>Solutions can be ‘good’ or ‘bad’, but not ‘true’ or ‘false’</td><td>reductionism
order</td><td rowspan="2">Determinism:
processes flow along orderly and predictable paths that have clear beginnings and rational ends</td></tr>
<tr><td>4</td><td>No immediate and no ultimate test of a solution may exist</td><td>predictability</td></tr>
<tr><td>5</td><td>Solutions are “one-shot-operations”</td><td>predictability
order</td><td rowspan="3">Predictability:
once global behaviour is defined, the future course of events could be predicted by application of the appropriate inputs to the model</td></tr>
<tr><td>6</td><td>The set of alternative solutions, as well as the set of actions that they endorse, cannot be exhaustive</td><td>determinism</td></tr>
<tr><td>7</td><td>Every problem is unique</td><td>order</td></tr>
<tr><td>8</td><td>Every problem can be seen as a symptom of another problem</td><td>order</td><td rowspan="3">Reductionism:
the behaviour of a system could be understood, clockwork fashion, by observing the behaviour of its parts; there are no hidden surprises; the whole is the sum of the parts, no more and no less</td></tr>
<tr><td>9</td><td>A problem can be explained in numerous ways</td><td>determinism</td></tr>
<tr><td>10</td><td>The planner has no right to be wrong</td><td>all</td></tr>
</table>

Table 2.1: Rittel and Webber’s (1973 [125]) attributes of planning are contrasted with Geyer’s (2003 [43]) four characteristics of linear systems, demonstrating that planning is a complex process. The last attribute indicates contradiction with all features of simple systems: when causes, beginnings and behaviour in the linear system are incompletely described, the solutions provided will indeed be evaluated as “wrong”.

A point that I find relevant here is the difference between treating planning as multidisciplinary and treating it as transdisciplinary. Forrester, (2009, [38] p.315) defines the two terms as follows:

> *"Academic disciplines working together: the disciplines simply come together, each plays an agreed role in establishing jointly agreed aims, and then the disciplines work separately to achieve those aims. Transdisciplinarity is more complex: here research itself involves 'double loop learning' where individuals and organisations (research and practitioner) acquire new knowledge in social groups rather than by independent invention."*

Based on these definitions, it seems that multidisciplinarity could work with an operational approach, but transdisciplinarity could not: it is simply a different worldview and a different epistemology.

The incongruousness of planning and the operational systems approach is therefore not merely a theoretical one. It has been reflected in planning, viewed either from the perspective of the territorial system or from its process perspective, considering the latter as a system per se. Pragmatically, voices of discontent have signaled planning's persistent lack of ability to meet the needs of the society (e.g., Marcuse, 1976 [92]), characterising it, inter alia, "incomprehensible" and "irrelevant" (deBettencourt *et al.*, 1982 [29]) and accusing it of leading to less understandable and less interrelated spaces (Healey, 1996 [54]).

Amid scepticism regarding its effectiveness, planners' responses split into two directions: some concentrated on improving the methods for goal-setting and data collection, analysis and modelling for evaluation and forecast; others focused more on the governance and social aspects of the art of planning, including organizational structures, actors' relationships and communication, and philosophical planning paradigms (deBettencourt, 1982 [29]).

The current sustainable planning progress

The decades of consciousness over this Hydra-like nature of planning, bolstered birth of new theoretical approaches, which came hand-in-hand with the era of European spatial planning and the global sustainability agendas. In present practice, however, and with regard to the integrative process of planning, there appears to be space for improvement. Faludi (2017 [35]) notices that, despite improvements in networking and exchange of knowledge, European planning has so far done less well than expected. Campbell (2016

[18]) observes that the discussion around sustainable planning has largely progressed and ripened, but practice may lag behind.

As an example of the issues faced when trying to achieve integration in practice, Te Brömmelstroet (2010 [138]) concludes that obstacles crop up from engagement of multiple stakeholders in the process. This causes three types of problems: institutional fragmentation, procedural segmentation, and divergence of practices. The first one, institutional fragmentation, introduces horizontal discrepancies in governance, starting from the tradition of delegating planning sectors to different ministries. The second factor, procedural segmentation, represents fragmentation within the planning process, with responsibilities delegated in a disassociating fashion, either vertically across different levels of governance and administration or horizontally in different sectors.

Both factors end up rendering policy integration and consistency within planning domains and with the rest of the government sectors arduous (Curtis and James, 2004 [23]), if not hardly existing (Hull, 2008 [60]), which, in turn, results in divergent planning goals and priorities, even within joint ventures. Financing, for example, proves difficult in such cases, as identified in the UK between local transport authorities that require funding for sustainable modes of transport and the government's financial department that prioritises travel time saving (Hull, 2009 [61]).

The third factor is practical divergence among planning sectors as to the components of a planning process. Ties between concepts, like for example the connection between transport and health impact by pollution, although recognised as no less than substantive (Hull, 2008 [60]) and considerable efforts to reinforce them through planning regulations have taken effect (for example, the SEA Directive [34]), they are not necessarily reflected in practical implementation. Reasons have been located in the difficulty of grasping conceptually the scale, scope and complexity of sustainability and translating them into planning components for eventual strategy adoption (Ferrary, 2008 cited in Hull, 2009, p.203 [61]).

As a result of complexity, sustainability ventures seem to underperform as well. In her study of eco-city development projects across the globe, Saiu (2017 [127]) identifies indeed an important gap between the theory of planning for sustainability and its implementation, which accounts for poor results on the ground. Specifically, she names three pitfalls commonly encountered in the projects: a) Cities are treated as businesses, with their time and space aspects ignored, and within the rational frame that business projects are normally managed with. b) Consideration of the integrated and indivisible nature of environmental, economic and social systems is meagre, giving rise to oversimplification of planning. And c) space, its inhabitants and urban development are treated as optimizable products, whose ideal status, once established, should be standardised for efficiency.

It therefore becomes quite apparent that planning practice has not shifted substantially from the well-known and efficient in time, space and costs rational approach to accommodate for complexity. The intentions are good, but implementation fails. An integrative process runs the risk of getting out of hand and this is counteracted by oversimplifying it and by taking a business management approach to it that seeks product and process optimization. Such optimality and perfection, however, can hardly be approximated by any real city or regional system (Harris and Batty, 1993 [52]). Analogously, the creation and enactment of a universal, optimal planning process has proven an illusion (Batty, 2007 [5]).

Paradigms and approaches for interactive, collaborative and communicative planning, like the ones described by Healey (1996 [54]), Innes and Booher (2015 [67]) and Faludi (2017 [35]), as well as frameworks, like Steinitz's (2012 [135]) Geodesign approach, already exist and help in shaping sustainability mindsets. However, if implementation largely fails, one might want to look into the tools assisting planners in their job. These would be the Planning Support Systems, for which a renewed interest in research and development has been noted in the 21st century, accompanied by a more positive attitude regarding their potential (Geertman, Stillwell and Toppen, 2013 [40]). The question is whether they meet the requirements of contemporary paradigms for complexity endorsement and flexibility support and whether they consequently befit the interests of sustainability and resilience initiatives.

2.3 Planning Support Systems in the era of sustainable planning

Planning, over its long history of practice, has seen an extensive effort for delivery of tools to back its activities. Information systems were already being used by 1960, having emerged as loosely-coupled computer tools that brought data and simulation for building models, principally land use and traffic ones (Harris, 1960 [53]), together. With the subsequent introduction of Geographic Information Systems, the technical part of the planning process seemed to have acquired a good assortment of means to spur its implementation. Planning Support Systems (PSS), a term coined in the 1987-1988 Urban and Regional Information Systems Association (URISA) conferences in Fort Lauderdale and Los Angeles respectively, started as an attempt to address these tools collectively and place them under the umbrella of planning science, aspiring to see them becoming more targeted and delivering more functional results (Batty, 2002 [4]).

The struggles, however, of planning practice through the years are also reflected in the PSS that professionals have employed. First emerging in the era of interrelated problems hype in the 1960s, the early planning information systems followed the systems' analysis–synthesis approach (Harris and Batty, 1993 [52]). A great part of research on PSS up until recently targeted the technical part of the instruments (Te Brömmelstroet, 2010 [138]), which, although theoretically coherent, the results they were giving were not consistently accurate, robust or validated and they were eventually viewed as black boxes (Cecchini, 1999 [19]).

Figure 2.2: In ancient Greek mythology, Chimaera was a hybrid being, partly goat, partly lion and partly snake. Nowadays, "chasing a chimaera" means to chase the impossible. In one of the possible analogies to PSS, the use of the same form of representation for knowledge about the planning context and knowledge about how a planning process may be synthesised, could smooth out the chimaera effect, i.e., the internal heterogeneity of a PSS composed of loosely coupled tools and models. This could prove a step towards the realisation of Wilensky's (1981 [162]) "homogeneous planner". The scene in the figure depicts Bellerophontes (centre) killing Chimaera (right); stone plate from Laconia, Greece, dated around 560B.C. Source: https://argolikivivliothiki.gr/

The practical, or superficial, reasons of the comprehensive planning information system failure were the vastness of the task, due to its targeting several purposes simultaneously, and the difficulty in building satisfactory large-scale models, due to the complexity of the planning polysystem (Lee, 1973 [80]). The theoretical reasons of the failure, underlying the practical ones, stand in the hydra-like nature of planning problems, which renders the creation of a complete planning information system, as this was idealised by systems approach advocates, unachievable.

In other words, if intractability had turned planning into a Hydra, the complete realisation of its perfect microcosm, namely a Planning Support System that aspires to govern the planning process, to model the current situation of the area of interest and to guide changes and decisions, all to their full extent, could not but result into a Chimaera: the implausible sibling of the Hydra (Figure 2.2). The operational approach seeking functional perfection in a PSS, either with regard to the territorial representation or to the planning process itself was simply not a realistic endeavour (Batty, 2007 [5]), for it befitted linear and closed, rather than open systems.

Several decades into the study of PSS, and despite a turn towards software for sustainable planning, proof of the role and effectiveness of existing tools is still limited and so is their actual use by practitioners (Te Brömmelstroet, 2015 [139]). The true problem seems to lie in the instruments' integration into planning practice and is due to their obscure, and in any case weak, tying to the planning process (Te Brömmelstroet, 2010 [138]).

In fact, existing PSS do not seem to have severed ties with the systems approach. Their conceptual design allows for very little or no flexibility, assuming an optimal workflow established in the beginning, before any actual planning takes place. Specifically, aspects in which current PSS fall short, and therefore consist the main targets for improvement, are integration of the Information Systems and of their underlying models, transparency of the software's rationale and design, as well as of the information and reasoning methods employed, and interactivity and flexibility of the tools (Geertman, Toppen and Stillwell, 2013 [41]).

PSS failure interpretations

The underlying reasons of PSS lagging behind planning practice have been investigated from two directions: a) from planning practice to software development, and b) from software development to planning practice. Regarding the former, Geertman and Stillwell (2003 [39]), pointed out that planners find PSS inflexible and strictly rational, and emphasised the need for targeted support to planning tasks. Studying the problem from the opposing direction, Vonk, Geertman and Schot (2005 [153]) spoke of little awareness among planners regarding the existence and value of PSS, lack of experience with software and low intention of using it. In perhaps the most recent analysis of the situation, Te Brömmelstroet (2017 [141]) confirms the above issues and identifies ways of tackling them. It appears therefore that the problem may be addressed through upgrade of planners' education, improvement of tools' user-friendliness, improvement of the task execution process, even with better marketing.

The current work, however, suggests that tools' weak tying to the planning process could be interpreted in two ways (Figure 2.3): a) from the perspective of the PSS conceptual design or b) from the perspective of PSS use and usability. Current literature and technology seem to concentrate on the second gap, while the first one is perhaps equally important in order to fully address the major gap, that between planning theory and practice.

More specifically, a disagreement between the complex nature of the planning procedure and the architecture of the software is suggested here. Existing PSS do not seem to have severed ties with the operational approach. Their conceptual design, when process-based, allows for very little or no flexibility, assuming an optimal workflow established at the beginning, before any actual planning takes place. On the other hand, function-based software specialises in specific tasks in a silo-like manner, with little consideration of the process in which they are embedded.

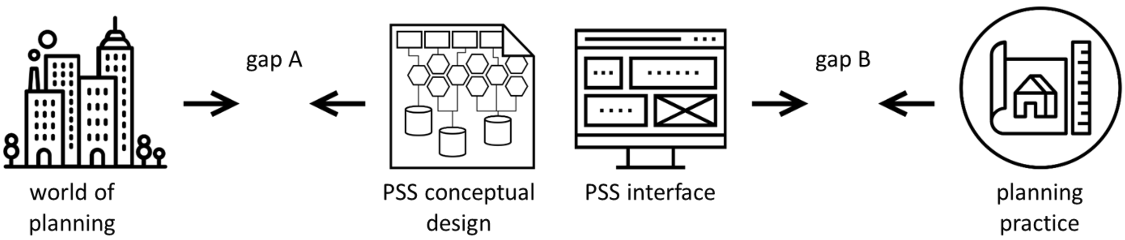


Figure 2.3: The two gaps that explain restricted use (or restricted effect of use) of Planning Support Systems. The first one lies between the complex nature of planning and the software's conceptual design. The second one regards software usage issues.

Campagna, Ivanov and Massa (2014 [17]) proposed Business Process Management and Service-Oriented Architectures to address flexibility, while remaining process-based. The work presented here further proposes user support in configuring the process before physically assembling its components. The following section introduces the idea of semantic modelling, setting a theoretical foundation that suggests fitness of use. Ultimately, the goal is to accommodate for the complex nature of the planning process that asks for knowledge integration and extensibility, as well as for adaptability to the case at hand, in the Information System for planning process support.

2.4 Semantic modelling for the planning process

Drawing from research in foresight

It has been adequately (I hope) argued so far that a universal process for planning is but a utopia and each planning case should have its own process planned to fit its context. This inadequacy of a single, well-defined process for all cases has also been acknowledged in *foresight*, the discipline that explores, in a structured way, the future - open and complex, but malleable - of technological developments and their impacts (Figure 2.4), in planning, for example, for policymaking.

Figure 2.4: Foresight can be envisaged as a triangle combining "thinking the future", "debating the future" and "shaping the future". Source: [JRC-IPTS]

In their report to the European Commission (European Commission, 2015 [33]), a group of foresight modelling experts introduced the concept of *Concurrent Design Foresight,* drawing upon three case studies: low-carbon housing, 3D printing, and sustainable mobility. The concept is founded upon the ideal of decision support through transdisciplinarity and participation. It is materialised through a process-oriented framework that consists of the pilot foresight process proposed by EFFLA (2012 [44]) for the European Research & Innovation strategy planning, as well as of modelling activity. Finally, a platform for practical implementation was also developed to demonstrate attainability of the concept.

The reason I am bringing forward this example is for its similarity to the aim of this PhD, which is to test the feasibility of supporting the planning process configuration and achieving the identified targets for improvement in the field of PSS development, namely flexibility, adaptability and underlying model integration. Starting from the fact that both foresight and planning refer to open, complex objects of studies and processes (for a quick comparison of foresight and the planning framework of Steinitz (2012 [135]), see the Annex at the end of the thesis), lessons learnt during the development of the Concurrent Design Foresight concept and its implementation platform have proven very influential in the shaping of the current research project.

In *Concurrent Design Foresight*, the EC group adopts modelling not only in the sense of analytical, i.e., mathematical, models, but with regard to the overall process, too, aiming at knowledge integration for decision support. Three types of modelling in EU foresight are acknowledged in the report: quantitative, qualitative and hybrid approaches. Quantitative (numerical) models are mostly used to analyse scenarios or trends and calculate future projections.

Qualitative approaches often involve desk, as opposed to field, research, as well as workshops and conceptual analysis and they normally fit participatory projects. Their models contribute to the exploration of the domain of discourse beyond measurable reality and the admission of the open status of a use case's future. Hybrid approaches consist in using figures produced by numerical models to illustrate qualitative outputs. They favour cross-disciplinary expert involvement, and thus formation of breakthrough ideas, but are usually restricted by the length of time it takes the heterogeneous group of participants to agree on a common terminology for their communication.

With regard to the complex process itself, the EC expert group for foresight urges for a whole-(poly)system approach in its implementation, that renders it capable of embedding every stage of the process and every system representative (participant or expert) into decision-making. The way to integration passes through knowledge and process modelling.

Semantic modelling: fitness for purpose

Putting the above models in perspective in representing a system (as in a physical arrangement that is found in the world, not as in an Information System), the choice of modelling approach is in agreement with the nature of the target system itself and the study purpose. Regarding the purpose, Tuomi (2012 [145]), in his work on future-oriented research and policymaking, pointed out the relationship between two world abstractions, namely simulations of what scientists call "natural systems" and formal conceptual modelling (Figure 2.5). Natural – or, extending Tuomi, social and economic as well - systems are a means of categorising the total and simulating its processes. These simulations reflect causal interrelationships and thus predict future states, as well.

Semantic, or "formal" models, on the other hand, focus on structural and logical relations. These are the so-called ontologies of the polysystem and they consist the solid conceptual base on which simulation models are founded. They can be enriched by rules of inference and they are highly dependent on time as well (Tuomi, 2012 [145]). In the case of planning and its process however, they are also highly dependable on space, expressed, for example, as differences in cultural mindsets or local/regional normative guidelines. The following equation could therefore be added at the bottom right of Figure 2.5: $y = f\,(l)$, where l is the location of the process case study.

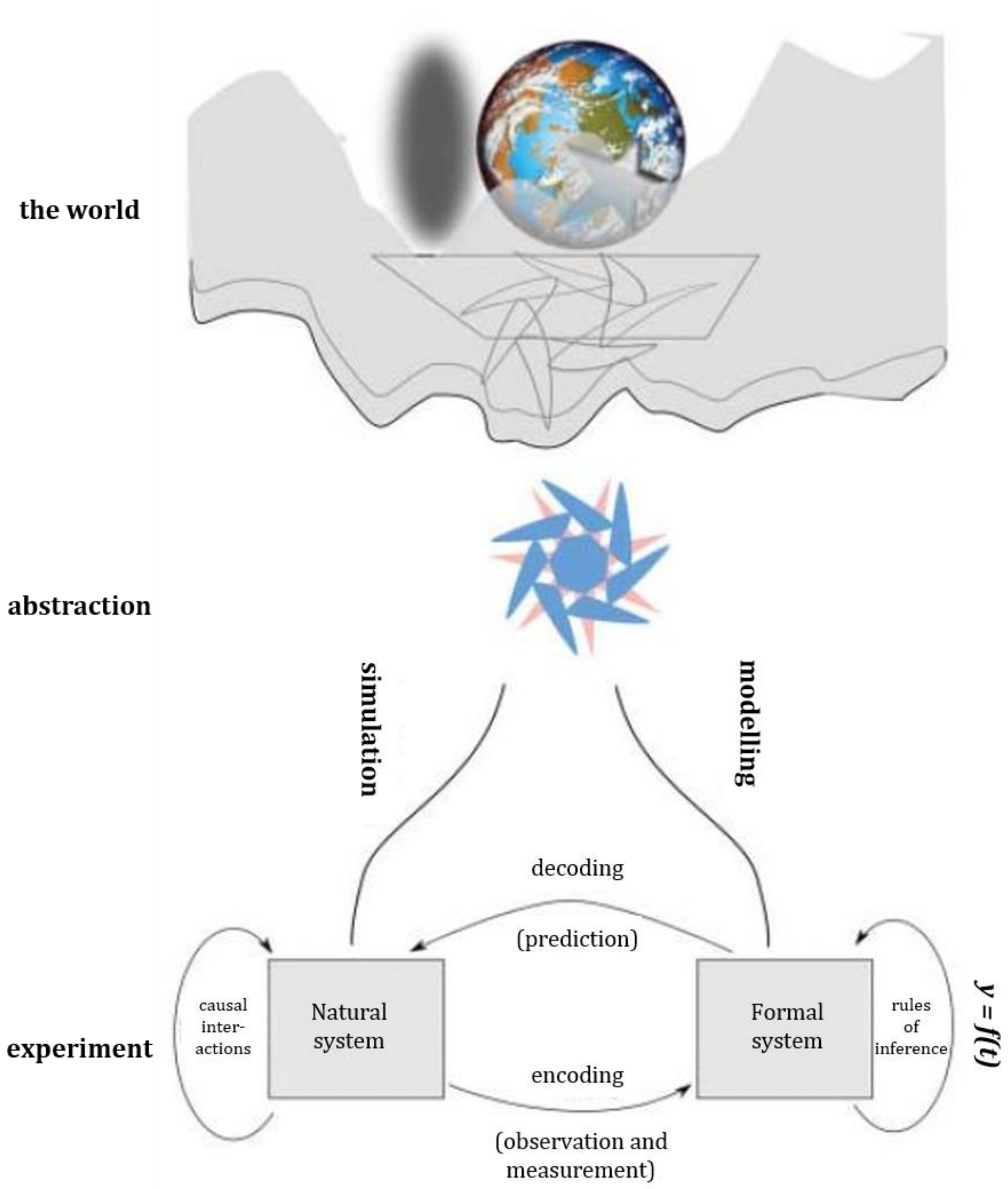


Figure 2.5: Relation between natural system simulation and formal system modelling of the real world (Tuomi, 2012 [145]).

Considering Tuomi's (2012 [145]) and the EC foresight group's report (European Commission, 2015 [33]) presented above, activities that concern the object of interest, i.e., the natural or planning system, require mostly the deployment of numerical simulation models for their analysis. On the other hand, formal models that describe the current structure, i.e., the ontology, of a polysystem as an abstraction of reality generally require a qualitative approach. Such models can be conceptual ones, for example cognitive and causal maps. They are suitable for structuring complexity, allowing for elements and relationships to be established explicitly and thus transparently. Furthermore, serving as a common conceptual platform, they play an essential role in improving understanding, participation and consistency throughout the process, by achieving underlying knowledge integration.

Characteristics of semantic modelling

Taking a more concrete step towards semantic modelling in Information Systems, virtually synonym to complexity and the open system world is the Open World Assumption (OWA), a term encountered often in Artificial Intelligence and in disciplines that employ Semantic Web technologies. Keet (2013 [73]) defines it as *"the assumption that what is not known to be true or false might be true, or absence of information is interpreted as unknown information, not as negative information"*. In other words, what is not explicitly stated in the territorial representation, in the description of its context or in the planning process model is not necessarily untrue: it is simply unknown.

The OWA is the opposite of the Closed World Assumption, implemented in database management systems and fit for modelling closed, highly structured environments, analogous, for example, to highly controlled laboratory experiments. On the other hand, the OWA mindset is used when modelling open, loosely structured environments, where not all relevant information may be available, as in the Semantic Web (Patel-Schneider and Horrocks, 2006 [110]), analogous, for example, to social systems. It does not come as a surprise, therefore, that Semantic Web technologies may offer an array of tools with plausible usability in the planning process.

The OWA is not, however, the only feature of modelling with open world semantics that could prove beneficial to representing the planning process' complex nature. To make the affinity between complexity and semantic models more apparent, one could look for possible agreement between characteristics of such open world models and the behavioural properties of complex systems (Table 2.2). The former are based on Patel-Schneider and Horrocks' (2006 [110]) work, as well as on Bergman (2009 [7]). The identifying aspects of complex behaviour are those listed by Mitleton-Kelly (2003 [97]). They are based on a range of complexity analyses from both the natural and social sciences and may not necessarily apply in every complex system, but are indeed strong indicators of complexity.

Characteristics of semantic models	**Principles of complexity**
no completeness of information assumed	emergence, far from equilibrium
can have the same word referring to different objects or concepts, or different words referring to the same ones	connectivity
several data interpretations allowed	space of possibilities, path-dependence
new knowledge can arise (inferencing)	feedback, interdependence, co-evolution, creation of new-order
reusable and extensible	self-organisation, emergence, far from equilibrium, co-evolution, historicity and time, creation of new order
inherent graph structure, supporting linkage and connectivity analysis	connectivity, interdependence, path-dependence, creation of new order

Table 2.2: Semantic models have characteristics that correspond well with behaviour indicative of complexity. Affinity of characteristics on the left column with corresponding principle on the right column is based on their individual definitions and might benefit from deeper investigation.

Ontologies in planning

Ontologies, perhaps the most renowned type of semantic models, are not new to planning. Aiming at improving communication in urban civil engineering projects, COST Action "Towntology" was one of the first extensive efforts towards a formalised and unified ontology for urban planning (Teller *et al.*, 2007 [142]). More recently, the Spatial Decision Support (SDS) Consortium developed ontologies for several domains that are to be used collectively as a conceptual framework for organising SDS knowledge and resources (Li *et al.*, 2012 [86]). In more domain- and location-specific initiatives, Lai and Zoppi (2011 [78] and Zoppi and Lai, 2014 [166]) built an ontology for strategic environmental assessment (SEA), taking into account the process steps identified in the regional guidelines for

Sardinia, Italy, while Lin, Liao and Lin (2013 [87]) developed an ontology fit for climate-change adaptation planning for local government purposes in Taiwan.

In applications – that may or may not qualify as Planning Support Systems - ontologies have been mainly used for two purposes:

i. Classification, e.g., of water samples in water pollution management (Salah, 2014 [128]), of land in vulnerability mapping for the strategic environmental assessment (Lombardini, 2016 [89]), of planning programmes in terms of structure and content (Scorza, Las Casas and Murgante, 2012 [130]) or of land use (Montenegro *et al.*, 2011 [100]).

ii. Browsing and querying, e.g., of photovoltaic information for sustainable building technology (Tah and Abanda, 2011 [136]), of Spatial Decision Support information through a dedicated portal (Li *et al.*, 2012 [86]) or of information regarding policies, projects, plans, and programmes, in the form of semantic wiki (Murgante and Garramone, 2013 [102]).

It appears therefore that use of semantic modelling in planning up till now regards mostly the creation of shared conceptualisations for a specific domain of discourse and for overcoming semantic interoperability issues in retrieving and comparing information. Computational reasoning in the applications, if any, is restricted to consistency checks and ontology verification. The proposal of the work for this thesis, however, consists in taking semantic modelling a step further into the Information System, to support the composition of the planning process according to contextual requirements. In this way, we can talk of a flexible, extensible and adaptable PSS that considers the use case before configuring the process.

2.5 Conclusion

This chapter aimed at laying the theoretical foundations upon which the remaining project is built. It is quite important to note that this has not been a presentation of the state-of-art in planning or in PSS. Rather, it has been a form of abductive research, with literature playing the role of observations and with a number of conclusions, links and ideas stemming from it. The hypothesis constructed is that semantic modelling in an IS may prove helpful in bridging the gap between planning theory and practice that may be caused by the closed world character of current PSS. To this end, and keeping the peculiarity of the object of study in this PhD, a methodology is described in the following chapter, which will guide design and implementation of a probable solution.

3 RESEARCH LAYOUT: PARADIGM AND PLAN

3.1 Introduction

If a large part of the second chapter was an investigation of the nature of planning and of its process, as well as an acknowledgement of the modern paradigmal theory and the struggle of planning practice to catch up with it, this chapter shifts towards ontological and epistemological stances relevant to research practices for the second part of this PhD. In laying out the structure of this study, it presents the choices that underpin the research paradigm for the implementation of the aspired Planning Support System and it subsequently argues for the selection of methodology.

Although paradigms for research are a somewhat subjective field, it is not the author's intention to present any personal philosophical conviction here. What I attempt to make is ontological, epistemological, and methodological selections that may fit both the purposes of this PhD and the research resources at my disposal. And although methodological investigations in engineering academic environments tend to focus merely on selection of qualitative or quantitative methods, this project requires pondering over the research ontology and epistemology indeed, for the simple reason that a different paradigm would lead to a different choice of strategies, perhaps even to a completely different interpretation of the scientific problems examined in it.

The objective addressed in this chapter is Objective 5 (page 6) and it refers to research involving Information System (IS) design and development.

3.2 Research paradigm

The concept of research paradigm has been explored through several prisms in the literature, rendering the choice of a single, concise definition an endeavour in itself. One of them appears fitting the understanding of the author of this thesis and is given by Bogdan and Biklen (2007, p.24 [10]):

> *"A paradigm is a loose collection of logically related assumptions, concepts, or propositions that orient thinking and research."*

In other words, it is the worldview underpinning the research and guiding the setup and accomplishment of its tasks.

According to Guba and Lincoln (1994 [49]), this worldview can be structured by way of three questions: the ontological, the epistemological and the methodological ones. The ontological question seeks answers regarding the nature of reality, i.e., what is perceived as real and true. The second one, the epistemological, refers to the nature of the relationship between the researcher and the world and it also outlines what there is to know in this world, as the latter is described by the researcher's ontological assumptions. Last, the methodological question expects answers about how the knowledge outlined in the epistemology can be obtained. It therefore seems quite clear that, starting with the ontological question, decisions taken influence the choice of epistemology, which, in turn, restricts the range of methodologies that may be considered.

Conveniently, literature schematises the most widely used paradigms, ultimately directing in this way the choice of methods. The systematic presentation in Table 3.1 of certain paradigms and the elements that characterise them served as an initial prompt for selecting the philosophical position for this PhD. Further reading revealed that certain schools of thought may be partly commensurable – particularly the ones to which a single common column has been dedicated in Table 3.1, namely positivism/postpositivism and constructivism/interpretivism –, while in some cases one has to dig into the methodological differences to decide fitness for use.

The paradigm chosen for this second part of the PhD is pragmatism. Classical pragmatism originated in the United States of America in the 1870s, as a form of "mediating philosophy", trying to bridge differences between determinists and idealists (Hookway, 2016 [59]). Pragmatism has therefore been conceived as a conciliatory approach and treats theories and theoretical hypotheses as instruments towards problem solving, rather than answers to problems per se (James, 1907, pp.51-53 [69]). This is a stance this current project takes, too: the hypothesis of the gap between Planning Support System architecture and the nature of the planning process is not one sought to be proven or rejected, but rather one to be utilised to construct a usable, process-aware Planning Support System (and perhaps to evaluate its usefulness during later-stage research).

Positivism / Postpositivism	**Constructivism / Interpretivism**	**Transformative**	**Pragmatism**
Determination Reductionism Empirical observation and measurement Theory verification Causal comparative Normative	Hermeneutic Multiple participant meanings Social and historical construction Theory generation Naturalistic Phenomenological Theory generation Symbolic interaction	Political Power and justice oriented Collaborative Change-oriented Critical theory	Consequences of actions Problem-centred Pluralistic Real-world practice oriented

Table 3.1 Summary of the most characteristic elements of a number of widely discussed worldviews in research, adapted from Creswell and Creswell (2018 [21]) and Mackenzie and Knipe (2006 [90]).

Charles Peirce, the first one to defend the paradigm, was also referring to it as a method that identifies with the logic of abduction. In fact, he stated that pragmatism's maxim, "*if sound, must render needless any further rule as to the admissibility of hypotheses to rank as hypotheses, that is to say, as explanations of phenomena held as hopeful suggestions*" (1903, p.234 [113]). In conjunction with the real-world practice orientation of the paradigm (Creswell and Creswell, 2018 [21]), one can conclude that such "hopeful suggestions", having emerged as products of inference of abductive logic, may thus be validated in a pragmatic worldview, as long as they make indeed a difference when applied in practice.

These features of pragmatism have a two-fold relevance to this PhD. First, further to providing a research frame for the development of the Information System itself, it appears appropriate for its evaluation as well, by way of investigating the difference it may make in real-life usage situations. In this way, it promotes the second expected outcome of the current (page 8), namely paving future research.

Second, if the paradigm chosen for the Planning Support System implementation is relevant to abductive reasoning, then it ensures cohesion of approach between the first and the second part of the project. This characteristic assumes particular meaning in Information Systems research, because the discipline potentially incorporates scientific, technological, engineering, organisational, managerial, psychological and societal aspects. Such multi-faceted studies call for a clearly stated theoretical framework, to achieve *“internal continuity and cohesion in the reasoning process”* (de Villiers, 2005 [27]).

Although a profound study and comparison of pragmatism has not been carried out by the author of this thesis, certain features of the remaining three classes of paradigms of Table 3.1 have contributed to their exclusion. Positivism and postpositivism attend to verifying or falsifying hypotheses, assuming an immutable reality (Guba and Lincoln, 1994 [49]), and are generally suitable for deterministic, normative studies.

Constructivism and interpretivism move away from positivism’s ontological realism towards ontological relativism. However, the former’s final methodological aim is consensus construction (Guba and Lincoln, 1994 [49]), which is not the purpose of any part of this thesis. Interpretivism, on the other hand, is considered more suitable in studies of software user experience, e.g., for interactive design of IS (Preece, Rogers and Sharp, 2002 – Chapter 12: Observing users. [118]). Last, the transformative paradigm assumes a world that has been shaped through history and has reached a problematic social and political reality, lending itself to shaping of revolutionary theories and actions (Mertens, 2010 [96]), which holds little relevance to this PhD.

Pragmatism’s ontological, epistemological and methodological positions that bear applicability in the current research study are presented in the following sections. It must be noted here that pragmatism underwent a period of obscurity over half of the twentieth century, only to re-emerge in the 1970s. The revival has been accompanied by a new wave of thinkers, called “neo-pragmatists”, which, although continuing the tradition of classical pragmatism, bring both doubt and innovation to it (Hookway, 2016 [59]). It is for this reason that, since a deeper philosophical study of the paradigm is out of scope in this thesis, pragmatism is not treated as a methodological panacea and focus remains on the points of agreement with the needs of this PhD.

Ontology

A specific definition of the concept of ontology may be given by the sentence "the study of what is". However, most texts define it using descriptive approximations that fit the purpose of the specific document or study, and this thesis is no exception to it. Drawing on Hofweber's entry in the Stanford Encyclopedia of Philosophy (2018 [58]), the word "ontology" is hereby used to denote what this study takes for granted to exist and the features of what exists. In simpler terms, it is the stance that a researcher takes with regard to the definition and description of reality and plays its role in shaping the targets and the concrete further steps of a research project.

Pragmatism, been initially conceived more as a method to overcome ontological or other differences among paradigms in science, is not presumed to adhere to any explicit definition of reality or existence (Mackenzie and Knipe, 2006 [90]). This has often led to the assumption that an ontological position needs not be taken by the researcher and that focus should instead be placed directly on the epistemological and methodological questions (Pratt, 2016 [117]). This is not the case in the current study, particularly because of the intention to use ontologies written in a logic-based language in the implementation of the Planning Support System.

The most important ontological positions to be discussed regard reality and existence. Defenders of pragmatism apparently have embraced diverse and at times unclear viewpoints regarding this terminology. Peirce, for example, although he argues that what is real and what exists are two different things, he sometimes uses the terms as distinct, sometimes as one inclusive of the other and sometimes as identical. James, on the other hand, considers any differences between reality and existence of less importance than other ontological issues, while Quine treats the phrases "there is…", "exists…" and "…is real" as unambiguous (Haack, 1977 [50]). Because of this, some studying and reasoning have been involved in choosing the definitions of reality and existence for this thesis.

Under the shadow of pragmatism, reality is defined through application-specific experiences and perceptions. Therefore, no theory is expected to be anything more than an approximation, but it may well lend itself to fulfilling contextual, pragmatic needs and be proven useful in practice (James, 1907, pp.56-57. [69]). Consequently, reality in pragmatism –and by extension in this project as well - is meant in terms of a theoretical hypothesis' capacity to solve human problems (Powell, 2001 [116]).

A hypothesis thus proven can therefore be called "real enough in the current circumstances". This shifts the mandate of science, from seeking absolute truth or reality to facilitating problem solving. In view of this ontological approach, this PhD is oriented towards designing a solution to the problem of configuring processes for spatial planning, rather than trying to prove either what the indisputable cause of the problem is or whether the suggested solution is indeed the best one.

Existence, on the other hand, is meant in terms of ontological commitment in a particular universe of discourse, i.e., of the objects that are accepted in the language of the specific field of study (Bricker, 2016 [12]). Certainly, a number of criteria for acceptance of such objects in the language are required and the ones established by Quine have been chosen for this study, as presented followingly.

Quine holds the verbs “to be” and “to exist” equivalent, regardless of the object declared to be or to exist. This is usually demonstrated in literature using the example about prime numbers (taken from Crane, 2011 [20]): The phrases “prime numbers exist” and “there is at least one prime number” are equivalent to the phrase “some thing is a prime number”. All three phrases would be formalised in first-order logic by ‘$(\exists x)[P(x)\&N(x)]$’, where the logical quantifier $\exists$ - known also as the “existential quantifier” - symbolises “exists”, “some” and “there is”, $P(x)$ abbreviates “x is prime” and $N(x)$ abbreviates “x is a number”.

As seen from the example above, Quine, like James, does not distinguish between “real” and “unreal” objects. Prime numbers simply “are”. Similarly, he acknowledges existence of any object in a language, as long as it can be treated as a value to a variable. Values may be eliminated or replaced by definitions, but variables themselves are indispensable (Quine, 1969 [123]). This can be understood through the following examples, all of which involve values or definitions whose existence may be accepted:

- Words (values), which are assigned to objects of discourse (variables) that refer to real-life objects.
- The name “John” (value), assigned to the generalisation “person” (variable).
- “Some thing” (variable), defined as both prime and a number (variable’s definition).

In this way, every object that can be identified through a variable of reference, observable or unobservable, concrete or abstract, specific or general, entity or idea, simple or complex, has a place in the universe of discourse. This criterion, namely committing ontologically any identifiable object with relevance to the field of study, guides in the current project the choice of methods towards those that implement the idea of reference, i.e., of a generalisation into variables that are treated as vehicles of reference to the objects relevant to the domain. These generalisations are the formal ontologies used by the Semantic Web technology stack.

Quine further maintains that the referred object should have a clear role to play in the specific application. This is implied first by his opinion that, while vehicles of reference may be retained at the end of a study, values may be replaced by definitions or may even be eliminated altogether (Haack, 1977 [50]), freeing up the variables that may be re-used in a subsequent study with new values. This, as well as his position in favour of elimination of unnecessary things in general, be they values or variables, during the course of a study, form the second criterion that Quine places for ontological commitment and is called ontological economy (Quine, 1973 [124]). This criterion will prove useful in the evaluation of existing, formal ontologies for fitness-for-use in this project and in the creation of new ones.

The ontological views described, although somewhat subjective, serve the purpose of achieving coherence and continuity between the two main parts of this research project, namely the setting of the theoretical framework and the technical implementation of a plausible solution to the described problems. The ontology has hopefully specified the target of the PhD, which, abiding by pragmatism, is the exploration of the hypothesis that Semantic Web techniques may provide useful solutions to support spatial planners in configuring planning processes and procedures. Having defined the terms “reality” and “existence” in the context of this research project, the following section is dedicated to the epistemological question and is expected to be a (yet another somewhat subjective) step towards concretisation of the methodology.

Epistemology

If one were to cite a very broad definition of epistemology, this would read “the study of knowledge” and it would involve examining knowledge from two angles: its nature and its extent. The study of its nature covers the question of what constitutes knowledge and focuses on three necessary and jointly sufficient qualities, namely belief, truth and justification. The extent of knowledge is about how much we can know from sources, them being either our senses or empirical ones, e.g., data collection and experiments (Truncellito, n.d. [144]). Stepping on this general description of knowledge, an attempt to build an epistemology fit for this PhD and the selected research paradigm is presented here.

With regard to the nature of knowledge through the lens of pragmatism, one would first have to consider the ontological positions presented before, in particular this project’s uninterest in the quest for truth as an epistemic certainty, as well as its aim at facilitating problem solving. The former of these two stances entails that the current project, in general terms, is not a doctrinal study, but rather a conceptual one. Conceptual studies, according to Quine (1969, p.71 [122]), deal with the contextual definition of concepts – and by extension of theories and hypotheses - in the realm of domain knowledge, and are therefore concerned with the meaning of things, as opposed to whether they are true.

The preference of *meaning* over *truth* is also expressed by John Dewey (Morgan, 2014 [101]), one of the most important figures in the discussion of pragmatic epistemology (although he avoided the terms "knowledge" and "epistemology" himself). Dewey intends meaning as the end result of an inquiry into beliefs and actions (*idem*, [101]), an inquiry that was prompted by a problem. A problem itself is illustrated as *"a situation of hesitation and confusion"*, whose examination improves our theoretical understanding and reveals elements that step out as bearing adverse effects on actions (Thayer, 1990 [143]). This knowledge derived from the inquiry is *meaning*, and includes differences, similarities, changes, and relations within the problematic situation (Johnson, 2010 [71]).

In this manner, Dewey joins beliefs and actions, or theory and practice, in the original problem, i.e., since the very start of the process of research, thus confirming epistemologically the orientation of pragmatism towards real-life practical problems. In light of the above, it would therefore be prudent to substitute *truth* with *meaning* in the triad of knowledge qualities, as well as *beliefs and actions* for merely *beliefs*, before advancing further.

The final quality, *justification*, is also influenced by the unity of theory and practice that Dewey maintains, in that it contributes, for example, to judging data as relevant or reliable, theories as applicable to the case at hand, and hypotheses as plausible (Putnam, 2010 [121]). The purpose therefore of justification in Dewey's pragmatic epistemology is to provide evidence with every belief&action inquiry step, in order to support the researcher's subsequent decision-making in the context of his application, rather than providing a universal, prescriptive law to guide him blindly.

In other words, evidence from beliefs guides informed action, while the latter's outcome verifies or falsifies beliefs, by way of showing whether the practical changes they bring to the original problematic situation promote the goals of the inquiry (Levi, 2010 [84]). At the same time, judgements themselves are being evaluated for their effectiveness and adequacy (Putnam, 2010 [121]), thus completing the three functions of a pragmatic epistemology as stated by Koons (2009, p.189 [76]): *"beliefs are evaluated and found justifiable or unjustifiable, scientific methods are judged and found rational or irrational, and criteria for justification are also constantly assessed and revised"*.

Moving on from the qualities that constitute knowledge, it is evidenced in literature that Dewey considers epistemology from the aspect of the inquiry process aimed at attaining meaning through the aforementioned qualities. This differs not only from the classical definition presented at the start of this section, but also from the approach other defenders of pragmatism have taken. Koons, for example, considers it a collection of practices (2009, p.189 [76]) rather than a process, while Quine (1969, p.69 [122]) speaks of it as the study of the foundations of science. Embracing Dewey's process-based approach in this PhD, a frame for research in the form presented in Figure 3.1 is eventually taking shape.

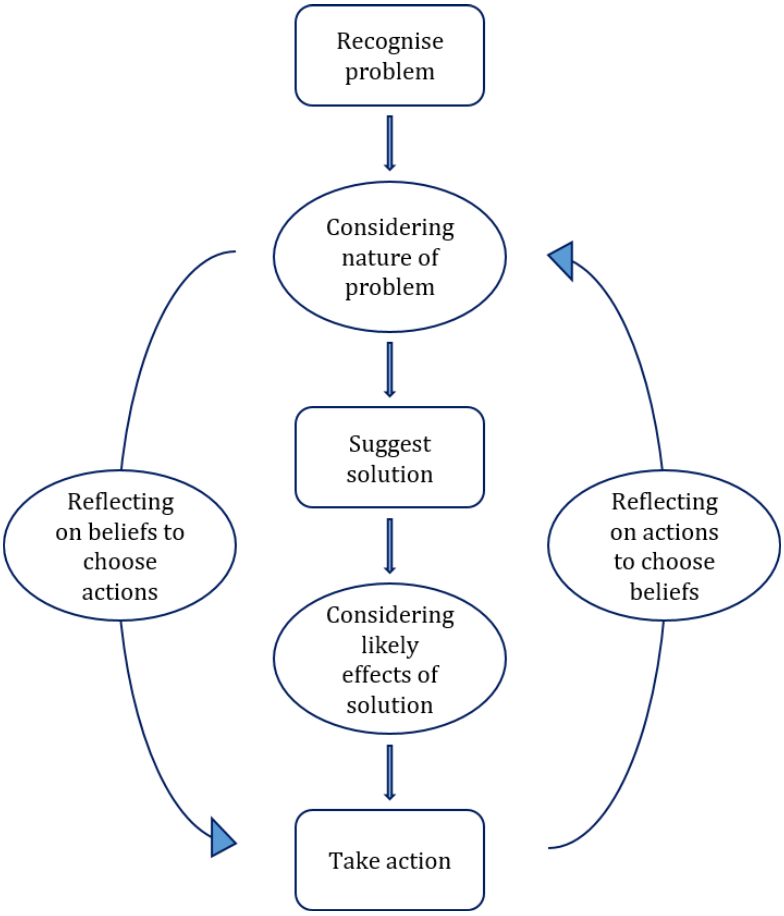


Figure 3.1: Dewey's model of inquiry (Morgan, 2014 [101]). Ovals indicate generation of *meaning*, i.e., researching, reflecting and decision making with regard to the following step. Rectangles indicate informed steps of action. The process is not necessarily linear and more than one cycles may be involved before finalising the inquiry.

Dewey's model of inquiry starts with recognition of a problematic situation, which normally comes with some beliefs already pre-existing in the researcher's mind. Delving into the nature of the problem increases clarity of the situation and its context and gathers evidence, hard or interpretable, for identification of one or more potential solutions. Subsequently, through experimentation, the researcher examines likely effects of each solution, verifying or refuting its candidacy on the basis of results and interpretation. Verified solutions are ultimately put under test through reconstruction of the problematic situation and examination of the difference they make in practice.

The inquiry is not a linear procedure. Outcomes from every step serve to inform beliefs, i.e., theories and hypotheses, which in turn inform actions, i.e., experiments, in a pragmatic frame that regards every element of the research as an instrument dedicated to problem-solving. In this way, the original problematic situation is constantly acquiring more meaning for the researcher, while experimentation directs change through altering the relations among objects in the problem's context. Eventually, knowledge created through this continuous, cyclic process transforms an indeterminate situation of hesitation and confusion into one of a more determinate nature (Putnam, 2010 [121]).

With regard to this PhD research, the study of the original problem presented in the chapter Theoretical Foundations, namely of the planners' difficulty in laying down the path to a final plan that meets all specifications, reflects the initial stage of the inquiry. Due to the author's lack of spatial planning background, recognition, study and reflection over the nature of the issue commenced without any prior knowledge or belief. It cannot be denied though that subjectivity of interpretation and of context as professed in the epistemological frame, and abductive reasoning as expected by the ontological outline of the previous section kicked in during the course of inquiry.

Evidently, and as Morgan (2014 [101]) notes as well, Dewey's style of inquiry is a process of context-based, self-conscious decision-making, and as such is fallible. On one hand, this distinguishes it from the purely rational, prescriptive evidence that has been derived from deductive logic and that renders choices one-way streets. On the other hand, it must be emphasised that Dewey does not reject principles of rationality, but is willing to employ both sides of science for the sake of solving the problem (Levi, 2010 [84]), thus staying true to the reconciling character of pragmatism.

The implication of this observation for the current project is the freedom it offers as to the choice of methods. Dewey regarded pursuing of research interests in ways most meaningful to the individual researcher and to his contextual environment – which includes the school of research to which he subscribes when he chooses a paradigm - as a central moral value of pragmatism (Morgan, 2014 [101]). This leaves the choice of methods and tools to the informed discretion of the researcher, as long as selection is appropriate for the application at hand, without constraining him with a dilemma between quantitative or qualitative techniques.

The last issue to be clarified here with regard to the epistemology is the extent of knowledge that can be expected from the inquiry. Although arriving at one absolute truth that would signal the natural termination of the research project is not a target of this PhD, a degree of satisfaction from the overall outcome would still be required for the study to come to a resolution. Siding with Dewey, "satisfaction" may mean both a positive outcome from the action&belief analysis and the sense of meeting the needs of the problematic situation (idem [101]).

The rule of satisfaction applies to the whole inquiry, be it the overall research frame of Figure 3.1 or the individual steps in it, the latter possibly consisting of individual cyclic inquiries themselves. It is therefore possible that the more the research of an issue lasts, the higher the degree of satisfaction or the higher the level of meaning one discovers and documents as acquired knowledge, at least up to a certain point. Realistically though, the extent of knowledge gained through this investigation is limited by resources, in particular time.

In selecting Dewey's epistemology as the base to this PhD's theory of knowledge, I attempt to achieve continuity between inquiry in theory and inquiry in practice, as this philosopher of pragmatism is the one who challenged the dichotomy between theoretical beliefs and reflection of actions more than anyone else (Hookway, 2016 [59]). Furthermore, restrictions on the selection of methods for every part of the research are waived, due to pragmatism's allowance for both a rational and an empirical approach, depending on the object under investigation and its context. Last, its problem-solving character shines through the fact that, when arguing in favour of a certain solution, justification relies on the solution's utility.

As with each paradigm, what follows the epistemological stance is the associated methodological strategies. These, although according to the definition by Guba and Lincoln (1994 [49]) form part of the paradigm itself, will be treated in a section of their own, for their length, complicatedness in the current research case and importance.

3.3 Methodology

In the previous sections of this chapter, I illustrated the ontological and epistemological positions as the primary philosophical points of departure in this study. The epistemology was rounded off with Dewey's model of inquiry (Figure 3.1), which schematised the course of meaning generation and use through a non-linear, iterative process. In this section, the methodology presented aims at concretising Dewey's model, answering the question "in order to meet the project's objectives, what means can we employ that will help acquire and use pertinent knowledge?"

The investigation in this second part of the PhD is clearly identified as Information System research. However, the theoretical framework regarding spatial planning plays a pivotal role – in fact, it distinguishes this project from user-centric, software engineering ones - and selecting a research model that takes the theory as initiating point is imperative. Having though already paid particular attention to this aspect when articulating the paradigmal stances in the previous sections, suffice to find an approach that fits Dewey's model, to achieve coherence and continuity between the bottom-up (abductive) style of the first part and the top-down (deductive) approach of the second one.

In the field of IS research there exists an issue that concerns the distinction between design and development of an artifact - an Information Technology application, for example - as work undertaken in and for the universe of practitioners, and design and development of the same artifact within the frame of academic research requirements. The interpretation of this differentiation is usually expressed in two ways. The first one claims that professional system building is not necessarily research, as the former deals with application of existing knowledge to organisational problems, while the latter seeks to solve problems in innovative ways, often starting off with inadequate requisite knowledge (Hevner and Chatterjee, 2010, p.15 [55]). The second interpretation speaks of Information Systems research detached from the IS community, due to a mechanistic rather than social view of the artifacts, which results in inadequate connection to real-life situations (O'Donovan and Roode, 2002 [104]; du Plooy, 2003 [30]).

Solutions with regard to the first interpretation consider an in-depth investigation of the nature of the problematic situation, in conjunction with the current IS expertise and experiences in the field of study. In the course of relating to the contextual environment of the application domain and to the artifacts already existing in it, they require a significant amount of critical thinking, creativity, and trial-and-error cycles (Hevner and Chatterjee, 2010 [55]). Innovation is therefore consciously sought after and the outcomes of the study often involve the researcher's personal "signature".

With regard to the second explanation, cure at the stage of methodological design is proposed, with the introduction of techniques falling within the qualitative or the common space of qualitative and quantitative methods as these are arranged in Figure 3.2, to complement purely positivist/behavioural science expectations (e.g., Du Plooy, 2004 cited in de Villiers, 2005 [27]). Other times, bridging the gap between determinism and interpretivism is attempted at a higher philosophical level, embracing, for example, critical realism as an ontological position (e.g., Pather and Remenyi, 2004 [111]).

Pragmatism resolves the issue from both aspects of interpretation views. The first explanation is attended to at the epistemological level, by expecting an inquiry into the problematic situation and incrementally and iteratively using a) new theoretical knowledge to shape actions and b) new, action-based technical knowledge to shape the discipline of interest. As far as the second interpretation is concerned, both approaches may well be absorbed by way of pragmatism, which overcomes dilemmas on the paradigmal spectrum and places no restriction on the methods chosen for research, as long as they fit the purpose and produce satisficing results.

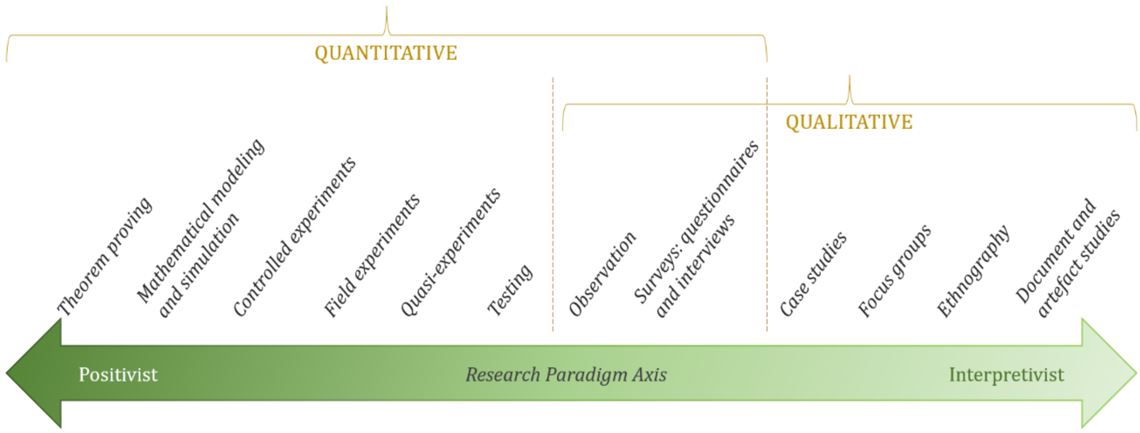


Figure 3.2: Methods commonly applied in research and their classification along the research paradigm axis, from the deterministic, theorem-proving stance on the left, to interpretivism of multiple realities on the right (de Villiers, 2005 [27]). Pragmatism overcomes the dualism of the spectrum by implementing the principle that any method is suitable, as long as it gives satisficing results for the problem at hand.

Although the literature that guided the selection of a research model in this project was mostly by experts that favoured interpretivism in bridging the gap between practitioners and academia (e.g., de Villiers, 2012 [28]) and did not mention pragmatism (perhaps because pragmatism is sometimes not regarded as a paradigm itself), I found that a number of research models they proposed had a truly pragmatic view, from their ontology and epistemology to the choice of methods.

What appears to make a difference is that use of these same models under different paradigms seems to be putting the emphasis of the research on different foci. For example, if Dewey's process of knowledge acquisition and use is rooted in the study of a problematic situation, interpretivism seems to drive user-centred research. Consequently, if pragmatism targets complex real life problems, interpretivism may target usability, user-experience and user-friendliness issues, possibly rendering it more suitable for evaluation of a software at the stage of deployment.

The following section presents the research model selected for this study and the breakdown of the project into implementation cycles for the Planning Support System constituent parts. Followingly, the research is designed more concretely for each individual work package and a research strategy for each design is specified. This creates the frame for the proposition of data required, as well as the specific techniques of its acquisition and analysis that follow in Chapter 4.

Research model

According to de Villiers (2005 [27]), a research model is "*the underlying research approach used to guide and operationalise the study*". As mentioned in the previous section, the criteria I looked for in the chosen model were affinity to pragmatism, agreement with Dewey's inquiry model, and befitting both academic and practice requirements, through encouragement of innovation, closeness to the real-world problem at hand and freedom of choice when it comes to choosing the methods of the study.

The family of design research

The methodological model for this PhD belongs to the family of design science (or design research), a branch that, although having started slow, it has been receiving increasing attention and has become a well-accepted research approach within the Information Systems community over the past three decades (Wang and Wang, 2010 [160]; Peffers, Tuunanen and Niehaves, 2018 [112]). Its origins are attributed to Herbert Simon's "The Sciences of the Artificial" (1996 [133]), who distinguished between natural and design sciences. Simon connected the former to physical phenomena, while claimed the latter deal with artificial, man-made objects and phenomena.

Design research has spread over a great range of disciplines, including architecture, engineering, education, psychology, and the fine arts. The term "design" may therefore be encountered with varying definitions, while corresponding methodologies differ, as well. This thesis follows literature relevant to the field of Information Systems only. Regarding the definition of "design", it takes after Walls, Widmeyer and El Sawy's (1992 [159]) proposal as both a noun and a verb, denoting design as a product and design as a process, respectively.

The science of design in IS focuses on seeking means by which Information Technology artifacts may meet the scientist's goal and is particularly adept at designing systems that deal with wicked problems, as in cases of organisations that need to choose among alternative processes or organisations in a state of continual change - emergence (Pries-Heje and Baskerville, 2008 [119]). This being the exact case in spatial planning as described in the Theoretical Foundations chapter, with design research one could indeed have high hopes of being on the correct path towards building a Planning Support System for helping planners decide on the complex planning process.

Further to its suitability at tackling complex problems, design research demonstrates affinity to the abductive-then-deductive structure of this PhD already at this higher level, before turning to a more explicit research model. In fact, it is Takeda *et al.*'s (1990 [137]) model of the reasoning process, i.e., of the process of knowledge creation and manipulation during the course of design (Figure 3.3) that, although stepping on certain different ontological and epistemological positions due to the team's different object of research, it appears to cover every step and knowledge flow of Dewey's model of inquiry (Figure 3.4) and even make it a little less generic.

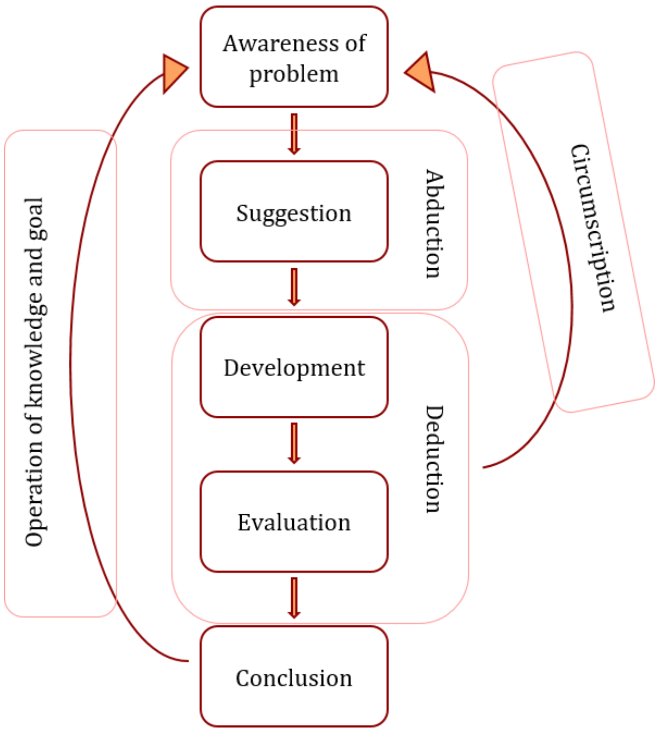


Figure 3.3: Reasoning during design (Takeda *et al.*, 1990 [137]). Awareness of problem is followed by abduction to arrive at proposals and deduction to test feasibility. Circumscription refers to knowledge generated by construction of the artifact and is pertinent to the problem at hand, while operation of knowledge is testing the artifact for meeting the goal.

The family of design science sees many research frameworks, complete with ontological or at least epistemological positions, hence they are sometimes referred to as research paradigms themselves. This, however, I believe stems from the fact that, in the Information Systems literature I have encountered, pragmatism seems to be somewhat understated as a paradigm in itself, considered merely as a solution-geared research "attitude", due to the freedom it allows researchers in choosing their positions and methods. In this thesis, the design research framework is considered a model for research lending itself to relevant paradigms, as supported by de Villiers (2012 [28]). In the following section, the selected framework is presented and defended.

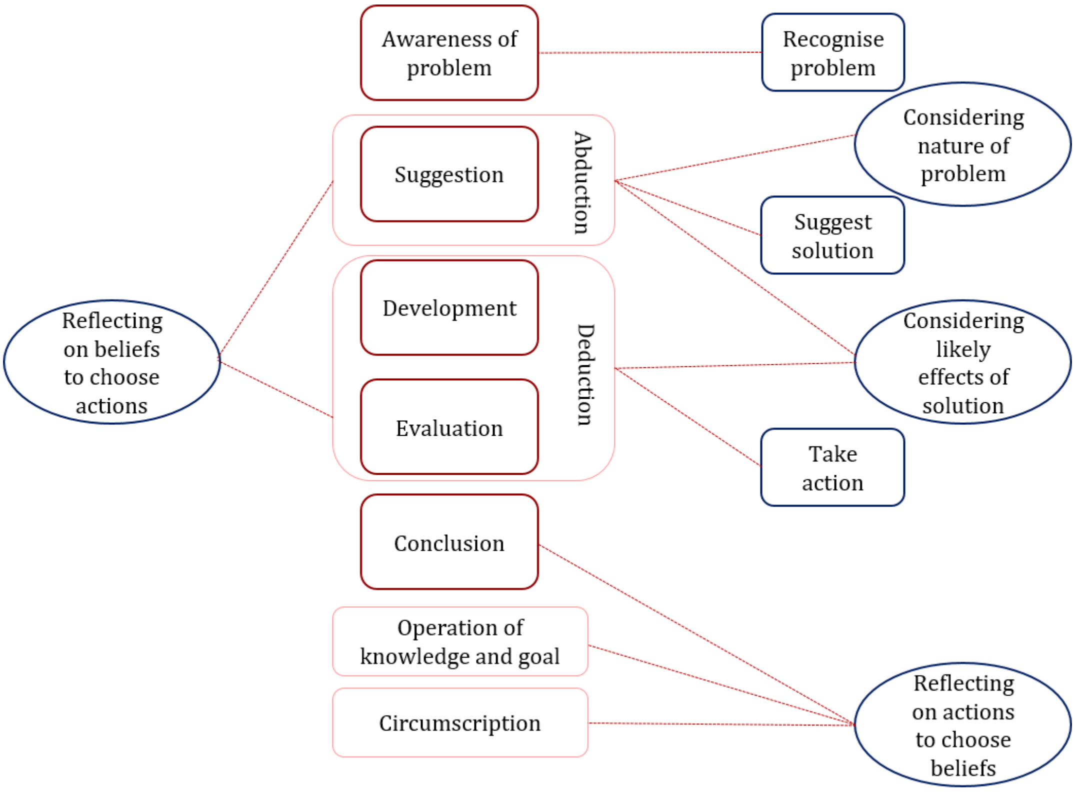


Figure 3.4: Takeda *et al.*'s model of reasoning (red shapes) mapped to Dewey's model of inquiry (blue shapes). Although correspondence is not 1:1, all steps of knowledge generation and manipulation are catered for. Knowledge flow has been taken into account, but is not explicitly depicted in the figure for reasons of image clarity.

The Design Science Research model

The design research framework chosen for this PhD is called Design Science Research (DSR). DSR was introduced by Hevner *et al.* (2004 [56]) and has been one of the most influential design research frameworks in the field of Information Systems (Wang and

Wang, 2010 [160]). The model aims at design that answers questions directly relevant to human problems, by means of innovative artifact construction and evaluation, aspiring both at developing useful solutions and at generating fundamental scientific knowledge (Hevner and Chatterjee, 2010 [55]).

The framework's ties with pragmatism are immediately obvious in the aim statement above and are reinforced by DSR's stance that evaluation of scientific research should pass through its practical implications, assigning equal value to research result and to research rigour (*idem*, [55]). Such influence from the paradigm of pragmatism has actually been indicated since Simon's (1996 [133]) emphasis on design for creation of innovative artifacts for real-life problems and his view that such artifacts should target satisfaction, rather than optimality (Gregor and Jones, 2007 [46]).

In fact, the latter point makes an excellent pass to argue for the model's suitability to wicked problems, to which Hevner and Chatterjee (2010 [55]) make particular reference. In specific, they maintain that Design Science Research addresses situations characterised by ill-defined problems and contexts, complex interactions among components of the problem, a high need for flexibility of the process and of the artifact itself, relevance to social factors through networks and teamwork, and critical dependence upon human cognition, like logic, reasoning and creativity.

Such complex problems require indeed creative, novel solutions, which seem to be restricted when following traditional approaches for software development (*idem*, [55]). On the contrary, DSR is founded on the idea that innovation contributes to scientific knowledge and constitutes research. In this way, it encompasses creativity and serendipity, drawing inspiration both from expected and unexpected sources: from opportunities and problems in the application environment to analogies and metaphors (Iivari, 2007 [64]), like, for example, spatial planning's process analogy to foresight and to the Lernaean Hydra in the chapter on Theoretical Foundations.

Through encouraging innovation, DSR deals with the gap between academia and practice that has been haunting the field of Information Systems. This, however, is only one side of the interpretation of this issue, as explained in a previous section. The way DSR attends to the other side of it, namely to the questionable connection to professional practice of systems developed for research purposes, is evidenced in the evaluation of artifacts by means of field tests and is perhaps better demonstrated through the structure of the model conceived by Hevner *et al.* (2004 [56]).

Structure of the research model

Hevner *et al.*'s framework comprises three cycles of work, operating within their own, but also influencing adjacent environments, as illustrated in Figure 3.5. The Relevance Cycle is about understanding the requirements of the application domain, its people, organisation and technology, as context of the problem situation. This understanding is brought into the Design Cycle, guiding the design and development of the artifact. Evaluation is performed both at the level of functionality testing of the (not yet fully developed) software solution and by passing it back to the application domain for field trials, to assess fitness, enrich the problem description and, in turn, enter the Design Cycle again, for more informed development.

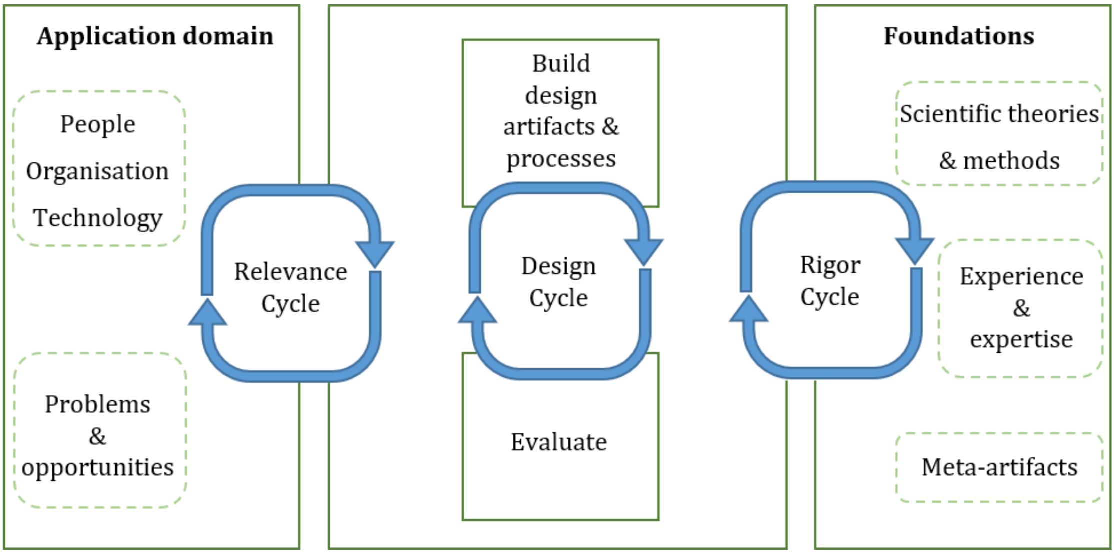


Figure 3.5: The Design Science Research framework, as re-designed in Hevner and Chatterjee, 2010 [55]. The three cycles of work ascertain relevance to the application domain and rigour of research through awareness of the state of the art in methodologies and existing artifacts. The cyclic nature of the model ensures movement of generated knowledge across environments, for an incrementally informed inquiry into the problem at hand.

The Rigour Cycle concerns scientific knowledge about design research, including theories, models and methods. It also deals with the current state of the art, together with the existing artifacts and processes ("meta-artifacts", as in metaphors and models) in the application domain. This cycle therefore starts off with existing knowledge that is passed on to the Design Cycle. Knowledge is subsequently iteratively enriched as the artifact is evaluated with regard to the theories, models and methods, thus fulfilling Design Science Research's parallel goal of contributing to the scientific field, and not purely solving a practical problem in it.

Such oscillation between environments and cycles cannot be linear, for the simple reason they are not always deliberately conscious acts performed by the designer. This, although not explicitly stated in DSR, it adheres to the epistemology defined in this thesis. With this awareness, the current project, although its manuscript is structured in a somewhat traditional and linear fashion, still corresponds to the cycles and the environments of Hevner *et al*.'s research model.

To claim the correspondence more categorically, the Relevance Cycle initiated with the examination of the nature and the context of the problem in spatial planning, whose story has been unfolded in the chapter Theoretical Foundations. Similarly, the Rigour Cycle started off in the same chapter with an account of the status in the field of Planning Support Systems. From the two views of the problem, in conjunction with input from the field of semantic modelling, a proposal for a plausible solution or a hypothesis has been generated and awaits design and development in the Design Cycle.

The Rigour Cycle is being further developed in the current chapter, which investigates research approaches and lays out a research structure relevant to the story so far, at the end of which the Design Cycle will result further informed. The slightly different path this thesis takes with regard to Hevner *et al.*'s model consists in establishing a more direct knowledge exchange between the application domain context for the planning problem at hand and the decisions taken with regard to the research layout in the course of the Rigour Cycle.

This perhaps consists a minor innovation in itself. In other words, the research layout is not entirely an off the shelf choice, but is rather put together to order, step by step from the ontology to the epistemology to the methodology, based on the awareness acquired from the information gathered and reasoned with in the 2nd chapter. The inverse approach would see perhaps the decision to embrace design science taken first and would accept Design Science Research as a paradigm in its own right, i.e., as a research layout package. Only then would it start inquiring into the nature of the problem and its context.

Outputs

Theoretically, "*a design research artifact can be any designed object in which a research contribution is embedded in the design*" (Hevner and Chatterjee, 2010 p.29 [55]). More specifically, however, there are five types of output in DSR, namely constructs, models, methods, instantiations, and better theories. The first four ones compose what is called an "Information Technology artifact". Constructs, formal or informal, are the vocabulary and symbols used to describe the problem and specify the solution. Models are abstractions and representations of the relationships between constructs, useful in designing an application. Methods are algorithms and practices that rely on constructs and models to perform activities. Instantiations are implemented and prototype systems that operationalise constructs, models and methods.

The fifth output, added later to the original DSR framework, refers to the conclusions derived at the end of a design project. Better theories may refer to new insights into the initial problem or into the methodology and methods of the completed study. They may also regard experiences gained, while the question "has the problem been solved in an adequately satisfactory way?" is central to them.

Last, accepting Järvinen's (2007 [70]) proposal for a more resource-oriented perspective, a sixth type of output is added to the list for the current PhD project, namely new informational resources. These are resources potentially created to achieve the requested functionality of the technical artifact and may well be evaluated and added in the existing research knowledge pool of the Rigour Cycle.

Evaluation of the artifact

In order to claim that one full loop of the Design Cycle has been completed, evaluation of the artifact built to test the feasibility of the hypothesis needs to have taken place. Evaluation takes place within the Design Cycle environment, i.e., inside the laboratory. It aims at creating a robust product, modelled and tested iteratively for relevance and rigour, e.g., through experimental procedures that assess its functionality. The whole process may require several iterations of design, development and evaluation before the artifact may be deployed for testing in the real-world application domain (Hevner and Chatterjee, 2010 [55]).

At this point, advocates for Design Science Research call for attention when applying standards of rigour that might make sense in other research paradigms. Gleasure (2014 [44]), for example, makes it clear that *"there are occasions where the initial design theorising is so challenging and complex as to warrant a contribution in its own right."* This means that artifacts at the end of a design project may well still be in a conceptual state, i.e., they may not have been implemented, evaluated and prepared for deployment, due to a lack of resources (Figure 3.6). Such outputs are in essence meta-artifacts, awaiting a future opportunity for implementation and testing, and therefore constitute useful additions to the scientific pool of knowledge.

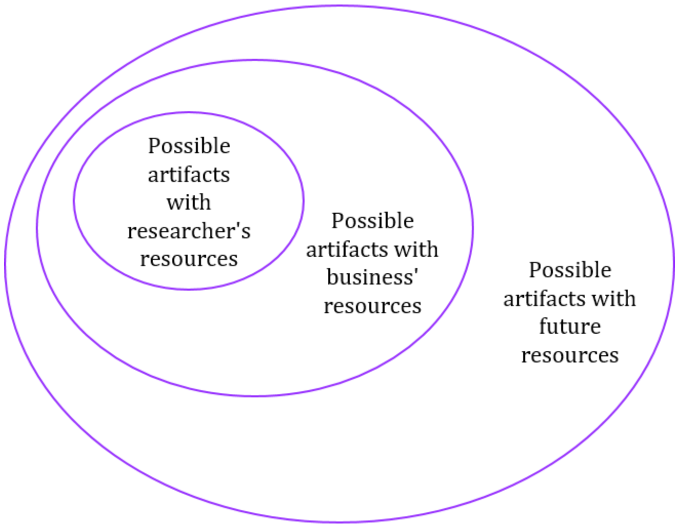


Figure 3.6: The space of realisable Information Technology artifacts increases with an increase of resources (Gleasure, 2014 [44]).

A functional artifact is made ready for assessing its problem-solving capabilities in the real world as part of the Relevance Cycle. Acceptance criteria for the initial hypothesis are defined by the application context itself, with evaluation taking place through appropriate field studies. As an example, the participatory method of action research, found similar to design science (Järvinen, 2007 [70]), has been deemed suitable for exploring the introduction of technological changes in organisations, or, in other words, for business process improvement (Kock, 2004 [75]). This PhD, however, is not going as far as this assessment stage.

Overall evaluation of a design project

A final issue to be discussed is the evaluation of a research project that employs the Design Science Research framework. Due to the uniqueness of design science in general, which, among others, is also expressed through the fact that rigorous evaluation methods are difficult to apply in it, Hevner *et al*. (2004 [56]) accompanied the model with guidelines for quality assessment. Hevner and Chatterjee (2010 [55]) took these a step further, by turning them into a checklist of eight explicit questions. These are presented in Table 3.2, along with the environment and framework cycle they refer to.

These questions serve to assess the PhD project after the presentation of the results, but it is also a useful guide for the research plan and strategy that follow up in the next section, always as part of the Rigour Cycle. These move one step closer to concretising the implementation methodology and include the breaking-down of the Design Cycle into work packages and deciding upon useful data and method strategies to employ.

Quality Assessment Questions	**Environment**	**Cycle**
1. What is the research question?	Application domain	Relevance
2. What is the artifact? How is it represented?	Build design artifacts and processes	Design
3. What design processes will be used to build the artifact?	Build design artifacts and processes	Design
4. How are the artifact and the design processes grounded by the fundamental scientific knowledge? What, if any, theories support the artifact design and the design process?	Foundations	Rigour
5. What evaluations are performed during the internal design cycles? What design improvements are identified during each design cycle?	Evaluate	Design
6. How is the artifact introduced into the application environment and how is it field-tested?	Application domain	Relevance
7. What new knowledge is added to fundamental scientific knowledge and in what form?	Foundations	Rigour
8. Has the research method been satisfactorily addressed?	Application domain	Relevance

Table 3.2: Questions to assess the quality of a Design Science Research project (Hevner and Chatterjee, 2010 [55]). The environment and the framework cycle they correspond to are also indicated.

Research plan and strategies

Having introduced the selection of research framework that fits the type and purposes of this study, this section presents a plan for the remaining part of the PhD and strategies to follow for meeting its targets. At this stage, literature on research methodologies refers to “research design” rather than “plan”. However, the word “design” is being heavily used in this chapter and it may well become a source of confusion. I therefore go for the term “research plan” instead.

The distinction among the contents of a research plan, a research strategy and the data and methods layout is not always crystal clear in literature that speaks of methodology construction. This is the reason why I do not follow any author's explicit guidelines, in contrast to what I did for the definition of a research paradigm, for example. Instead, I take a research plan to answer three "what" questions and a research strategy to deal with three "how" questions. Both the plan and the strategy focus more on the logical sequence of research steps, while I leave logistic issues and further detail for the chapter on data and methods.

This will complete the methodology and pave the way to data acquisition and analysis. As a reminder, the current sections up until the end of this chapter remain parts of the Rigour Cycle and they deal with scientific knowledge to be used and procedures and techniques to be carried out in the course of the Design Cycle.

Research plan

A research plan is a kind of blueprint for a study. In the current project, it includes answers to three "what" questions, namely:

- what questions to study,
- what data is relevant, and
- what output is suitable.

The Design Cycle consists in determining the artifact's functionality and architecture and then creating and testing the actual artifact (Hevner and Chatterjee, 2010 p.29 [55]). This divides the work into two potentially iterative packages, i.e., design of the artifact and implementation of its parts. Each package is structured with its own plan and strategy, but one is highly dependent on the other, as the output of the design is used for implementation, while evaluation of the implemented parts may prompt corrections and alterations in the design.

Examining the definition of the desired artifact, the first package delivers answers to

i. what the desired functionality is, and
ii. what the desired architecture is.

The data relevant to the questions comes from the application domain, namely from spatial planning, and concerns the upper three components of its environment, namely people, organisation and technology, as illustrated in Figure 3.5. This implies a passage to the Relevance Cycle to draw from the planning process definition, the planner's role, the organisation of a spatial planning process and the technological tools employed. The latter include Geographical Information Systems technology, as well as an account of what aspects a Planning Support System should take into account, in general as well as in specific with regard to a process-aware PSS to be used for process-configuration consultation.

Last, in order to account for relevance to the application domain, realistic spatial planning cases are required, to fit the design on them. The real-world cases are found within the academic environment of the author of the thesis. One of them is drawn from work done by colleagues of the University of Cagliari in Italy and one by those of the University of Twente, in the Netherlands. The cases are chosen with consideration of two criteria, namely correspondence of the designed functionalities to realistic needs in planning and re-use of knowledge, case expertise and meta-artifacts that possibly come with the cases.

The final output expected from this work package is a conceptual model of the envisioned PSS, i.e., a meta-artifact that defines the constructs of the PSS and a series of models representing the relationships among the constructs, the Information Technology functionality and the IT components that support it. These outputs will guide the second work package into implementation of the PSS parts.

Creation of the actual artifact has one question to answer, namely

i. what some possible solutions for achieving the desired functionality are.

The primary data necessary for this package is the design generated in the previous step. Secondly, the spatial planning cases with their relevant artifacts, pre-existing or designed by the author will be used to construct the software parts. Last, the possibilities offered by Semantic Web technologies need to be known and taken advantage of.

This time, the expected result of the study may be any of the six outputs defined in the Design Science Research model (page 48). The factor that plays the most important role as to how far into the realisation of the IT artifact this PhD can reach is resources, particularly time and material, for example software for the analysis of the data or learning material for training the researcher’s skills.

Research strategies

The research plan having roughly outlined the Design Cycle in terms of study themes and data requirements, the strategies assigned to the two work packages aspire at answering three “how” questions, in specific

- how to collect relevant data,
- how to represent the output(s), and
- how to evaluate the output(s).

Design Cycle Research Plan

<table>
<tr><td rowspan="13">DESIGN</td><td colspan="6">Questions</td></tr>
<tr><td colspan="6">What is the desired functionality?</td></tr>
<tr><td colspan="6">What is the desired architecture?</td></tr>
<tr><td colspan="6">Data</td></tr>
<tr><td colspan="3">Type</td><td colspan="3">Collection Strategy</td></tr>
<tr><td colspan="3">Process disambiguation</td><td colspan="3" rowspan="4">Literature review</td></tr>
<tr><td colspan="3">Planner’s role</td></tr>
<tr><td colspan="3">Organisation of planning process</td></tr>
<tr><td colspan="3">Technology involved</td></tr>
<tr><td colspan="3">Spatial planning cases</td><td colspan="3">Found within the researcher’s academic environment.
Chosen for:
• Correspondence of functionalities to realistic needs
• Re-use of knowledge, case expertise and meta-artifacts that come with the cases</td></tr>
<tr><td colspan="6">Output</td></tr>
<tr><td colspan="2">Type</td><td colspan="2">Representation Strategy</td><td colspan="2">Evaluation Strategy</td></tr>
<tr><td colspan="2">Conceptual model of the artifact (meta-artifact)</td><td colspan="2">Models/diagrams for easy communication and storage</td><td colspan="2">Consistency checks that complement the method/language/notation used.</td></tr>
<tr><td rowspan="9">IMPLEMENTATION</td><td colspan="6">Question</td></tr>
<tr><td colspan="6">What are possible solutions for achieving the desired functionality?</td></tr>
<tr><td colspan="6">Data</td></tr>
<tr><td colspan="3">Type</td><td colspan="3">Collection Strategy</td></tr>
<tr><td colspan="3">Conceptual models of the artifact and of the planning cases (meta-artifacts)</td><td colspan="3">Outputs produced in the Design step above and new ones for the planning cases</td></tr>
<tr><td colspan="3">Knowledge and skills on Semantic Web techniques</td><td colspan="3">Researcher’s training through courses and tutorials</td></tr>
<tr><td colspan="6">Output</td></tr>
<tr><td colspan="2">Type</td><td colspan="2">Representation Strategy</td><td colspan="2">Evaluation Strategy</td></tr>
<tr><td colspan="2">Any of the six outputs defined in the Design Science Research model</td><td colspan="2">Models/diagrams for easy communication and storage</td><td colspan="2">Consistency checks that complement the method/language/notation.
Functionality testing through experiments.
Field studies are out of scope.</td></tr>
</table>

Table 3.3: The research plan for the Design Cycle, including the strategies for data collection and output representation and evaluation.

The collection of data with regard to people, organisation and technology in spatial planning is done through literature review. The knowledge acquired is used to take decisions that regard the design of the Planning Support System, which is represented through a series of model-diagrams, as a form of documentation. Diagrams are chosen because their syntax and semantics can be easily communicated across expertise and stored with economy of constructs and text, rendering them ready for any future use, as meta-artifacts. Their evaluation will be based on consistency checks, which normally come with the choice of modelling language or notation.

Collection of data for the second work package starts off with the design diagrams previously produced. The main model of the Planning Support System is then divided into parts by functionality, for better organisation and structure of the work. Subsequently, knowledge and skills regarding Semantic Web techniques for the implementation of the PSS parts comes mostly from relevant literature, online courses and tutorials, i.e., through training of the researcher.

The strategy for the representation of the intermediate or the final outputs in this second work package does not differ from that of the first one. Models are mostly represented diagrammatically. Consistency evaluation of the models is also done by means of evaluation techniques matching the method of representation. Last, functionality testing is carried out through experiments in the office/laboratory, to prepare the PSS parts for deployment to the point realistically possible by the availability of resources. However, final deployment for conducting field studies is not within the limits of this PhD, due to time limitations.

Table 3.3 above summarises somewhat schematically the structure of the work as outlined in the research plan and strategies section. The next chapter presents in detail all data input and elaboration methods required for the Design Cycle, adhering of course to the above table.

4 DATA AND METHODS

4.1 Introduction

The nature of the current research project being exploratory, the type range of data and techniques to choose from covers quite the entire spectrum of possibilities (Yin, 2014 [164]) and therefore leaves ample space for consideration of the actual needs of each part of the study. This is in perfect agreement to the paradigm presented in sections 3.2 and 3.3 above, as well as to the fact that, in any case, qualitative and quantitative data and methods are not considered mutually exclusive in any single study anymore (Mackenzie and Knipe, 2006 [90]).

This chapter presents the data specified for each of the work packages defined in the research plan, starting with information gathered through secondary research for the phase of Design and continuing with technical knowledge and case description for Implementation. For each of the parts, after the data is presented, the section moves to describing the practical means of data presentation, evaluation and analysis, as well as for the composition of the artifact design and its implementation. In contrast to Research plan and strategies, this includes mostly logistical reasons for choices and decisions.

4.2 Design

The stage of artifact design requires information about the planner and the planning process that may come from two sources, namely direct observation of spatial planning in the act, including, for example, interviews with practitioners, or secondary research. The first choice requires a methodological approach very well planned out, with the observer knowing what to look for in the case he is following, and sufficient time, contacts and funding for fieldwork. This would better suit design of an artifact to fit one specific, thoroughly investigated case study.

Secondary research assumes the object of study has been investigated well in the past and there is no need to re-invent the wheel. It is also the alternative in the event of lack of the resources mentioned above and is a better fit to problem research on a broader, more general scale, rather than an approach befitting one particular case study. The latter, i.e., lack of resources and an eventual more generic approach to the problem, are realistically to be expected in many PhDs. This is the sole, purely logistical reason behind the decision to use literature review to get informed on the planning process, the role of the planner and the technological tools he uses.

Data

In this first work package, data is in the form of information drawn from literature review, evaluated through critical thinking and used to take decisions as to the design of the Information Technology artifacts. The first round of information regards the term "process", its disambiguation and relation to other, similar terms. Subsequently, the role of the planner is clarified in a contemporary frame. Both these sections provide information on the organisation of the process; the first one with regard to its laying out and the second one with reference to the participative planning approach that the choice of roles implies. Last, work with technological tools is discussed, with a focus on the use of Geographical Information Systems, as well as a view as to what aspects are considered indispensable in designing a Planning Support System.

Planning process disambiguation

The need to provide a disambiguation of the term "process" did not arise since the beginning of this project, but is the result of certain doubt that ensued process modelling for the experiments of the Implementation phase. However, it was later made obvious that a disambiguation would contribute to a better initial design of the Planning Support System as well, hence it is included in this part of the thesis. Such a back-and-forth in the course of research is typical of Dewey's inquiry model and of the Design Science Research framework, as is of any complex endeavour in fact.

As also stated in earlier chapters of the thesis, the aim of the artifact in construction in this PhD is to provide support in laying out the planning process. This step, i.e., the planning of the process, has been called "metaplanning" (*see also* Terminology). The term, however, bears connotations that may not do justice to the wicked nature of planning, a fact that I attempt to explain hereafter.

Metaplanning was already in use in the field of process and product management before it was picked up by spatial planning academics. Emshoff (1978 [32]), for example, presents it as a method to improve the planning process, starting off with its current description and adapting it to fit a prescriptive model. In his analysis, Emshoff follows the operations research paradigm, which, like its parent concept "systems approach", envisions an ideal final state of the system and, having examined its behaviour, looks to devising a conversion procedure that renders it optimal. This in fact seems to be the prevalent perspective in management science, as one sees it evidenced also in Hoffman's (2006 [57]) Meta-planning© methodology, where the final product is very well defined and the processes of production well documented to prescription.

Process prescriptions are also the mindset favoured by public authorities that are commissioned to approve funds and projects (DeBettencourt *et al.*, 1982 [29]), particularly in highly centralised planning administrations. DeBettencourt *et al.* were the first to speak of metaplanning as *"the planning of planning products and processes"*, urging planners to form at least an idea, direct or indirect, of the needs of the final beneficiaries of the plan, in an attempt to fit the product and the process to the final purpose.

Although writing from within the reality of rational planning, DeBettencourt *et al.* (idem [29]) acknowledge that in spatial planning the method may be applied to a certain type of situations or up to a certain degree, according to the contextual environment of the planning problem. They therefore leave it up to the planner to decide when and in how much detail to plan the process. They even suggest that it would be beneficial to "*abandon the single-minded notion that the relevant flow of events is: planning produces information, which leads to decision*".

In other words, DeBettencourt *et al.* (idem [29]) question the rigidity of a planned-out sequence of steps even at the highest, most generic level of the process. In this way, they leave space for paradigms different to comprehensive rational planning, whose assumption of planning as "*a well-ordered stepwise process, where every step represents a specific task*" (Khakee, 1998 [74]) would in any case fit the prescriptive attitude of management science. It seems therefore that the pioneers of metaplanning in spatial planning had picked up on the contradiction of interests and approaches that Sager (2009 [126]) expresses as follows:

> *"The social forces surrounding many planners seem simultaneously to produce dialogical ideals pulling them in one direction and efficiency-obsessed realpolitik pushing in the opposite direction."*

Nevertheless, even though DeBettencourt *et al*. put the approach in a perspective suitable to the planning process' complex nature, the recent revival of metaplanning appears to bear a closer resemblance to the vision of management science. Campagna (2016a [15]) encourages investigation to establish possible advantages of a highly structured decomposition of the entire life cycle of the planning process, in a business process management fashion. Modelling would start from steps identified in planning paradigm definitions and continue all the way down to the very technical workflows. He then proposes a modelling notation used for Business Process Management, namely Business Process Model and Notation (BPMN), to represent the planning process in a diagram, as a step-wise sequence of actions.

However, when modelling the planning process using BPMN, a notation specified for business process management, i.e., for standardising communication between business analysts, technical developers, and business people (Object Management Group, 2011 [107]), it may be tempting to envision planning as a business. Indeed, the two types of processes share characteristics, like a potentially significant number of actors involved, the engagement of external or separately managed organisations, interactions with other types of processes, and a multitude of tools used per task and per context.

Despite similarities, however, one cannot necessarily identify planning processes with business processes. Two substantial differences between them are a) the business requirement for measurable outcomes in its processes and b) automation. The former of the two, namely measurable outcomes of processes, is connected to the monitoring and optimisation of business production and service lines, and has several methodologies formed to support them, including metaplanning for Information Technology projects (Hoffman, 2006 [57]). However, complexity of the planning process does not leave much space for such an operational approach, as already discussed in the chapter on Theoretical Foundations (Planning and the operational approach).

Considering the above, it might be wise to defer from using the term “business process” when modelling spatial planning in this thesis. That said, at lower level abstractions within a planning process, one could identify perfectly legitimate business processes. For example, human or other resource allocation for tasks – the lowest level of activity abstraction, corresponding to atomic actions in the Unified Modeling Language - can indeed be seen as validating a business aspect of planning. A geoprocessing workflow at its final resolution, i.e., ready for execution in a software, could also be seen as a business process, since some cost (e.g., in computational time or memory) might well be assigned to each atomic action. In these cases, there is space for optimisation of the process.

In analogy to process optimisation, automation in spatial planning is also relevant solely to low-level abstractions of the process. Instead, in more generic abstraction levels, it may take away from the complexity of the process, with potential loss of adaptability to individual contexts and circumstances. An example is, once again, a geoprocessing workflow: At a more generic, scientific workflow level, i.e., where the input "rainfall" may be in any admissible format and "calculate effective rainfall" is not known which software-specific geoprocessing activity may entail, process design should be careful to retain abstraction for the sake of workflow usability in different contexts. Such generic workflows cannot be automated, unless converted to a lower-level model (Ubels, 2018 [146]).

In view of the above, I propose a list of terms referring to processes identified inside spatial planning. The list is pictured in Figure 1.3 of the introductory chapter (*also below for ease of access*). Each term may correspond to one or more abstraction levels; for example, Strategic Environmental Assessment (SEA) is a planning sub-process or procedure, according to the level of centralisation of planning administration. The same goes for Scoping, a sub-process or sub-procedure of the SEA itself. In other words, procedures refer to levels where repeatability of sequences of actions is observed, a fact highly dependent on the local planning system and local practices.

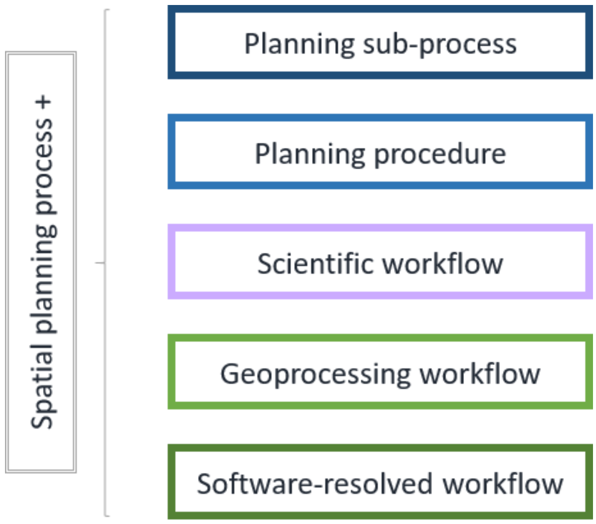


Figure 4.1 List (not necessarily a hierarchy!) of process abstraction terminology for this study. The spatial planning process comprises all parts on the right hand side, but its complex nature entails that its whole is more than the sum of its parts. This particularity is denoted by the + symbol.

Advancing to processes that deal with scientific problem solving, we can adopt the commonly used term of "scientific workflows". These are usually computation-intensive flows of structured – although at times somewhat less structured - activities that come at several abstractions and may require extensive human intervention and flow management. Drawing upon their similarities with business processes, Singh and Vouk (1996 [134]) comment that *"[…] scientific workflows will be to problem-solving environments what business workflows are to enterprise integration"*.

The same authors (Singh and Vouk, 1996 [134]), however, also note differences between the two process types, which stem from the higher stress on enactment for the scientific workflows. The latter, for example, necessitate quite a broad selection of analysis tools. Additionally, scientific research tends to produce unique workflows, as processes pre-configured for automation do not normally fit all contexts. Fully automatic distributed systems are therefore case restrictive in scientific workflows and, consequently, just like in planning processes, mechanisation is only relevant in low-level abstractions.

For the purposes of this PhD project, workflows that fully or partially entail geoprocessing operations can be considered geoprocessing workflows, in the same way the terms have been used in the Open Geospatial Consortium engineering report for the OGC Web Service testbed 6 on geoprocessing workflow architecture (OGC, 2009 [108]). As an initial step, I consider processes comprising exclusively geoprocessing activities. The definition, however, does not exclude interaction and integration with other types of activities, only workflow management would have to be more intensive in these cases.

Last, geoprocessing workflows are in turn resolved to executable sequences of atomic activities, fit for specific software or chains of atomic geoprocessing services. It is at this level of abstraction that automation makes the most sense, as does the evaluation through quantified measures, in a true business process-like fashion. Making a small leap forward in this project, although the issue of workflow resolution has been dealt with, no measures for quantified evaluation have been considered in the PhD, for shortage of time.

The essence of the analysis above and the conclusion to which I have come is that any type of planning process, at any abstraction level that is not too wicked – therefore does not completely lack structure – can be modelled. But modelling has to be loose, in the form, for example, of an unordered list of broad activities, possibly identified as interwoven and operating within a communicative medium, if one really wants to model it graphically. If it illustrates repeatability of actions in a specific order, then it definitely has a certain structure that makes it worth modelling with the use of a notation. And if it can be automated and quantified measures of evaluation make sense for it, then it can be treated as a business process, modelled with Business Process Model and Notation and passed on to a machine to read and enact it.

The question is whether the stated conclusion – and stance with which I continue this thesis with regard to planning process, business process, modelling and notation – may be called "metaplanning". I believe that in the sense given to it by deBettencourt *et al*. (1982 [29]) it might be called so, although with reservations due to its influence from the fields of management and marketing. However, the question somewhat lacks substance, as implementation of metaplanning in real spatial planning cases and evaluation of its usefulness possibly concerns a different research project altogether.

The planner's role

The responsibilities of a planner in the course of a planning undertaking has undergone an evolution much reflective of significant historical points in science and society (Marcuse, 1989 [93]). In 1964, in his article "The planner as a bureaucrat", Beckman ([6]) distinguishes between two prominent roles, namely the technical planner and the planner-politician, or, in other words, the professional and the decision-maker. The political figure was mainly the coordinator of antagonistic interests and cared to reconcile experts' advice with people's will.

However, the decision-maker's expertise in goal-setting, planning coordination and mediating was contested by the professional planner. Ultimately, other than technical skills, the latter had to develop legal, organisational, economic, political, and public relations competencies, if he were ever to convince or at least influence the decision-maker into getting things done in his ideal way. This need guided an emphasis on the planning process, which had to become more flexible and accommodating of the fluid nature of politics, in contrast to the final product, the plan, which was difficult to change.

Two decades later, in their article about metaplanning, deBettencourt *et al*. (1982 [29]) refer to planning as a process non-exclusive to planners. In fact, they use the term "actors" when they speak of who might be contributing to the laying out of the process, to denote, for example, managers, engineers, and policy analysts, other than the planner himself. Required skills for these actors were planning experience and communication skills, not only for convincing stakeholders and public of the quality of the plan, but also for soliciting information from potential plan-users, in a professional-client type of relationship.

By 1999, Cecchini ([19]) was noting that planning had become multi-faceted and planners had become consultants, experts in Information and Communication Technology (ICT) and Geographical Information Systems (GIS), as well as evaluators and negotiators – on top of actually being planners, of course. Planning itself was projected as more flexible, participative and transparent in its objectives and methods, while he claims relationships among planners, stakeholders and ICT technicians had become "closer, interactive, interdependent, and interchangeable". Planning had entered the era of new ICT and from then onwards its professionals, although potentially helped by mediators for the use of PSS (te Brömmelstroet, 2017a [140]), would be expected to know the Information Systems they use, their potential and their limits, as well as how to achieve synergy with other IS.

At the same time, complexity as an epistemology started shaping the scientific world and the planner's role could not be a series of predefined tasks anymore. Instead, he should be ready to deal with the unexpected and to train and get training in new ICT. Furthermore, ICT-enabled participation of the community was now to be considered fundamental in the planning process. In view of the above, Cecchini (1999 [19]) points out and favours a modern role for planners, which regards them as craftsmen rather than scientists, always aware of which Information and Communication tools to use and to what extent, as well as settling for satisfying - but not of the "optimal" type anymore - solutions to complex problems.

Twenty-five years later, Zanon (2014 [165]) confirms the multi-faceted role of planners, which makes their profile quite loose, while at the same time he backs Crosta's (1996 [22]) earlier claim that consciousness of planning's complexity cannot allow reduction of the planner's responsibilities to coordination of a client-professional type of relationship. In fact, the role depends on the planning approach adopted and is tightly connected to the local political and administrative system or, in other words, the attitude of a society towards free business and control by the state.

Larsson (2006, p.5 [79]), for example, presented France, U.S.A., and the Soviet Union as evidence of attitude diversity. The latter had adopted a planning system where land use decisions used to be centrally directed in their entirety. In France, planning appears analytically defined, having been designed to function in a centrally administered way of governance, allowing, however, for public-private participation. The U.S.A., on the other hand, restrict state planning to a more general zoning of the space, underlining their position for power of the individual.

This balance between state control, expressed as regulation, administration, and design of space on one hand and freedom that bolsters personal initiatives on the other is a function of space – as are social attitudes and people's mentality – and time – as are the needs of a certain society. This determines the objectives and methods of spatial planning (Larsson, 2006, p.5 [79]), and ultimately the evolution of the planner's profile from one who designs the plan and manages the process to one requiring many more competencies (Zanon, 2014 [165]).

Although in reality participants' roles are not always well defined, resulting in planners assuming multiple responsibilities, Zanon (2014 [165]) eventually identifies seven profiles with the type of knowledge necessary to fulfil each one (Table 4.1), with reference to the

Italian planning culture. The first profile regards the process manager who knows how the planning system works from its legal perspective, coordinates the procedure with all its stakeholders and organises the contribution of the involved experts. The second one, the urban designer, is perhaps the most traditional profile in the Italian reality and is expected to physically plan the space and add value to it. Other than the creative part of it, his role makes use of technical data and analysis.

The infrastructure engineer requires expertise in structures and models of their effects on space and society. The expert in local development usually operates under economic development initiatives that promote the local society and its natural and historical heritage. The expert in assessment is one to evaluate alternative proposals, as well as goals and actions with reference to environmental, social and economic effects, as, for example, required by the Directive for the Strategic Environmental Assessment. The facilitator is a role defined by the advancement of the participative and communicative planning approaches and can contribute to the better organisation of a complex planning process. Last, the regulator's work is relevant to landuse and development rights assessment, usually involving the application of laws.

	Knowledge involved				
Planner's profile	Empirical / sectoral	Managerial / planning process	Communication / interaction	Legal / procedural	Normative / value laden
Process manager		✓	✓	✓	
Urban designer	✓	✓		✓	
Infrastructure engineer	✓				
Expert in local development	✓		✓		✓
Expert in assessment	✓		✓		✓
Facilitator*		✓	✓	✓	
Regulator	✓		✓	✓	✓

Table 4.1: Planner's roles and corresponding type of knowledge required to fulfil them, as mapped by Zanon (2014 [165]) for the Italian planning reality. (*Zanon does not include the facilitator in the table of his article. Mapping to the type of knowledge here is inferred from implications in his text.)

The profile of the planner most relevant to the current research project is a combination of the process manager and the facilitator. The former, according to Zanon's definition, is the one to configure and coordinate the process, as he possesses the knowledge for it. His role may be restricted in the event of a procedural, clearly defined process. However, it may be well extensive, when for example he assumes the responsibility of adapting the planning process to accommodate innovative technologies or new outputs or when a more communicative planning approach is chosen. The latter case is the reason the expertise of a facilitator would benefit the process. This type of planner knows better how to engage a multitude of participants and stakeholders with possibly antagonistic interests or conflicting objectives and may better contribute to the management of a complex process.

In the course of the design of the artifact, the need to describe one more post was revealed, that of the process participant who is expected to perform spatial data analysis. This role does not fit with any specific of the planner's profiles above. Instead, it refers to a responsibility that potentially any profile may undertake, for spatial analysis within their own expertise. In fact, the task is not even restricted to planners per se, but to non-planners too, i.e., experts in environmental protection, for example, who need to communicate their information in the form of maps. This is the second role considered in this thesis, for purposes that are made clearer later on in this chapter.

Zanon's profiles of planners were identified specifically from and for the planning actuality in Italy. This may seem at odds with the more generic character of the approach to the problem of process configuration, which, as mentioned in the introduction of the section Design, is a fact down to logistics of resources for a specific case study. However, the case on which experimentation with process configuration has been performed (see later in the section for Implementation), is indeed an Italian case, so there is no issue of inconsistency here. If, at a future stage, the design of the artifact is put to test in a different planning context, the planner's role may be redefined and the design adapted accordingly.

Planning cases for this project

Two planning situations have been considered for this PhD, corresponding to needs of two different types of processes within spatial planning, with reference to the types described in Figure 4.1. The cases have been drawn from the academic environment of the author and they concern the events of Strategic Environmental Assessment (SEA) in Sardinia and of rangeland management in conservancies of southwestern Kenya.

The first case, regarding SEA on the island of Sardinia, is a planning procedure aiming at the protection and betterment of the environment, rendered obligatory for certain plans and projects by Directive 2001/42/EC (2001 [34]). The process, even though in practice different approaches exist, comes with quite some structure for its implementation on the island, thanks to established regional guidelines, and can therefore be modelled with the use of a notation.

The rationale behind considering the case a good candidate is that implementation of the assessment on the island, is still far from satisfactory. The municipalities in Sardinia that had adjusted their masterplans to the SEA guidelines by 2014 totalled 10%. If one excludes reasons of inadequate political will and financial resources, lack of standardized SEA procedures that take into account different contexts is a crucial issue (De Montis *et al.*, 2014 [25]). In other words, support for process configuration appears vital.

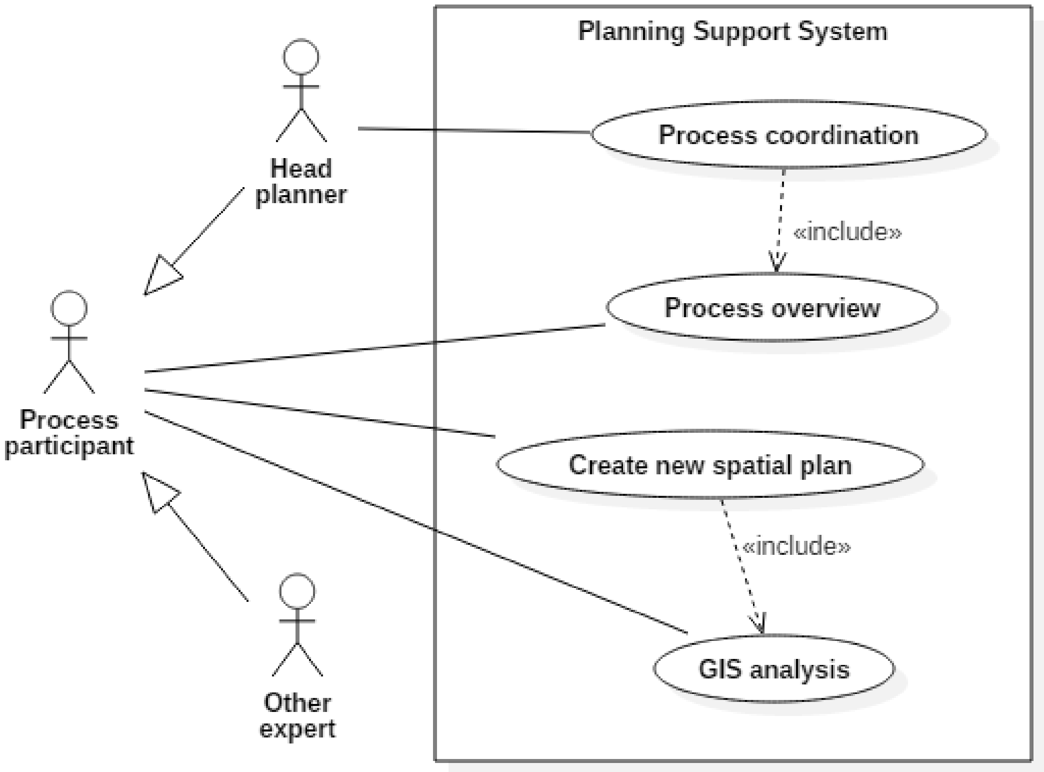


Figure 4.2: Diagram of responsibilities of the planning process participants. The head planner is responsible for the coordination of the process. All types of participants – including other experts, for example – can view the process for information and awareness, and can contribute to the creation of a new spatial plan through GIS analysis. The SEA case concerns the role of the head planner. The Mara rangeland case refers to another process participant, one who has been tasked with GIS analysis.

The second case regards sustainable management of the Maasai Mara rangeland in Kenya as part of the Mau Mara Serengeti Sustainable Water Initiative (MaMaSe), funded by the embassy of the Netherlands in Kenya (Lemmens *et al.*, 2018 [82]). The part concerning this thesis is the geoprocessing workflow for the calculation of forage biomass production in the enclosed conservancies, as modelled and executed in the Integrated Land and Water Information System (ILWIS [66]).

The case has been chosen as an example of a different type of spatial planning process, one that is well structured and implemented in a Geographical Information Systems software. The advantage is that of having a number of artifacts ready for use in this PhD and of its suitability for experimenting with tool - rather than knowledge - integration, to combat the issue of different software within a single process of planning. This becomes more apparent and coherent in the following section, while the complementarity of the two cases is shown in Figure 4.2.

Information Technology and the planning process

An important part of the literature review regarding Planning Support Systems has been presented in the 2nd chapter, Theoretical Foundations. Here the purpose is to investigate aspects relevant to the IT artifact design, which in turn should form the basis on which to develop the process-aware PSS. This section is not disconnected from the earlier sections of the current chapter, but rather builds on them and also adds new information deemed relevant.

Basic elements of a PSS

As mentioned when discussing the planner's role, the planning process is dependent on factors that change with time and location. Open systems like planning, in which ontological expansion, i.e., the time- and space-dependency of their formal model, is the law, present a difficulty in their modelling when we intend to use them for inference of implicit information. The difficulty lies in the incompatibility between the act of introducing new knowledge (ontological expansion) and the act of predicting its impact. This is due to the fact that we process the new information using methods and rules that may well have become unfit or obsolete by the ontological expansion itself (Tuomi, 2012 [145]).

When, therefore, an Information System that concerns the entire planning process, including both process management and spatial data analysis, needs to stay up to date, it must provide for development and evolution in four elements:

i. its knowledge representation (formal) model,

ii. its inference engine,

iii. the endorsed categorization of urban planning into smaller, networked systems, and

iv. the algorithms that perform simulations.

Novelties in the representation model improve concurrently problem and solution descriptions or knowledge and inferred information respectively, because in a homogeneous IS those two come from the same body of knowledge (Wilensky, 1981 [162]). Advances in reasoning capabilities bring the transition between problem and solution closer to a satisfying feasibility. A better articulation of systems could guarantee a better use case analysis and, last, ameliorated simulation would result in befitting anticipations of future in real or hypothetical cases. Such an IS would cater for flexibility and ability to adapt to new conditions of both the models and the platforms that administer them, and would thus abide with the crucial trait of ontological expansion.

An IS dealing only with process configuration and management would not have to include all four elements, but only the first two from the above list. To make these elements a little more explicit to the case of spatial planning, a view by Planning Support System experts is also considered. Harris and Batty (1993 [52]) recognise four bodies of theory related to the design of Information Systems for planning: theories of computation, social and functional theories of the systems being planned, theory of planning, and theory of spatial representation or description.

In a process-aware PSS, and as far as the process configuration is concerned, we can identify four knowledge domains drawing from and tailoring Harris and Batty's list. These will form the backbone on which to construct the PSS. They are:

i. theories of reasoning with a body of knowledge

ii. planning process theory

iii. theory of planning

iv. theory of process knowledge representation

Theories of reasoning are required to draw conclusions based on the information fed to the Information System. A planning process theory has been presented in the earlier section of Planning process disambiguation. The theory of planning as investigated and presented in Chapter 2 has served as the prompt to the formulation of the hypothesis that drives design of this Planning Support System. Last, process knowledge representation has been mentioned in Chapter 2 as well, when discussing fitness of semantic modelling to the purpose of this PhD.

Character of the PSS

The character of this PSS is pertinent to the possibly wicked nature of any specific process at hand and, as such, it does not look into computing absolute solutions to planning process problems. Its aim is to provide consultation to planners commissioned with configuring and managing the planning process. It does not matter whether their assignment is to be accomplished entirely by them or if they could delegate some coordination responsibilities to other participants of the process, e.g., in the manner Wagenaar (2007 [157]) describes. The essence is that they may need some help organising the course of the endeavour.

Indeed, one could not speak of a solution to a wicked problem, at least not in the "hard" interpretation of the term, which might carry the adjectives "right" and "wrong". Rather, one can speak of approaches to the problem that may bring about a satisfying conclusion. And - although it may sound ironic considering the stance I take versus systems analysis already in the 2nd chapter - the idea of using approaches instead of chasing solutions comes from Williams and van 't Hof's book on a systems approach to complex problems (2016 [163]).

Indeed, this PhD project has looked to construct a methodology to work with the planning process problem and take advantage of its complexity, as also suggested by several scholars in complexity of spatial planning (e.g., Huys and van Gils, 2010 [62]). The PSS itself does not aspire at producing processes written in stone, but suggestions that fit the context and possibly help the planner in deciding how to do his job. Technologies chosen for implementation of the PSS should adhere to this principle.

Another point that signifies the character of the designed artifact is the differentiation between the terms "knowledge" and "know-how", as this is stated by Zanon (2014 [165]). Knowledge in planning is usually constructed within a social frame, but knowledge construction is also the aim of problem-solving systems. The know-how on the other hand is the competence of using this knowledge to achieve results. The planner, in order to claim expertise, combines knowledge with competence, in specific knowledge of the type corresponding to his role (Table 4.1) and the technical and technological means for taking advantage of it. The PSS proposed in this thesis aims at helping with the know-how for the planning process configuration and is therefore expected to use some of the required knowledge, represented in a way that is machine-understandable.

Last, another feature associated with the fact that this is not a problem-solving Information System, is that it is not intended to be foolproof. Even at a (much) later stage of deployment, when user-friendliness and interface design may be seriously taken into account, a "single button does it all" approach is very unsuitable to systems based on a representation of knowledge and processes that require flexibility (Cecchini, 1999 [19]). Instead, it will be expected that an investment in a learning environment will be made and the planner, although he may not delve into the purely technical software aspects, will invest time and effort to appreciate the limits and potentials of the tool, as required by the responsibilities of his role in a modern society.

Characteristics of a PSS for process configuration

The configuration of the planning process is a problem with difficulty ranging from straightforward to wicked. Its complexity stems from being participative, dynamic, space-, time- and theme- related, and from spanning across domains and levels of administration. In an era of fast technological changes and large data and information influx, a planner responsible for coordination and quick adaptation of the process to the technological abundance faces a challenge even greater than before.

To assist the planner in his role, an Information System should be equally flexible and adaptive to the process it supports. The current situation with regard to PSS sees two categories: systems that are function-based and systems that are process-based. The former are normally specialised in a single or at maximum a restricted number of specific planning tasks, for example in geodata analysis and mapping or in stakeholder communication. These Information Technology tools manage tasks in a silo-like fashion, with little - if any – awareness of the process in which they are embedded.

Software that appears to be process-based may indeed deal with a greater part of the planning process. Process-awareness is found in two types of PSS: a) those that are designed in a "one stop shop" fashion, i.e., aspiring to provide a single software to be used nearly throughout the planning process (for example the Geodesign Hub [42]), and b) those that incorporate process management through the operational coupling of Business Process Management suites (BPMS) and other software tools in a Service Oriented Architecture (Campagna, Ivanov and Massa, 2014 [17]).

The pitfall of the "one stop shop" solutions is that they still fail to provide for alternative processes and end up somewhat disconnected from the reality of planning. Integration of the components of these multi-tools is tight and adapting to new data, technologies, models or methods means having to redesign the software. The second solution, although more flexible indeed, promotes the idea of pre-configured processes stored in a process catalogue. However, considering that planning processes are highly dependent on factors of transient nature, like, for example, political mindsets and administrative personnel whose status may be highly dependent on contemporary state politics, this still leaves the planner somewhat helpless when the planning context changes.

A Planning Support System that would act as the planner's consultation box in configuring processes involved in spatial planning would therefore need to achieve three characteristics: The first one is knowledge integration, which refers to seamless integration of bodies of knowledge within the Planning Support System, resulting in what Wilensky (1981 [162]) calls a "homogeneous planner". The second characteristic is knowledge expandability. This is linked to the ontological expansion Tuomi (2012 [145]) spoke about. The system should be able to integrate new information, methods, models, and tools and make them part of the process.

The last characteristic is flexibility and adaptability of a planning process. The user would not reach out to the Information System to get a step by step prescriptive model, but rather a proposal of, e.g., who should and could be doing what in the process and under which legislation he should be acting. He would then expect to be able to translate this process into processes suitable to different sets of requirements, to different software tools, for example, for enactment of executable procedural tasks.

Capabilities of the proposed PSS

The capabilities of the designed Information System are decided on the basis of adherence to the artifact characteristics as these are presented above, namely achievement of knowledge integration, knowledge expandability, and adaptable processes. The principle behind the design of the capabilities is that the actual strength of the profession, according to Zanon (2014 [165]), is the ability to integrate the different branches of knowledge and tools and in this way master the planning process.

Planning knowledge integration may be realised through the use of common languages and data models for its description and representation in the IS. Common reference models of the universe of discourse, i.e., ontologies, would further contribute to integration of the semantics of planning concepts and individuals. On a larger scale, this could involve integration of software descriptions with their own vocabulary and mapped relationships, achieving in this way integration of knowledge about planning tools, too, within the same Planning Support System.

Knowledge expandability can be achieved when the Information System is provided with a suitable type of model for representation of the process knowledge. Such conceptual models, formalised for the needs of the IS, can offer resilience and adaptivity to the configured planning process, as they can be extended with elements that may not exist physically or may not have been considered yet. In this way, they cater for new problematic situations and provide new inferred information, in the form of prototype processes (European Commission, 2015 [33]).

Other types of models might be adding different capabilities to the PSS. Explorative models, for example, are used in cases of prevalent uncertainty, a characteristic typical of open systems. This type of models are deployed in experiments, in representing different system (as in social, environmental, economic, etc. systems) behaviour. They are used mostly to deal with hypothetical, plausible 'what if' scenarios in policy or planning support (Kwakkel and Pruyt, 2013 [77]).

On the other hand, organisational or governance models can represent an entire organisational frame, from its type of structure (e.g., hierarchical or flat), to its goals, roles and responsibilities of the members. Modelling can be carried out on the basis of functions, i.e., competencies and responsibilities of groups within the organisation, or on a market base, i.e., following cross-function production processes or customer groups or geographical areas. Furthermore, there exist approaches that merge function and market ones, to create the so-called "matrix models" (Famuyide, 2016 [36]). In planning, as in foresight, organisational models are indispensable when dealing with multi-expert participation, as they support agent networking and cross-section coordination (European Commission, 2015 [33]).

In an integral framework for planning, there is space and necessity for all types of models. Explorative models, such as agent-based ones, could be used, for example, to understand the behaviour of interested parties, including the local community. With regard to the planning process, it could provide insight into participant interactions in forming dynamic relations before, during, and after the completion of planning tasks, and in this way predict possible trends or problems, in a manner similar, for example, to agent-based model implementation in city logistics realised by Anand, van Duin and Tavasszy (2016 [1]).

However, finding a case study for which all such models are available may not be realistically feasible. In fact, one would be glad to find one such model and concentrate his complexity-related research translating them to a type of model that allows knowledge expansion, then test process configuration by incrementally adding and subtracting complexity elements from the model. In fact, this is one of the ideas for further research after completion of this PhD.

This compromise is not the same as making the assumption that actors in our process, for example, do not reach out to each other or, if they do, this does not affect the planning process. In all honesty, a similar assumption might not be far from reality in silo-like, highly centralised administration structures, where planning has an increased level of centrally administered character and power differences among process participants are high (Figure 4.3). However, the compromise in the current project merely means that the focus here is somewhat restricted on designing an Information System with the capability to deal with expandable knowledge models, while additional models and complexity can be the focus of a subsequent study.

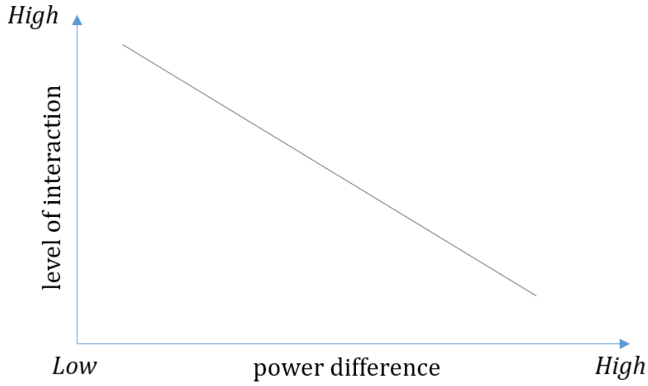


Figure 4.3: Representation of the trend between power difference among participants of a group and level of interaction among them. Adapted from van Nistelrooij *et al.*, 2012 [152].

The third characteristic of the IS is to provide for flexible, adaptable planning processes, because a Planning Support System, even if destined for use within a restricted, quite homogeneous area, requires flexibility to adapt to planning paradigms and associated methods. This may be partly achieved with the capability to expand the knowledge base and use new information and methods for inference, as noted above.

Another way is through model translations. Many planning tools – in this case software tools, for example Geographical Information Systems – give the possibility to their users to model the workflows they want to execute. Models consist of rather simple graphical constructs, the elements of which correspond to inputs, local operators, and outputs. A Planning Support System with the capability to translate between workflow models of different software would provide great flexibility and adaptability to tool variations among planning cases, but also among participants of the same planning process.

Functionality of the PSS

The functionality of the Information System draws from the responsibilities of the profile of process coordinator, with consideration of a possibly participative character of the planning paradigm the planning endeavour follows. It is designed for each planning case separately, although the most generic use case of Figure 1.2 is applicable to both. Each design of functionality is generic enough to fit the initial steps of the actor (planner) in arranging the course of action for the two types of processes. A number of these steps, however, are common to both cases and they involve:

i. Browsing of previously modelled processes, in case he wants to re-use or see examples of previous cases.

ii. Checking the process for soundness, to avoid scenarios of infinite loops through tasks or of tasks that the flow of work never reaches them.

iii. Creating, editing and executing the process.

iv. Editing the underlying knowledge model.

The rest of the functionality is more specific to each case. In particular, for the Strategic Environmental Assessment the possibility to select the location of the area of interest should be considered, so that local regulations can be linked to the process, as well as the possibility to select type of participants/roles for the process. In the Mara rangeland management case, one may wish to edit the geoprocessing workflow; the ability to do so, however, may depend on the competence of the user with geoprocessing. He may therefore need to edit the software-resolved model directly in the GIS software, using the local notation, or he may want to edit the geoprocessing workflow on a more generic level of abstraction. These functionalities will be represented in the models of the design of the artifacts.

Methods

The methods for the design of the Information System refer to the representation of the artifact's aspects, as well as its evaluation, as described in the methodology of Chapter 3. For the overall approach to the development of the software, although an agile methodology and the principles of the Agile Manifesto had been considered at the beginning, these have been rejected for two reasons: First, because any contact between the researcher/developer and any planner/user was put out of the question early on in the project. Second, because the Design Science Research framework seemed to fit the academic requirements of a PhD and there was therefore no real need for a software development approach for the time being. The latter may in fact be required at the stage of software deployment, i.e., before and during field-testing it.

Representation

As indicated in the research plan and questions of design quality, the means of representation must be defined for the IS. Representation refers to two things, namely to the design of the artifact from a number of aspects and to the representation model of the knowledge the Information System will be using. The former requires specification of languages and notations, while the latter refers to semantic modelling, as already given away since the 2nd Chapter of the thesis. Semantic modelling needs not be dealt with here, in the Design section, as it is used as data input in the following section, Implementation.

Any process with some structure can be modelled using graphical notation/languages according to needs. Information System processes can be viewed as business processes, and can therefore be modelled with appropriate notations. Examples of the latter include the Business Process Model and Notation and the Decision Model and Notation (BPMN, Object Management Group Inc. [105]), the Event-driven Process Chains (EPC; Scheer, Thomas and Adam, 2005 [129]), and the Knowledge Modelling and Description Language (KMDL; Gronau, Müller and Korf, 2005 [47]), with the former two being employed more often (Cabral, Norton and Domingue, 2009 [13]).

The processes designed for each planning case in this project are modelled with BPMN. The reason a business process notation was selected over a software development one, like the Unified Modeling Language (UML) for example, is threefold. First, BPMN from its 2.0 version onwards comes with an eXtensible Markup Language notation for process semantics and diagram interchange information. This potentially enables platform independence, a feature that I take advantage of in the implementation phase.

Second, the BPMN diagram is expected to show the tasks and their sequence from the moment the user accesses the IS, until the moment he enacts the planning process. The notation allows also for illustration of the inputs and outputs, as well as storage, processing and other units, as needs request. This means that one can have a single diagram illustrating several aspects of the process, while with UML one would need a number of separate diagrams to achieve this. For the rest of the aspects, mostly including use cases and components, UML is indeed used. In fact, a number of figures included in the text so far have been UML diagrams (e.g., Figure 4.2).

Last, the importance of viewing a process as a business-type one is for the possibility to apply measures of quality on them, including ones for times and costs, and thus performing evaluations, finding bottlenecks and accomplishing optimisation. Although this is not within the scope of this thesis, it may prove useful for the preparation of the artifact in the phase of deployment.

Evaluation

Evaluation of the designed IS processes is performed based on the type of language or notation used. For UML diagrams, this refers to syntactic consistency and is performed internally by the software during modelling, by way of disallowing, for example, nonsensical types of connections between certain constructs. This is also true for diagrams of Business Process Model and Notation, but the editor used goes one step further, indicating errors and providing modelling advice through warnings, helping in this way the modeller to discover best practices.

The specific software used (Signavio), although only an online academic licence version of it, provides also for Petri Net analysis of the diagrams, which caters for evaluation of soundness, i.e., of semantic correctness. Petri Nets, devised by Carl Adam Petri (1962 [115]), are directed graphs that capture behavioural anomalies in the processes. Diagrams in BPMN are first translated into the Petri Net notation and graph evaluation starts with the initial conditions for structural soundness:

i. The process model has exactly one start event *i*.

ii. The process model has exactly one end event *o*.

iii. Each node in the process model is on a path from *i* to *o*.

They then check for the three properties of overall soundness, which are expressed by the following statements (Weske, 2016 [161]):

i. Once a process has started, regardless of which decisions are taken by the process, at some point the process will reach the end event *o.*

ii. If and when it reaches *o*, the process has completely terminated, i.e., no further activities can be executed by the process anymore.

iii. Each process activity participates in at least one execution.

The following table (Table 4.2) summarises the types of models used for the design of the IS, the language/notation, methods for evaluation and the corresponding software.

	Type of diagram	**Language / Notation**	**Software**
Representation	Process	BPMN	Signavio
	Use case	UML	StarUML
	Component	UML	StarUML
	Activity	UML	Enterprise Architect
Evaluation	Process	Petri Net	Signavio

Table 4.2: Summary of representation and evaluation tools for the design of the IS.

4.3 Implementation

Implementation of the designed artifacts follows from the meta-artifacts produced in the phase of Design. Although these are presentd in the next Chapter, this section lists and describes the data used for implementation, as well as methods and software used.

Data

Three types of data is used for functionality implementation. First of all, the designs – mainly the process diagrams – of the Information System. Second, the artifacts collected with regard to the two planning cases. Wherever these were not enough, artifacts were created to fulfil the needs. Last, experience in the use of Semantic Web technologies has been collected through online courses and through the author's traineeship at the Department of Geoinformation Processing of the University of Twente. Experience is difficult to prove or document, therefore this Data section focuses on the data relevant to the two planning cases.

Data for the Strategic Environmental Assessment in Sardinia

The functionality for the SEA case in Sardinia focuses on reasoning with data, in order to get the components of a new process. In searching for ready semantic models for this purpose, two ontologies have been discovered. Their formalised knowledge base was requested by their creators, who, in both cases, have been kind enough to offer them for the project. The first model is a generic ontology for Spatial Decision Support (SDS) created by the SDS Consortium (Li *et al.*, 2012 [86]). The second one is an ontology specific to the SEA in Sardinia, created by Lai and Zoppi (2011 [78]).

The SDS ontology (Figure 4.4) is in fact a collection of 54 ontologies, each one concerning a different field in spatial decision making, while a significant part of it is dedicated to the planning framework (Geodesign) by Steinitz (2012 [135]). All original ontologies were in *.n3* files, with a few of them in *.ttl* as well. In order to display them with software different from the one they were created with, I had to translate their serialisation to OWL/XML.

The second ontology was created for the SEA of city masterplans in the Region of Sardinia and consists of seven graphs (Figure 4.5). This was created with OWL 1, which was based on frames rather than axioms. This has created some issues of parent-sibling type of relationship when used with the current, second version of OWL, so it might be a good idea to be updated for further use.

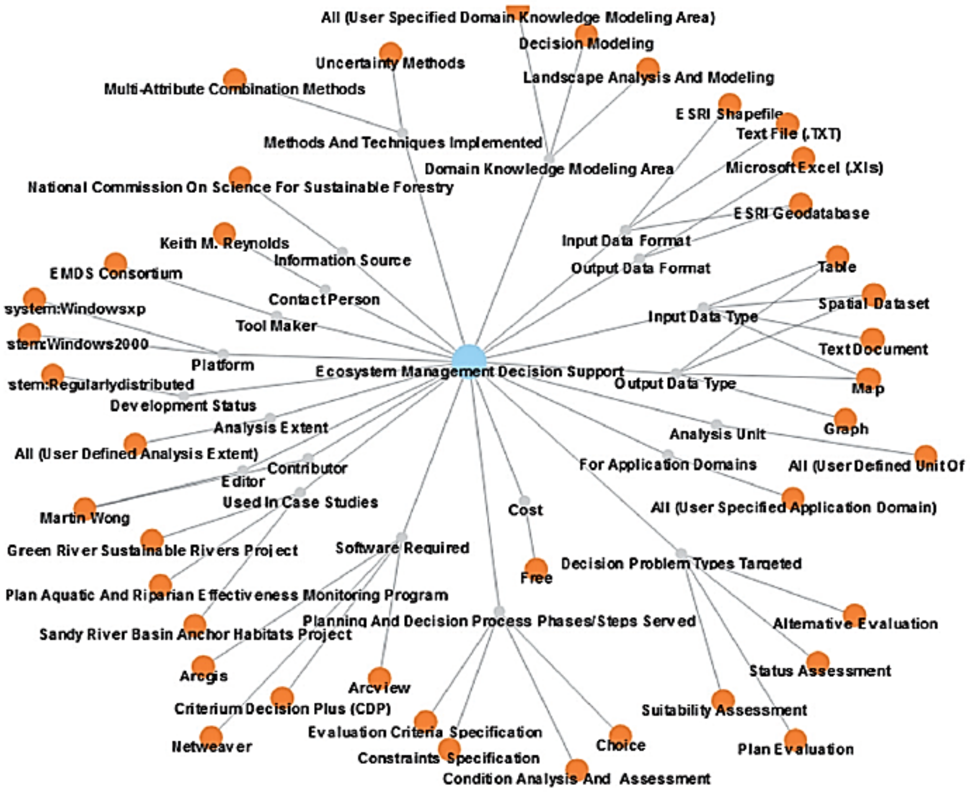


Figure 4.4: Part of the Spatial Decision Support ontology. Screenshot from the SDS Knowledge Portal (http://sdsportal.sdsconsortium.org/).

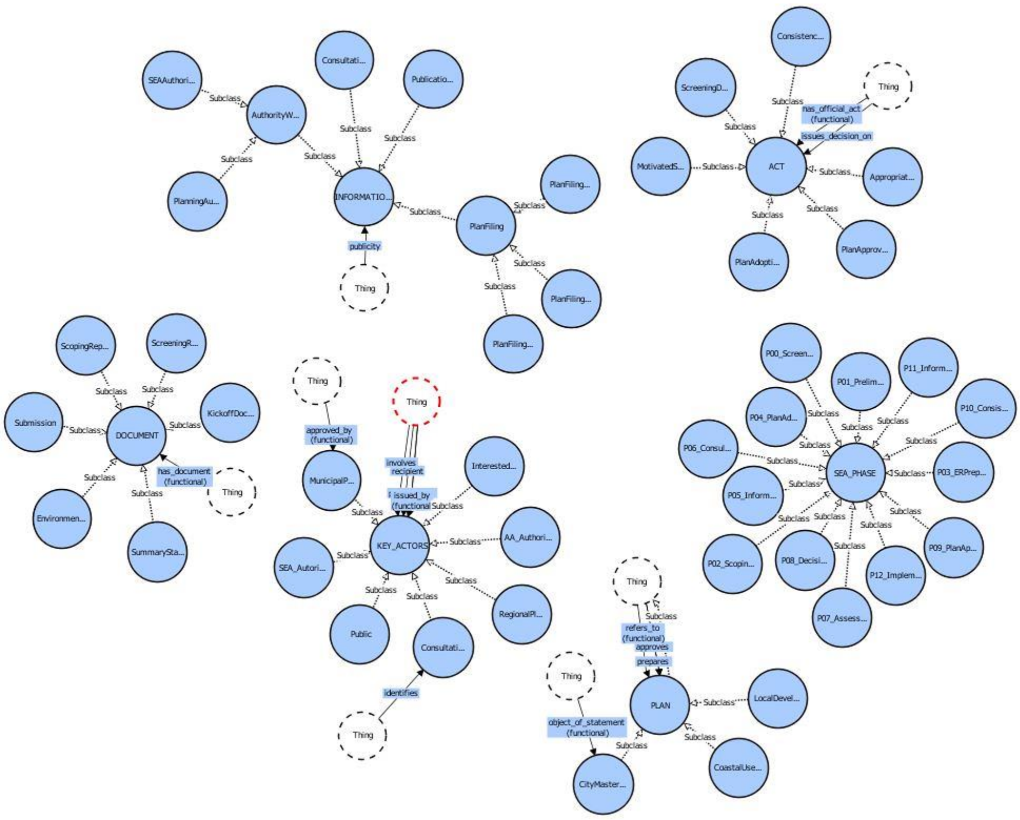


Figure 4.5: The SEA ontology used in this study. Visualisation with VOWL (2016 [154]).

Data for the Mara rangeland management case

The Mara rangeland management case is used in this project in order to experiment with geoprocessing workflow transformations between GIS software. A workflow is taken to be a representation of a stepwise process, with its logic and tasks designed to be understood and carried out by processing machines. Building workflows in a visual, graphical way is a particularly useful feature for process planners, the latter spanning from inexperienced users seeking simple, repetitive procedures to professionals designing complex flows of geodata processing.

Such graphical icons on the software's interactive canvas usually come with rather intuitive semantics, which renders workflow design quite a straightforward operation and further facilitates exchange of knowledge among users of the same software. Standardisation of such graphical notations boosts interoperability between software packages that choose to use them, allowing for workflow transfer and correct process enacting from different platforms.

Geographical Information System (GIS) software often comes with a graphical geoprocessing workflow builder. Yet, graphical notations vary among software in terms of both constructs and semantics, a fact that blocks cross-platform transfer of workflow diagrams. The problem is equally valid whether one speaks of workflows as abstract templates or as concrete procedures with all their parameters resolved for a certain case at hand. If, however, a standardized notation suitable for geoprocessing flows were to be employed, the problematic situation could potentially be eased.

The idea here is based on the eXtensible Markup Language (XML) description of BPMN, which can be used as the intermediate model among GIS workflow descriptions, assuming the latter are also in XML. XML is a text-based data representation format for exchange of data between applications, easy to read by humans and simple to parse by computers. It is therefore a good choice when aiming at increasing the interoperability of applications. Javascript Object Notation (JSON), on the other hand, is an equally good choice for interoperability and even easier to parse. The decision to work with XML was ultimately based not on advantages of one format or the other, but merely on the fact that BPMN is XML-defined, which means that all BPMN diagrams can be - and normally are in BPMN 2.0 compliant editors - serialised in XML.

BPMN is a widely used notation for processes. Its visual language, comprising elements, shapes/connections and markers, is easy to understand, while its richness allows for modelling from atomic tasks to complicated, cross-platform, multi-actor processes, with loops, events, communications and decisions. Implementation passes through an alignment of schemata between BPMN and the geo-operators. A fundamental feature of BPMN is its platform neutrality. It means that one could potentially load a process described in XML to any BPMN editor and have it displayed diagrammatically.

Theoretically, therefore, for the current project one could have used any editor that is BPMN 2.0 compliant. In practice, however, experience showed that each one requires the XML file to follow the editor's style for process and element *id* allocation. Yaoqiang-BPMN-Editor-5.3.12 (https://sourceforge.net/projects/bpmn/) simply requires that *id* numbers be preceded by an underscore, while it also provides for a very user-friendly interaction between the source (the XML encoding) and the diagram tabs, traits convincing enough for the needs of this study.

Another significant aspect of BPMN is that its version 2.0 incorporates BPEL, therefore tools that claim BPEL process execution conformance can further enact the modelled workflow by connecting to desktop applications or web services. This means that resolved geoprocessing workflows are potentially directly executable if the GIS software provides an API. Last, business process management suites working with BPMN may allow for cost allocation and process analysis for monitoring and eventual optimisation.

For this part of the PhD project, two artifacts have been provided by the University of Twente. The first is the geoprocessing workflow for forage drymass production and the second is an XML description of all geooperations in ILWIS, which is the software the geoprocessing model was implemented with. The geoprocessing workflow was created in order to calculate production of grass in a conservancy of the Maasai Mara rangeland. It therefore started as a scientific workflow with activities referring to rainfall prediction and grass growth factors and was then resolved for execution in ILWIS (Figure 4.6).

ILWIS (http://52north.org/communities/ilwis) is a GIS and Remote Sensing open source software, used for professional and training activities with geoinformation and serving as a platform for research projects (ILWIS, 2016 [65]). The software, currently in its 4th version, comes with an interactive workflow builder, capable of supporting large and complex geoprocessing workflows (Lemmens *et al*., 2018 [83]). The notation used includes boxes representing data and operations, and arrows indicating the flow between them. These visual workflows can be exported in JavaScript Object Notation (JSON) format, rendering them shareable and deployable through web applications (Lemmens *et al*., 2016 [81]).

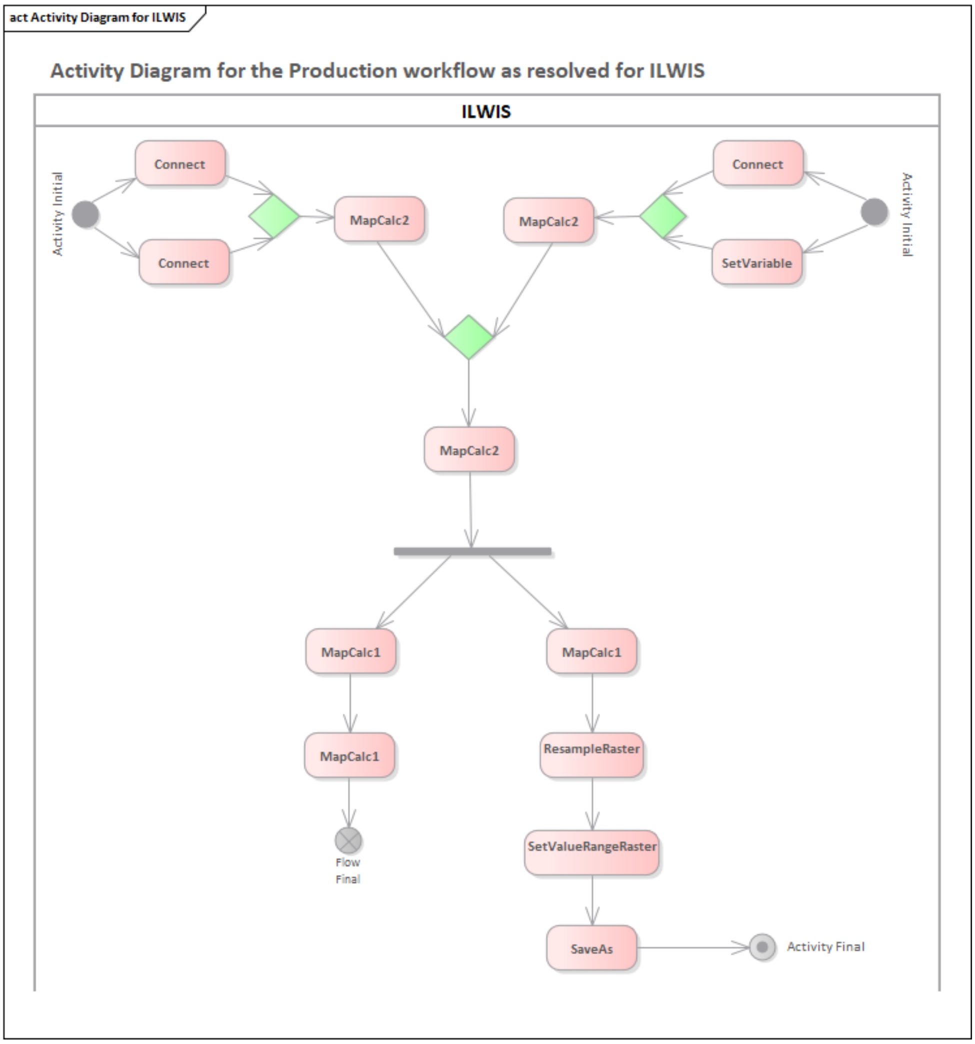


Figure 4.6: Part of the geoprocessing workflow, as resolved for ILWIS. The names of the activities in the diagram correspond to names of the geo-operations in ILWIS.

An additional reason for ILWIS' suitability for this study is that its development team has already embarked on research for converting workflows from more abstract definitions to concrete, case-based ones (De Carvalho Diniz, 2016 [24]). This, together with work on describing and linking geo-operators from different sources, can provide the solution to adapting workflows to different GIS software. Considering also the fact that the software is currently being redesigned to include APIs, ILWIS emerges as an optimal platform to experiment on every step of the approach described above.

The second artifact is the XML description of all ILWIS geo-operators, extracted automatically with a Python script. Part of the file is shown in Figure 4.7.

```xml
<operation>
  <name>mapcalc</name>
  <longname>MapCalc 1</longname>
  <description>Generates a new numerical rastercoverage based on the operation, applied to all the pixels</description>
  <namespace>ilwis</namespace>
  <keywords>
    <keyword>raster</keyword>
    <keyword>numeric</keyword>
    <keyword>math</keyword>
  </keywords>
  <syntax>mapcalc(expression,gridcoverage|number)</syntax>
  <input_parameters>
    <parameter>
      <name>Expression</name>
      <types>
        <type>String</type>
      </types>
      <desc>The expression is an abstract expression were the numbers indicate indexes in the parameter list</desc>
      <optional>false</optional>
      <needsquotes>true</needsquotes>
    </parameter>
    <parameter>
      <name>raster or number</name>
      <types>
        <type>RasterCoverage</type>
      </types>
      <desc>Rasters with numerical domain</desc>
      <optional>false</optional>
      <needsquotes>false</needsquotes>
    </parameter>
  </input_parameters>
  <output_parameters>
    <parameter>
      <name>raster coverage</name>
      <types>
        <type>RasterCoverage</type>
      </types>
```

Figure 4.7: Extract from the XML file that describes ILWIS' operator "mapcalc".

A third group of data input has subsequently served, namely the BPMN specification files and the informative, machine consumable documents of BPMN 2.0, that were downloaded from the Object Management's Group website (Object Management Group, 2011 [106]). These include all the XML Schema Definition (XSD) files (Figure 4.8). BPMN20.xsd is the top-level schema, while the process semantics are defined in Semantic.xsd and the definitions for the graphical presentation of the process diagrams are in BPMNDI.xsd. Last, DI.xsd and DC.xsd define diagram object elements like shapes and edges.

dtc/10-05-04	BPMN20.xsd	XSD	BPMN/20100501/BPMN20.xsd
dtc/10-05-04	BPMNDI.xsd	XSD	BPMN/20100501/BPMNDI.xsd
dtc/10-05-04	DC.xsd	XSD	BPMN/20100501/DC.xsd
dtc/10-05-04	DI.xsd	XSD	BPMN/20100501/DI.xsd
dtc/10-05-04	Semantic.xsd	XSD	BPMN/20100501/Semantic.xsd

Figure 4.8: The XSD documents used.

Methods

Since the functionality implemented for each planning case was different from the other one, methods were also different, with the SEA case requiring experimentation and the Mara case consisting mostly of artifact creation.

Implementation for the Strategic Environmental Assessment in Sardinia

The first thing to do for this planning case is the evaluation of the available ontologies for fitness for use. Each person/group of experts that creates an ontology of a field has an approach and considers – consciously or inadvertently – a philosophical ontology of his own. Some consider only the structure of objects/individuals, some the interaction of objects with their environment (other objects), some assume what exists is real and restrict ontologies to include real objects only, some find themselves in need to introduce abstract concepts to make the ontology cohesive or to represent reality better from a behavioural point of view. This is why not necessarily all ontologies fit all purposes.

The first criterion is thematic fitness, with the SEA ontology being obviously relevant to the theme. The SDS one, however, is much broader. This is because it was created for browsing purposes and therefore aimed at comprehensiveness of the entire field of spatial decision support, rather than at ontological economy. The latter is indispensable when reasoning is involved, because large knowledge bases may exceed the expressiveness of the Description Logic used by the language of the formalisation and render, in this way, the problem of inference computationally hard.

One way of treating this issue would be to invest in exploration of the SDS ontology, select the concepts and the relationships deemed relevant to the description of the SEA planning process, possibly add concepts that are missing, and then use this much simplified version to make inferences about SEA process instances. Exploration of large knowledge bases, however, is a problem still troubling the field of Linked Data and would require a large amount of time to achieve the required result.

Another decisive criterion is fitness to the purpose. The SEA ontology was created to define the components of this planning procedure, but not the procedure itself. Considering that it was written in an older version of OWL and that adjusting it both to OWL 2 and to the needs of the Information System designed in this project would require close collaboration with the ontology's developers (which was not possible for purely logistical reasons), I decided to create a small, controllable, knowledge base of a part of the SEA process, namely for desertification risk mapping. The approach I followed for the development of the knowledge base (KB) that fits the task of component configuration is ideally outlined by Tuomi's (2012

[145]) analogy: *"If the nature is a lock, we try different keys until one opens the lock."* Basically, this means that the eventual form of the KB has been achieved through trial and error.

Therefore, the experimental process eventually concerns desertification risk mapping for Alghero (a town in Sardinia), instead of the entire SEA procedure for the whole island. The data required for the map is the Environmental Sensitive Areas index, available through ARPAS, the regional agency for environmental protection in Sardinia. The municipal planning authority responsible for acquiring the data relevant to the area planned and classifying the territory according to given thresholds is the municipality of Alghero. Finally, the map is to be integrated in the SEA scoping report.

The first step is to analyse the experimental process and build a workflow model. This will serve as the control, against which the information inferred by the semantic model will be compared. A knowledge base (KB) is subsequently created that represents formally the structure of the process. The difference between an ontology and a KB is that the latter does not aspire at a comprehensive description of the domain of discourse. Rather, it abstracts the elements required for the application at hand. The constructs used are the same as with any other type of semantic model, as long as the same representation language is used. The language used is OWL 2 (W3C, 2012 [155]) and its structure is shown in Figure 4.9.

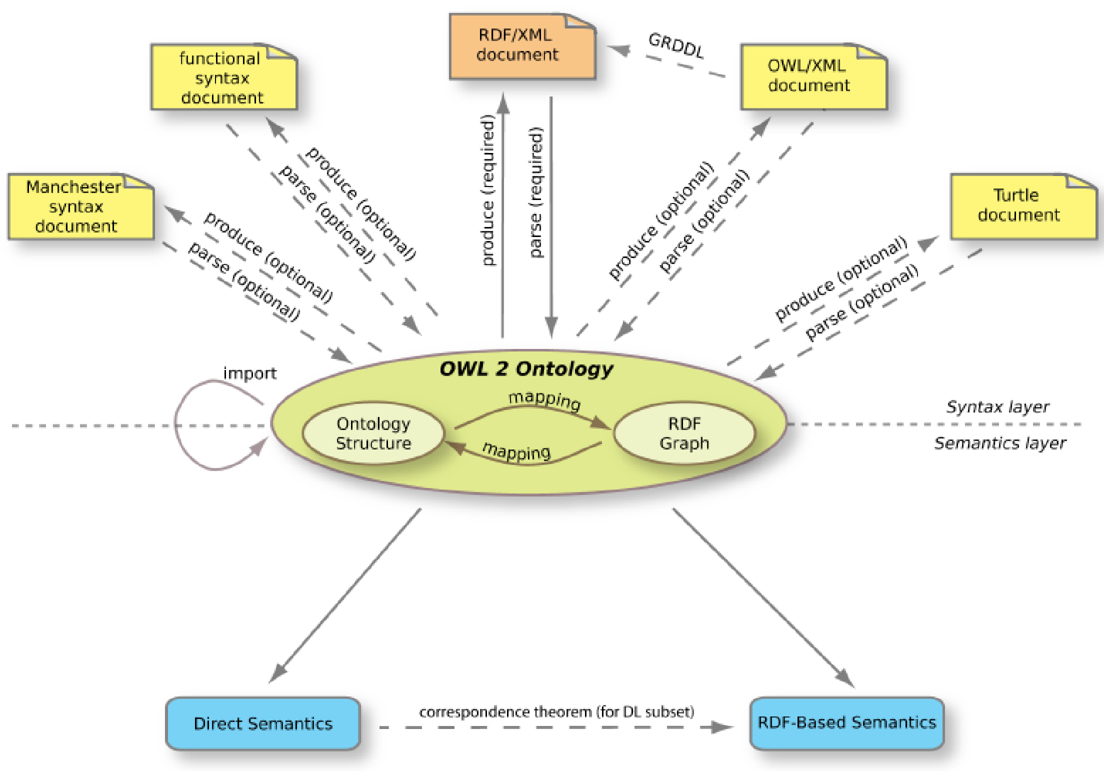


Figure 4.9: The structure of Web Ontology Language 2 with its semantics and its syntactical serialisations ([109]).

Once the elements and inter-relations of the control process are formally described, the original SEA ontology is then put to a new use, namely to comparison with the KB for the possibility of aligning the two. Therefore, the ontology is explored, to find exact or similar matches to the elements-concepts and the links between them. Exploration is performed in three ways: a) through visual inspection for a first overview, b) through indexing and text search for concept discovery, and c) through network analysis for discovery of paths connecting concepts. Given that models are built for specific purposes and are not expected to cover the needs of all possible applications, certain process elements and relationships represented in the KB may be missing in the SEA ontology. Elements and relationships existing in both bodies of knowledge are ultimately connected for ontology-KB integration.

With every step of its development, the integrated KB undergoes a consistency check and verification. Both procedures rely on the capabilities of the reasoner used; in this experiment the reasoner used is Pellet (2015 [114]), embedded in Protégé (Musen, 2015 [103]). The consistency check amounts to testing for class unsatisfiability, i.e., for classes that, by way of axiom interaction in the KB, become unable to host any instances. Since the KB is of a relatively restricted size, cases of class unsatisfiability are dealt with by manual inspection of the causes and subsequent repair that restores retrieval of meaningful conclusions from the axioms.

Verification, on the other hand, is accomplished by inserting test constructs, namely classes and instances, and controlling the newly inferred knowledge. Repair solutions are devised in two cases: a) when an instance results subsumed by two disjoint classes, and b) when an instance is subsumed only by one of the several classes intended. Consistency checks and verifications are performed until the KB results error- and inconsistency-free. At this stage, the KB is ready to be tested against the case study.

The experiment starts with an instance of the class “Process” being created and provided with incomplete information, namely only with the area the process refers to and its expected final product. The experiment may be considered successful if the reasoner manages to find all elements required for desertification risk mapping in Alghero, as these are shown in the control.

Implementation for the Mara rangeland management

There are two aspects to consider when adapting a geoprocessing workflow from one software to another. The first one is conversion of the notation specific to a GIS software to an intermediate, standardised notation and back. This aims at mapping notation constructs and semantics, as well as flow logic, in a way that preserves their meaning and ultimately allows for correct execution of the process. It therefore appears imperative that the intermediate notation is rich in constructs and semantics and expressive enough in flow logic, to cover complex process modelling requirements adequately.

The second aspect to consider is detection of geo-operators, i.e., low-level tasks synthesizing a geoprocessing workflow, which are similar or even correspond exactly to those of the software used to create the original workflow. This feature presumes description of geo-operators in a way that links their attributes, for example their required inputs and outputs, their preconditions, their functionality, or the mathematical models they apply.

The approach therefore starts with the creation of a workflow in the original GIS software and moves on to convert it to a process in a standardised notation. It then finds corresponding geo-operators in the target GIS software, using a geo-operators ontology and descriptions of each software's operators as Linked Data. Finally, it adjusts the intermediate workflow model to the new geo-operators and translates the standardised notation to the notation of the target software. If the target software has APIs for its functions, then the solution may well be completed one step ahead of the final translation, provided that the intermediate notation can connect to the APIs and execute the process directly from its own management platform.

To describe a workflow that will serve as the artifact to experiment with in the following phase (conversion to BPMN), we need information that defines the geo-operators of our GIS software, as well as information that describes their connection in a workflow. ILWIS, in its role as a research platform, does not include a unique schema for definition of both geo-operators and workflows at the moment, as no imperative need had arisen before this study. This does not affect its performance in professional and educational activities, but adds some extra work for schema definition in this preparatory phase.

Starting with the XML description of all ILWIS geo-operators (the second artifact provided by the University of Twente), one can automatically derive an XML Schema Definition. There are a number of online tools that can do that, although I have found Freeformatter (https://www.freeformatter.com/) to be the only one offering a selection of schema extraction designs, namely Russian Doll, Venetian Blind and Salami Slice. The design selected is Venetian Blind, because it allows for some globally defined reusable elements and types, as well as for local ones that need not be reused anywhere else. This XSD cannot be used for a direct comparison to the XSD of the BPMN, because it lacks information on the structure of a workflow, i.e., it contains no elements to describe connections that define the sequence of the geo-operators.

In ILWIS, geo-workflow descriptions are not in XML, but in Javascript Object Notation (JSON). The path to derive an XSD for the structure of geoprocessing workflows is therefore slightly more complex. Starting with the sample workflow (the first artifact provided by the University of Twente), its JSON file is translated into XML. An automatic one to one translation is usually not completely accurate, because item types in one format do not necessarily have an equivalent in the other, so post-processing is then performed to confirm that the derived XML file is meaningful.

Subsequently, the same procedure as for the geo-operators above is followed, in order to get an XSD. The complexity of the sample workflow used is sufficient to cover the basic structure of any simple workflow, but will have to be increased for later experiments to include splits and decisions in the flow. Finally, a unique schema can be proposed by aligning the two XSDs.

The resulting, unique XSD for ILWIS is then compared to the XSD documents of BPMN 2.0 and a correspondence between the most basic elements of both sides is established. Afterwards, an eXtensible Stylesheet Language (XSLT) document is prepared, which contains the rules for transforming ILWIS XML to XML for BPMN. The XSLT is a language for transforming XML documents, expressed in the form of a stylesheet that states the rules for conversion from one schema to another (Kay, 2017 [72]).

In order to test the conversion rules, the stylesheet is loaded to an XML-to-XML converter, together with the XML describing the example workflow, which is the object of conversion. The converter used is Treebeard (https://sourceforge.net/projects/treebeard/) and produces an XML file describing the example workflow with BPMN elements. The converted geoprocessing workflow, represented in XML, is then loaded to the BPMN editor for visual inspection.

The approach has so far presented only the first step of this functionality implementation, namely conversion of a geoprocessing workflow from software-specific to an intermediate, standardized notation, i.e., from a process implementable solely in ILWIS to one modeled in BPMN. In order to complete the frame of this approach, two additional steps are required: selection of corresponding geo-operators from other GIS software based on their descriptions and their substitution in the example workflow.

Selection of geo-operators from other software passes through a conceptual description of the links among different software. This can then be formalised as an ontology and a Linked Data repository of geo-operators. Inferencing and SPARQL queries may then be used to locate similar functions and substitute one for the other in a workflow. The last step, namely that of converting from the intermediate BPMN workflow to a GIS software-specific notation is not being dealt with in this PhD.

5 ARTIFACTS OF THE PLANNING SUPPORT SYSTEM

5.1 *Introduction*

This chapter presents all artifacts created by means of Design Science Research. Research contribution is accomplished by consideration of the information collected and the decisions taken in preparing the context and selecting the methods for PSS design, as these have been unfolded in Chapter 4.

Illustration of the outcomes in Chapter 5 also follows the structure set in the previous chapter, starting with the design of the Planning Support System and of its sequence of tasks that fulfil a use case in each of the two planning instances viewed in this thesis. It then proceeds into describing experimentation and implementation of functionalities representative of the two planning cases at hand.

5.2 *Design of the Planning Support System*

Design of the PSS is hereby demonstrated by means of diagrammatic representation. This is meant in two ways: a) as design of the PSS as an Information System, looking at its use-cases and its task sequence description, and b) as representation of the planning process knowledge that the PSS uses to fulfil its functionalities (see also Representation). These, in turn, are grouped by planning case studied, namely the Strategic Environmental Analysis in

Sardinia case and the Mara rangeland management one in Kenya, and so are presented in the following sub-sections.

Some of the functionality is common to both planning cases, like browsing, checking for process soundness, creating and editing models. The rest of the functionality is more specific to each case.

Design for the SEA planning case

The first planning case deals with the need to figure out the components of a planning procedure. The actor/head planner is assumed to have some knowledge of how to handle a semantic model and edit it by adding instances that suit his needs. Based on the suggestions he gets by using the ontology with the inference engine, he can create and edit planning procedures, as well as store them for future reference.

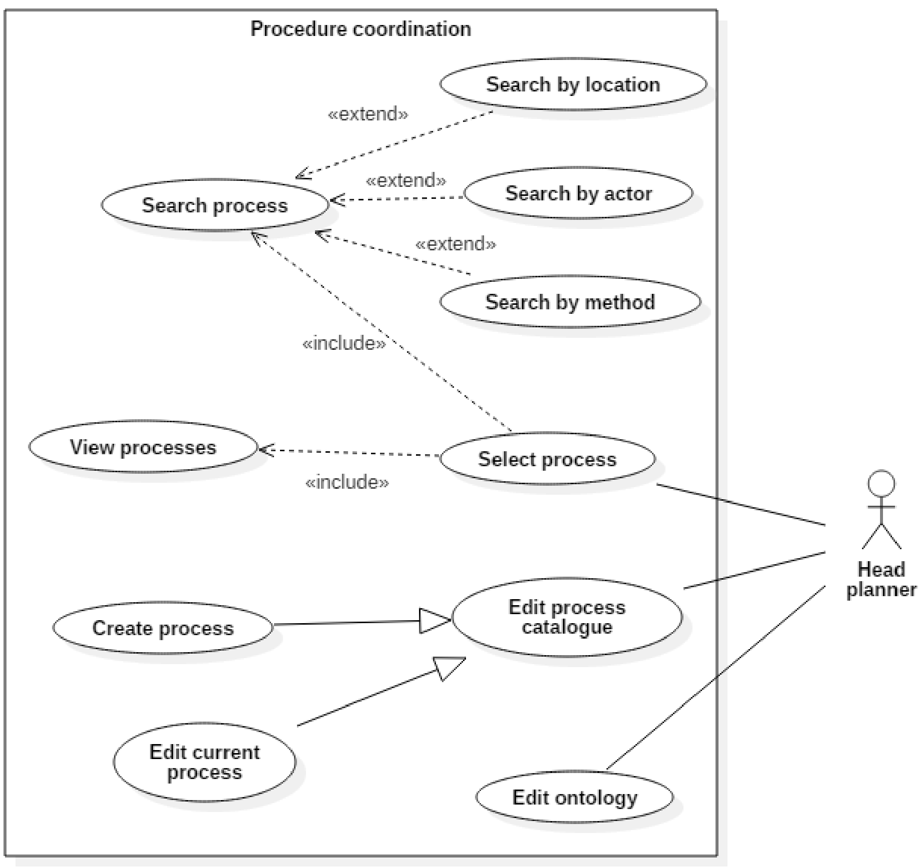


Figure 5.1: The use cases for the planner-coordinator. He is expected to be able to select an existing process, to edit it or create a new one, and to edit the underlying ontology to fit his case, if he needs and knows how to do it.

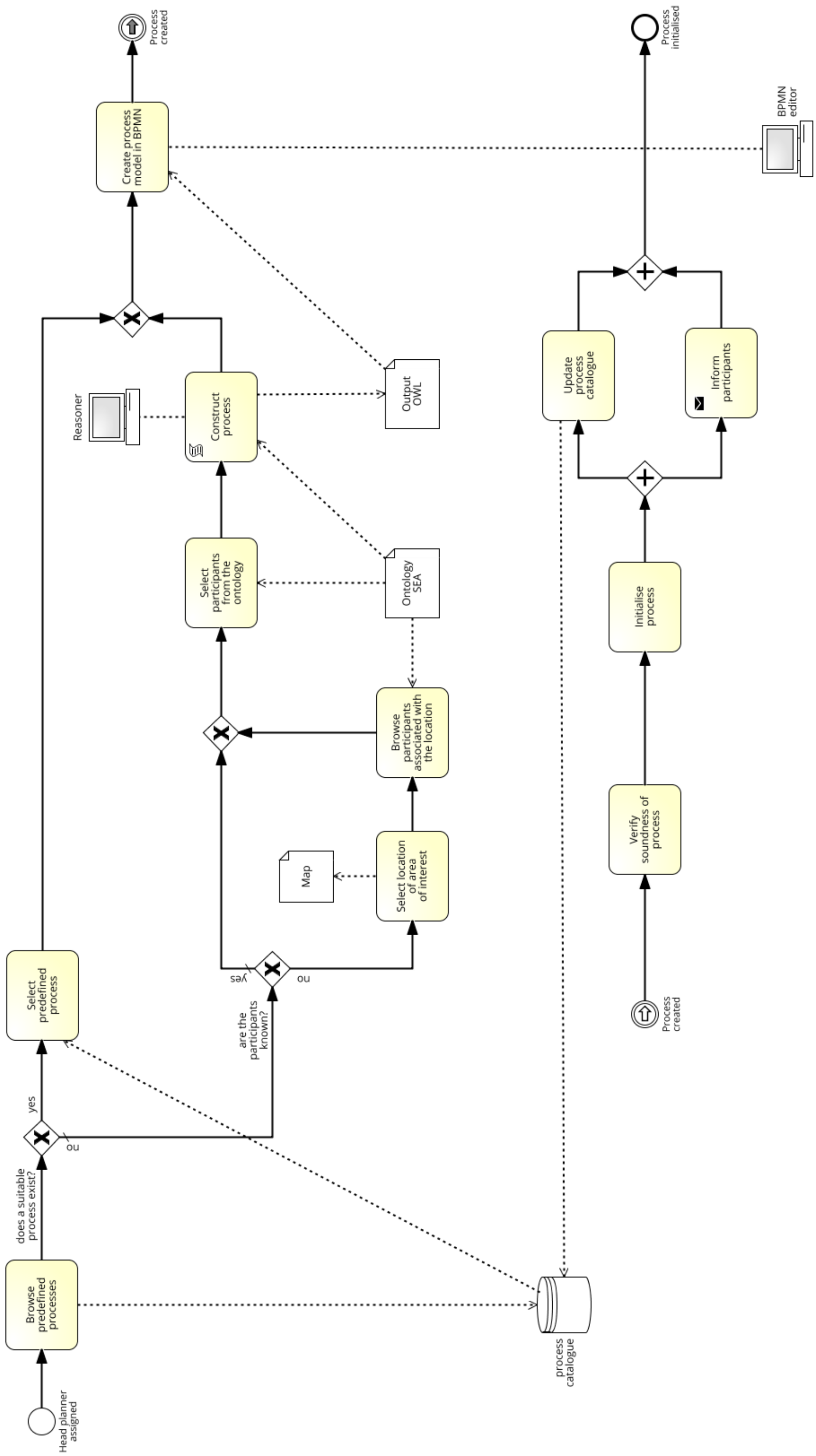


Figure 5.2: Process diagram with the tasks and their sequence that correspond to the SEA planning procedure. The functionality experimented with is that of the task "Construct process".

Design for the Mara rangeland management case

The second planning case deals with the need to process geodata. The actor/livestock manager is assumed to have access to a GIS software of his choice, which may or may not coincide with the software used by other livestock managers or by the rangeland management authorities that supervise and coordinate the environmental planning project for the Maasai Mara area.

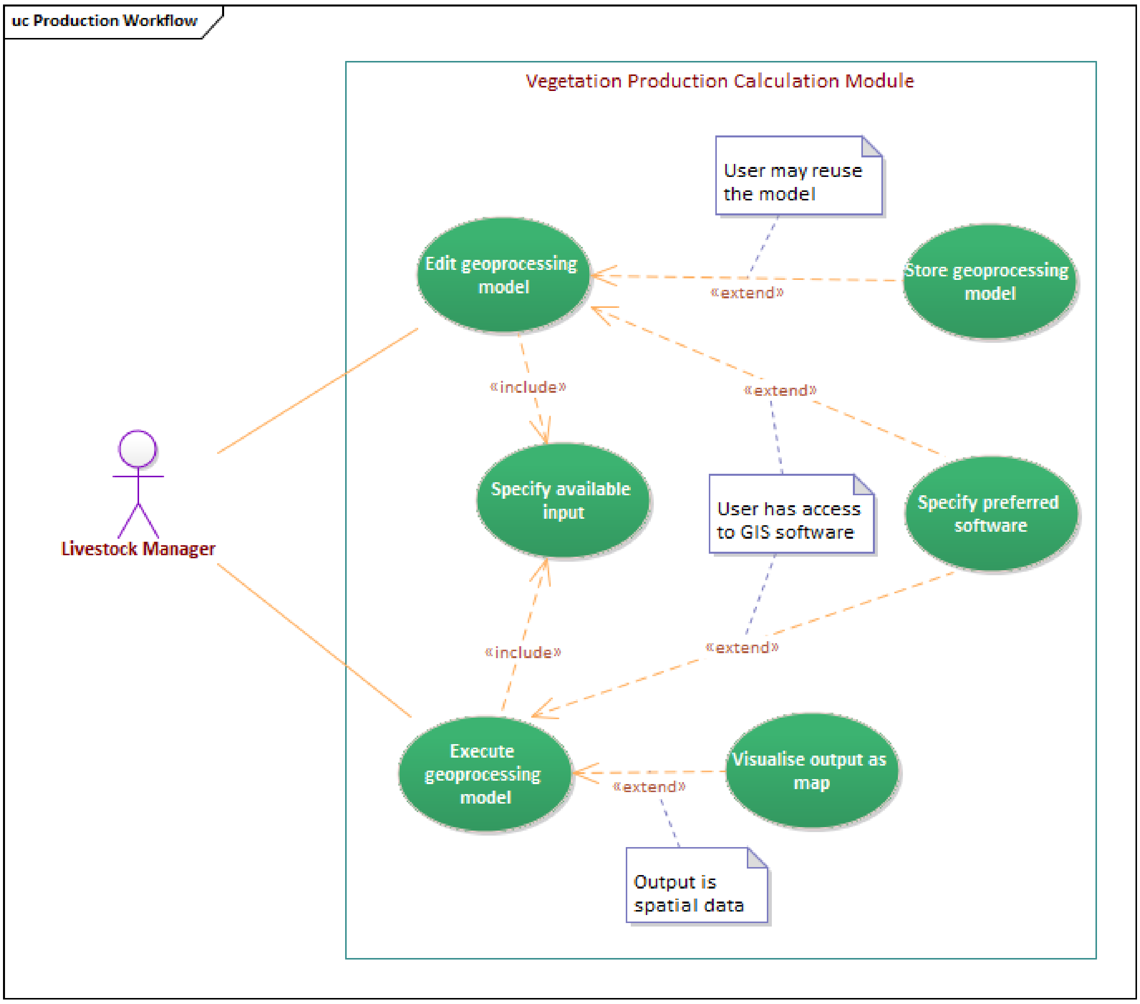


Figure 5.3: Use cases for the livestock manager to calculate and map grass production in his area of responsibility, as part of planning for the sustainable management of the Maasai Mara area.

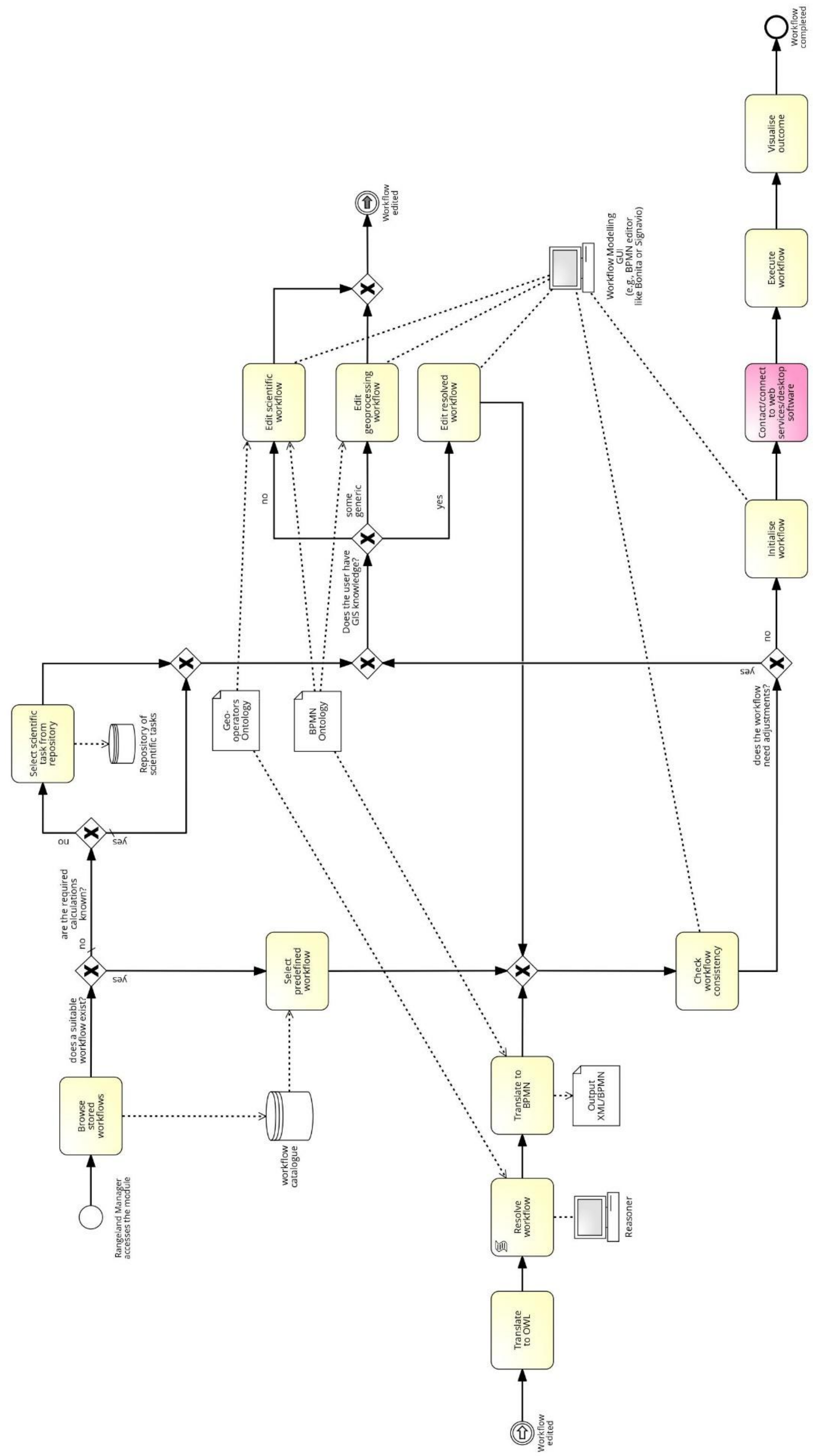


Figure 5.4: Process design for the Mara rangeland case. The functionality implementation for this case focuses on the editing of the geoprocessing workflow to fit the user's choice of GIS software.

5.3 Functionality Development

This section presents implemented functionalities for the two planning cases, which realise the capabilities requested for in the section Capabilities of the proposed PSS, namely knowledge integration, knowledge expandability, and adaptable processes. The first of the three capabilities, knowledge integration, is achieved through the use of a common knowledge representation and language, the Web Ontology Language (OWL 2). Knowledge expandability is fulfilled by means of ontologies and Knowledge Bases, while processes/workflows become adaptable through model conversions.

It is worth noting here that certain functionalities depicted in the diagrams of the previous section are identical in both planning cases. In specific, common uses include browsing of previously modelled processes, creating, editing, checking for soundness and enacting a modelled process, and editing the underlying knowledge model. These are functionalities known to be implemented by relevant software, namely by Business Process Model and Notation editors (creating, editing and soundness checking for processes), Business Process Management Suites (browsing for and enacting a planning process), and ontology editors (editing of the knowledge model). Attempting to re-develop them would therefore not be of particular scientific appeal. Instead, the focus here is on functionality that showcases capabilities specifically pertinent to the subject of the thesis.

Implementation for the SEA planning case

<u>Control</u>: The workflow of the control process is reconstructed in Figure 5.5 and Figure 5.6. The information modelled comprises *actors*, *tasks*, *task sequences*, *input/output* of tasks, and a yes/no *decision*. The elements *location* and *SEA guidelines* cannot be represented, because BPMN does not provide for geo-location of elements and, although individual tasks can be associated to documents, processes in their entirety cannot.

<u>Knowledge Base</u>: The KB, a body of knowledge completely independent from the SEA ontology of Figure 4.5, was constructed around the main concepts of the process, as these were identified from the control model. Furthermore, the class *Process* was added, to host instances of planning process cases. Figure 5.7 displays concepts and properties after consistency and verification checks, while the entire KB, serialised in OWL XML, can be found appended in Knowledge Base for the SEA.

With regard to Figure 5.7, there is much more to what the ontology visualisation tool (Lohman *et al.*, 2016 [88]) can display. Relationships have their own characteristics and many had to be defined as chains of other relationships. The property *hasGuidelines*, for example, links the concepts *Region*, *Municipality* and *SEAguideline* through chaining of the properties *belongsTo* and *refersTo*, expressing in this way the fact that each municipality has to take into consideration the SEA guidelines of the region it belongs to.

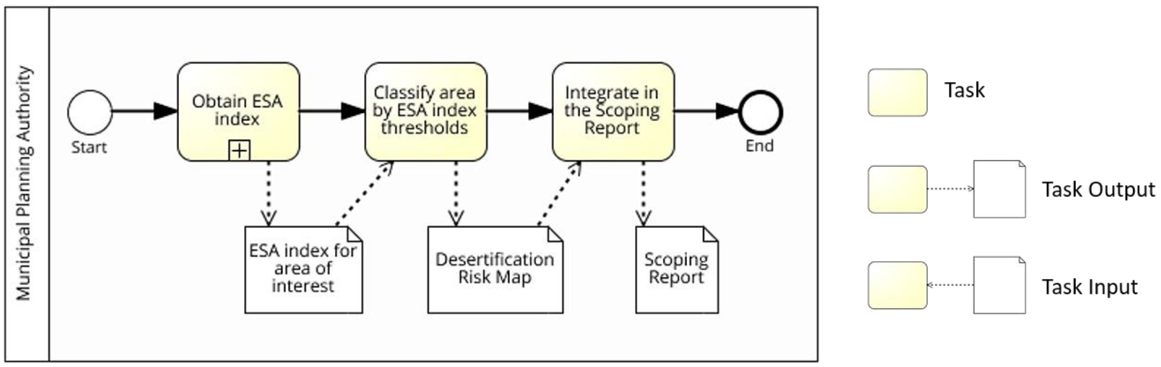


Figure 5.5: The control workflow for desertification risk mapping used in this study. “Obtain ESA index” is a composite task of the workflow and is analysed in its atomic tasks in Figure 5.6. Model created with Signavio (2018 [132]).

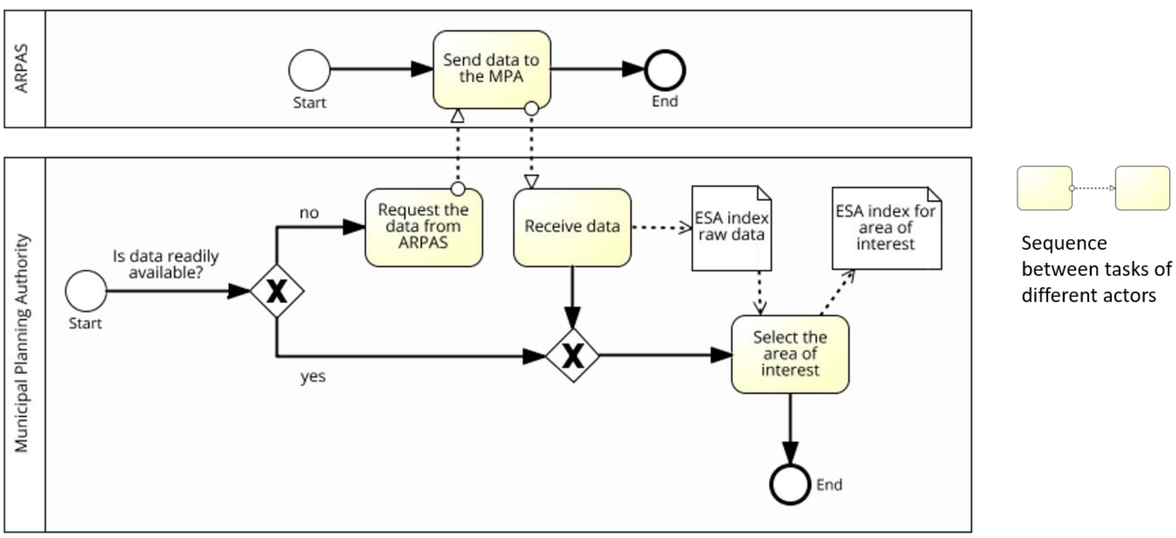
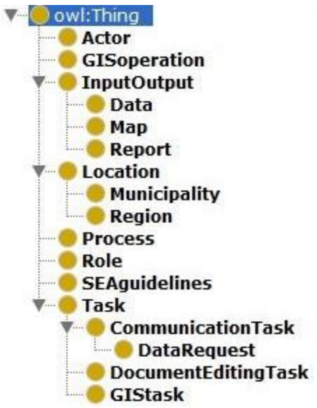


Figure 5.6: Analysis of the sub-process “Obtain ESA index”, whose tasks require a yes/no decision, as well as the involvement of a second actor. Model created with Signavio (2018 [132]).



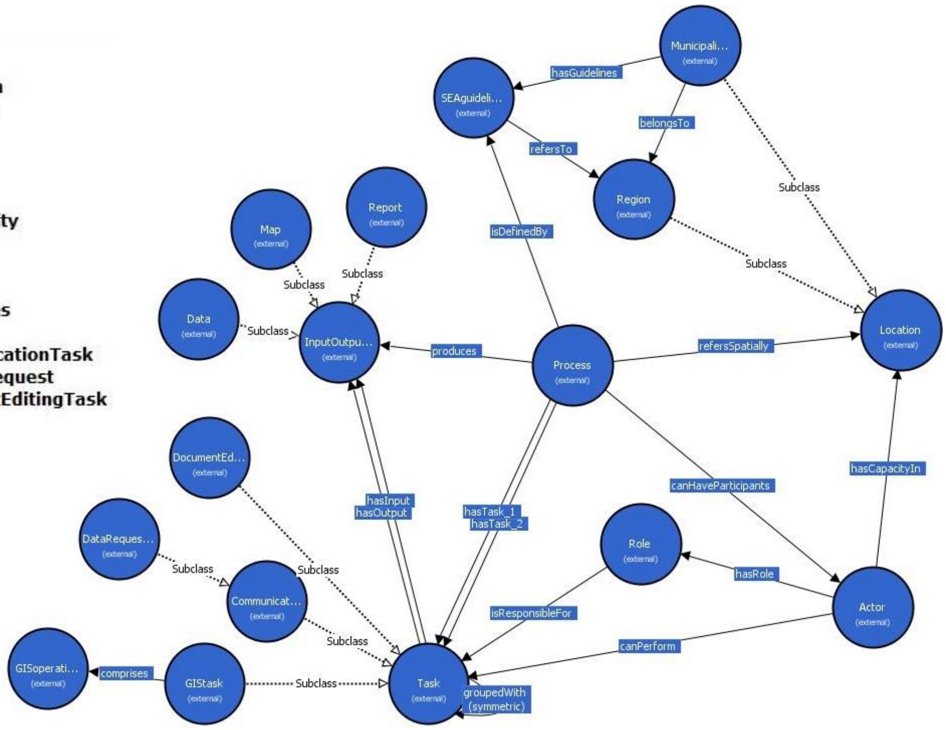


Figure 5.7: Hierarchy of the KB concepts (upper left), created with Protégé (2016 [120]); visualization of the non-hierarchical links between concepts (main figure), created with VOWL (2016 [154]). "External" refers to the URI of the concept.

Another important point is that certain concepts form groupings of subconcepts. The tasks, for example, of the process were split into three categories: communication, GIS, and document editing ones, as shown in Table 5.1. This was deemed necessary as two different strategies for the discovery of eligible tasks were followed: a) through specification of their input and output and b) through inclusion of tasks grouped together. The former involves tasks that can be assigned a concrete input and/or output; the latter is for communication tasks that come naturally into groups: data cannot be received if it is previously neither requested nor sent.

Communication tasks	**GIS tasks**	**Document editing tasks**
- Request the data from ARPAS	- Select the area of interest	- Integrate in the Scoping Report
- Send data to the Municipal Planning Authority	- Classify by ESA index thresholds	
- Receive data		

Table 5.1: Task groupings in the knowledge base.

<u>Ontology exploration and integration</u>: Visual inspection of the SEA ontology, rendered possible by its relatively restricted size, revealed the obvious, i.e., that purpose of creation plays indeed a very important role in semantic modelling. The majority of relationships are hierarchical, while major concepts are not directly connected among them. The KB instead was developed for knowledge inference and required more linkage between concepts, which also affected decisions on whether something should be represented as a concept or as instance; reasoning with instances contributes greatly to inference and particular attention was paid to it.

SEA ontology	**KB**
Key_Actors	Actor
Key_Actors	Role
Document	Report
SEA_Phase	Task

Table 5.2: Correspondence of concepts between the SEA ontology and the KB.

Indexing of all properties for search purposes took advantage of the RDF triples comprising the ontology, with the use of Gruff (2014 [48]) on the AllegroGraph triple store. Search was performed using names of the KB concepts or synonyms, resulting in the correspondence between the two models shown in Table 5.2 that takes into consideration the definition of the concepts rather than the name itself: *Key_Actors* in the ontology, for example, is more like a combination of *Actor* and *Role* from the KB.

The last method, path finding for exploration of relationships among the three concepts of interest, namely *Key_Actor*, *Document* and *SEA_Phase*, revealed that they are mostly connected through the properties *prepared_by, has_document* and *involves (*Figure 5.8*)*. The paths convey the meaning *Document-prepared_by-Key_Actors, SEA_Phase-has_document-Document*, and *SEA_Phase-involves-Key_Actors*. This indicates first that *Key_Actors* may indeed be interpreted as a combination of *Actor* and *Role* and second that *has_document* is comparable to *hasOutput* in the KB.

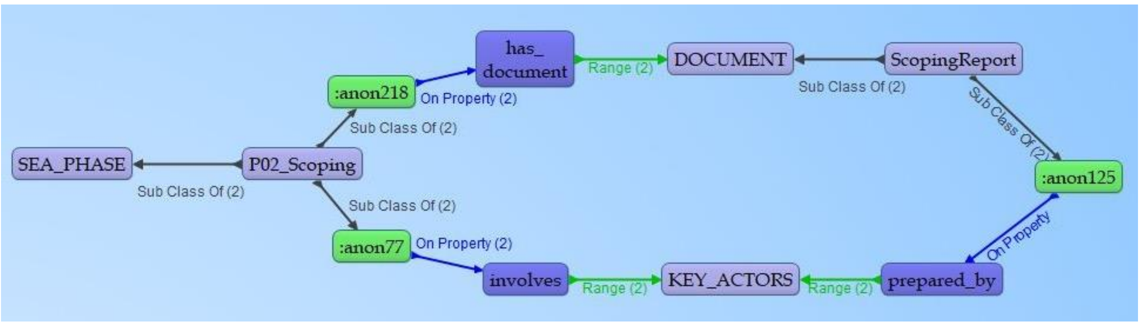


Figure 5.8: Example of a path connecting the concepts SEA_Phase, Document and *Key_Actors*. Anonymous nodes represent restrictions on the properties *has_document*, *involves* and *prepared_by*. Created with Gruff (2014 [48]) software.

Based on the results of the ontology exploration, the KB and the ontology were integrated through linking concepts and properties as shown in Table 5.3.

Element of the KB	Property	Element of the SEA ontology
ARPAS *(Actor instance)*	rdf:type	ConsultationAuthority
Alghero *(Municipality instance)*	rdf:type	MunicipalPlanningAuthority
hasRole *(Property)*	rdfs:domain	Key_Actors
hasRole: Planning *(Actor subset)*	inverse(rdfs:subClassOf)	MunicipalPlanningAuthority
hasRole: Consulting *(Actor subset)*	inverse(rdfs:subClassOf)	ConsultationAuthority
ScopingReport *(Report instance)*	rdf:type	ScopingReport

Table 5.3: Rows in this table show the elements of the two semantic models and the properties used to connect them.

<u>Experiment</u>: The experiment was performed on the instance *ProcessDesertificationRisk*. The information asserted was that its spatial reference is Alghero and its final product is a scoping report. As shown in the Protègè (2016 [120]) screenshot (Figure 5.9), the reasoner made all the correct inferences regarding the participants of the process, the SEA guidelines applicable and the tasks required. "*HasTask_2*" lists tasks selected through the input-output sequencing, while "*hasTask_1*" lists those selected due to a task of the first list being dependent upon and grouped together with them.

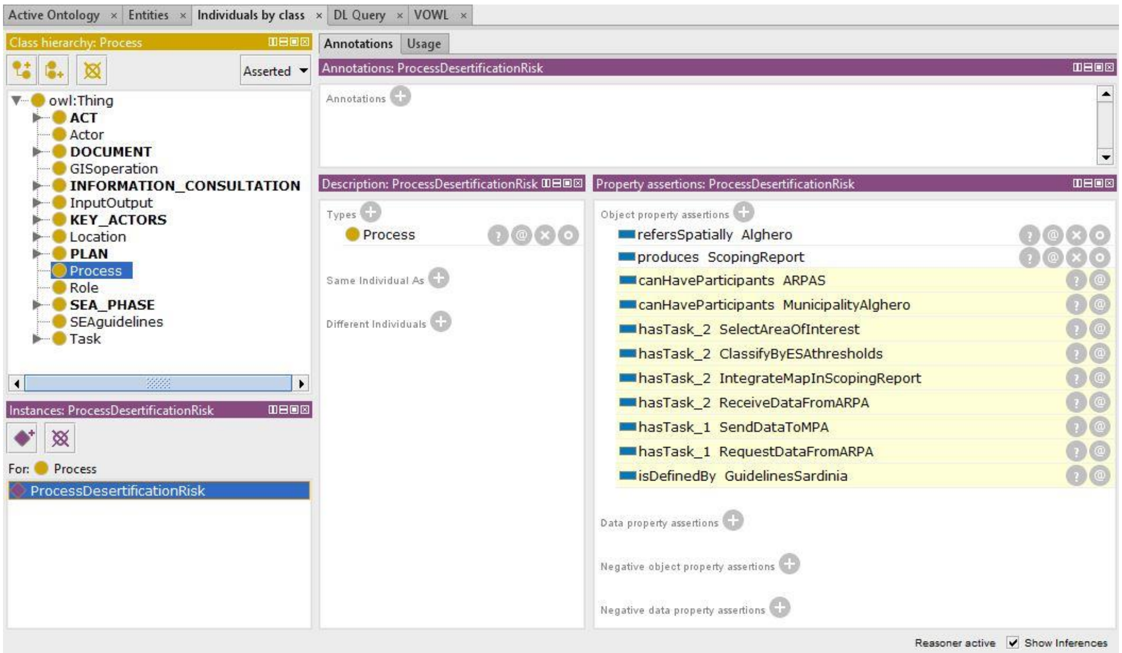


Figure 5.9: Screenshot from Protégé (2016 [120]), showing the asserted information for the process instance (Property assertions tab, in white background) and the information inferred (Property assertions tab, in coloured background.

Importantly, after verification, the reasoner did not make any wrong inferences. This was checked by introducing instances of participants/guidelines referring to locations other than Alghero and Sardinia, as well as tasks with inputs or outputs different from those required for risk desertification. These instances were excluded by the reasoner and tasks that did not fit in with both their input and output specifications were not considered either. However, the yes/no decision in the control model has not been represented or reasoned with successfully in the KB, meaning that the experimental process instance used considers solely the case of no data availability.

The experiment executed has provided some positive results. From a technical point of view, follow-up work should address the issue of reasoning for decisions, through both fine-tuning of the semantic model and possibly combining Description Logic reasoning with rules. Furthermore, introduction of SPARQL queries in the KB reasoning process could improve information inference and include entire sets of alternatives instead of single instances. This would prove useful when, for example, a range of potential actors is deemed suitable for performing one task.

Last, the usefulness of semantic modelling and reasoning in configuring planning processes should be assessed through experiments that range in complexity. This would be the first step planned for future work, possibly followed by usability assessments in real life situations. The latter would contribute in the development of a concrete PSS that endorses several aspects of a process' complex behaviour.

Implementation for the Mara rangeland management case

The implementation for the second planning case consists mainly of a series of artifacts, which are necessary for the translation between ILWIS geoprocessing workflows and BPMN. The presentation of the artifacts follows the flow of steps described in Implementation for the Mara rangeland management.

XML Schema Definition for geoprocessing workflows

The first artifact is the schema for ILWIS geo-operators, extracted automatically from their XML descriptions. This was further inspected and corrections were made, particularly with regard to global and local elements. The modified version can be found as an appendix (XSD for ILWIS geo-operators). The second artifact is the XSD extracted and amended from the JSON description of the sample geoprocessing workflow and its corrected version can also be found as an appendix (XSD from the sample ILWIS workflow).

The final, unique schema for geoprocessing workflows in ILWIS was created through alignment of the two XSDs. Its most fundamental elements, adopted to proceed with the study, are shown in Table 5.4, along with their types and the XSD indicators where relevant. *Workflow*, *operation*, *input* and *output* define the components of a process, while *connection*, *fromOperationID* and *toOperationID* describe the flow of tasks. Attributes of the elements are not shown, but include an *id*, a *description*, a *resource* (in this study all values would be *ILWIS*), and a *name* for each.

Elements	**Types**	**Indicators**
workflow	workflowType	xsd:sequence
operation	operationType	xsd:sequence
input	inputType	xsd:sequence
output	outputType	xsd:sequence
connection	connectionType	xsd:sequence
fromOperationID	xsd:type	
toOperationID	xsd:type	

Table 5.4: The proposed unique XSD for ILWIS geoprocessing workflows.

Transformation to BPMN

An example geoprocessing workflow

Using ILWIS' workflow builder and from the schema of Table 5.4, an example of a geo-processing workflow in its simplest possible form was created. The workflow in graphical form is shown in Figure 5.10, while its XML serialisation is shown in Figure 5.11. It consists of two operators, each identified by an *id* number and a *name*, and a connection between them, indicating the direction of the flow. Input and output datasets are not considered at this stage.

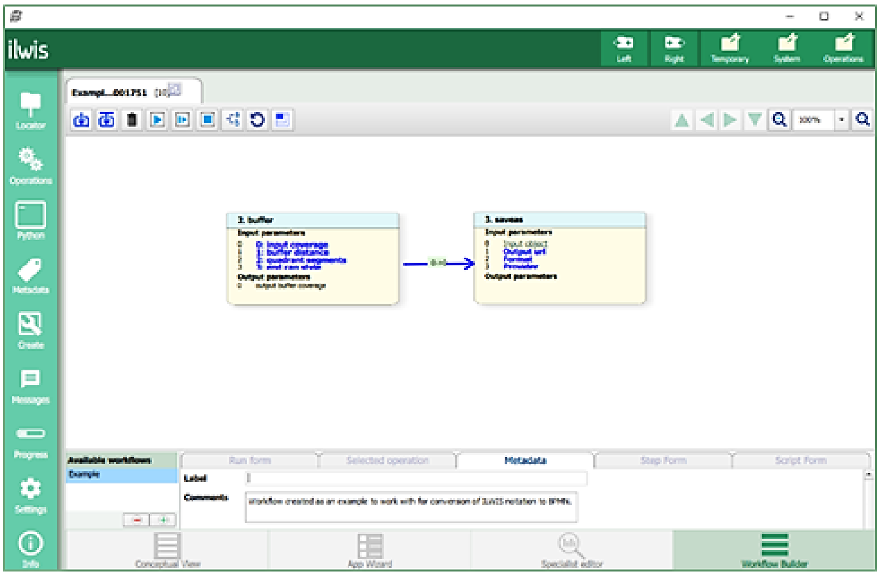


Figure 5.10: A simple workflow in ILWIS, comprising two operations: *buffer* and *saveas*.

```xml
<workflow id="_1">
    <connections>
        <connection id="_6">
            <fromOperationID>_2</fromOperationID>
            <toOperationID>_3</toOperationID>
        </connection>
    </connections>
    <operations>
        <operation id="_2" name="buffer"/>
        <operation id="_3" name="saveas"/>
    </operations>
</workflow>
```

Figure 5.11: The example workflow of Figure 5.10 in XML.

Mapping of ILWIS elements to BPMN

Based on the study of the BPMN specification document and its XSD files, the mapping shown in Table 5.5 was created.

ILWIS elements	BPMN elements	BPMN types
workflow	process	tProcess
operation	scriptTask	tScriptTask
input	dataInput	tDataInput
output	dataOutput	tDataOutput
connection	sequenceFlow	tSequenceFlow
fromOperationID	incoming	xsd:QName
toOperationID	outgoing	xsd:QName

Table 5.5: Mapping of the elements in Table 5.4 to BPMN elements and types.

Structural soundness of BPMN diagrams

Noting that ILWIS workflow notation does not include events, additional elements were inserted to the example XML, to serve as placeholders for a start and an end event. Connective flow elements that adhere to the very first and the very last operators of the workflow were also added, as shown in Figure 5.12. Note that, unlike the *connection* element of Figure 5.11, id values in Figure 5.12 are random, properly because they are placeholders rather than hardcoded to the specific operators of this workflow. Resolution of flow connections to the very first operator for the start event and the very last operator for the end event takes place in the following step, through conversion rules.

```
<startIDs>
    <firstID>_11</firstID>
    <secondID>_22</secondID>
</startIDs>
<endIDs>
    <firstID>_99</firstID>
    <secondID>_88</secondID>
</endIDs>
<flowIDs>
    <firstID>_112</firstID>
    <secondID>_223</secondID>
</flowIDs>
```

Figure 5.12: The additional elements that ensure structural soundness of the example workflow.

Conversion of workflow notations with XSLT

Conversion rules between ILWIS notation and BPMN were set with XSLT. Figure 5.13 shows an excerpt of the stylesheet that transforms every ILWIS *operation* element to a BPMN *scriptTask* element and assigns the attributes and connections of the first to the second. The entire stylesheet can be found appended (The XSLT that converts ILWIS geoprocessing workflows to BPMN).

```xml
<xsl:for-each select="/workflows/workflow/operations/operation">
    <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    <scriptTask>
        <xsl:attribute name ="id">
            <xsl:value-of select="@id"/>
        </xsl:attribute>
        <xsl:attribute name ="name">
            <xsl:value-of select="@name"/>
        </xsl:attribute>
        <xsl:choose>
            <xsl:when test="/workflows/workflow/connections/connection/toOperationID=@id">
                <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
                <incoming><xsl:value-of select="/workflows/workflow/connections/connection/@id"/></incoming>
            </xsl:when>
            <xsl:otherwise>
                <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
                <incoming></incoming>
            </xsl:otherwise>
        </xsl:choose>
        <xsl:choose>
            <xsl:when test="/workflows/workflow/connections/connection/fromOperationID=@id">
            <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
                <outgoing><xsl:value-of select="/workflows/workflow/connections/connection/@id"/></outgoing>
            </xsl:when>
            <xsl:otherwise>
            <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
                <outgoing></outgoing>
            </xsl:otherwise>
        </xsl:choose>
        <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    </scriptTask>
</xsl:for-each>
```

Figure 5.13: Excerpt of the XSLT file.

Using the ILWIS XML workflow as input and providing the XSLT file as conversion rules, Treebeard produced an XML file with BPMN elements. Figure 5.14 shows an excerpt of the produced file, including the two *scriptTasks* and the single *startEvent*. The entire XML description is appended in XML description of the BPMN diagram produced by convertion.

```xml
<process id="_1" isClosed="false" isExecutable="true" processType="None">
    <scriptTask id="_2" name="buffer">
        <incoming/>
        <outgoing>_6</outgoing>
    </scriptTask>
    <scriptTask id="_3" name="saveas">
        <incoming>_6</incoming>
        <outgoing/>
    </scriptTask>
    <startEvent isInterrupting="true" id="_11">
        <outgoing>_2</outgoing>
        <outputSet/>
    </startEvent>
```

Figure 5.14: Excerpt of the produced XML file with BPMN elements.

The XML file produced from converting the ILWIS workflow through the stylesheet is a valid BPMN diagram (Figure 5.15), with two script tasks corresponding to the two geo-operators, one start and one end event, and flow of process correctly displayed among the constructs. Normally, with regard to structural soundness, diagrams should be translated into a Petri Net language and have a relevant software perform a behavioural analysis of the modelled workflow to check whether the three conditions are met. However, the example ILWIS workflow prepared and used for the thesis is simple enough, so the BPMN diagram it produces may be evaluated and found sound merely by inspection.

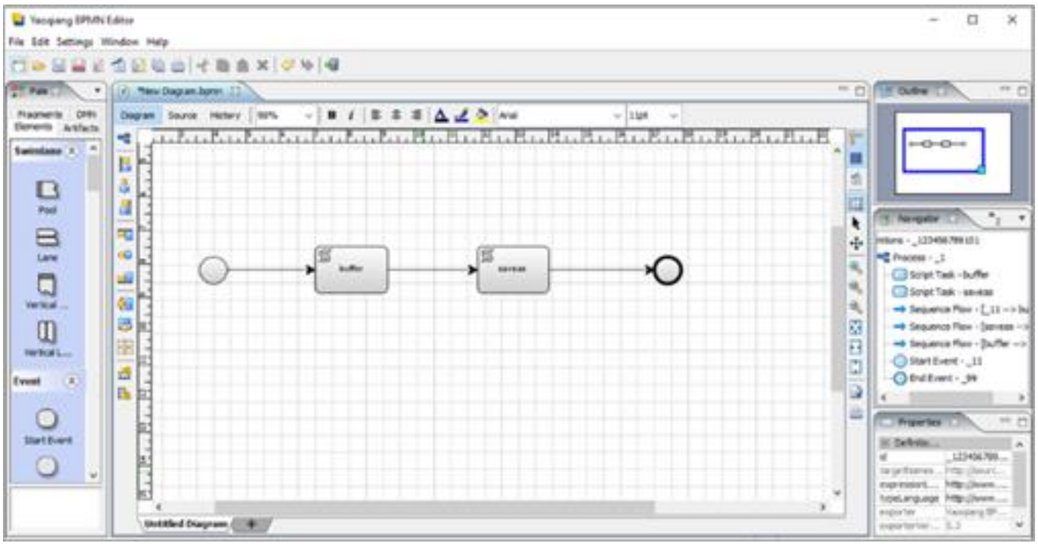


Figure 5.15: The BPMN diagram of the geoprocessing workflow, as displayed by Yaoqiang-BPMN-Editor.

Locating corresponding geo-operators

An initial effort to implement this functionality has been made and two crucial and well thought out artifacts have been produced and can be used in future research. The first one, a meta-artifact, is a model of relationships between GIS software, utilising keywords and functionality descriptions. The UML diagram of Figure 5.16 illustrates these connections: *ILWIS*, *ArcGIS* and *GRASS* are all members of the *GIS Software* class. Each GIS software comprises members of the *Operator* class and members of the collective class *Keyword*, which in turn are associated to each other and also mapped to concepts in the Living Textbook class with similarity or *sameAs* links.

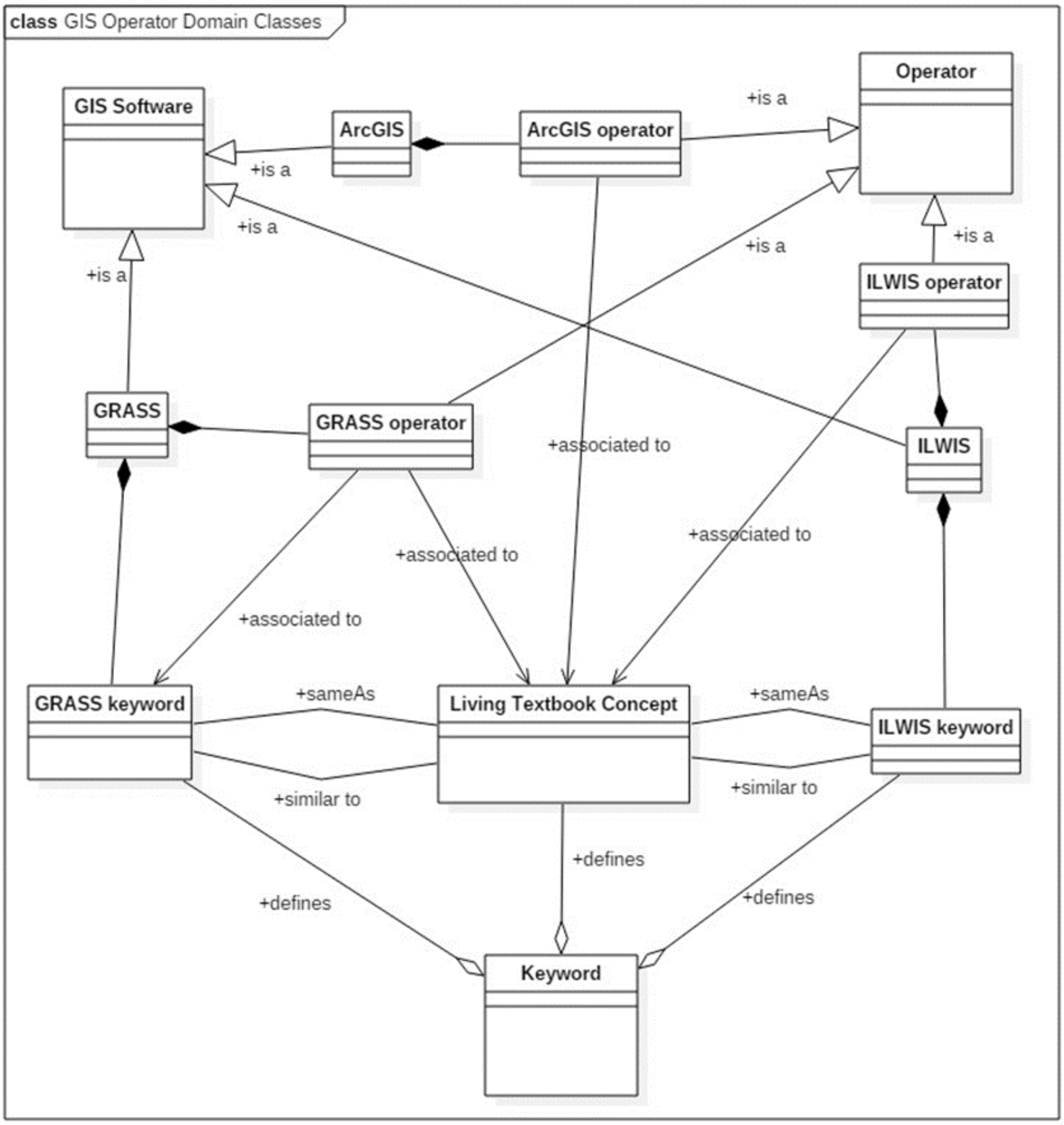


Figure 5.16: A proposed model for linking GIS software. Links pass through the Living Textbook (Augustijn *et al.*, 2018 [3]).

The Living Textbook is an interactive, web-based textbook, built on an ontology of the GI-Science domain (Augustijn *et al.*, 2018 [3]). The ontology, therefore, includes core domain concepts and their relationships, as these are defined by teachers of GI-Science, and may ultimately serve as the connective point for similar functionalities of different GIS software.

The second artifact created is the start of an implementation of the above model. It regards the software GRASS version 7 (https://grass.osgeo.org/grass7/) and is a description in Resource Description Framework (RDF) format, as this is specified by the World Wide Web Consortium – W3C. The description, in Turtle serialisation, contains the entire list of operators and associated keywords for the software, as these have been defined by its developers. The file contains 4 012 triples and can be found appended in GRASS geo-operators in RDF.

Implementation of this functionality is not yet complete. Similar work for another software has to be done before experimenting with retrieval of similar operators and their substitution in a geoprocessing workflow. However, the approach that is already well-defined and the artifacts that are presented above render complete implementation simply a matter of resources.

6 DISCUSSION AND CONCLUSIONS

6.1 Introduction

This final chapter aims at rounding off research undertaken in this PhD project, connecting targets with results and indicating ways forward. Thus, it aims at fulfilling Objective 9 "Discuss the prototype results" (p.6 Research objectives and questions), through three questions:

Question 1. What has been/has not been implemented and why?

Question 2. How could the prototype be evaluated further?

Question 3. What conclusions may be drawn with regard to the PhD project?

To answer the first question, the chapter begins with an account of the course of research as this unfolded over the previous chapters of the thesis and incorporates a discussion of outcomes, in relation to the objectives that were set in the 1st chapter. Subsequently, the chapter notes limitations that restricted the development and the products of the study and points out ways to carry on with the inquiry into process-aware Planning Support Systems with Semantic Web technologies, both in extent and in depth, so as to render it further robust and impactful.

The chapter then proceeds to make an assessment of the hitherto impact of the project, using a model conceived and discussed during a training in social science research impact that the author attended in the course of the PhD. This assessment may also be regarded as a different aspect in the prototype evaluation, completing, in this way, the answers to the research questions of the 9th and final PhD objective.

6.2 Recapitulating the study

Since the start of the 21st century, Semantic Web technologies are being used to render the meaning of data machine-processable and infer implicit knowledge from it, combining diverse information from distributed sources. In this way, they contribute to answering complicated questions that users pose to Information Systems, alleviating issues of information incompleteness, semantic heterogeneity, and knowledge model rigidity.

Semantic Web technologies, in specific formal ontologies and inference, have been previously used in Planning Support Systems to deduce information not explicitly stated in any form. However, they have not been involved in studies that concern the design of the spatial planning process. The latter, complex due to its participative, dynamic, space-, time- and theme-related nature, and its cross-domain and cross-governance-levels arrangement, is indeed a good candidate for investigations that attempt to combat incompleteness, lack of interoperability due to heterogeneity, and rigidity in its design.

This being a PhD in spatial planning rather than one in informatics, the aim was first to explore the identity of the problem at hand from the discipline's perspective and then propose a design for an IS that may assist the planner in overcoming some of the more specific issues entailed. In particular, the problematic situation was identified as the difficulty planning process designers and managers have in laying out the process, especially within the context created by an increased request for meeting sustainability goals, which results in escalation of planning process complexity.

Support to planning process designers in this PhD research has been proposed through a PSS that embraces the perspective of the Semantic Web and employs its technologies. Such an IS is called to avoid the common pitfall of becoming silo-like and of eventually not promoting a coherent planning process. It has therefore been designed with acknowledgement of the necessity of planning's complex but seamless nature, and with care not to oversimplify it for reasons of taming and management.

This study did not follow the linear procedure of *data collection - data analysis - discussion* form. Instead, it consisted of a series of *knowledge acquisition - application consideration* iterations, which provided reasoning for decisions that shaped subsequent cycles of investigation. It started off with the fundamentals of planning theory and scientific investigation, constructing a central connective logic between the two, which was fittingly based on the paradigm of Pragmatism and pertained the ontology, the epistemology and, ultimately, the favoured, Dewey's model of inquiry.

The formation of the methodological course followed naturally from the precedent decisions, and therefore stayed true to the track of thought established by them. This comprised the selection of a research model - the Design Science Research framework - and thereupon the structuring of a research plan and research strategies for data collection, output representation and output evaluation in each step of the design and the implementation of the Information System (Table 3.3).

Strategies were subsequently translated to methods, by means of which information was gathered and decisions regarding crucial disambiguations were taken that went beyond terminological clarifications. Such information included a discussion on whether planning processes may be modelled by a business process notation; the planner's role through history as well as that of the target user of the conceived Planning Support System; the basic elements of a PSS; and the character, characteristics, capabilities and functionalities of the one envisioned in this study.

Last, the research culminated in the experimental development of a number of selected functionalities, aiming at the three capabilities that best represent the initial targets of the PSS: knowledge integration, knowledge expandability, and adaptable processes. Implementation was achieved by means of Semantic Web technologies. The latter have mainly been ontologies, a Knowledge Base created with the Web Ontology Language, and a translation between workflow descriptions written in the eXtensible Markup Language. In parts, the Resource Description Framework and its Schema have also been used, as well as – unavoidably – Uniform Resource Identifiers. Results were demonstrated by example of two planning cases, one referring to the Strategic Environmental Assessment in Sardinia, Italy, and the other to the sustainable conservancy management of the Maasai Mara rangeland in Kenya.

What was ultimately achieved in this study is not trivial: A proposal has been constructed through abductive and deductive research as to how the development of a Planning Support System that does not overlook the wicked nature of planning processes either in its design or in its technological implementation phase may be approached. Schematically, this translates into filling-in the gaps in Figure 2.3, and thus creating a complete picture of the pathway that connects planning theory and planning practice, when building up a process-aware PSS. Figure 6.1 and Figure 6.2 below present the bridging of the two gaps as a two-step Information System development course.

With regard to the thesis write-up, and in view of the iterative and non-linear course of investigation in this PhD, a log-like description of the research journey would have been very difficult to apprehend, even for the author herself. The final structure of the thesis was therefore not a time-series account of the research steps, but rather a logical summation of knowledge that permits the reader to follow the researcher's train of thought in an organised manner.

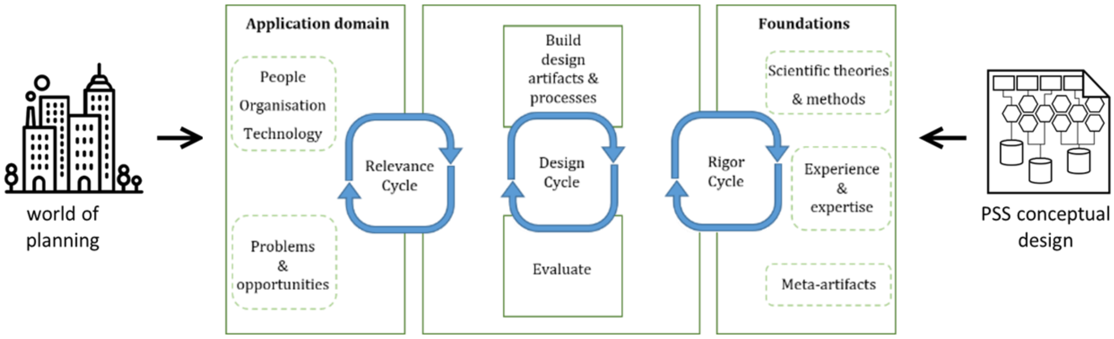


Figure 6.1: Conceptual design of a process aware PSS started with planning's theoretical foundations and passed through Hevner's (Hevner and Chatterjee, 2010 [55]) Design Science Research framework.

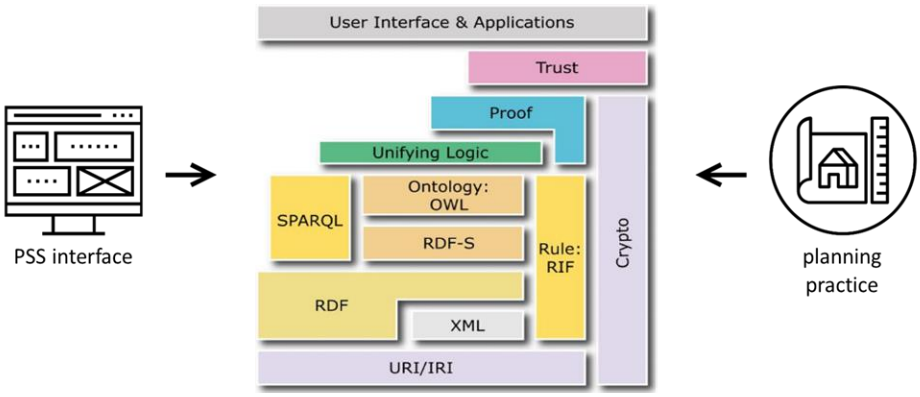


Figure 6.2: Implementation of PSS functionalities designed over the previous step was realised with the use of Semantic Web technologies.

6.3 Revisiting the research objectives

The thesis was divided into two parts: Part A comprised only one chapter, Theoretical Foundations, but corresponded to four objectives and nine research questions. Part B comprised chapters 3 to 5, fulfilling another four objectives and answering their five questions. Specifically, chapter 3, Research Layout: Paradigm and Plan, dealt with Objective 5. Chapter 4, Data and Methods, determined Objectives 6 and 7, while Chapter 5, Artifacts of the Planning Support System, presented the outcomes for Objective 8. The current chapter, Discussion and Conclusions, fulfils the final Objective 9.

The following sections revisit the objectives and research questions as they were stated in the Introduction. These are discussed, presenting the approach used to tackle each one, the main points of the research conducted on them, and the outcomes of the investigation in the form of knowledge, decisions, or tangible artifacts, each where relevant.

Part A

Part A aspired at setting the foundation knowledge that would guide subsequent selection of a methodology for this PhD. The purpose was accomplished by means of abductive research strategy, which aimed at formulating an explanatory hypothesis from sufficient literature review and from critical and connective thinking. Abduction, also known as "*the logic of discovery*", led indeed to insight and eventually to development of an original idea as to a plausible pathway to the problem's resolution. This is accounted for followingly, in Objectives 1 to 4.

Objective 1

> *"Review the theoretical background of the planning process."*

The first objective was the initial attempt to become acquainted with the field of spatial planning, in particular with the problematic situation this research project studies. The means were literature review and study for more profound understanding. The path to this objective's fulfilment passed through three research questions, all of which were amply answered.

Question 1. What is the nature of the planning process?

Planning is a complex process, whose properties defy the four major characteristics of linear, Newtonian systems namely *determinism*, *order*, *reductionism*, and *predictability* (Table 2.1). This is equivalent to acknowledging its being an open world, rather than a world comprising closed, deterministic systems, and therefore dealing with it necessitate pertinent methodologies. Awareness of such complexity was already demonstrated in the 1950s, while it was not much later that planning's incongruousness with the operational approach, employed for resolving complex planning problems and aspiring at optimising the planning process, was also admitted.

According to the operational approach, a full description of the planning case at hand would first be expected, assuming tractability of all causes and effects among the actors engaged in the process and among the participating systems – social, economical, physical, and so forth. It would then be assumed that changes could be predicted and guided and effects foreseen, aiming at single, best, repeatable solutions, an endeavour that may in fact be no less than a chimaera (Figure 2.2).

Question 2. With regard to the planning process, what problems have been detected through time?

Until the revelation of planning's complexity was broadly accepted, achievement of consensus in designing spatial interventions was relatively uncomplicated, as it tended to deal with planning problems in a symptom-treating fashion. This approach was resulting in solutions disconnected from the complex reality, illustrated through failure in establishing fair living conditions for everyone in the human communities.

From the 1950s onwards, professionals were being called to solve planning problems within communities that demonstrated pluralism of opinions, curiosity of the cause-effect chains in the environment and concern about consequences of actions. To this change, they responded with embracing the systems theory and its associated operations research approach, treating planning as a linear system in effect, possibly in the face of lack of established, alternative ideas.

Even though the illusion of operational optimality and of universal solutions in the planning process had been recognised quite early on, planning practice did not shift substantially from the well-known and efficient in time, space and costs rational approach to accommodate for complexity. The specific issues that emerge from the Hydra-like nature of the planning process (Figure 2.1) and are still pertinent to the current day have been studied through cases of attempted integration of multiple stakeholders and are being expressed as institutional fragmentation, procedural segmentation, and divergence of practices.

Likewise, studies of eco-city development cases have pointed out the shortcomings of the planning process managers' approach to complexity. The weaknesses named are a) business-like rationality that ignores the time and space aspects, b) oversimplification of the process that results in weak attention to pluralism and to integration of involved environmental, economic and social systems, and c) treatment of space, people and development as optimisable products that can be, efficiently enough, standardised.

However, embracing complexity of the planning process is nowadays even more of a requirement in the quest for sustainable planning and this renders the importance of studies on its intractability and on possible approaches to prevent or mitigate its consequences higher. Current sustainability initiatives agree upon the fact that integration of environmental information into decision-making and inclusion of cross-sectoral, cross-administrative level, cross-expertise and even geographically transboundary sets of actors are keys to improve sustainable planning.

Question 3. What solutions have been proposed and how well have they performed?

The decades of consciousness over this Hydra-like nature of planning, bolstered birth of new theoretical approaches, which came hand-in-hand with the era of European spatial planning and the global sustainability agendas. Paradigms and approaches for interactive, collaborative and communicative planning, as well as practical frameworks for planning, already exist and help in shaping mindsets for sustainability.

With regard to the integrative process of planning in practice, however, there appears to be space for improvement. Despite advances in networking and exchange of knowledge, European planning has so far done less well than expected, while the discussion around sustainable planning has largely progressed and ripened, but practice still lags behind. Therefore, although theory has significantly evolved towards the required direction, the problem of complex planning processes remains in practice, and this might well be the point where one investigates into the tools assisting planners in their job.

Objective 2

"Investigate the problem of PSS' limited use by planners."

The second objective of the PhD aimed at establishing acquaintance with the field of Planning Support Systems and at investigating the issues of their moderate to low use in planning practice. The outcomes of the first objective served as the prism through which I looked for common points between the problematic situation that complex planning processes create and the fact of low PSS usage. The outcomes of study and connective thinking are presented followingly as answers to the three research questions.

Question 1. What has been the rationale behind PSS' development through time?

The first Planning Support Systems emerged in the 1960s and were therefore designed and used from the systems' approach perspective of "analysis, then synthesis". The ideal PSS was therefore conceived as a comprehensive representation of the world, which aspired to govern the planning process, to model the current situation of the area of interest and to rationalise changes and decisions, all to their full extent.

Eventually, this was demonstrated to be an unrealistic endeavour that was not providing consistent, robust or validated results, for it befitted linear and closed, rather than open systems. However, despite awareness of this fact, great part of research on Planning Support System until recently has still been targeting the technical part of the instruments, rather than attempting a different viewpoint of their conceptualisation.

Ultimately, despite a turn towards software for sustainable planning, existing PSS do not seem to have severed ties with the systems approach, which seems to partly reflect in essence the struggles between planning theory and practice, as these were revealed through research for the first objective of this current work.

Question 2. What has PSS' low impact been attributed to?

The problem of low impact of PSS in planning practice has been studied from two perspectives: The first one views the software as having low usability in the complex reality of planning, attributed to the assumption of an optimal planning workflow upon which development of the entire instrument is based. More specifically, aspects in which current PSS fall short are integration of the Information Systems that consist the PSS components and of their underlying models, transparency of the software's rationale and design, as well as of the information and reasoning methods employed, and interactivity and flexibility of the tools.

On the other hand, a second viewpoint of the problem speaks of little awareness among planners regarding the existence and value of PSS, lack of experience with software and low intention of using it. Both perspectives, however, seem to be two sides of the same coin, i.e., of a certain gap between software development and the planner as a user. In sum, available studies suggest that the problem may be addressed through an upgrade of planners' education, improvement of tools' user-friendliness, improvement of the task execution process, even with better marketing.

Question 3. Can any additional aspects of the problem be identified?

Existing PSS do not seem to have severed ties with the operations approach and this seems to create a gap between planning theory and PSS architecture, which potentially may be the precursor of the gap between the software and the practitioner (Figure 2.3). In other words, further to the perspective of PSS use and usability that current literature and technology development seem to focus on, this PhD suggests the aspect of software conceptual design as a candidate aspect of the problem.

Objective 3

"Draft a plausible solution."

The third objective of the PhD referred to the drafting of a proposal that, in turn, would be examined further in the rest of the project. Indeed, subsequent to fulfilment of the previous objectives and persisting on the combination of existing literature studying and connective thinking, an idea for a possible conceptualisation of a Planning Support System was formed, which took into account both the problem of complexity that planners face in charting the planning process and the individual problematic aspects identified in existing PSS.

Question 1. What technologies could fit the needs of the problematic aspects of the PSS?

Fitting the PSS to the planning process translates into conceptualisation and development of a process-aware Information System, in contrast to a silo-like, function-based one. This by itself, however, does not constitute an antidote to lack of precious flexibility: process-based IS may well – as is the case - allow for very little or no flexibility, if they establish an optimal workflow as early as before any actual planning takes place. In other words, they fit the planning process to the PSS.

The work presented here proposes a higher affinity to the nature of the planning process, through the use of Semantic Web technologies. These endorse the Open World Assumption mindset, fit for modelling open, loosely structured environments. Other characteristics of semantic modelling may also be suggestive of similarities with behavioural properties of complex systems, and they include assumption of incomplete information, inferencing of new knowledge, extensibility, and support for linkage and connectivity (Table 2.2).

The space of interest with regard to Semantic Web technologies being the provision of support to planners for the design of their processes, the uses envisioned included rendering information search more intelligent through usage of logic and inference rules, while also facilitating translations between process models. In this way, the contemplated PSS would propose the activities, participants and software functionalities called for by the particular planning context.

Objective 4

"Examine the literature for Semantic Web technologies in the planning process."

The fourth objective was very straightforward and clear as to the approach required to answer its questions, as well as to the point of interest. Unfortunately, scarcely any literature was found dedicated to the combination of Semantic Web technologies and the planning process. It was therefore decided to split the term "planning process" into "planning" and "process", which yielded interesting results, but somewhat broader in terms of relevance.

Certainly, the length of text in this thesis and the time dedicated during the PhD does not do justice to the importance of this objective. That is not to say that more was required in order to complete a sound PhD. However, in a more technology-oriented project, one that would have its focus on the implementation and deployment of a PSS already conceptually designed as a software, this would serve as the first and foremost research objective and more time and effort would have been dedicated to reach satisfactory accomplishment, especially as far as use of Semantic Web technologies in domains other than planning.

Question 1. Which Semantic Web technologies have been used in planning?

Semantic Web technologies in planning are encountered mostly in the form of ontologies that serve as shared conceptualisations of the domain of discourse. These exist either as structured knowledge collections with no practical use foreseen or they have a dedicated browsing application developed, aiming at easier access to the knowledge represented.

Taking matters one stage further, a number of planning applications use semantic modelling and reasoning to overcome semantic interoperability issues in comparing, classifying and selecting pieces of information. The latter range from choosing suitable technologies in sustainable engineering to evaluating and colour coding spatial data objects.

Question 2. How have Semantic Web technologies been used for the configuration of processes in other domains?

Languages based on Description Logic, such as the Web Ontology Language, have been used for configuration of suitable components in assemblies and this has been the prompt behind the idea of semantic modelling for process composition. In general, the final structure and content of the Knowledge Bases created for such applications are decidedly fit-for-purpose, with the concept of ontological economy highly exercised. Inference is the other important part of these applications, although results often show that additional rules that "close" in a certain sense the universe of discourse are required to achieve the expected configuration results.

Part B

Part B aimed at arranging the path to the envisioned Planning Support System and at describing the output artifacts after implementation of the chosen methods and strategies. This second major section of the PhD thesis recounted a series of decisions, mostly deductive in nature, which provided answers to the remaining Objectives (5-8). Ultimately, by maintaining strong links to the essentials of Part A and by emphasising both fundamental scientific research and technical implementation, it succeeded in better shaping and partly testing the path from planning theory to practice, through an Information System.

Objective 5

> *"Pore over methodologies for prototype design and development."*

When the fifth objective of this PhD study was formulated, it was not expected to become such a cornerstone of the thesis, nor to form in essence a major part of the solution to the problematic situation this research was focusing on. Instead, it turned out that an investigation and careful selection of research paradigm, model of inquiry, and methodological model were all calling for detailed attention before any implemental action was to be taken.

The importance lied in keeping up with the line of thought established in Part A and which regarded the wickedness of the planning process and the difficulty of connecting the planning theory to the practice. In fact, the author considers this objective to be the best researched, most inspired and forward-looking, and of most interesting – albeit of fundamental science – outcomes in the thesis.

Question 1. Which existing research methodologies are suitable to this PhD project?

The path to this answer passed through deciding on the ontological and epistemological stances that pertained the project and guaranteed coherence throughout, before the choice of methodology was finalised. In other words, the research paradigm was defined first and only then, through it, the methodological decisions were taken.

There were four characteristics sought for in the selection of research paradigm and they were all fulfilled by Pragmatism. In specific, Pragmatism's focus on the problematic situation – as opposed to being user-centred, for example – was assuring of the project's effort to retain affinity to the wicked nature of the planning process. At the same time, its orientation towards real-world practice could pull the research towards planning practice, without losing contact with the theory. Its pluralism means that it seeks to validate hypotheses as to their worthiness of investigation, not to prove or disprove them in absolute terms. Finally, it endorses abduction as a perfectly valid research strategy and, like this, the conclusions drawn and the ideas developed in Part A can form a solid source of knowledge in Part B.

The ontological viewpoint on the nature of reality adopted in this research and in agreement with Pragmatism is meant in terms of a theoretical hypothesis' capacity to solve human problems. The epistemology embraces an iterative, non-linear way of generating knowledge, best represented by Dewey's model of inquiry, with its abduction-deduction cycles and its interchanging steps of theory and action that ensure both theoretical and practical scientific contributions within the project.

Pragmatism offers freedom as to the choice of methodology, breaking free from qualitative vs quantitative debates and welcoming all that fits the purpose. Within this fundamental frame, decisions that regarded the methodology of Information System development were guided by three needs: a) coherence with Pragmatism and Dewey's model of inquiry, b) focus on the problematic situation rather than the planner as software user, and c) attention to research rigour, rather than solely to the end result of a technical implementation.

In view of these needs, the methodological model selected is Design Science Research, with its suitability to wicked problems noted also by the model's developers. The framework comprises three cycles of work, namely (application) Relevance, (IS) Design and (scientific) Rigour. The outputs of DSR may be formal or informal constructs, models as abstract representations of construct relationships, methods as in algorithms or practices, instantiations of the designed IS, and better theories in terms of new insight into the initial problematic situation or into the methodology and methods of the completed study.

For the purposes of this research project, new informational resources have been accepted as additional, valid, expected outputs, as well. This, rather than an arbitrary decision, it is a proposal derived from IS literature and serves to cover the possibility of artifacts that may well be reused in future projects or, if not exactly fit for them, at least provide useful insight to other research studies.

Objective 6

"Design a prototype PSS."

The sixth objective implied the prerequisite of a detailed research plan and strategies for the collection of the information essential to the design of the Planning Support System. The plan was developed in accordance with the methodological framework, i.e., the DSR model, and defined the questions under study, the relevant data, and the suitable outputs, with respect to two phases of IS creation: first its design and then its technical implementation. The strategies referred to the plan of action for collecting the relevant data, and for representing and evaluating the outputs.

Following the strategies, came the methods that actualise them. As collection of relevant data was entirely about literature review with critical thinking, about choice of planning cases to experiment with and about knowledge acquisition through technical training of the author, definition of practical methods was solely required for representation and evaluation of the outputs in the two phases, design and implementation. This is exactly what the single question under this Objective was asking for.

Question 1. Which languages/notations can be used for the design?

As mentioned above, the research plan and the strategies were divided into two phases, corresponding to the design and the implementation of the Planning Support System as any other Information System. The design was called to answer the question "What are the desired functionality and the desired architecture?" of the IS and it was expected to do so through knowledge building, including the disambiguation of the meaning of "process" in planning and the definition of who the main PSS user would be, as well as the selection of examples of planning cases with which to experiment. The outputs of the design phase would be conceptual models of the artifact, represented as diagrams and checked for consistency.

The IS implementation work package attended to the question "What are possible solutions for achieving the desired functionality?". The data required to answer it comprised the conceptual models created during design, and knowledge and skills of Semantic Web techniques. The outputs could be any of the six types foreseen by the Design Science Research framework, with their consistency checked and their functionality tested through experiments on the example planning cases. Table 3.3 lays out the entire plan in a structured and organised way and can serve as a good reference.

The plan and the strategies it encompasses targeted the logical sequence of research steps. On the other hand, the methods for data representation and evaluation considered the logistical aspects of IS design and implementation. In design, the processes for each planning case were modelled with Business Process Model and Notation for three reasons: First, for its readily usable eXtensible Markup Language description; second, for its comprehensiveness and the rich semantics; and third, for rendering the models suitable for application of measures of quality - although the latter refers to future research possibilities, not to the current project. Except for the processes, other aspects of the IS were designed with the Unified Modelling Language, while evaluation of the diagrams was based on the type of language or notation used. Table 4.2 summarises the representation and evaluation tools for the design of the Information System.

This question, formulated early on in the course of the PhD, aimed only at defining the practical means through logistical decisions, but its extent was enhanced, due to the detail that Objectives 5 and 6 went into and which reflected the needs of the project. This constitutes a research design vulnerability, not because the question was not formulated in a perfectly comprehensive way since the beginning, but because it was not reformulated appropriately (which was a matter of time restrictions) when it was realised that it does not adequately cover the needs and that it definitely does not represent the extent of work and knowledge building achieved. However, this is an error that is not reflected in the research quality itself; it is purely a matter of poor structure of the research objectives and questions, not of the structure of the thesis or of the research presented in it.

Objective 7

"Acquire data pertinent to the implementation of the prototype."

The seventh Objective related to one category of actions planned in the research scheme (Table 3.3), namely to data collection, that would serve first for designing and then for technically implementing the Planning Support System. Adhering to the Design Science Research framework, data regards both the application domain, i.e., the composition of the planning process, and the fundamental principles of the domain science. The latter refers to any scientific domain of potential interest to the project, including in the current project the fields of planning, IS design, and Semantic Web.

Although the term "data" is being used here, the concept encompasses also information and knowledge, gathered through literature scanning or created through the process of critical and connective thinking and of decision-making, all majorly employed in this PhD. A great amount of this information has been presented in answers to the research questions of Part A. The rest comes mostly from Chapter 4, Data and Methods.

Question 1. How can existing data/models be explored to determine fitness to the purposes of the PhD?

Implementation of PSS functionalities was accomplished through two rather complementary planning instances that served as example cases on which to experiment. The first implementation example concerned Strategic Environmental Assessment procedures on the island of Sardinia, focusing on reasoning with data in order to get the components of a new process, and therefore necessitated ontologies. The second example regarded sustainable management of the Maasai Mara rangeland in Kenya as part of the Mau Mara Serengeti Sustainable Water Initiative (MaMaSe) and focused on conversion of processes between GIS software. Complementarity of the cases lied in the first instance dealing with knowledge integration, while the second one targeting integration of tools.

In the first planning instance, and promoting the principle of linking, sharing and re-using ontologies, the researcher searched for and was granted access to an existing collection of 54 individual, formal ontologies, altogether comprising the ontology for Spatial Decision Support (SDS) created by the SDS Consortium, as well as to an ontology specific to the Strategic Environmental Assessment in Sardinia. Fitness of the models to the purpose of the PhD was examined with respect to the example case.

The features inspected through ontology exploration were content, structure and size of the ontologies, all of which had ultimately been determined by the original purpose of their development. The exploration methods used were three: a) visual inspection, b) indexing and text-based search, and c) network analysis. It is important to note here that ontology/Knowledge Base/Linked Data exploration is a persistent issue in the field of Semantic Web. Eventually, exploration of semantic networks is heavily dependent on their size and complexity and on the amount of time that the user can allocate to this task.

The SDS ontology was created aiming at comprehensiveness in describing the spatial decision support domain and is to be used for browsing purposes. It therefore proved a poor candidate for reasoning with, although I still believe that it may be useful for application-specific information retrieval through alignment with a suitable, application-tailored Knowledge Base. The SEA ontology, on the other hand, was small enough to allow being explored. Its relevance to the example case was evident, but it could still not be used for the implementation of the process component configuration: although it was created to define components of the SEA procedure, it did not describe the example procedure itself adequately enough to achieve the reasoning results this project required.

For the second planning instance, no semantic models for a GIS software existed for re-use. However, the geoprocessing model developed in ILWIS for the calculation of grass production was readily available. To be deemed suitable for use in the implementation example it simply needed be extensive and complicated enough to allow extraction of an adequate underlying schema in eXtensible Markup Language and work from there. Since the experimental workflow was of minimal complexity, the schema derived from the given geoprocessing model was indeed more than enough. Last, the XML schema definitions for processes modelled with Business Process Model and Notation were available from the Object Management's Group website and were therefore verified and official.

Question 2. If not already existing, how can required data/models be generated?

As for the entire 7th Objective, the project plan of Table 3.3 serves as a compass to this answer. Data is divided into the two aforementioned categories: design and implementation. Information drawing from the literature, as well as knowledge generation, commence in design, describing the application domain and the aspired Information System. They then act as the basis for the creation of data in the form of models fit for the purposes of this study, in the implementation phase.

Design

Design involved the disambiguation of the term "process", the definition of the roles of the Planning Support System principal users, the description of the two example planning cases, and the portrayal of the PSS in terms of its elements, character, characteristics, capabilities, and functionalities. The planning cases have been treated in the previous research question, so only the remaining information is included here.

With regard to modelling a planning process, one decision has been to avoid the term “metaplanning”, due to its management science connotations that may ultimately undermine the complex nature of planning. Analogously, the term “business process” has been ruled out, since it may fit only specific types of structured procedures. In view of these, a list of terms referring to types of processes identified inside spatial planning has been proposed (Figure 1.3 on p.10 and p.60) and process modelling with Business Process Model and Notation has been reserved for the types that may be automated and can have quantified measures of evaluation applied to. The leading arguments can be found in the Planning process disambiguation section.

The users of the designed PSS fall mainly within two categories of roles. The first is that of the process manager and facilitator, responsible for configuring and coordinating the process. The task, although associated with the planning profession, is not exclusive to planners. This is the reason why the user’s role, rather than the user himself, has been described in this project. The second type of role is that of the spatial data analyst. Neither is this responsibility restricted to planners only, as any participating expert may in fact find himself in need of analysing and presenting geodata. An account of these roles through history and further detail as to the choices pertinent to the PhD may be found in the section The planner’s role.

Passing on to the main elements of an IS dealing with process configuration, these comprise the machine-understandable knowledge representation model and a suitable inference engine, while the knowledge domains involved originate both in the sphere of application and in the scientific fundamentals of relevant fields (Basic elements of a PSS). The character of the PSS itself is influenced by the complex character of planning processes. Its aim therefore is to make use of the profession’s know-how, in order to provide support to users in the task of workflow modelling, rather than supply them with absolute, prescriptive, foolproof process models (Character of the PSS).

With regard to its characteristics, an Information System should be flexible and adaptable if it aspires at supporting an equally flexible and adaptive planning process. As a consequence, it is called upon to achieve knowledge integration, knowledge expandability, and versatility in employment of different tools (Characteristics of a PSS for process configuration). The fulfilment of these characteristics is the guide to the designed capabilities of the Planning Support System. Knowledge integration may be realised through the use of common languages and models. Knowledge expandability can be achieved if a suitable type of model for representation of the process knowledge is selected. And if knowledge expandability is in place, adaptability of planning processes is partly there and may be complemented through model translations among the employed tools (Capabilities of the proposed PSS).

The last piece of information on the designed IS concerns its functionalities, as these are inferred by the roles of the users defined above and the planning cases serving as corresponding examples for experimentation. The functionalities common to both roles are: browsing of modelled processes; creating, editing, checking for soundness, and enacting the processes; and editing the underlying knowledge model. The remaining functionalities have been designed to fit each example case (Functionality of the PSS).

Implementation

For implementation of the PSS functionality that corresponded to the first planning instance, namely of the task of component configuration for part of a Strategic Environmental Assessment in Sardinia, an appropriate Knowledge Base was constructed. The KB was written in OWL 2 and represented the structure of the example procedure. Its final form was achieved through trial and error, was checked for consistency and was verified to include no subsumption errors (Implementation for the Strategic Environmental Assessment in Sardinia).

The sustainable management of Mara rangeland planning case involved more steps in preparation of the data necessary for implementation of the model conversion functionality. Four sets of information had to be generated in this instance: First, the XML Schema Definition (XSD) for geo-operators in ILWIS was derived automatically from their XML descriptions. The decision made here was about selecting a suitable schema extraction design and this turned out to be the Venetian Blind one.

The second set of information prepared was the XSD for geo-workflows. For this, the JSON file of the grass production geoprocessing workflow was first translated into XML, before repeating the same XSD extraction procedure used for the geo-operators XSD. The third step was to compare and align the two XML Schema Definitions, ultimately creating a unique XSD for ILWIS workflows. Last, this latter XSD was compared to the BPMN 2.0 XSD files, mapping elements between them and constructing an eXtensible Stylesheet Language (XSLT) document that reflected the correspondences (Implementation for the Mara rangeland management).

All these sets of information, called “artifacts”, can be found in the Appendices, while the way they were used is described in the 5th chapter of this thesis.

Objective 8

> *“Implement the prototype.”*

The 8th Objective referred to the implementation of the designed Planning Support System functionalities, with regard to the two planning instances used as cases for experimentation.

Note here that not all designed functionalities have been technically implemented for this PhD project. The ones common to both cases, like browsing and editing processes, may be fulfilled through use of appropriate software, as they have already been in place by suites for management of BPMN modelled processes. For the rest, experimentation concerned two functionalities, each representative of the corresponding planning case: 1. figuring out of the procedure components for part of a Strategic Environmental Assessment, and 2. converting workflow models between GIS software.

Question 1. What results do the data/models and the applied methods provide?

For an extensive and detailed account of how implementation was technically achieved and what results have been attained, together with an evaluative discussion on them, all parts of the Functionality Development section in the 5th Chapter, as well as all Appendices are relevant. What follows is but a summary, divided by planning instance.

In the first planning instance experiment, the aim was to construct a Knowledge Base, which, together with a suitable reasoner, would provide correct suggestions as to the components required to bring an example SEA procedure to fulfilment. This example procedure, described in the control model, was not the simplest one possible, but had a certain level of complexity in it. The KB was worked up to the level of being able to provide error-free results for the set of SEA guidelines, the actor roles, and the tasks involved in the procedure. Experimentation ended at that point only due to time restrictions; however, ideas as to how it may be continued are included further down in this chapter.

In the application concerning the second planning instance, the aim was to convert an ILWIS geoprocessing workflow into an equivalent workflow of another GIS software, by means of XML descriptions and with BPMN acting as a mediating notation between the two GIS processes. Indeed, the final XML file produced by conversion from ILWIS is one that the BPMN editor recognises as a valid BPMN diagram and therefore the task can be deemed successful up to this point. What remains as future work is a repeat of the same series of steps for a second GIS software and inference of similar geo-operations through use of semantic models. A number of artifacts and meta-artifacts have already been prepared in the course of this PhD and completion of application development is, once again, a matter of resources.

6.4 Limitations and further research

One of the targets of this thesis has been to open paths for further research and the global perspective followed throughout the work served this purpose. This section is an attempt to acknowledge the limitations of the study conducted within the frame of this PhD, but in a way that also presents them as opportunities for further research, rather than dead end points.

The first recognisable issue is the lack of a systematic investigation of the existing Planning Support Systems. The theoretical foundations are largely based on literature review and would benefit from a more thorough inquiry into the Information Systems developed for planning. Gaining such direct experience of PSS, both through observation and interviews with users, as well as through hands-on involvement, could in fact give an advantage to the entire project – from understanding the problematic situation to design and functionality implementation - without taking away from its abductive nature.

Indeed, lack of interaction with planning practitioners has perhaps been the greatest drawback in this research. With no intention of downplaying the innovation in both academic and practical terms contributed by the study, the only way to complete a full cycle of Design Science Research is be to deploy the developed PSS functionalities in real life situations, following, examining and intervening in their use from within the practitioners' group. Action research, or a modified version of it, could be an interesting approach in that stage of the research, followed possibly – and ultimately - by an interpretive methodology, which would pay more attention to the user-software interaction.

That is not to say that the Information System is currently at a stage of deployment and ready to be tested in the field. First of all, the functionalities should be discussed and their design made more suitable to the example applications. This, once again, implies interaction with interested planners involved in Strategic Environmental Assessment in Sardinia and in sustainable rangeland management in Kenya. Secondly, greater emphasis should be put in the process-aware aspect of the IS. This is a particular category in the science of IS, whose surface this PhD project has barely scratched.

In addition to revisiting the Planning Support System design, technical implementation is in need of further work too. The Knowledge Base created for the SEA planning case does not fully cover the complexity of the example procedure. It requires experimentation with Description Logic and SPARQL Protocol and RDF Query Language queries, while the use of rules may be investigated, too. On the other hand, the second planning case is actually on a more straightforward path to further research. The model of relationships between GIS software is in place and so is an exhaustive RDF description of keywords and geo-operators for GRASS 7.0, which could serve as the second GIS software opposite ILWIS.

Another issue I would have liked to investigate further is the network analysis of the ontologies, which currently occupies a very restricted part in the thesis. Indeed, although a number of centrality measures have been estimated for the Spatial Decision Support set of ontologies using Gephi 0.9.2 (copyright Gephi contributors 2008-2017; www.gephi.com), interpretation of the values in connection to Description Logic expressiveness and to inference possibilities and decidability would merit an entire project of their own. Additionally, path-finding in such a large ontology desperately needed further software functionalities, as the control offered by Gruff for Allegrograph 3.3 was far from enough for an exhaustive network exploration.

Passing on to topics of more academic concern, Table 2.2 would benefit from further investigation that would establish (or not) a more sound correspondence between characteristics of semantic models and behaviour indicative of wicked situations. One way to this end would be to incrementally add complexity to a semantic model and see up to which point it can represent and be useful in a planning environment. A specifically interesting point here is that data uncertainty in modelling for spatial planning, particularly in cases that are decidedly less structured (Figure 4.1).

Last but not least, there exist two subjects that could make this PhD flare up into two very different, but also very interesting ways. One is the study of the tense dynamics between approaching a planning research project from a global perspective, as is the case in the current project from the theoretical foundations up to the design of the PSS, but being practically forced to develop functionalities that are very local in their application. This is relevant to the characteristic of expandability, mentioned in the section for the Characteristics of a PSS for process configuration and targeted by means of the expandable character of semantic models, although no further emphasis was put on this aspect in the thesis.

Finally, the second direction is that of process mining. Process mining targets performance of business processes in Information Systems, revealing patterns and enhancing process discovery. Although one would stumble once again on the issue of treating planning processes as business ones, the disambiguation of the terms presented in this thesis could serve as a solid base to avoid misconceptions. The idea here is that process mining could possibly discover patterns that may be used as semantic information for process descriptions, initiating an interesting series of studies on planning process similarities and differences within their contexts.

6.5 Evaluation of research impact

The evaluation of the impact of a research study beyond academia has emerged as a hot new topic over the past ten years, with numerous assessment models attempting to measure or characterise the influence that projects may have (*ex ante*), are having (over the course of the study), or have had (*ex post*). Such influence may be assessed on a number of levels, starting with comprehensive state or organisation approaches that attempt to homogenise evaluation frameworks across disciplines, to models developed specifically for judging personal projects like PhDs by the PhD candidates themselves.

One such approach, developed specifically for internal assessment, is MARIA, a model created by Manrique, Wróblewska, and Good (2018 [91]). The foundations for the model were established during group work conducted with the participation of the author of this thesis, over the EU COST action European Network for Research Evaluation in the Social Sciences and the Humanities (ENRESSH) training school, held in February 2018 at the Institute of Social Sciences Ivo Pilar in Zagreb, Croatia.

MARIA, standing for Multidimensional Approach for Research Impact Assessment, is an approach that considers five dimensions as pivotal attributes to ethical impact assessment in any field of study: *Responsiveness*, *Accessibility*, *Reflexivity*, *Ecology* and *Adaptability*. In the application of the framework, attribute evaluation is expressed in three ways: a) as answers to suitable questions formulated by the model developers, b) as a grade on a scale from 0 to 5 assigned by the assessor himself for each attribute, and c) collectively, as a radar chart.

The self-evaluation of this PhD project is hereby presented for each attribute individually, as well as collectively for all five, with questions marked in **bold**.

Responsiveness

Does my research respond to real problems and needs in society? Am I contributing to current public debates?

The way this PhD has been treated, it has indeed tried to address a real problematic situation in planning: that of establishing a connection between theory and practice by means of Information Systems. Although recurring every few years or so, the debate over the ability of practice to embrace the complex nature of planning actually sees to remain somewhat dormant, despite lack of a valid conclusion to it, and literature reveals that the planning community has rather lost its faith in PSS. Hopefully, this study will shake the apparent staticity of this subject.

Grade: 4.0/5.0

Accessibility

Are my research outputs accessible to different stakeholders and society in general? Do I communicate and disseminate them broadly and effectively?

My scientific output have mainly been in the form of conference contributions. These conferences proved to be somewhat poor choices in terms of audience extent and publicity, as I only managed to afford low-cost events.

On the plus side, I gave a talk at the Department for Geo-information Science and Earth Observation (ITC) of the University of Twente (Netherlands), which engaged stakeholders with interests in both fundamental research and technical implementation of Semantic Web technologies in the planning process.

Although fieldwork that could have put me in contact with planners in real cases was also not a possibility, I managed to make personal contact with academics and practitioners involved in planning projects in Sardinia and in Kenya, who have shown interest in following my work and eventually testing the IS after completion of the PhD.

Grade: 1.5/5.0

Reflexivity

Do I reflect on how comprehensive, well-planned, ethical and critical my research is? Have I evaluated and critiqued my theories and analyses?

Every step taken in this research has been a thoroughly examined and conscious decision, with argumentation in favour and disclosure of eventual vulnerabilities. The approach has been comprehensive, considering the entire space between planning theory, planning practice, the fundamentals of conducting research, and how to design an IS. This has been documented throughout the thesis.

On the other hand, feedback during my work has been largely scarce, with the exception of the thesis review by the external examiners, which significantly helped me acquire a more critical view of my own work.

Grade: 4.0/5.0

Ecology

Does my research consider the relationships and connections among stakeholders and subjects? Was I collegial while conducting this research?

Interrelationships and connections that boost complexity in planning has been a fundamental topic in this thesis.

The work relationship with my research group in Cagliari has been feeble, rendering this thesis a largely solitary endeavour. However, I connected research conducted by four different groups within my faculty and used it in the theoretical foundations and in the first planning case in the project (Strategic Environmental Assessment).

On the other hand, collegiality at the University of Twente over my 9-month stay has been a source of inspiration and pushed the limits of my research. I tried to fit my project – an external body of research – into their research and vice versa and it went well.

Grade: 4.0/5.0

Adaptability

Is my research impact usable in different contexts and among different stakeholders? Am I aware of the limitations and unanswered or emerging questions from my research?

Usability of the research outcomes in different contexts and among planning stakeholders has been a main issue in this study. Limitations and further research possibilities have been documented throughout the thesis and in a separate section in this last chapter.

Grade: 4.0/5.0

The radar chart representing collectively the self-evaluation of the impact of this PhD project is shown in Figure 6.3. Overall, the weakest point is accessibility of the research outputs, which will logically improve through a number of publications and contact with interested parties in the near future.

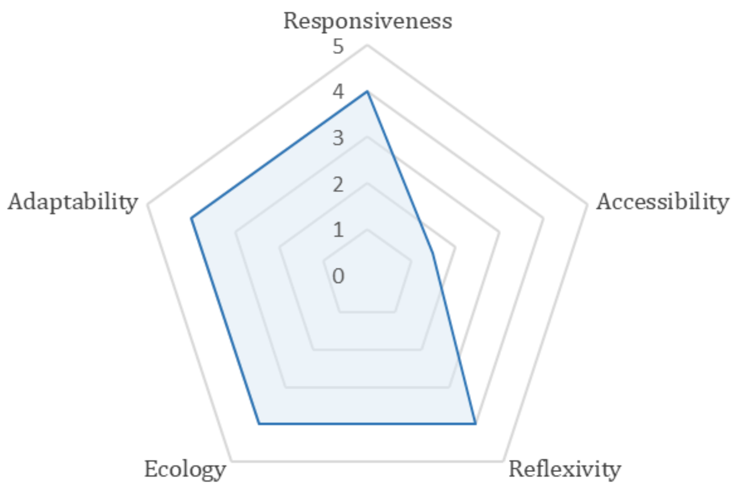


Figure 6.3: The radar chart depicting graphically the *ex post* evaluation of the current PhD project by the author of the thesis.

6.6 Conclusions

The complexity of an integrative planning process, acknowledged both in theory and in practice and held accounted for some poor results in the implementation of sustainability initiatives, might have to gain from the use of semantic modelling and reasoning. This work aspired at setting the path towards deeper investigation of the capabilities of Semantic Web technologies in configuring workflows for planning and supporting in this way practitioners and projects in different planning contexts.

The methodology followed was not an off-the-shelf solution, but was constructed and each step of it supported argumentatively. What was not fitting was omitted - thankfully Pragmatism offers great liberty in this - and what was considered useful was given a role, even if not included in the original methodological framework documented in the literature. And so, this work made a journey through cycles of abduction and deduction, building the path to connect planning theory and planning practice, by means of an Information System.

When the time for shaping the IS came, the principle followed was that stated by Zanon (2014 [165]): the actual strength of the planning profession is the ability to integrate the different branches of knowledge and tools and in this way master the planning process. Development followed design, but not all functionalities considered in the design have been implemented in this PhD. Some have been cut short by time limits, some have reached half-way, but all aspects experimented with have been thought through and meta-artifacts await a second chance to be put to use in planning.

I believe that further to contributing a certain innovation both to the theory and to the practice of the field of planning, this PhD thesis has achieved to pose questions that could spark discussions and attract further research interest. And I hope that cohesion and continuity have been illustrated loud and clear, because these are the ingredients that can sustain the track of thought throughout the journey from theory to practice and back.

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Symbols in Figure 2.3: "Spark Gap" by Arthur Shlain; "City" by Made by Made; "Plan" by Dev Patel; "Interface" by Creative Stall; "Software Architecture" by Richard Slater. All from thenounproject.com .

8 APPENDICES

This part of the thesis includes all the appended artifacts that are referred to in the Functionality Development section of the 5th Chapter.

8.1 Knowledge Base for the SEA

```
<?xml version="1.0"?>
<rdf:RDF xmlns="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#"
    xml:base="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20"
    xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
    xmlns:owl="http://www.w3.org/2002/07/owl#"
    xmlns:xml="http://www.w3.org/XML/1998/namespace"
    xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
    xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#">
   <owl:Ontology
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20"/>


   <!--
   ///////////////////////////////////////////////////////////////////////////////////////
//////////
   //
   // Object Properties
   //
   ///////////////////////////////////////////////////////////////////////////////////////
//////////
    -->


   <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Requires -->
```

```
    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Requires">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Process"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#GIS_functions"/>
        <owl:propertyChainAxiom rdf:parseType="Collection">
            <rdf:Description
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasDefaultTasks"/>
            <rdf:Description
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#comprises"/>
        </owl:propertyChainAxiom>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#assignsRole -->

    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#assignsRole">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Guidelines"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Role"/>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#assignsTask -->

    <owl:ObjectProperty
```

```
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#assignsTask">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Guidelines"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Task"/>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#canUndertake -->

    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#canUndertake">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Actor"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Role"/>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#composedBy -->

    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#composedBy">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#ESAindex"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#EnvironmentalIndices"/>
    </owl:ObjectProperty>
```

```
    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#comprises -->

    <owl:ObjectProperty rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#comprises">
        <rdfs:domain rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#GIS_task"/>
        <rdfs:range rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#GIS_functions"/>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasDefaultRole -->

    <owl:ObjectProperty rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasDefaultRole">
        <rdfs:domain rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
        <rdfs:range rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Role"/>
        <owl:propertyChainAxiom rdf:parseType="Collection">
            <rdf:Description rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#isDefinedBy"/>
            <rdf:Description rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#assignsRole"/>
        </owl:propertyChainAxiom>
    </owl:ObjectProperty>
```

```
<!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasDefaultTasks -->

<owl:ObjectProperty rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasDefaultTasks">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
    <rdfs:range rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Task"/>
    <owl:propertyChainAxiom rdf:parseType="Collection">
        <rdf:Description rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#refersSpatially"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasGuidelines"/>
        <rdf:Description rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#assignsTask"/>
    </owl:propertyChainAxiom>
</owl:ObjectProperty>

<!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasFormat -->

<owl:ObjectProperty rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasFormat">
    <rdfs:domain rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#EnvironmentalIndices"/>
    <rdfs:range
```

```
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Format"/>
  </owl:ObjectProperty>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasGuidelines -->

  <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasGuidelines">
    <owl:inverseOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#hasName"/>
    <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Location"/>
    <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Guidelines"/>
  </owl:ObjectProperty>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasInput -->

  <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasInput">
    <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Task"/>
    <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Format"/>
  </owl:ObjectProperty>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasName -->
```

```
    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasName">
        <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#FunctionalProperty"/>
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Guidelines"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Location"/>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasOutput -->

    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#hasOutput">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Task"/>
        <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Format"/>
    </owl:ObjectProperty>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#isAssignedTo -->

    <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#isAssignedTo">
        <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Actor"/>
        <rdfs:range
```

```
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
  </owl:ObjectProperty>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#isDefinedBy -->

  <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#isDefinedBy">
    <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
    <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Guidelines"/>
    <owl:propertyChainAxiom rdf:parseType="Collection">
      <rdf:Description
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#refersSpatially"/>
      <rdf:Description
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#hasGuidelines"/>
    </owl:propertyChainAxiom>
  </owl:ObjectProperty>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#isResponsibleFor -->

  <owl:ObjectProperty
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#isResponsibleFor">
    <rdfs:domain
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Role"/>
    <rdfs:range
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
```

```
ontology-20#Task"/>
    </owl:ObjectProperty>
    


    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#refersSpatially -->

    <owl:ObjectProperty rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#refersSpatially">
        <rdfs:domain rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
        <rdfs:range rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Location"/>
    </owl:ObjectProperty>
    


    <!-- 
    ///////////////////////////////////////////////////////////////////////////////////////
    //
    // Classes
    //
    ///////////////////////////////////////////////////////////////////////////////////////
     -->

    


    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Actor -->

    <owl:Class rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Actor">
        <rdfs:comment>an individual or a group of people</rdfs:comment>
    </owl:Class>
```

```
    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Classification -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Classification">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#GIS_functions"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#ClimateQuality -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#ClimateQuality">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#EnvironmentalIndices"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#ESAindex -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#ESAindex">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#GIS_task"/>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#hasOutput"/>
                <owl:allValuesFrom
```

```
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Raster"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#composedBy"/>
                <owl:qualifiedCardinality
rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger">4</owl:qual
ifiedCardinality>
                <owl:onClass
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#EnvironmentalIndices"/>
            </owl:Restriction>
        </rdfs:subClassOf>
        <rdfs:subClassOf>
            <owl:Restriction>
                <owl:onProperty
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#comprises"/>
                <owl:qualifiedCardinality
rdf:datatype="http://www.w3.org/2001/XMLSchema#nonNegativeInteger">1</owl:qual
ifiedCardinality>
                <owl:onClass
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#RasterCalculation"/>
            </owl:Restriction>
        </rdfs:subClassOf>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#EnvironmentalIndices -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
```

```
20#EnvironmentalIndices"/>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Format -->

    <owl:Class rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Format"/>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#GIS_functions -->

    <owl:Class rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#GIS_functions"/>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#GIS_task -->

    <owl:Class rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#GIS_task">
        <rdfs:subClassOf rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Task"/>
        <rdfs:comment>a piece of GIS work</rdfs:comment>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Guidelines -->

    <owl:Class rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Guidelines">
        <owl:disjointWith rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
```

```
  </owl:Class>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#LandManagementQuality -->

  <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#LandManagementQuality">
     <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#EnvironmentalIndices"/>
  </owl:Class>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Location -->

  <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Location"/>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Map -->

  <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Map">
     <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Format"/>
  </owl:Class>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Municipality -->

  <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Municipality">
```

```
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Location"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Process -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Process">
        <rdfs:comment>a planning process</rdfs:comment>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Raster -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Raster">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Map"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#RasterCalculation -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#RasterCalculation">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#GIS_functions"/>
    </owl:Class>
```

```
    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Region -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Region">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Location"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Role -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Role">
        <rdfs:comment>a responsibility</rdfs:comment>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SoilQuality -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SoilQuality">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#EnvironmentalIndices"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Task -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Task">
```

```
        <rdfs:comment>a piece of work</rdfs:comment>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Vector -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Vector">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Map"/>
    </owl:Class>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#VegetationQuality -->

    <owl:Class
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#VegetationQuality">
        <rdfs:subClassOf
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#EnvironmentalIndices"/>
    </owl:Class>

    <!--
    ///////////////////////////////////////////////////////////////////////////////////////
//////////
    //
    // Individuals
    //
    ///////////////////////////////////////////////////////////////////////////////////////
//////////
     -->

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#AdoptMasterPlan -->
```

```
    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#AdoptMasterPlan">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Task"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Assessor -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Assessor">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Role"/>
        <isResponsibleFor
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#CreateEnvironmentalReport"/>
        <isResponsibleFor
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Scoping"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#BillieJean -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#BillieJean">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Actor"/>
        <canUndertake
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
```

```
ontology-20#Mapper"/>
   </owl:NamedIndividual>

   <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Cagliari -->

   <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Cagliari">
      <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Municipality"/>
   </owl:NamedIndividual>

   <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Classify -->

   <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Classify">
      <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#GIS_task"/>
      <comprises
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#SomeClassificationFunction"/>
   </owl:NamedIndividual>

   <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#CreateEnvironmentalReport -->

   <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#CreateEnvironmentalReport">
      <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Task"/>
```

```
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#GuideSardinia -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#GuideSardinia">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Guidelines"/>
        <assignsRole
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Assessor"/>
        <assignsTask
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Classify"/>
        <assignsTask
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#SomeESAindex"/>
        <hasName
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Sardinia"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#GuideSicily -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#GuideSicily">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Guidelines"/>
        <assignsRole
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Assessor"/>
```

```
        <assignsRole
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Planner"/>
        <hasName
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Sicily"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Mapper -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Mapper">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Role"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#MichaelCorleone -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#MichaelCorleone">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Actor"/>
        <canUndertake
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Assessor"/>
        <canUndertake
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Planner"/>
    </owl:NamedIndividual>
```

```
<!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Planner -->

<owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Planner">
    <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Role"/>
    <isResponsibleFor
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#AdoptMasterPlan"/>
</owl:NamedIndividual>

<!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process1 -->

<owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process1">
    <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Process"/>
    <refersSpatially
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Sardinia"/>
</owl:NamedIndividual>

<!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Sardinia -->

<owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Sardinia">
    <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-20#Region"/>
```

```
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Scoping -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Scoping">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Task"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Sicily -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Sicily">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Region"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeClassificationFunction -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeClassificationFunction">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Classification"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeESAindex -->
```

```
    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeESAindex">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#ESAindex"/>
        <comprises
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#SomeRasterCalculation"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeRaster -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeRaster">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Raster"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeRasterCalculation -->

    <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeRasterCalculation">
        <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#RasterCalculation"/>
    </owl:NamedIndividual>

    <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeVector -->
```

```
  <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#SomeVector">
      <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Vector"/>
  </owl:NamedIndividual>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Table -->

  <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Table">
      <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Format"/>
  </owl:NamedIndividual>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#TextFile -->

  <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#TextFile">
      <rdf:type
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Format"/>
  </owl:NamedIndividual>

  <!-- http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Varese -->

  <owl:NamedIndividual
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Varese">
      <rdf:type
```

```
rdf:resource="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-
ontology-20#Municipality"/>
  </owl:NamedIndividual>

  <!--
  ///////////////////////////////////////////////////////////////////////////////////////
  //
  // General axioms
  //
  ///////////////////////////////////////////////////////////////////////////////////////
   -->

  <rdf:Description>
    <rdf:type rdf:resource="http://www.w3.org/2002/07/owl#AllDifferent"/>
    <owl:distinctMembers rdf:parseType="Collection">
      <rdf:Description
rdf:about="http://www.semanticweb.org/xenia/ontologies/2017/5/untitled-ontology-
20#Sardinia"/>
    </owl:distinctMembers>
  </rdf:Description>
</rdf:RDF>

<!-- Generated by the OWL API (version 4.2.6.20160910-2108)
https://github.com/owlcs/owlapi -->
```

8.2 XSD for ILWIS geo-operators

```
<xs:schema attributeFormDefault="unqualified" elementFormDefault="qualified"
xmlns:xs="http://www.w3.org/2001/XMLSchema">
 <xs:element name="operations" type="operationsType"/>
 <xs:element name="parameter" type="parameterType"/>
 <xs:complexType name="keywordsType">
  <xs:sequence>
```

```
<xs:element type="xs:string" name="keyword" maxOccurs="unbounded"
minOccurs="0"/>
  </xs:sequence>
 </xs:complexType>
 <xs:complexType name="typesType">
  <xs:sequence>
   <xs:element type="xs:string" name="type" maxOccurs="unbounded" minOccurs="0"/>
  </xs:sequence>
 </xs:complexType>
 <xs:complexType name="parameterType">
  <xs:choice maxOccurs="unbounded" minOccurs="0">
   <xs:element type="xs:string" name="name"/>
   <xs:element type="typesType" name="types"/>
   <xs:element type="xs:string" name="term"/>
   <xs:element type="xs:string" name="desc"/>
   <xs:element type="xs:string" name="optional"/>
   <xs:element type="xs:string" name="needsquotes"/>
   <xs:element type="xs:string" name="output_is_input"/>
   <xs:element type="xs:string" name="altUIType"/>
   <xs:element type="xs:string" name="validationsource"/>
   <xs:element type="xs:string" name="validationcondition"/>
  </xs:choice>
 </xs:complexType>
 <xs:complexType name="input_parametersType">
  <xs:sequence>
   <xs:element ref="parameter" maxOccurs="unbounded" minOccurs="0"/>
  </xs:sequence>
 </xs:complexType>
 <xs:complexType name="output_parametersType">
```

```
    <xs:sequence>
      <xs:element ref="parameter" maxOccurs="unbounded" minOccurs="0"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="operationType">
    <xs:sequence>
      <xs:element type="xs:string" name="name"/>
      <xs:element type="xs:string" name="longname" minOccurs="0"/>
      <xs:element type="xs:string" name="description" minOccurs="0"/>
      <xs:element type="xs:string" name="namespace"/>
      <xs:element type="keywordsType" name="keywords"/>
      <xs:element type="xs:string" name="syntax"/>
      <xs:element type="input_parametersType" name="input_parameters"/>
      <xs:element type="output_parametersType" name="output_parameters"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="operationsType">
    <xs:sequence>
      <xs:element type="operationType" name="operation" maxOccurs="unbounded"
minOccurs="0"/>
    </xs:sequence>
  </xs:complexType>
</xs:schema>
```

8.3 XSD from the sample ILWIS workflow

```
<xs:schema attributeFormDefault="unqualified" elementFormDefault="qualified"
xmlns:xs="http://www.w3.org/2001/XMLSchema">
  <xs:element name="workflows" type="workflowsType"/>
```

```
<xs:complexType name="connectionType">
  <xs:sequence>
    <xs:element type="xs:byte" name="fromOperationID"/>
    <xs:element type="xs:byte" name="fromParameterID"/>
    <xs:element type="xs:byte" name="toOperationID"/>
    <xs:element type="xs:byte" name="toParameterID"/>
  </xs:sequence>
</xs:complexType>
<xs:complexType name="connectionsType">
  <xs:sequence>
    <xs:element type="connectionType" name="connection" maxOccurs="unbounded"
minOccurs="0"/>
  </xs:sequence>
</xs:complexType>
<xs:complexType name="metadataType">
  <xs:sequence>
    <xs:element type="xs:string" name="description"/>
    <xs:element type="xs:string" name="final" minOccurs="0"/>
    <xs:element type="xs:byte" name="inputparametercount"/>
    <xs:element type="xs:string" name="keywords" minOccurs="0"/>
    <xs:element type="xs:string" name="label" minOccurs="0"/>
    <xs:element type="xs:string" name="longname"/>
    <xs:element type="xs:byte" name="outputparametercount"/>
    <xs:element type="xs:string" name="resource"/>
    <xs:element type="xs:string" name="syntax"/>
  </xs:sequence>
</xs:complexType>
<xs:complexType name="inputType">
  <xs:sequence>
```

```
      <xs:element type="xs:string" name="change"/>
      <xs:element type="xs:string" name="description"/>
      <xs:element type="xs:byte" name="id"/>
      <xs:element type="xs:string" name="local"/>
      <xs:element type="xs:string" name="name"/>
      <xs:element type="xs:string" name="optional"/>
      <xs:element type="xs:string" name="show"/>
      <xs:element type="xs:string" name="type"/>
      <xs:element type="xs:string" name="datamodel" maxOccurs="unbounded" minOccurs="0"/>
      <xs:element type="xs:string" name="url"/>
      <xs:element type="xs:string" name="value"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="inputsType">
    <xs:sequence>
      <xs:element type="inputType" name="input" maxOccurs="unbounded" minOccurs="0"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="outputType">
    <xs:sequence>
      <xs:element type="xs:string" name="description"/>
      <xs:element type="xs:byte" name="id"/>
      <xs:element type="xs:string" name="local"/>
      <xs:element type="xs:string" name="name"/>
      <xs:element type="xs:string" name="optional"/>
      <xs:element type="xs:string" name="show" minOccurs="0"/>
      <xs:element type="xs:string" name="type" minOccurs="0"/>
```

```
      <xs:element type="xs:string" name="datamodel"/>
      <xs:element type="xs:string" name="url"/>
      <xs:element type="xs:string" name="value"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="outputsType" mixed="true">
    <xs:sequence>
      <xs:element type="outputType" name="output" minOccurs="0"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="operationType">
    <xs:sequence>
      <xs:element type="xs:byte" name="id"/>
      <xs:element type="inputsType" name="inputs"/>
      <xs:element type="metadataType" name="metadata"/>
      <xs:element type="outputsType" name="outputs"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="operationsType">
    <xs:sequence>
      <xs:element type="operationType" name="operation" maxOccurs="unbounded" minOccurs="0"/>
    </xs:sequence>
  </xs:complexType>
  <xs:complexType name="workflowType">
    <xs:sequence>
      <xs:element type="connectionsType" name="connections"/>
      <xs:element type="xs:byte" name="id"/>
      <xs:element type="metadataType" name="metadata"/>
```

```
    <xs:element type="operationsType" name="operations"/>
   </xs:sequence>
  </xs:complexType>
  <xs:complexType name="workflowsType">
   <xs:sequence>
    <xs:element type="workflowType" name="workflow"/>
   </xs:sequence>
  </xs:complexType>
</xs:schema>
```

8.4 The XSLT that converts ILWIS geoprocessing workflows to BPMN

```
<?xml version="1.0" encoding="utf-8"?>
<!--
	Author:
	File:
	Date:
	Purpose:
-->
<xsl:stylesheet version="1.0" xmlns:xsl="http://www.w3.org/1999/XSL/Transform">
    <xsl:output method="xml" indent="yes" encoding="utf-8" />
    <xsl:template match="/">
      <xsl:text>definitions&#xA;&#x9;</xsl:text>
      <process>
        <xsl:attribute name="id">
          <xsl:value-of select="/workflows/workflow/@id"/>
        </xsl:attribute>
        <xsl:attribute name="isClosed">false</xsl:attribute>
```

```
    <xsl:attribute name="isExecutable">true</xsl:attribute>
    <xsl:attribute name="processType">None</xsl:attribute>
    <xsl:for-each select="/workflows/workflow/operations/operation">
      <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
      <scriptTask>
        <xsl:attribute name ="id">
          <xsl:value-of select="@id"/>
        </xsl:attribute>
        <xsl:choose>
          <xsl:when
test="/workflows/workflow/connections/connection/toOperationID=@id">
            <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
            <incoming><xsl:value-of
select="/workflows/workflow/connections/connection/@id"/></incoming>
          </xsl:when>
          <xsl:otherwise>
            <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
            <incoming></incoming>
          </xsl:otherwise>
        </xsl:choose>
        <xsl:choose>
          <xsl:when
test="/workflows/workflow/connections/connection/fromOperationID=@id">
          <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
            <outgoing><xsl:value-of
select="/workflows/workflow/connections/connection/@id"/></outgoing>
          </xsl:when>
          <xsl:otherwise>
          <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
```

```
        <outgoing></outgoing>
      </xsl:otherwise>
    </xsl:choose>
    <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
  </scriptTask>
</xsl:for-each>
<xsl:for-each select="/workflows/workflow/operations/operation">
  <xsl:if
test="/workflows/workflow/connections/connection/toOperationID!=@id">
    <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    <startEvent isInterrupting="true">
      <xsl:attribute name="id">
        <xsl:value-of select="/workflows/startIDs/firstID"/>
      </xsl:attribute>
      <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
      <outgoing><xsl:value-of select="@id"/></outgoing>
      <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
      <outputSet></outputSet>
      <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    </startEvent>
    <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    <sequenceFlow>
    <xsl:attribute name="id">
      <xsl:value-of select="@id/workflows/flowIDs/firstID"/>
    </xsl:attribute>
      <xsl:attribute name ="sourceRef">
        <xsl:value-of select="/workflows/startIDs/firstID"/>
      </xsl:attribute>
      <xsl:attribute name ="targetRef">
```

```
        <xsl:value-of select="@id"/>
      </xsl:attribute>
      <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    </sequenceFlow>
  </xsl:if>
  <xsl:if
test="/workflows/workflow/connections/connection/fromOperationID!=@id">
    <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    <endEvent>
      <xsl:attribute name="id">
        <xsl:value-of select="/workflows/endIDs/firstID"/>
      </xsl:attribute>
      <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
      <incoming><xsl:value-of select="@id"/></incoming>
      <xsl:text>&#xA;&#x9;&#x9;&#x9;</xsl:text>
      <inputSet></inputSet>
      <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    </endEvent>
    <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
    <sequenceFlow>
    <xsl:attribute name="id">
      <xsl:value-of select="@id/workflows/flowIDs/secondID"/>
    </xsl:attribute>
      <xsl:attribute name ="sourceRef">
        <xsl:value-of select="@id"/>
      </xsl:attribute>
      <xsl:attribute name ="targetRef">
        <xsl:value-of select="/workflows/endIDs/firstID"/>
      </xsl:attribute>
```

```
            <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
          </sequenceFlow>
        </xsl:if>
      </xsl:for-each>
      <xsl:for-each select="/workflows/workflow/connections/connection">
        <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
        <sequenceFlow>
          <xsl:attribute name="id">
            <xsl:value-of select="@id"/>
          </xsl:attribute>
          <xsl:attribute name="sourceRef">
            <xsl:value-of
select="/workflows/workflow/connections/connection/fromOperationID"/>
          </xsl:attribute>
          <xsl:attribute name="targetRef">
            <xsl:value-of
select="/workflows/workflow/connections/connection/toOperationID"/>
          </xsl:attribute>
          <xsl:text>&#xA;&#x9;&#x9;</xsl:text>
        </sequenceFlow>
      </xsl:for-each>
    <xsl:text>&#xA;&#x9;</xsl:text>
  </process>
 </xsl:template>
</xsl:stylesheet>
```

8.5 XML description of the BPMN diagram produced by convertion

```xml
<?xml version="1.0" encoding="UTF-8" standalone="yes"?>
<definitions xmlns="http://www.omg.org/spec/BPMN/20100524/MODEL"
xmlns:bpmndi="http://www.omg.org/spec/BPMN/20100524/DI"
xmlns:dc="http://www.omg.org/spec/DD/20100524/DC"
xmlns:di="http://www.omg.org/spec/DD/20100524/DI"
xmlns:tns="http://sourceforge.net/bpmn/definitions/_123456"
xmlns:xsd="http://www.w3.org/2001/XMLSchema"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:yaoqiang="http://bpmn.sourceforge.net" exporter="Yaoqiang BPMN Editor"
exporterVersion="5.3" expressionLanguage="http://www.w3.org/1999/XPath"
id="_123456" name=""
targetNamespace="http://sourceforge.net/bpmn/definitions/_123456"
typeLanguage="http://www.w3.org/2001/XMLSchema"
xsi:schemaLocation="http://www.omg.org/spec/BPMN/20100524/MODEL
http://bpmn.sourceforge.net/schemas/BPMN20.xsd">
  <process id="_1" isClosed="false" isExecutable="true" processType="None">
    <task completionQuantity="1" id="_2" isForCompensation="false" startQuantity="1">
      <incoming>_3</incoming>
      <outgoing>_6</outgoing>
    </task>
    <sequenceFlow id="_3" sourceRef="_4" targetRef="_2"/>
    <startEvent id="_4" isInterrupting="true">
      <outgoing>_3</outgoing>
      <outputSet/>
    </startEvent>
    <endEvent id="_5">
      <incoming>_7</incoming>
      <inputSet/>
    </endEvent>
    <sequenceFlow id="_6" sourceRef="_2" targetRef="_8"/>
    <sequenceFlow id="_7" sourceRef="_8" targetRef="_5"/>
```

```
    <task completionQuantity="1" id="_8" isForCompensation="false" startQuantity="1">
      <incoming>_6</incoming>
      <outgoing>_7</outgoing>
    </task>
  </process>
  <bpmndi:BPMNDiagram id="Yaoqiang_Diagram-_1" name="Untitled Diagram" resolution="96.0">
    <bpmndi:BPMNPlane bpmnElement="_1">
      <bpmndi:BPMNShape bpmnElement="_8" id="Yaoqiang-_8">
        <dc:Bounds height="55.0" width="85.0" x="257.0" y="188.5"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="19.84" width="6.0" x="296.5" y="208.08"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="_5" id="Yaoqiang-_5">
        <dc:Bounds height="32.0" width="32.0" x="402.0" y="200.0"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="19.84" width="6.0" x="415.0" y="240.08"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="_4" id="Yaoqiang-_4">
        <dc:Bounds height="32.0" width="32.0" x="20.0" y="200.0"/>
        <bpmndi:BPMNLabel>
          <dc:Bounds height="19.84" width="6.0" x="33.0" y="240.08"/>
        </bpmndi:BPMNLabel>
      </bpmndi:BPMNShape>
      <bpmndi:BPMNShape bpmnElement="_2" id="Yaoqiang-_2">
        <dc:Bounds height="55.0" width="85.0" x="112.0" y="188.5"/>
        <bpmndi:BPMNLabel>
```

```
        <dc:Bounds height="19.84" width="6.0" x="151.5" y="208.08"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNShape>
    <bpmndi:BPMNEdge bpmnElement="_7" id="Yaoqiang-_7">
      <di:waypoint x="342.0" y="216.0"/>
      <di:waypoint x="402.0" y="216.0"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="19.84" width="6.0" x="369.0" y="206.08"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNEdge>
    <bpmndi:BPMNEdge bpmnElement="_6" id="Yaoqiang-_6">
      <di:waypoint x="197.0" y="216.0"/>
      <di:waypoint x="257.0" y="216.0"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="19.84" width="6.0" x="224.0" y="206.08"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNEdge>
    <bpmndi:BPMNEdge bpmnElement="_3" id="Yaoqiang-_3">
      <di:waypoint x="52.0" y="216.0"/>
      <di:waypoint x="112.0" y="216.0"/>
      <bpmndi:BPMNLabel>
        <dc:Bounds height="19.84" width="6.0" x="79.0" y="206.08"/>
      </bpmndi:BPMNLabel>
    </bpmndi:BPMNEdge>
  </bpmndi:BPMNPlane>
 </bpmndi:BPMNDiagram>
</definitions>
```

8.6 GRASS geo-operators in RDF

```
@base <http://example.org/GRASS> .
@prefix gisop: <http://example.org/GISoperation> .
@prefix owl: <http://www.w3.org/2002/07/owl#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .
@prefix gwiki: <https://grasswiki.osgeo.org/wiki/> .
@prefix gkeywords: <https://grass.osgeo.org/grass72/manuals/keywords#> .
@prefix gmanuals: <https://grass.osgeo.org/grass72/manuals/> .

<http://example.org/GRASS> a owl:Ontology ;

  rdfs:comment "Class names in one word, capitalise new word, unless previous ends with capital letter. Labels in separate words, only the first one capitalised. Properties start with small letter, capitalise every new word, whole name in one word." ,

  "Top classes can be moved out of the GRASS ontology" .


##########################################
# Classes
##########################################

##########################################
# Top Classes
##########################################

<#Capability> a owl:Class ;
  rdfs:label "Software capabilities" ;
  rdfs:comment "This class groups together the capabilities of GIS software" ;
  rdfs:seeAlso "https://grass.osgeo.org/documentation/general-overview/" .

<#Application> a owl:Class ;
  rdfs:label "Software application domains" ;
```

```
  rdfs:comment "This class groups together the application domains GIS software is
known to be used in" ;
  rdfs:seeAlso gwiki:Applications .

<#Functionality> a owl:Class ;
  rdfs:label "Software functionality" ;
  rdfs:comment "This class groups together GIS software functionalities" ;
  rdfs:seeAlso "https://grass.osgeo.org/documentation/first-time-users/" .

<#Keyword> a owl:Class ;
  rdfs:label "Keywords" ;
  rdfs:comment "This class groups together GIS software keywords for function
indexing" ;
  rdfs:seeAlso gkeywords: .

<#CaseStudy> a owl:Class ;
  rdfs:label "Case studies" ;
  rdfs:comment "This class is about case studies in which the GIS software has been
used" ;
  rdfs:seeAlso gwiki:Case_studies .


##########################################
# Second Level Classes
##########################################

  ##########################################
  # Subclasses of Capability
  ##########################################

<#RasterAnalysis>
  rdfs:label "Raster analysis" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Automatic rasterline and area to vector conversion, Buffering of line
structures, Cell and profile dataquery, Colortable modifications, Conversion to vector and
point data format, Correlation / covariance analysis, Expert system analysis , Map algebra
(map calculator), Interpolation for missing values, Neighbourhood matrix analysis, Raster
```

```
overlay with or without weight, Reclassification of cell labels, Resampling (resolution),
Rescaling of cell values, Statistical cell analysis, Surface generation from vector lines" .

<#VoxelAnalysis>
   rdfs:label "3D raster (voxel) analysis" ;
   rdfs:subClassOf <#Capability> ;
   rdfs:comment "3D data import and export, 3D masks, 3D map algebra, 3D interpolation
(IDW, Regularised Splines with Tension), 3D Visualization (isosurfaces), Interface to
Paraview and POVray visualization tools" .

<#VectorAnalysis>
   rdfs:label "Vector analysis" ;
   rdfs:subClassOf <#Capability> ;
   rdfs:comment "Contour generation from raster surfaces (IDW, Splines algorithm),
Conversion to raster and point data format, Digitizing (scanned raster image) with mouse,
Reclassification of vector labels, Superpositioning of vector layers" .

<#PointDataAnalysis>
   rdfs:label "Point data analysis" ;
   rdfs:subClassOf <#Capability> ;
   rdfs:comment "Delaunay triangulation, Surface interpolation from spot heights,
Thiessen polygons, Topographic analysis (curvature, slope, aspect), LiDAR" .

<#ImageProcessing>
   rdfs:label "Image processing" ;
   rdfs:subClassOf <#Capability> ;
   rdfs:comment "Support for aerial and UAV images, satellite data (optical, radar,
thermal), Canonical component analysis (CCA), Color composite generation, Edge
detection, Frequency filtering (Fourier, convolution matrices), Fourier and inverse fourier
transformation, Histogram stretching, IHS transformation to RGB, Image rectification
(affine and polynomial transformations on raster and vector targets), Ortho photo
rectification, Principal component analysis (PCA), Radiometric corrections (Fourier),
Resampling, Resolution enhancement (with RGB/IHS), RGB to IHS transformation, Texture
oriented classification (sequential maximum a posteriori classification), Shape detection,
Supervised classification (training areas, maximum likelihood classification),
Unsupervised classification (minimum distance clustering, maximum likelihood
classification)" .
```

```
<#DTManalysis>
  rdfs:label "DTM analysis" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Contour generation, Cost / path analysis, Slope / aspect analysis, Surface generation from spot heigths or contours" .

<#Geocoding>
  rdfs:label "Geocoding" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Geocoding of raster and vector maps including (LiDAR) point clouds".

<#Visualisation>
  rdfs:label "Visualisation" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "3D surfaces with 3D query (NVIZ), Color assignments, Histogram presentation, Map overlay, Point data maps, Raster maps, Vector maps, Zoom / unzoom -function".

<#MapCreation>
  rdfs:label "Map creation" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Image maps, Postscript maps, HTML maps" .

<#SQLsupport>
  rdfs:label "SQL support" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Database interfaces (DBF, SQLite, PostgreSQL, mySQL, ODBC)" .

<#Geostatistics>
  rdfs:label "Geostatistics" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Interface to 'R' (a statistical analysis environment), Matlab, ..." .

<#TemporalFramework>
  rdfs:label "Temporal framework" ;
  rdfs:subClassOf <#Capability> ;
```

```
  rdfs:comment "support for time series analysis to manage, process and analyse (big)
spatio-temporal environmental data. It supports querying, map calculation, aggregation,
statistics and gap filling for raster, vector and raster3D data. A temporal topology builder
is available to build spatio-temporal topology connections between map objects for 1D, 3D
and 4D extents" .

<#Furthermore>
  rdfs:label "Furthermore" ;
  rdfs:subClassOf <#Capability> ;
  rdfs:comment "Erosion modelling, Landscape structure analysis, Solution transport,
Watershed analysis" .


  #########################################
  # Subclasses of Application
  #########################################

<#Archeology>
  rdfs:label "Archeology" ;
  rdfs:seeAlso gwiki:Archeology ;
  rdfs:subClassOf <#Application> .

<#AgricultureAndHPC>
  rdfs:label "Agriculture and High Performance Computing" ;
  rdfs:seeAlso gwiki:Agriculture_and_HPC ;
  rdfs:subClassOf <#Application> .

<#BurnedAreaMapping>
  rdfs:label "Burned area mapping" ;
  rdfs:seeAlso gwiki:Burned_Area_Mapping ;
  rdfs:subClassOf <#Application> .

<#Cartography>
  rdfs:label "Cartography" ;
  rdfs:seeAlso gwiki:Cartography ;
  rdfs:subClassOf <#Application> .
```

```
<#EnergyCalculations>
  rdfs:label "Energy calculations" ;
  rdfs:seeAlso gwiki:Energy_calculations ;
  rdfs:subClassOf <#Application> .

<#EnvironmentalProtectionAndMonitoring>
  rdfs:label "Environmental protection and monitoring" ;
  rdfs:seeAlso gwiki:Environmental_Protection_and_Monitoring ;
  rdfs:subClassOf <#Application> .

<#Geology>
  rdfs:label "Geology" ;
  rdfs:seeAlso gwiki:Geology ;
  rdfs:subClassOf <#Application> .

<#Geomorphometry>
  rdfs:label "Geomorphometry" ;
  rdfs:seeAlso gwiki:Geomorphometry ;
  rdfs:subClassOf <#Application> .

<#Geophysics>
  rdfs:label "Geophysics" ;
  rdfs:seeAlso gwiki:Geophysics ;
  rdfs:subClassOf <#Application> .

<#HydrologicalSciences>
  rdfs:label "Hydrological sciences" ;
  rdfs:comment "Including ice cover and groundwater flow" ;
  rdfs:seeAlso gwiki:Hydrological_Sciences ;
  rdfs:subClassOf <#Application> .

<#InvasiveSpeciesModelling>
  rdfs:label "Invasive species modelling" ;
  rdfs:seeAlso gwiki:Invasive_Species_modelling ;
  rdfs:subClassOf <#Application> .

<#LandscapeEcology>
```

```
  rdfs:label "Landscape ecology" ;
  rdfs:seeAlso gwiki:Landscape_ecology ;
  rdfs:subClassOf <#Application> .

<#LandscapeGenetics>
  rdfs:label "Landscape genetics" ;
  rdfs:seeAlso gwiki:Landscape_Genetics ;
  rdfs:subClassOf <#Application> .

<#MarineScience>
  rdfs:label "Marine science" ;
  rdfs:seeAlso gwiki:Marine_Science ;
  rdfs:subClassOf <#Application> .

<#Meteorology>
  rdfs:label "Meteorology" ;
  rdfs:seeAlso gwiki:Meteorology ;
  rdfs:subClassOf <#Application> .

<#NaturalHazards>
  rdfs:label "Natural hazards" ;
  rdfs:seeAlso gwiki:Natural_Hazards ;
  rdfs:subClassOf <#Application> .

<#PlanetaryMapping>
  rdfs:label "Planetary mapping" ;
  rdfs:seeAlso gwiki:Planetary_mapping ;
  rdfs:subClassOf <#Application> .

<#Planning>
  rdfs:label "Planning" ;
  rdfs:seeAlso gwiki:Planning ;
  rdfs:subClassOf <#Application> .

<#PublicHealth>
  rdfs:label "Public health" ;
  rdfs:seeAlso gwiki:Public_Health ;
```

```
  rdfs:subClassOf <#Application> .

<#RemoteSensing>
  rdfs:label "Remote sensing" ;
  rdfs:seeAlso gwiki:Image_processing ;
  rdfs:subClassOf <#Application> .

<#SearchAndRescue>
  rdfs:label "Search and rescue" ;
  rdfs:seeAlso gwiki:Search_and_Rescue ;
  rdfs:subClassOf <#Application> .

<#SoilScience>
  rdfs:label "Soil science" ;
  rdfs:seeAlso gwiki:Soil_Science ;
  rdfs:subClassOf <#Application> .

<#WildlifeZoology>
  rdfs:label "Wildlife zoology" ;
  rdfs:seeAlso gwiki:Wildlife_Zoology ;
  rdfs:subClassOf <#Application> .


  ##########################################
  # Subclasses of Functionality
  ##########################################

<#RasterFunctionality>
  rdfs:label "Raster (functionality)" ;
  rdfs:subClassOf <#Functionality> .

<#VectorFunctionality>
  rdfs:label "Topological vector (functionality)" ;
  rdfs:subClassOf <#Functionality> .

<#ImageProcessingFunctionality>
  rdfs:label "Image processing (functionality)" ;
```

```
   rdfs:subClassOf <#Functionality> .

<#GraphicsProductionFunctionality>
   rdfs:label "Graphics production (functionality)" ;
   rdfs:subClassOf <#Functionality> .



   ##########################################
   # Subclasses of Keyword
   ##########################################

   ####
   # 3
   ####

<#3D>
   rdfs:label "3D (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:3D .

<#3Draster>
   rdfs:label "3D raster ()" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#3D%20raster> . #I
need white space between 3D and raster and don't know how to insert one in turtle.

   ####
   # a
   ####

<#ACCA>
   rdfs:label "ACCA (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:ACCA .

<#Accumulation>
```

```
  rdfs:label "Accumulation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:accumulation .

<#ActualEvapotranspiration>
  rdfs:label "Actual evapotranspiration (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#actual%20evapotra
nspiration> .

<#Addons>
  rdfs:label "Addons (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:addons .

<#Aggregation>
  rdfs:label "Aggregation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:aggregation .

<#Albedo>
  rdfs:label "Albedo (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:albedo .

<#Algebra>
  rdfs:label "Algebra (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:algebra .

<#Animation>
  rdfs:label "Animation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:animation .

<#Area>
  rdfs:label "Area (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:area .

<#AreaEstimation>
  rdfs:label "Area estimation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#area%20estimation
> .

<#ArticulationPoints>
  rdfs:label "Articulation points (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#articulation%20poi
nts> .

<#ASCII>
  rdfs:label "ASCII (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:ASCII .

<#Aspect>
  rdfs:label "Aspect (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:aspect .

<#ASTER>
  rdfs:label "ASTER (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:ASTER .

<#AtmosphericCorrection>
  rdfs:label "Atmospheric correction (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#atmospheric%20co
rrection> .

<#AttributeColumns>
```

```
  rdfs:label "Attribute columns (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#attribute%20colum
ns> .

<#AttributeTable>
  rdfs:label "Attribute table (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#attribute%20table
> .

<#Attributes>
  rdfs:label "Attributes (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:attributes .

<#Autocorrelation>
  rdfs:label "Autocorrelation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:autocorrelation .

<#AVHRR>
  rdfs:label "AVHRR (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:AVHRR .

  ####
  # b
  ####

<#Binning>
  rdfs:label "Binning (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:binning .

<#Biomass>
  rdfs:label "Biomass (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:biomass .

<#BiophysicalParameters>
  rdfs:label "Biophysical parameters (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#biophysical%20par
ameters> .

<#BrightnessTemperature>
  rdfs:label "Brightness temperature (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#brightness%20tem
perature> .

<#Brovey>
  rdfs:label "Brovey (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:Brovey .

<#Buffer>
  rdfs:label "Buffer (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:buffer .

  ####
  # c
  ####

<#CanonicalComponentsAnalysis>
  rdfs:label "Canonical components analysis (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#canonical%20comp
onents%20analysis> .

<#Cartography>
  rdfs:label "Cartography (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:cartography .

<#Category>
  rdfs:label "Category (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:category .

<#CCA>
  rdfs:label "CCA - canonical components analysis (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:CCA .

<#CentralityMeasures>
  rdfs:label "Centrality measures (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#centrality%20meas
ures> .

<#Centroid>
  rdfs:label "Centroid (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:centroid .

<#ChartMaps>
  rdfs:label "Chart maps (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#chart%20maps> .

<#ChoroplethMap>
  rdfs:label "Choropleth map (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#choropleth%20ma
p> .

<#Circle>
  rdfs:label "Circle (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:circle .

<#Citing>
  rdfs:label "Citing (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:citing .

<#Classification>
  rdfs:label "Classification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:classification .

<#Clip>
  rdfs:label "Clip (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:clip .

<#CloudDetection>
  rdfs:label "Cloud detection (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#cloud%20detection
> .

<#Clump>
  rdfs:label "Clump (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:clump .

<#Clumps>
  rdfs:label "Clumps (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:clumps .

<#Cluster>
  rdfs:label "Cluster (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:cluster .

<#ColorTable>
  rdfs:label "Color table (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#color%20table> .

<#ColorTransformation>
  rdfs:label "Color transformation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#color%20transfor
mation> .

<#Colors>
  rdfs:label "Colors (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:colors .

<#Components>
  rdfs:label "Components (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:components .

<#Composite>
  rdfs:label "Composite (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:composite .

<#Compression>
  rdfs:label "Compression (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:compression .

<#ComputationalRegion>
  rdfs:label "Computational region (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#computational%20
```

```
region> .

<#ConnectionSettings>
  rdfs:label "Connection settings (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#connection%20sett
ings> .

<#Connectivity>
  rdfs:label "Connectivity (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:connectivity .

<#Contour>
  rdfs:label "Contour (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:contour .

<#Contours>
  rdfs:label "Contours (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:contours .

<#Conversion>
  rdfs:label "Conversion (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:conversion .

<#Copying>
  rdfs:label "Copying (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:copying .

<#Copyright>
  rdfs:label "Copyright (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:copyright .
```

```
<#Correlation>
   rdfs:label "Correlation (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:correlation .

<#CostAllocation>
   rdfs:label "Cost allocation (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#cost%20allocation
> .

<#CostSurface>
   rdfs:label "Cost surface (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#cost%20surface> .

<#Create>
   rdfs:label "Create (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:create .

<#CreateLocation>
   rdfs:label "Create location (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#create%20location
> .

<#CumulativeCosts>
   rdfs:label "Cumulative costs (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#cumulative%20cos
ts> .

<#Curvature>
   rdfs:label "Curvature (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:curvature .

  ####
  # d
  ####

<#Database>
  rdfs:label "Database (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:database .

<#Decimation>
  rdfs:label "Decimation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:decimation .

<#Densification>
  rdfs:label "Densification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:densification .

<#Deposition>
  rdfs:label "Deposition (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:deposition .

<#Depressions>
  rdfs:label "Depressions (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:depressions .

<#Diagram>
  rdfs:label "Diagram (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:diagram .

<#Difference>
```

```
  rdfs:label "Difference (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:difference .

<#Digitizer>
  rdfs:label "Digitizer (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:digitizer .

<#Displacement>
  rdfs:label "Displacement (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:displacement .

<#Display>
  rdfs:label "Display (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/display.html> .

<#Dissolve>
  rdfs:label "Dissolve (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:dissolve .

<#Distance>
  rdfs:label "Distance (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:distance .

<#DiversityIndex>
  rdfs:label "Diversity index (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#diversity%20index
> .

<#Download>
  rdfs:label "Download (keyword)" ;
```

```
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:download .

<#Drainage>
    rdfs:label "Drainage (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:drainage .

<#DXF>
    rdfs:label "DXF (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:DXF .

    ####
    # e
    ####

<#E00keyword>
    rdfs:label "E00 (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:E00 .

<#Edgeskeyword>
    rdfs:label "edges (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:edges .

<#Editingkeyword>
    rdfs:label "Editing (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:editing .

<#Elevationkeyword>
    rdfs:label "Elevation (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:elevation .
```

```
<#Emissivitykeyword>
   rdfs:label "Emissivity (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:emissivity .

<#EnergyBalanceKeyword>
   rdfs:label "Energy balance (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#energy%20balance
> .

<#ErosionKeyword>
   rdfs:label "Erosion (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:erosion .

<#EvaporativeFractionKeyword>
   rdfs:label "Evaporative fraction (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#evaporative%20fra
ction> .

<#EvapotranspirationKeyword>
   rdfs:label "Evapotranspiration (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:evapotranspiration .

<#ExportKeyword>
   rdfs:label "Export (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:export .

<#ExtensionsKeyword>
   rdfs:label "Extensions (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:extensions .
```

```
<#ExtentKeyword>
   rdfs:label "Extent (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:extent .

<#ExternalKeyword>
   rdfs:label "External (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:external .

<#ExtractKeyword>
   rdfs:label "Extract (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:extract .

   ####
   # f
   ####

<#FastFourierTransformKeyword>
   rdfs:label "Fast Fourier transform (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#Fast%20Fourier%2
0Transform> .

<#FillSinksKeyword>
   rdfs:label "Fill sinks (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#fill%20sinks> .

<#FilterKeyword>
   rdfs:label "Filter (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:filter .

<#FireKeyword>
   rdfs:label "Fire (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:fire .

<#FloodKeyword>
  rdfs:label "Flood (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:flood .

<#FlowKeyword>
  rdfs:label "Flow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:flow .

<#FocalStatisticsKeyword>
  rdfs:label "Focal statistics (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#focal%20statistics>
.

<#FPARkeyword>
  rdfs:label "FPAR - fraction of Photosynthetically Active Radiation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:FPAR .

<#FractalKeyword>
  rdfs:label "Fractal (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:fractal .

<#FrameKeyword>
  rdfs:label "Frame (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:frame .

<#FusionKeyword>
  rdfs:label "Fusion (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:fusion .

  ####
  # g
  ####

<#GazetteerKeyword>
  rdfs:label "Gazetteer (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:gazetteer .

<#GCPkeyword>
  rdfs:label "GCP (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:GCP .

<#GeneralKeyword>
  rdfs:label "General (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/general.html> .

<#GeneralizationKeyword>
  rdfs:label "Generalization (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:generalization .

<#GeometryKeyword>
  rdfs:label "Geometry (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:geometry .

<#GeomorphologyKeyword>
  rdfs:label "Geomorphology (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:geomorphology .

<#GeorectificationKeyword>
```

```
  rdfs:label "Georectification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:georectification .

<#GradientKeyword>
  rdfs:label "Gradient (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:gradient .

<#GraphicalModelerKeyword>
  rdfs:label "Graphical modeler (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#graphical%20mode
ler> .

<#GraphicsKeyword>
  rdfs:label "Graphics (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:graphics .

<#GraticuleKeyword>
  rdfs:label "Graticule (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:graticule .

<#GreatCircleKeyword>
  rdfs:label "Great circle (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#great%20circle> .

<#GridKeyword>
  rdfs:label "Grid (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:grid .

<#GroundwaterFlowKeyword>
  rdfs:label "Groundwater flow (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#groundwater%20fl
ow> .

<#GrowKeyword>
  rdfs:label "Grow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:grow .

<#GUIkeyword>
  rdfs:label "GUI (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:GUI .

  ####
  # h
  ####

<#HazardKeyword>
  rdfs:label "Hazard (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:hazard .

<#HeatmapKeyword>
  rdfs:label "Heatmap (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:heatmap .

<#HelpKeyword>
  rdfs:label "Help (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:help .

<#HexagonKeyword>
  rdfs:label "Hexagon (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:hexagon .
```

```
<#HillshadeKeyword>
   rdfs:label "Hillshade (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:hillshade .

<#HISkeyword>
   rdfs:label "HIS - hue, intensity, saturation (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:HIS .

<#HistogramKeyword>
   rdfs:label "Histogram (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:histogram .

<#HistoryKeyword>
   rdfs:label "History (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:history .

<#HotspotKeyword>
   rdfs:label "Hotspot (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:hotspot .

<#HydrologyKeyword>
   rdfs:label "Hydrology (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:hydrology .

   ####
   # i
   ####

<#IDWkeyword>
   rdfs:label "IDW - Inverse Distance Squared Weighted (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:IDW .

<#IHSkeyword>
  rdfs:label "IHS - intensity, hue, saturation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:HIS .

<#ImagerKeyword>
  rdfs:label "Imagery (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:imagery .

<#ImageryQualityAssessmentKeyword>
  rdfs:label "Imagery quality assessment (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#imagery%20qualit
y%20assessment> .

<#ImportKeyword>
  rdfs:label "Import (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:import .

<#InstallationKeyword>
  rdfs:label "Installation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:installation .

<#InterpolationKeyword>
  rdfs:label "Interpolation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:interpolation .

<#IntersectionKeyword>
  rdfs:label "Intersection (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:intersection .

<#IsolinesKeyword>
  rdfs:label "Isolines (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:isolines .

  ####
  # k
  ####

<#KernelDensityKeyword>
  rdfs:label "Kernel density (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#kernel%20density>
.

<#KernelFilterKeyword>
  rdfs:label "Kernel filter (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#kernel%20filter> .

  ####
  # l
  ####

<#LandFluxKeyword>
  rdfs:label "Land flux (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#land%20flux> .

<#LandSurfaceTemperatureKeyword>
  rdfs:label "Land surface temperature (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#land%20surface%2
0temperature> .
```

```
<#LandformKeyword>
  rdfs:label "Landform (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:landform .

<#LandsatKeyword>
  rdfs:label "Landsat (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:Landsat .

<#LandscapeStructureAnalysisKeyword>
  rdfs:label "Landscape structure analysis (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#landscape%20structure%20analysis> .

<#LatitudeKeyword>
  rdfs:label "Latitude (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:latitude .

<#LayerKeyword>
  rdfs:label "Layer (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:layer .

<#LegendKeyword>
  rdfs:label "Legend (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:legend .

<#Level1Keyword>
  rdfs:label "Level 1 (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:level1 .

<#LicenseKeyword>
```

```
  rdfs:label "License (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:license .

<#LIDARkeyword>
  rdfs:label "LIDAR (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:LIDAR .

<#LineKeyword>
  rdfs:label "Line (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:line .

<#LineOfSightKeyword>
  rdfs:label "Line of sight (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#line%20of%20sigh
t> .

<#LinearReferenceSystemKeyword>
  rdfs:label "Linear reference system (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#linear%20referenc
e%20system> .

<#ListKeyword>
  rdfs:label "List (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:list .

<#LongitudeKeyword>
  rdfs:label "Longitude (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:longitude .

<#LOSkeyword>
```

```
  rdfs:label "LOS - line of sight (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:LOS .

  ####
  # m
  ####

<#ManualKeyword>
  rdfs:label "Manual (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:manual .

<#MapAnnotationsKeyword>
  rdfs:label "Map annotations (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#map%20annotatio
ns> .

<#MapManagementKeyword>
  rdfs:label "Map management (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#map%20managem
ent> .

<#MaskKeyword>
  rdfs:label "Mask (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:mask .

<#MaximumLikelihoodClassificationKeyword>
  rdfs:label "Maximum Likelihood Classification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#Maximum%20Likel
ihood%20Classification> .

<#MeasurementKeyword>
```

```
  rdfs:label "Measurement (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:measurement .

<#MergeKeyword>
  rdfs:label "Merge (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:merge .

<#MetadataKeyword>
  rdfs:label "Metadata (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:metadata .

<#MiscellaneousKeyword>
  rdfs:label "Miscellaneous (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:miscellaneous .

<#MLCkeyword>
  rdfs:label "MLC - Maximum Likelihood Classification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:MLC .

<#ModelKeyword>
  rdfs:label "Model (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:model .

<#MODISKeyword>
  rdfs:label "MODIS (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:MODIS .

<#ModulesKeyword>
  rdfs:label "Modules (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:modules .

<#MonitorsKeyword>
  rdfs:label "Monitors (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:monitors .

<#MosaickingKeyword>
  rdfs:label "Mosaicking (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:mosaicking .

<#MultispectralKeyword>
  rdfs:label "Multispectral (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:multispectral .

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<#NDVIkeyword>
  rdfs:label "NDVI (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:NDVI .

<#NeighborKeyword>
  rdfs:label "Neighbor (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:neighbor .

<#NetRadiationKeyword>
  rdfs:label "Net radiation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#net%20radiation> .

<#NetCDFkeyword>
```

```
  rdfs:label "NetCDF - Network Common Data Form (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:netCDF .

<#NetworkKeyword>
  rdfs:label "Network (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:network .

<#NetworkGeneralizationKeyword>
  rdfs:label "Network generalization (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#network%20gener
alization> .

<#NetworkMaintenanceKeyword>
  rdfs:label "Network maintenance (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#network%20maint
enance> .

<#NodeKeyword>
  rdfs:label "Node (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:node .

<#NullDataKeyword>
  rdfs:label "Null data (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#null%20data> .

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<#ObjectRecognitionKeyword>
  rdfs:label "Object recognition (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#object%20recogniti
on> .

<#OGCwebServicesKeyword>
  rdfs:label "OGC web services (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#OGC%20web%20s
ervices> .

<#OGRkeyword>
  rdfs:label "OGR (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:OGR .

<#OrthorectifyKeyword>
  rdfs:label "Orthorectify (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:orthorectify .

<#OutputKeyword>
  rdfs:label "Output (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:output .

<#OverlandFlowKeyword>
  rdfs:label "Overland flow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#overland%20flow>
.

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<#PaintLabelsKeyword>
  rdfs:label "Paint labels (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#paint%20labels> .

<#PatchIndexKeyword>
  rdfs:label "Patch index (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#patch%20index> .

<#PatchingKeyword>
  rdfs:label "Patching (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:patching .

<#PCAkeyword>
  rdfs:label "PCA - principal components analysis (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:PCA .

<#PercentileKeyword>
  rdfs:label "Percentile (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:percentile .

<#PermissionKeyword>
  rdfs:label "Permission (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:permission .

<#PNGkeyword>
  rdfs:label "PNG (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:PNG .

<#PointKeyword>
  rdfs:label "Point (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:point .
```

```
<#PointCloudKeyword>
  rdfs:label "Point cloud (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#point%20cloud> .

<#PointDensityKeyword>
  rdfs:label "Point density (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#point%20density> .

<#PointPatternKeyword>
  rdfs:label "Point pattern (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#point%20pattern> .

<#PointsKeyword>
  rdfs:label "Points (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:points .

<#PolarKeyword>
  rdfs:label "Polar (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:polar .

<#PositionKeyword>
  rdfs:label "Position (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:position .

<#PostGISkeyword>
  rdfs:label "PostGIS (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:PostGIS .

<#PostscriptKeyword>
```

```
    rdfs:label "Postscript (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/postscript.html> .

<#PrincipalComponentsAnalysisKeyword>
    rdfs:label "Principal components analysis (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#principal%20comp
onents%20analysis> .

<#PrintingKeyword>
    rdfs:label "Printing (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:printing .

<#ProfileKeyword>
    rdfs:label "Profile (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:profile .

<#ProjectionKeyword>
    rdfs:label "Projection (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:projection .

<#ProximityKeyword>
    rdfs:label "Proximity (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:proximity .

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<#QuantileKeyword>
    rdfs:label "Quantile (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:quantile .

<#QuantizationKeyword>
  rdfs:label "Quantization (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:quantization .

<#QueryingKeyword>
  rdfs:label "Querying (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:querying .

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<#RadianceKeyword>
  rdfs:label "Radiance (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:radiance .

<#RadiometricConversionKeyword>
  rdfs:label "Radiometric conversion (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#radiometric%20co
nversion> .

<#RainfallKeyword>
  rdfs:label "Rainfall (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:rainfall .

<#RandomKeyword>
  rdfs:label "Random (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:random .
```

```
<#RasterKeyword>
   rdfs:label "Raster (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/raster> .

<#Raster3dKeyword>
   rdfs:label "Raster 3D (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/raster3d> .

<#RasterizationKeyword>
   rdfs:label "Rasterization (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:rasterization .

<#RateOfSpreadKeyword>
   rdfs:label "Rate of spread (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#rate%20of%20spre
ad> .

<#ReclassKeyword>
   rdfs:label "Reclass (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:reclass .

<#ReclassificationKeyword>
   rdfs:label "Reclassification (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:reclassification .

<#RecodeCategoriesKeyword>
   rdfs:label "Recode categories (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#recode%20categori
es> .
```

```
<#RectifyKeyword>
  rdfs:label "Rectify (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:rectify .

<#ReflectanceKeyword>
  rdfs:label "Reflectance (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:reflectance .

<#RegisterKeyword>
  rdfs:label "Register (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:register .

<#RegressionKeyword>
  rdfs:label "Regression (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:regression .

<#ReliefKeyword>
  rdfs:label "Relief (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:relief .

<#RemoveKeyword>
  rdfs:label "Remove (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:remove .

<#RenameKeyword>
  rdfs:label "Rename (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:rename .

<#ResampleKeyword>
  rdfs:label "Resample (keyword)" ;
```

```
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:resample .

<#RescaleKeyword>
  rdfs:label "Rescale (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:rescale .

<#ResolutionKeyword>
  rdfs:label "Resolution (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:resolution .

<#RGBkeyword>
  rdfs:label "RGB (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:RGB .

<#RhumblineKeyword>
  rdfs:label "Rhumbline (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:rhumbline .

<#RSTkeyword>
  rdfs:label "RST - regularized spline with tension (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:RST .

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<#SalesmanKeyword>
  rdfs:label "Salesman (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:salesman .
```

```
<#SamplingKeyword>
  rdfs:label "Sampling (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:sampling .

<#SatelliteKeyword>
  rdfs:label "Satellite (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:satellite .

<#ScriptsKeyword>
  rdfs:label "Scripts (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:scripts .

<#SearchKeyword>
  rdfs:label "Search (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:search .

<#SearchPathKeyword>
  rdfs:label "Search path (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#search%20path> .

<#SEBALkeyword>
  rdfs:label "SEBAL - surface energy balance algorithm for land (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:SEBAL .

<#SedimentFlowKeyword>
  rdfs:label "Sediment flow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#sediment%20flow>
.

<#SegmentKeyword>
```

```
  rdfs:label "Segment (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:segment .

<#SegmentationKeyword>
  rdfs:label "Segmentation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:segmentation .

<#SelectKeyword>
  rdfs:label "Select (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:select .

<#SeparateKeyword>
  rdfs:label "Separate (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:separate .

<#SeriesKeyword>
  rdfs:label "Series (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:series .

<#SettingsKeyword>
  rdfs:label "Settings (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:settings .

<#ShadowKeyword>
  rdfs:label "Shadow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:shadow .

<#SharpenKeyword>
  rdfs:label "Sharpen (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
```

```
  rdfs:seeAlso gkeywords:sharpen .

<#ShiftKeyword>
  rdfs:label "Shift (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:shift .

<#ShortestPathKeyword>
  rdfs:label "Shortest path (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#shortest%20path> .

<#ShrinkKeyword>
  rdfs:label "Shrink (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:shrink .

<#SignaturesKeyword>
  rdfs:label "Signatures (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:signatures .

<#SimpleFeaturesKeyword>
  rdfs:label "Simple features (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#simple%20features
> .

<#SimplificationKeyword>
  rdfs:label "Simplification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:simplification .

<#SinkKeyword>
  rdfs:label "Sink (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:sink .
```

```
<#SkeletonKeyword>
  rdfs:label "Skeleton (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:skeleton .

<#SlopeKeyword>
  rdfs:label "Slope (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:slope .

<#SMAPkeyword>
  rdfs:label "SMAP - sequential maximum a posteriori (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:SMAP .

<#SmoothingKeyword>
  rdfs:label "Smoothing (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:smoothing .

<#SnappingKeyword>
  rdfs:label "Snapping (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:snapping .

<#SoilKeyword>
  rdfs:label "Soil (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:soil .

<#SoilHeatFluxKeyword>
  rdfs:label "Soil heat flux (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#soil%20heat%20fl
ux> .
```

```
<#SoilMoistureKeyword>
  rdfs:label "Soil moisture (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#soil%20moisture> .

<#SolarKeyword>
  rdfs:label "Solar (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:solar .

<#SoluteTransportKeyword>
  rdfs:label "Solute transport (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#solute%20transpor
t> .

<#SpanningTreeKeyword>
  rdfs:label "Spanning tree (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#spanning%20tree>
.

<#SpatialQueryKeyword>
  rdfs:label "Spatial query (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#spatial%20query> .

<#SplitKeyword>
  rdfs:label "Split (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:split .

<#SPOTkeyword>
  rdfs:label "SPOT (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:SPOT .
```

```
<#SpreadKeyword>
   rdfs:label "Spread (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:spread .

<#SQLkeyword>
   rdfs:label "SQL (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:SQL .

<#StatisticsKeyword>
   rdfs:label "Statistics (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso gkeywords:statistics .

<#SteinerTreeKeyword>
   rdfs:label "Steiner tree (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#steiner%20tree> .

<#StratifiedRandomSamplingKeyword>
   rdfs:label "Stratified random sampling (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#stratified%20rand
om%20sampling> .

<#StreamNetworkKeyword>
   rdfs:label "Stream network (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#stream%20networ
k> .

<#StreamPowerIndexKeyword>
   rdfs:label "Stream power index (keyword)" ;
   rdfs:subClassOf <#Keyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#stream%20power
%20index> .
```

```
<#SunEnergyKeyword>
  rdfs:label "Sun energy (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#sun%20energy> .

<#SunPositionKeyword>
  rdfs:label "Sun position(keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#sun%20position> .

<#SupervisedClassificationKeyword>
  rdfs:label "Supervised classification (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#supervised%20clas
sification> .

<#SupportKeyword>
  rdfs:label "Support (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:support .

<#SurfaceKeyword>
  rdfs:label "Surface (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:surface .

<#SurfaceInformationKeyword>
  rdfs:label "Surface information (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#surface%20inform
ation> .


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```
<#TasseledCapTransformationKeyword>
  rdfs:label "Tasseled Cap transformation flow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#Tasseled%20Cap%
20transformation> .

<#TerrainKeyword>
  rdfs:label "Terrain (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:terrain .

<#TestKeyword>
  rdfs:label "Test (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:test .

<#TextureKeyword>
  rdfs:label "Texture (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:texture .

<#TilingKeyword>
  rdfs:label "Tiling (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:tiling .

<#TimeKeyword>
  rdfs:label "Time (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:time .

<#TimeManagementKeyword>
  rdfs:label "Time management (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#time%20managem
ent> .
```

```
<#TimestampKeyword>
  rdfs:label "Timestamp (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:timestamp .

<#TopographicCorrectionKeyword>
  rdfs:label "Topographic correction (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#topographic%20co
rrection> .

<#TopographicIndexKeyword>
  rdfs:label "Topographic index (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#topographic%20in
dex> .

<#TopologyKeyword>
  rdfs:label "Topology (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:topology .

<#TransectKeyword>
  rdfs:label "Transect (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:transect .

<#TransformationKeyword>
  rdfs:label "Transformation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:transformation .

<#TriangulationKeyword>
  rdfs:label "Triangulation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:triangulation .
```

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<#UnionKeyword>
    rdfs:label "Union (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:union .

<#UnivariateStatisticsKeyword>
    rdfs:label "Univariate statistics (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#univariate%20stati
stics> .

<#UnregisterKeyword>
    rdfs:label "Unregister (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:unregister .

<#UserInterfaceKeyword>
    rdfs:label "User interface (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#user%20interface>
.

    ####
    # v
    ####

<#VariablesKeyword>
    rdfs:label "Variables (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:variables .

<#VectorKeyword>
```

```
  rdfs:label "Vector (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:vector .

<#VectorizationKeyword>
  rdfs:label "Vectorization (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/vector> .

<#VegetationKeyword>
  rdfs:label "Vegetation (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:vegetation .

<#VegetationIndexKeyword>
  rdfs:label "Vegetation index (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#vegetation%20inde
x> .

<#VersionKeyword>
  rdfs:label "Version (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:version .

<#VertexKeyword>
  rdfs:label "Vertex (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:vertex .

<#ViewshedKeyword>
  rdfs:label "Viewshed (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:viewshed .

<#VisibilityKeyword>
  rdfs:label "Visibility (keyword)" ;
```

```
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:visibility .

<#VisualizationKeyword>
    rdfs:label "Visualization (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:visualization .

<#VolumeKeyword>
    rdfs:label "Volume (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:volume .

<#VoxelKeyword>
    rdfs:label "Voxel (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:voxel .

<#VRMLkeyword>
    rdfs:label "VRML - Virtual Reality Modeling Language (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:VRML .

<#VTKkeyword>
    rdfs:label "VTK (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:VTK .

    ####
    # w
    ####

<#WatershedKeyword>
    rdfs:label "Watershed (keyword)" ;
    rdfs:subClassOf <#Keyword> ;
    rdfs:seeAlso gkeywords:watershed .
```

```
<#WetnessKeyword>
  rdfs:label "Wetness (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:wetness .

<#WorkflowKeyword>
  rdfs:label "Workflow (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:workflow .

  ####
  # y
  ####

<#YieldKeyword>
  rdfs:label "Yield (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso gkeywords:yield .

  ####
  # z
  ####

<#ZonalStatisticsKeyword>
  rdfs:label "Zonal statistics (keyword)" ;
  rdfs:subClassOf <#Keyword> ;
  rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/keywords#zonal%20statistics
> .



  ########################################
  # Subclasses of Case Study
  ########################################
```

```
##########################################
# Object properties
##########################################


<#associated_keyword>
  a owl:ObjectProperty ;
  rdfs:label "associated keyword" ;
  rdfs:domain gisop: ;
  rdfs:range <#Keyword> .

<#associated_capability>
  a owl:ObjectProperty ;
  rdfs:label "associated capability" ;
  rdfs:domain gisop: ;
  rdfs:range <#Capability> .


##########################################
# Individuals
##########################################

  #####
  # d.
  #####

<#d.barscale> a gisop: ;
  <#associated_keyword> <#CartographyKeyword> , <#DisplayKeyword> ;
  rdfs:seeAlso gmanuals:d.barscale .

<#d.colorlist> a gisop: ;
  <#associated_keyword> <#ColorsKeyword> , <#SettingsKeyword> , <#DisplayKeyword
> ;
  rdfs:seeAlso gmanuals:d.colorlist .

<#d.colortable> a gisop: ;
  <#associated_keyword> <#ColorTableKeyword> , <#DisplayKeyword> , <#RasterKeyw
```

```
ord> ;
   rdfs:seeAlso gmanuals:d.colortable .

<#d.correlate> a gisop: ;
   <#associated_keyword> <#CorrelationKeyword> , <#DiagramKeyword> , <#DisplayKey
word> , <#RasterKeyword> , <#StatisticsKeyword> ;
   rdfs:seeAlso gmanuals:d.correlate .

<#d.erase> a gisop: ;
   <#associated_keyword> <#GraphicsKeyword> , <#MonitorsKeyword> , <#DisplayKeyw
ord> ;
   rdfs:seeAlso gmanuals:d.erase .

<#d.font> a gisop: ;
   <#associated_keyword> <#SettingsKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.font .

<#d.fontlist> a gisop: ;
   <#associated_keyword> <#SettingsKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.fontlist .

<#d.frame> a gisop: ;
   <#associated_keyword> <#FrameKeyword> , <#GraphicsKeyword> , <#MonitorsKeywo
rd> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.frame .

<#d.geodesic> a gisop: ;
   <#associated_keyword> <#DistanceKeyword> , <#GreatCircleKeyword> , <#ShortestPat
hKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.geodesic .

<#d.graph> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.graph .

<#d.grid> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#GraticuleKeyword> , <#GridKeyw
```

```
ord> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.grid .

<#d.his> a gisop: ;
   <#associated_keyword> <#ColorTransformationKeyword> , <#GraphicsKeyword> , <#
HISkeyword> , <#IHSkeyword> , <#RGBkeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.his .

<#d.histogram> a gisop: ;
   <#associated_keyword> <#HistogramKeyword> , <#StatisticsKeyword> , <#DisplayKey
word> ;
   rdfs:seeAlso gmanuals:d.histogram .

<#d.info> a gisop: ;
   <#associated_keyword> <#GraphicsKeyword> , <#MonitorsKeyword> , <#DisplayKeyw
ord> ;
   rdfs:seeAlso gmanuals:d.info .

<#d.labels> a gisop: ;
   <#associated_keyword> <#PaintLabelsKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.labels .

<#d.legend> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#LegendKeyword> , <#DisplayKey
word> ;
   rdfs:seeAlso gmanuals:d.legend .

<#d.legend.vect> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#LegendKeyword> , <#DisplayKey
word> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:d.legend.vect .

<#d.linegraph> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.linegraph .

<#d.mon> a gisop: ;
```

```
    <#associated_keyword> <#GraphicsKeyword> , <#MonitorsKeyword> , <#DisplayKeyword> ;
    rdfs:seeAlso gmanuals:d.mon .

<#d.northarrow> a gisop: ;
    <#associated_keyword> <#CartographyKeyword> , <#DisplayKeyword> ;
    rdfs:seeAlso gmanuals:d.northarrow .

<#d.out.file> a gisop: ;
    <#associated_keyword> <#ExportKeyword> , <#DisplayKeyword> ;
    rdfs:seeAlso gmanuals:d.out.file .

<#d.path> a gisop: ;
    <#associated_keyword> <#NetworkKeyword> , <#ShortestPathKeyword> , <#DisplayKeyword> ;
    rdfs:seeAlso gmanuals:d.path .

<#d.polar> a gisop: ;
    <#associated_keyword> <#DiagramKeyword> , <#DisplayKeyword> ;
    rdfs:seeAlso gmanuals:d.polar .

<#d.profile> a gisop: ;
    <#associated_keyword> <#ProfileKeyword> , <#DisplayKeyword> , <#RasterKeyword> ;
    rdfs:seeAlso gmanuals:d.profile .

<#d.rast> a gisop: ;
    <#associated_keyword> <#GraphicsKeyword> , <#DisplayKeyword> , <#RasterKeyword> ;
    rdfs:seeAlso gmanuals:d.rast .

<#d.rast.arrow> a gisop: ;
    <#associated_keyword> <#MapAnnotationsKeyword> , <#DisplayKeyword> , <#RasterKeyword> ;
    rdfs:seeAlso gmanuals:d.rast.arrow .

<#d.rast.edit> a gisop: ;
```

```
  <#associated_keyword> <#EditingKeyword> , <#DisplayKeyword> , <#RasterKeyword>
;
  rdfs:seeAlso gmanuals:d.rast.edit .

<#d.rast.leg> a gisop: ;
  <#associated_keyword> <#CartographyKeyword> , <#LegendKeyword> , <#DisplayKey
word> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:d.rast.leg .

<#d.rast.num> a gisop: ;
  <#associated_keyword> <#MapAnnotationsKeyword> , <#DisplayKeyword> , <#Raster
Keyword> ;
  rdfs:seeAlso gmanuals:d.rast.num .

<#d.redraw> a gisop: ;
  <#associated_keyword> <#GraphicsKeyword> , <#MonitorsKeyword> , <#DisplayKeyw
ord> ;
  rdfs:seeAlso gmanuals:d.redraw .

<#d.rgb> a gisop: ;
  <#associated_keyword> <#GraphicsKeyword> , <#RGBkeyword> , <#DisplayKeyword>
, <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:d.rgb .

<#d.rhumbline> a gisop: ;
  <#associated_keyword> <#DistanceKeyword> , <#RhumblineKeyword> , <#DisplayKey
word> ;
  rdfs:seeAlso gmanuals:d.rhumbline .

<#d.shade> a gisop: ;
  <#associated_keyword> <#ElevationKeyword> , <#HillshadeKeyword> , <#ReliefKeywo
rd> , <#VisualizationKeyword> , <#DisplayKeyword> ;
  rdfs:seeAlso gmanuals:d.shade .

<#d.text> a gisop: ;
  <#associated_keyword> <#CartographyKeyword> , <#DisplayKeyword> ;
  rdfs:seeAlso gmanuals:d.text .
```

```
<#d.title> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.title .

<#d.to.rast> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#DisplayKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:d.to.rast .

<#d.vect> a gisop: ;
   <#associated_keyword> <#GraphicsKeyword> , <#Level1Keyword> , <#DisplayKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:d.vect .

<#d.vect.chart> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#ChartMapsKeyword> , <#DisplayKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:d.vect.chart .

<#d.vect.thematic> a gisop: ;
   <#associated_keyword> <#CartographyKeyword> , <#ChoroplethMapKeyword> , <#LegendKeyword> , <#DisplayKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:d.vect.thematic .

<#d.what.rast> a gisop: ;
   <#associated_keyword> <#DisplayKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:d.what.rast .

<#d.what.vect> a gisop: ;
   <#associated_keyword> <#DisplayKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:d.what.vect .

<#d.where> a gisop: ;
   <#associated_keyword> <#PositionKeyword> , <#QueryingKeyword> , <#SamplingKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:d.where .
```

```
#####
# db.
#####

<#db.columns> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> ;
  rdfs:seeAlso gmanuals:db.columns .

<#db.connect> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#ConnectionSettingsKeyword> ,
<#DatabaseKeyword> ;
  rdfs:seeAlso gmanuals:db.connect .

<#db.copy> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#SQLkeyword> , <#DatabaseKey
word> ;
  rdfs:seeAlso gmanuals:db.copy .

<#db.createdb> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#SQLkeyword> , <#DatabaseKey
word> ;
  rdfs:seeAlso gmanuals:db.createdb .

<#db.databases> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#SQLkeyword> , <#DatabaseKey
word> ;
  rdfs:seeAlso gmanuals:db.databases .

<#db.describe> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> ;
  rdfs:seeAlso gmanuals:db.describe .

<#db.drivers> a gisop: ;
  <#associated_keyword> <#ConnectionSettingsKeyword> , <#DatabaseKeyword> ;
  rdfs:seeAlso gmanuals:db.drivers .
```

```
<#db.dropcolumn> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.dropcolumn .

<#db.dropdb> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#SQLkeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.dropdb .

<#db.droptable> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.droptable .

<#db.execute> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> , <#SQLkeyword> ;
   rdfs:seeAlso gmanuals:db.execute .

<#db.in.ogr> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#ImportKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.in.ogr .

<#db.login> a gisop: ;
   <#associated_keyword> <#ConnectionSettingsKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.login .

<#db.out.ogr> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#ExportKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.out.ogr .

<#db.select> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#SQLkeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.select .
```

```
<#db.tables> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.tables .

<#db.test> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.test .

<#db.univar> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#StatisticsKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:db.univar .


   #####
   # g.
   #####

<#g.access> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#PermissionKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.access .

<#g.copy> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.copy .

<#g.dirseps> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#ScriptsKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.dirseps .

<#g.extension> a gisop: ;
   <#associated_keyword> <#AddonsKeyword> , <#DownloadKeyword>, <#ExtensionsKeyword> , <#InstallationKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.extension .
```

```
<#g.extension.all> a gisop: ;
  <#associated_keyword> <#ExtensionsKeyword> , <#InstallationKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.extension.all .

<#g.filename> a gisop: ;
  <#associated_keyword> <#MapManagementKeyword> , <#ScriptsKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.filename .

<#g.findetc> a gisop: ;
  <#associated_keyword> <#MapManagementKeyword> , <#ScriptsKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.findetc .

<#g.findfile> a gisop: ;
  <#associated_keyword> <#MapManagementKeyword> , <#ScriptsKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.findfile .

<#g.gisenv> a gisop: ;
  <#associated_keyword> <#ScriptsKeyword> , <#SettingsKeyword> , <#VariablesKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.gisenv .

<#g.gui> a gisop: ;
  <#associated_keyword> <#UserInterfaceKeyword> , <#GeneralKeyword> , <#GUIkeyword> ;
  rdfs:seeAlso gmanuals:g.gui .

<#g.gui.animation> a gisop: ;
  <#associated_keyword> <#AnimationKeyword> , <#GUIkeyword> , <#GeneralKeyword> , <#DisplayKeyword> ;
  rdfs:seeAlso gmanuals:g.gui.animation .

<#g.gui.datacatalog> a gisop: ;
  <#associated_keyword> <#GUIkeyword> , <#MapManagementKeyword> , <#GeneralKe
```

```
yword> ;
   rdfs:seeAlso gmanuals:g.gui.datacatalog .

<#g.gui.dbmgr> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#GUIkeyword> , <#GeneralKey
word> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.dbmgr .

<#g.gui.gcp> a gisop: ;
   <#associated_keyword> <#GCPkeyword> , <#GeorectificationKeyword> , <#GUIkeywor
d> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.gcp .

<#g.gui.gmodeler> a gisop: ;
   <#associated_keyword> <#GraphicalModelerKeyword> , <#GUIkeyword> , <#Workflow
Keyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.gmodeler .

<#g.gui.iclass> a gisop: ;
   <#associated_keyword> <#ClassificationKeyword> , <#GUIkeyword> , <#SignaturesKey
word> , <#SupervisedClassificationKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.iclass .

<#g.gui.mapswipe> a gisop: ;
   <#associated_keyword> <#GUIkeyword> , <#GeneralKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.mapswipe .

<#g.gui.psmap> a gisop: ;
   <#associated_keyword> <#GUIkeyword> , <#PrintingKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.psmap .

<#g.gui.rlisetup> a gisop: ;
   <#associated_keyword> <#GUIkeyword> , <#LandscapeStructureAnalysisKeyword> , <
#GeneralKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:g.gui.rlisetup .

<#g.gui.timeline> a gisop: ;
```

```
  <#associated_keyword> <#GUIkeyword> , <#GeneralKeyword> , <#TemporalKeyword> ;
  rdfs:seeAlso gmanuals:g.gui.timeline .

<#g.gui.tplot> a gisop: ;
  <#associated_keyword> <#GUIkeyword> , <#GeneralKeyword> , <#TemporalKeyword> ;
  rdfs:seeAlso gmanuals:g.gui.tplot .

<#g.gui.vdigit> a gisop: ;
  <#associated_keyword> <#DigitizerKeyword> , <#EditingKeyword> , <#GUIkeyword> , <#GeneralKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:g.gui.vdigit .

<#g.list> a gisop: ;
  <#associated_keyword> <#ListKeyword> , <#MapManagementKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.list .

<#g.manual> a gisop: ;
  <#associated_keyword> <#HelpKeyword> , <#ManualKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.manual .

<#g.mapset> a gisop: ;
  <#associated_keyword> <#SettingsKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.mapset .

<#g.mapsets> a gisop: ;
  <#associated_keyword> <#SearchPathKeyword> , <#SettingsKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.mapsets .

<#g.message> a gisop: ;
  <#associated_keyword> <#ScriptsKeyword> , <#SupportKeyword> , <#GeneralKeyword> ;
  rdfs:seeAlso gmanuals:g.message .
```

```
<#g.mkfontcap> a gisop: ;
   <#associated_keyword> <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.mkfontcap .

<#g.parser> a gisop: ;
   <#associated_keyword> <#GeneralKeyword> , <#ScriptsKeyword> , <#SupportKeywor
d> ;
   rdfs:seeAlso gmanuals:g.parser .

<#g.pnmcomp> a gisop: ;
   <#associated_keyword> <#GeneralKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:g.pnmcomp .

<#g.ppmtopng> a gisop: ;
   <#associated_keyword> <#GeneralKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:g.ppmtopng .

<#g.proj> a gisop: ;
   <#associated_keyword> <#CreateLocationKeyword> , <#ProjectionKeyword> , <#Gener
alKeyword> ;
   rdfs:seeAlso gmanuals:g.proj .

<#g.region> a gisop: ;
   <#associated_keyword> <#ComputationalRegionKeyword> , <#ExtentKeyword> , <#Le
vel1Keyword> , <#ResolutionKeyword> , <#SettingsKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.region .

<#g.remove> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#RemoveKeyword> , <#Gener
alKeyword> ;
   rdfs:seeAlso gmanuals:g.remove .

<#g.rename> a gisop: ;
   <#associated_keyword> <#RenameKeyword> , <#GeneralKeyword> , <#MapManageme
ntKeyword> ;
   rdfs:seeAlso gmanuals:g.rename .
```

```
<#g.search.modules> a gisop: ;
   <#associated_keyword> <#ModulesKeyword> , <#SearchKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.search.modules .

<#g.tempfile> a gisop: ;
   <#associated_keyword> <#ScriptsKeyword> , <#SupportKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.tempfile .

<#g.version> a gisop: ;
   <#associated_keyword> <#CitingKeyword> , <#CopyrightKeyword> , <#LicenseKeyword> , <#SupportKeyword> , <#VersionKeyword> , <#GeneralKeyword> ;
   rdfs:seeAlso gmanuals:g.version .


   #####
   # i.
   #####

<#i.albedo> a gisop: ;
   <#associated_keyword> <#AlbedoKeyword> , <#ASTERkeyword>, <#AVHRRkeyword> , <#LandsatKeyword> , <#MODISkeyword> , <#ReflectanceKeyword> , <#SatelliteKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.albedo .

<#i.aster.toar> a gisop: ;
   <#associated_keyword> <#ASTERkeyword> , <#BrightnessTemperatureKeyword> , <#RadianceKeyword> , <#RadiometricConversionKeyword> , <#ReflectanceKeyword> , <#SatelliteKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.aster.toar .

<#i.atcorr> a gisop: ;
   <#associated_keyword> <#AtmosphericCorrectionKeyword> , <#RadianceKeyword> , <#RadiometricConversionKeyword> , <#ReflectanceKeyword> , <#SatelliteKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.atcorr .
```

```
<#i.biomass> a gisop: ;
   <#associated_keyword> <#BiomassKeyword> , <#FPARkeyword> , <#YieldKeyword> ,
<#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.biomass .

<#i.cca> a gisop: ;
   <#associated_keyword> <#CanonicalComponentsAnalysisKeyword> , <#CCAkeyword> ,
 <#StatisticsKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.cca .

<#i.cluster> a gisop: ;
   <#associated_keyword> <#ClassificationKeyword> , <#SignaturesKeyword> , <#Imager
yKeyword> ;
   rdfs:seeAlso gmanuals:i.cluster .

<#i.colors.enhance> a gisop: ;
   <#associated_keyword> <#RGBkeyword> , <#SatelliteKeyword> , <#ColorsKeyword>, <
#ImageryKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.colors.enhance .

<#i.eb.eta> a gisop: ;
   <#associated_keyword> <#ActualEvapotranspirationKeyword> , <#EnergyBalanceKey
word> , <#SEBALkeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.eb.eta .

<#i.eb.evapfr> a gisop: ;
   <#associated_keyword> <#EnergyBalanceKeyword> , <#EvaporativeFractionKeyword>
 , <#SEBALkeyword> , <#SoilMoistureKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.eb.evapfr .

<#i.eb.hsebal01> a gisop: ;
   <#associated_keyword> <#EnergyBalanceKeyword> , <#EvaporativeFractionKeyword>
 , <#SEBALkeyword> , <#SoilMoistureKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.eb.hsebal01 .

<#i.eb.netrad> a gisop: ;
```

```
  <#associated_keyword> <#EnergyBalanceKeyword> , <#NetRadiationKeyword> , <#SE
BALkeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.eb.netrad .

<#i.eb.soilheatflux> a gisop: ;
  <#associated_keyword> <#EnergyBalanceKeyword> , <#SEBALkeyword> , <#SoilHeatF
luxKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.eb.soilheatflux .

<#i.emissivity> a gisop: ;
  <#associated_keyword> <#EmissivityKeyword> , <#EnergyBalanceKeyword> , <#Land
FluxKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.emissivity .

<#i.evapo.mh> a gisop: ;
  <#associated_keyword> <#EvapotranspirationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.evapo.mh .

<#i.evapo.pm> a gisop: ;
  <#associated_keyword> <#EvapotranspirationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.evapo.pm .

<#i.evapo.pt> a gisop: ;
  <#associated_keyword> <#EvapotranspirationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.evapo.pt .

<#i.evapo.time> a gisop: ;
  <#associated_keyword> <#EvapotranspirationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.evapo.time .

<#i.fft> a gisop: ;
  <#associated_keyword> <#FastFourierTransformKeyword> , <#TransformationKeywor
d> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.fft .

<#i.gensig> a gisop: ;
  <#associated_keyword> <#ClassificationKeyword> , <#MaximumLikelihoodClassificatio
```

```
nKeyword> , <#MLCkeyword> , <#SignaturesKeyword> , <#SupervisedClassificationKeyw
ord> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.gensig .

<#i.gensigset> a gisop: ;
  <#associated_keyword> <#ClassificationKeyword> , <#SignaturesKeyword> , <#SMAPk
eyword> , <#SupervisedClassificationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.gensigset .

<#i.group> a gisop: ;
  <#associated_keyword> <#MapManagementKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.group .

<#i.his.rgb> a gisop: ;
  <#associated_keyword> <#ColorTransformationKeyword> , <#HISkeyword> , <#IHSkey
word> , <#RGBkeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.his.rgb .

<#i.ifft> a gisop: ;
  <#associated_keyword> <#FastFourierTransformKeyword> , <#TransformationKeywor
d> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.ifft .

<#i.image.mosaic> a gisop: ;
  <#associated_keyword> <#GeometryKeyword> , <#MosaickingKeyword> , <#ImageryK
eyword> ;
  rdfs:seeAlso gmanuals:i.image.mosaic .

<#i.in.spotvgt> a gisop: ;
  <#associated_keyword> <#ImportKeyword> , <#NDVIkeyword> , <#SPOTkeyword> , <
#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.in.spotvgt .

<#i.landsat.acca> a gisop: ;
  <#associated_keyword> <#ACCAkeyword> , <#CloudDetectionKeyword> , <#LandsatKe
yword> , <#SatelliteKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.landsat.acca .
```

```
<#i.landsat.toar> a gisop: ;
  <#associated_keyword> <#AtmosphericCorrectionKeyword> , <#BrightnessTemperatureKeyword> , <#LandsatKeyword> , <#RadianceKeyword> , <#RadiometricConversionKeyword> , <#ReflectanceKeyword> , <#SatelliteKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.landsat.toar .

<#i.maxlik> a gisop: ;
  <#associated_keyword> <#ClassificationKeyword> , <#MaximumLikelihoodClassificationKeyword> , <#MLCkeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.maxlik .

<#i.modis.qc> a gisop: ;
  <#associated_keyword> <#ImageryQualityAssessmentKeyword> , <#LandSurfaceTemperatureKeyword> , <#MODISkeyword> , <#ReflectanceKeyword> , <#SatelliteKeyword> , <#VegetationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.modis.qc .

<#i.oif> a gisop: ;
  <#associated_keyword> <#MultisprectalKeyword> , <#StatisticsKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.oif .

<#i.ortho.camera> a gisop: ;
  <#associated_keyword> <#OrthorectifyKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.ortho.camera .

<#i.ortho.elev> a gisop: ;
  <#associated_keyword> <#OrthorectifyKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.ortho.elev .

<#i.ortho.rectify> a gisop: ;
  <#associated_keyword> <#OrthorectifyKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.ortho.rectify .

<#i.pansharpen> a gisop: ;
  <#associated_keyword> <#Broveykeyword> , <#Fusionkeyword> , <#HISkeyword> , <#
```

```
IHSkeyword> , <#PCAkeyword> , <#SharpenKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.pansharpen .

<#i.pca> a gisop: ;
   <#associated_keyword> <#PCAkeyword> , <#PrincipalComponentsAnalysisKeyword> ,
<#ImageryKeyword> , <#TransformationKeyword> ;
   rdfs:seeAlso gmanuals:i.pca .

<#i.rectify> a gisop: ;
   <#associated_keyword> <#RectifyKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.rectify .

<#i.rgb.his> a gisop: ;
   <#associated_keyword> <#ColorTransformationKeyword> , <#HISkeyword> , <#IHSkey
word> , <#RGBkeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.rgb.his .

<#i.segment> a gisop: ;
   <#associated_keyword> <#ClassificationKeyword> , <#ObjectRecognitionKeyword> , <
#SegmentationKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.segment .

<#i.smap> a gisop: ;
   <#associated_keyword> <#ClassificationKeyword> , <#SegmentationKeyword> , <#SM
APkeyword> , <#SupervisedClassificationKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.smap .

<#i.spectral> a gisop: ;
   <#associated_keyword> <#MultisprectalKeyword> , <#QueryingKeyword> , <#Imagery
Keyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:i.spectral .

<#i.target> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#ImageryKeyword> ;
   rdfs:seeAlso gmanuals:i.target .

<#i.tasscap> a gisop: ;
```

```
  <#associated_keyword> <#LandsatKeyword> , <#MODISkeyword> , <#TasseledCapTransformationKeyword> , <#TransformationKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.tasscap .

<#i.topo.corr> a gisop: ;
  <#associated_keyword> <#TerrainKeyword> , <#TopographicCorrectionKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.topo.corr .

<#i.vi> a gisop: ;
  <#associated_keyword> <#BiophysicalParametersKeyword> , <#VegetationIndexKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.vi.html .

<#i.zc> a gisop: ;
  <#associated_keyword> <#EdgesKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:i.zc .


  #####
  # m.
  #####

<#m.cogo> a gisop: ;
  <#associated_keyword> <#DistanceKeyword> , <#MiscellaneousKeyword> , <#PolarKeyword> ;
  rdfs:seeAlso gmanuals:m.cogo .

<#m.measure> a gisop: ;
  <#associated_keyword> <#AreaKeyword> , <#DistanceKeyword> , <#MeasurementKeyword> , <#MiscellaneousKeyword> ;
  rdfs:seeAlso gmanuals:m.measure .

<#m.nviz.image> a gisop: ;
  <#associated_keyword> <#GraphicsKeyword> , <#MiscellaneousKeyword> , <#VisualizationKeyword> , <#RasterKeyword> , <#VectorKeyword> , <#Raster3dKeyword> ;
  rdfs:seeAlso gmanuals:m.nviz.image .
```

```
<#m.nviz.script> a gisop: ;
   <#associated_keyword> <#GraphicsKeyword> , <#MiscellaneousKeyword> , <#Visualiz
ationKeyword> , <#RasterKeyword> , <#VectorKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:m.nviz.script .

<#m.proj> a gisop: ;
   <#associated_keyword> <#MiscellaneousKeyword> , <#ProjectionKeyword> , <#Transf
ormationKeyword> ;
   rdfs:seeAlso gmanuals:m.proj .

<#m.transform> a gisop: ;
   <#associated_keyword> <#GCPkeyword> , <#MiscellaneousKeyword> , <#Transformati
onKeyword> ;
   rdfs:seeAlso gmanuals:m.transform .

   #####
   # ps.
   #####

<#ps.map> a gisop: ;
   <#associated_keyword> <#PrintingKeyword> , <#PostscriptKeyword> ;
   rdfs:seeAlso gmanuals:ps.map .

   #####
   # r.
   #####

<#r.basins.fill> a gisop: ;
   <#associated_keyword> <#HydrologyKeyword> , <#WatershedKeyword> , <#RasterKe
yword> ;
   rdfs:seeAlso gmanuals:r.basins.fill .

<#r.blend> a gisop: ;
   <#associated_keyword> <#CompositeKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.blend .
```

```
<#r.buffer> a gisop: ;
   <#associated_keyword> <#BufferKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.buffer .

<#r.buffer.lowmem> a gisop: ;
   <#associated_keyword> <#BufferKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.buffer.lowmem .

<#r.carve> a gisop: ;
   <#associated_keyword> <#HydrologyKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.carve .

<#r.category> a gisop: ;
   <#associated_keyword> <#CategoryKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.category .

<#r.circle> a gisop: ;
   <#associated_keyword> <#BufferKeyword> , <#CircleKeyword> , <#GeometryKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.circle .

<#r.clump> a gisop: ;
   <#associated_keyword> <#ClumpsKeyword> , <#ReclassKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.clump .

<#r.coin> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.coin .

<#r.colors> a gisop: ;
   <#associated_keyword> <#ColorTableKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.colors .

<#r.colors.out> a gisop: ;
   <#associated_keyword> <#ColorTableKeyword> , <#ExportKeyword> , <#RasterKeyword> ;
```

```
   rdfs:seeAlso gmanuals:r.colors.out .

<#r.colors.stddev> a gisop: ;
   <#associated_keyword> <#ColorTableKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.colors.stddev .

<#r.composite> a gisop: ;
   <#associated_keyword> <#CompositeKeyword> , <#RGBkeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.composite .

<#r.compress> a gisop: ;
   <#associated_keyword> <#CompressionKeyword> , <#MapManagementKeyword> , <#
RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.compress .

<#r.contour> a gisop: ;
   <#associated_keyword> <#ContoursKeyword> , <#SurfaceKeyword> , <#RasterKeywor
d> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:r.contour .

<#r.cost> a gisop: ;
   <#associated_keyword> <#CostAllocationKeyword> , <#CostSurfaceKeyword> , <#Cum
ulativeCostsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.cost .

<#r.covar> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.covar .

<#r.cross> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.cross .

<#r.describe> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.describe .
```

```
<#r.distance> a gisop: ;
   <#associated_keyword> <#DistanceKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.distance .

<#r.drain> a gisop: ;
   <#associated_keyword> <#CostSurfaceKeyword> , <#HydrologyKeyword> , <#RasterKe
yword> ;
   rdfs:seeAlso gmanuals:r.drain .

<#r.external> a gisop: ;
   <#associated_keyword> <#ExternalKeyword> , <#ImportKeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.external .

<#r.external.out> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#ExternalKeyword> , <#OutputKeyword
> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.external.out .

<#r.fill.dir> a gisop: ;
   <#associated_keyword> <#DepressionsKeyword> , <#FillSinksKeyword> , <#Hydrology
Keyword> , <#SinkKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.fill.dir .

<#r.fillnulls> a gisop: ;
   <#associated_keyword> <#ElevationKeyword> , <#InterpolationKeyword> , <#RasterK
eyword> ;
   rdfs:seeAlso gmanuals:r.fillnulls .

<#r.flow> a gisop: ;
   <#associated_keyword> <#HydrologyKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.flow .

<#r.grow> a gisop: ;
   <#associated_keyword> <#DistanceKeyword> , <#ProximityKeyword> , <#RasterKeyw
ord> ;
```

```
  rdfs:seeAlso gmanuals:r.grow .

<#r.grow.distance> a gisop: ;
  <#associated_keyword> <#DistanceKeyword> , <#ProximityKeyword> , <#RasterKeyw
ord> ;
  rdfs:seeAlso gmanuals:r.grow.distance .

<#r.gwflow> a gisop: ;
  <#associated_keyword> <#GroundwaterFlowKeyword> , <#HydrologyKeyword> , <#Ra
sterKeyword> ;
  rdfs:seeAlso gmanuals:r.gwflow .

<#r.his> a gisop: ;
  <#associated_keyword> <#ColorTransformationKeyword> , <#HISkeyword> , <#IHSkey
word> , <#RGBkeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.his .

<#r.horizon> a gisop: ;
  <#associated_keyword> <#SolarKeyword> , <#SunPositionKeyword> , <#RasterKeywor
d> ;
  rdfs:seeAlso gmanuals:r.horizon .

<#r.import> a gisop: ;
  <#associated_keyword> <#ImportKeyword> , <#ProjectionKeyword> , <#RasterKeywo
rd> ;
  rdfs:seeAlso gmanuals:r.import .

<#r.in.ascii> a gisop: ;
  <#associated_keyword> <#ASCIIkeyword> , <#ConversionKeyword> , <#ImportKeywor
d> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.in.ascii .

<#r.in.aster> a gisop: ;
  <#associated_keyword> <#ASTERkeyword> , <#ElevationKeyword> , <#ImportKeywor
d> , <#RasterKeyword> , <#ImageryKeyword> ;
  rdfs:seeAlso gmanuals:r.in.aster .
```

```
<#r.in.bin> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.bin .

<#r.in.gdal> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.gdal .

<#r.in.gridatb> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.gridatb .

<#r.in.lidar> a gisop: ;
   <#associated_keyword> <#AggregationKeyword>, <#BinningKeyword>, <#Conversion
Keyword> , <#ImportKeyword> , <#LIDARkeyword> , <#StatisticsKeyword> , <#RasterKe
yword> ;
   rdfs:seeAlso gmanuals:r.in.lidar .

<#r.in.mat> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.mat .

<#r.in.png> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#PNGkeyword> , <#RasterKeyword> ;
   rdfs:seeAlso <https://grass.osgeo.org/grass72/manuals/r.in.png> .

<#r.in.poly> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.poly .

<#r.in.srtm> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.srtm .

<#r.in.wms> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#OGCwebServicesKeyword> , <#Raster
Keyword> ;
```

```
   rdfs:seeAlso gmanuals:r.in.wms .

<#r.in.xyz> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#ASCIIkeyword>, <#BinningKeywo
rd>, <#ConversionKeyword> , <#ImportKeyword> , <#LIDARkeyword> , <#StatisticsKey
word> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.in.xyz .

<#r.info> a gisop: ;
   <#associated_keyword> <#ExtentKeyword> , <#HistoryKeyword> , <#MetadataKeywor
d> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.info .

<#r.kappa> a gisop: ;
   <#associated_keyword> <#ClassificationKeyword> , <#StatisticsKeyword> , <#RasterKe
yword> ;
   rdfs:seeAlso gmanuals:r.kappa .

<#r.lake> a gisop: ;
   <#associated_keyword> <#FloodKeyword> , <#HazardKeyword> , <#HydrologyKeywor
d> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.lake .

<#r.latlong> a gisop: ;
   <#associated_keyword> <#LatitudeKeyword> , <#LongitudeKeyword> , <#ProjectionKe
yword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.latlong .

<#r.li> a gisop: ;
   <#associated_keyword> <#RasterKeyword> , <#LandscapeStructureAnalysisKeyword>
, <#PatchIndexKeyword> , <#DiversityIndexKeyword>  ;
   rdfs:seeAlso gmanuals:r.li .

<#r.li.cwed> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyw
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.cwed .
```

```
<#r.li.daemon> a gisop: ;
   <#associated_keyword> <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.daemon .

<#r.li.dominance> a gisop: ;
   <#associated_keyword> <#DiversityIndexKeyword> , <#LandscapeStructureAnalysisKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.dominance .

<#r.li.edgedensity> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.edgedensity .

<#r.li.mpa> a gisop: ;
   <#associated_keyword> <#PatchIndexKeyword> , <#RasterKeyword> , <#LandscapeStructureAnalysisKeyword> ;
   rdfs:seeAlso gmanuals:r.li.mpa .

<#r.li.mps> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.mps .

<#r.li.padcv> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.padcv .

<#r.li.padrange> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.padrange .

<#r.li.padsd> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyw
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```
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.padsd .

<#r.li.patchdensity> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyw
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.patchdensity .

<#r.li.patchnum> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyw
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.patchnum .

<#r.li.pielou> a gisop: ;
   <#associated_keyword> <#DiversityIndexKeyword> , <#LandscapeStructureAnalysisKe
yword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.pielou .

<#r.li.renyi> a gisop: ;
   <#associated_keyword> <#DiversityIndexKeyword> , <#LandscapeStructureAnalysisKe
yword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.renyi .

<#r.li.richness> a gisop: ;
   <#associated_keyword> <#DiversityIndexKeyword> , <#LandscapeStructureAnalysisKe
yword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.richness .

<#r.li.shannon> a gisop: ;
   <#associated_keyword> <#DiversityIndexKeyword> , <#LandscapeStructureAnalysisKe
yword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.shannon .

<#r.li.shape> a gisop: ;
   <#associated_keyword> <#LandscapeStructureAnalysisKeyword> , <#PatchIndexKeyw
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.shape .
```

```
<#r.li.simpson> a gisop: ;
   <#associated_keyword> <#DiversityIndexKeyword> , <#LandscapeStructureAnalysisKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.li.simpson .

<#r.mapcalc> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.mapcalc .

<#r.mask> a gisop: ;
   <#associated_keyword> <#MaskKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.mask .

<#r.mfilter> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#FilterKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.mfilter .

<#r.mode> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.mode .

<#r.neighbors> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#AlgebraKeyword> , <#FilterKeyword> , <#FocalStatisticsKeyword> , <#NeighborKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.neighbors .

<#r.null> a gisop: ;
   <#associated_keyword> <#NullDataKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.null .

<#r.out.ascii> a gisop: ;
   <#associated_keyword> <#ASCIIkeyword> , <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.ascii .
```

```
<#r.out.bin> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.bin .

<#r.out.gdal> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.gdal .

<#r.out.gridatb> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.gridatb .

<#r.out.mat> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.mat .

<#r.out.mpeg> a gisop: ;
   <#associated_keyword> <#AnimationKeyword>, <#ExportKeyword> , <#RasterKeywor
d> ;
   rdfs:seeAlso gmanuals:r.out.mpeg .

<#r.out.png> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#PNGkeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.png .

<#r.out.pov> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.pov .

<#r.out.ppm> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.ppm .

<#r.out.ppm3> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.ppm3 .
```

```
<#r.out.vrml> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#VRMLkeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.vrml .

<#r.out.vtk> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#VTKkeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.vtk .

<#r.out.xyz> a gisop: ;
   <#associated_keyword> <#ASCIIkeyword>, <#ConversionKeyword>, <#ExportKeyword
> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.out.xyz .

<#r.pack> a gisop: ;
   <#associated_keyword> <#CopyingKeyword>, <#ExportKeyword> , <#RasterKeyword>
 ;
   rdfs:seeAlso gmanuals:r.pack .

<#r.param.scale> a gisop: ;
   <#associated_keyword> <#ElevationKeyword> , <#GeomorphologyKeyword> , <#Landf
ormKeyword> , <#TerrainKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.param.scale .

<#r.patch> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#GeometryKeyword> , <#MergeKe
yword> , <#MosaickingKeyword> , <#PatchingKeyword> , <#SeriesKeyword> , <#RasterK
eyword> ;
   rdfs:seeAlso gmanuals:r.patch .

<#r.plane> a gisop: ;
   <#associated_keyword> <#ElevationKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.plane .

<#r.profile> a gisop: ;
   <#associated_keyword> <#ProfileKeyword> , <#TransectKeyword> , <#RasterKeyword
> ;
```

```
   rdfs:seeAlso gmanuals:r.profile .

<#r.proj> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#ProjectionKeyword> , <#Transformati
onKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.proj .

<#r.quant> a gisop: ;
   <#associated_keyword> <#QuantizationKeyword> , <#StatisticsKeyword> , <#RasterKe
yword> ;
   rdfs:seeAlso gmanuals:r.quant .

<#r.quantile> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#PercentileKeyword> , <#QuantileKey
word> , <#StatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.quantile .

<#r.random> a gisop: ;
   <#associated_keyword> <#Level1Keyword> , <#RandomKeyword> , <#SamplingKeywo
rd> , <#RasterKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:r.random .

<#r.random.cells> a gisop: ;
   <#associated_keyword> <#AutocorrelationKeyword> , <#RandomKeyword> , <#Sampli
ngKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.random.cells .

<#r.random.surface> a gisop: ;
   <#associated_keyword> <#RandomKeyword> , <#SurfaceKeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.random.surface .

<#r.reclass> a gisop: ;
   <#associated_keyword> <#ReclassificationKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.reclass .

<#r.reclass.area> a gisop: ;
```

```
  <#associated_keyword> <#AggregationKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.reclass.area .

<#r.recode> a gisop: ;
  <#associated_keyword> <#ReclassificationKeyword> , <#RecodeCategoriesKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.recode .

<#r.region> a gisop: ;
  <#associated_keyword> <#MetadataKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.region .

<#r.regression.line> a gisop: ;
  <#associated_keyword> <#RegressionKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.regression.line .

<#r.regression.multi> a gisop: ;
  <#associated_keyword> <#RegressionKeyword> , <#StatisticsKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.regression.multi .

<#r.relief> a gisop: ;
  <#associated_keyword> <#ElevationKeyword> , <#HillshadeKeyword> , <#ReliefKeyword> , <#TerrainKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.relief .

<#r.report> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.report .

<#r.resamp.bspline> a gisop: ;
  <#associated_keyword> <#InterpolationKeyword> , <#ResampleKeyword> , <#SurfaceKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.resamp.bspline .
```

```
<#r.resamp.filter> a gisop: ;
   <#associated_keyword> <#FilterKeyword> , <#KernelFilterKeyword> , <#ResampleKey
word> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.resamp.filter .

<#r.resamp.interp> a gisop: ;
   <#associated_keyword> <#InterpolationKeyword> , <#ResampleKeyword> , <#RasterK
eyword> ;
   rdfs:seeAlso gmanuals:r.resamp.interp .

<#r.resamp.rst> a gisop: ;
   <#associated_keyword> <#ResampleKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.resamp.rst .

<#r.resamp.stats> a gisop: ;
   <#associated_keyword> <#ResampleKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.resamp.stats .

<#r.resample> a gisop: ;
   <#associated_keyword> <#ResampleKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.resample .

<#r.rescale.eq> a gisop: ;
   <#associated_keyword> <#RescaleKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.rescale.eq .

<#r.rescale> a gisop: ;
   <#associated_keyword> <#RescaleKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.rescale .

<#r.rgb> a gisop: ;
   <#associated_keyword> <#RGBkeyword> , <#SeparateKeyword> , <#SplitKeyword> , <
#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.rgb .

<#r.ros> a gisop: ;
   <#associated_keyword> <#FireKeyword> , <#HazardKeyword> , <#ModelKeyword> , <
```

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#RateOfSpreadKeyword> , <#SpreadKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.ros .

<#r.series> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#SeriesKeyword> , <#RasterKeyw
ord> ;
   rdfs:seeAlso gmanuals:r.series .

<#r.series.accumulate> a gisop: ;
   <#associated_keyword> <#AccumulationKeyword> , <#SeriesKeyword> , <#RasterKey
word> ;
   rdfs:seeAlso gmanuals:r.series.accumulate .

<#r.series.interp> a gisop: ;
   <#associated_keyword> <#InterpolationKeyword> , <#SeriesKeyword> , <#RasterKeyw
ord> ;
   rdfs:seeAlso gmanuals:r.series.interp .

<#r.shade> a gisop: ;
   <#associated_keyword> <#ElevationKeyword> , <#HillshadeKeyword> , <#ReliefKeywo
rd> , <#VisualizationKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.shade .

<#r.sim.sediment> a gisop: ;
   <#associated_keyword> <#DepositionKeyword> , <#ErosionKeyword> , <#HydrologyK
eyword> , <#ModelKeyword> , <#SedimentFlowKeyword> , <#SoilKeyword> , <#RasterK
eyword> ;
   rdfs:seeAlso gmanuals:r.sim.sediment .

<#r.sim.water> a gisop: ;
   <#associated_keyword> <#FlowKeyword> , <#ModelKeyword> , <#OverlandFlowKeyw
ord> , <#SoilKeyword> , <#RasterKeyword> , <#HydrologyKeyword> ;
   rdfs:seeAlso gmanuals:r.sim.water .

<#r.slope.aspect> a gisop: ;
   <#associated_keyword> <#AspectKeyword> , <#CurvatureKeyword> , <#SlopeKeyword
> , <#TerrainKeyword> , <#RasterKeyword> ;
```

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  rdfs:seeAlso gmanuals:r.slope.aspect .

<#r.solute.transport> a gisop: ;
  <#associated_keyword> <#HydrologyKeyword> , <#SoluteTransportKeyword> , <#Rast
erKeyword> ;
  rdfs:seeAlso gmanuals:r.solute.transport .

<#r.spread> a gisop: ;
  <#associated_keyword> <#FireKeyword> , <#HazardKeyword> , <#ModelKeyword> , <
#SpreadKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.spread .

<#r.spreadpath> a gisop: ;
  <#associated_keyword> <#CumulativeCostsKeyword> , <#FireKeyword> , <#RasterKey
word> ;
  rdfs:seeAlso gmanuals:r.spreadpath .

<#r.statistics> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#ZonalStatisticsKeyword> , <#Raster
Keyword> ;
  rdfs:seeAlso gmanuals:r.statistics .

<#r.stats> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.stats .

<#r.stats.quantile> a gisop: ;
  <#associated_keyword> <#PercentileKeyword> , <#QuantileKeyword> , <#StatisticsKey
word> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.stats.quantile .

<#r.stats.zonal> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#ZonalStatisticsKeyword> , <#Raster
Keyword> ;
  rdfs:seeAlso gmanuals:r.stats.zonal .

<#r.stream.extract> a gisop: ;
```

<#associated_keyword> <#HydrologyKeyword> , <#StreamNetworkKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.stream.extract .

<#r.sun> a gisop: ;
<#associated_keyword> <#ShadowKeyword> , <#SolarKeyword> , <#SunEnergyKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.sun .

<#r.sunhours> a gisop: ;
<#associated_keyword> <#SolarKeyword> , <#SunEnergyKeyword> , <#SunPositionKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.sunhours .

<#r.sunmask> a gisop: ;
<#associated_keyword> <#ShadowKeyword> , <#SolarKeyword> , <#SunPositionKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.sunmask .

<#r.support> a gisop: ;
<#associated_keyword> <#MetadataKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.support .

<#r.support.stats> a gisop: ;
<#associated_keyword> <#StatisticsKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.support.stats .

<#r.surf.area> a gisop: ;
<#associated_keyword> <#AreaEstimationKeyword> , <#StatisticsKeyword> , <#SurfaceKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.surf.area .

<#r.surf.contour> a gisop: ;
<#associated_keyword> <#InterpolationKeyword> , <#SurfaceKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:r.surf.contour .

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<#r.surf.fractal> a gisop: ;
   <#associated_keyword> <#FractalKeyword> , <#SurfaceKeyword> , <#RasterKeyword>
 ;
   rdfs:seeAlso gmanuals:r.surf.fractal .

<#r.surf.gauss> a gisop: ;
   <#associated_keyword> <#RandomKeyword> , <#SurfaceKeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.surf.gauss .

<#r.surf.idw> a gisop: ;
   <#associated_keyword> <#IDWkeyword> , <#InterpolationKeyword> , <#SurfaceKeyw
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.surf.idw .

<#r.surf.random> a gisop: ;
   <#associated_keyword> <#RandomKeyword> , <#SurfaceKeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.surf.random .

<#r.terraflow> a gisop: ;
   <#associated_keyword> <#AccumulationKeyword> , <#FlowKeyword> , <#HydrologyK
eyword> , <#SinkKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.terraflow .

<#r.texture> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#StatisticsKeyword> , <#TextureKeywo
rd> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.texture .

<#r.thin> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.thin .

<#r.tile> a gisop: ;
   <#associated_keyword> <#TilingKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.tile .
```

```
<#r.tileset> a gisop: ;
   <#associated_keyword> <#TilingKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.tileset .

<#r.timestamp> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#TimeKeyword> , <#TimestampKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.timestamp .

<#r.to.rast3> a gisop: ;
   <#associated_keyword> <#ConversionKeyword> , <#VoxelKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.to.rast3 .

<#r.to.rast3elev> a gisop: ;
   <#associated_keyword> <#ConversionKeyword> , <#VoxelKeyword> , <#RasterKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r.to.rast3elev .

<#r.to.vect> a gisop: ;
   <#associated_keyword> <#ConversionKeyword> , <#GeometryKeyword> , <#VectorizationKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.to.vect .

<#r.topidx> a gisop: ;
   <#associated_keyword> <#HydrologyKeyword> , <#TopographicIndexKeyword> , <#WetnessKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.topidx .

<#r.topmodel> a gisop: ;
   <#associated_keyword> <#HydrologyKeyword> , <#ModelKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.topmodel .

<#r.transect> a gisop: ;
   <#associated_keyword> <#ProfileKeyword> , <#TransectKeyword> , <#RasterKeyword
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> ;
   rdfs:seeAlso gmanuals:r.transect .

<#r.univar> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#UnivariateStatisticsKeyword> , <#Zo
nalStatisticsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.univar .

<#r.unpack> a gisop: ;
   <#associated_keyword> <#CopyingKeyword> , <#ImportKeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.unpack .

<#r.uslek> a gisop: ;
   <#associated_keyword> <#ErosionKeyword> , <#HydrologyKeyword> , <#SoilKeyword
> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.uslek .

<#r.usler> a gisop: ;
   <#associated_keyword> <#ErosionKeyword> , <#HydrologyKeyword> , <#RainfallKeyw
ord> , <#SoilKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.usler .

<#r.viewshed> a gisop: ;
   <#associated_keyword> <#LineOfSightKeyword> , <#LOSkeyword> , <#ViewshedKeyw
ord> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.viewshed .

<#r.volume> a gisop: ;
   <#associated_keyword> <#ClumpsKeyword> , <#VolumeKeyword> , <#RasterKeyword
> ;
   rdfs:seeAlso gmanuals:r.volume .

<#r.walk> a gisop: ;
   <#associated_keyword> <#CostAllocationKeyword> , <#CostSurfaceKeyword> , <#Cum
ulativeCostsKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r.walk .
```

```
<#r.water.outlet> a gisop: ;
  <#associated_keyword> <#HydrologyKeyword> , <#WatershedKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.water.outlet .

<#r.watershed> a gisop: ;
  <#associated_keyword> <#AccumulationKeyword> , <#DrainageKeyword> , <#HydrologyKeyword> , <#StreamNetworkKeyword> , <#StreamPowerIndexKeyword> , <#TopographicIndexKeyword> , <#WatershedKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.watershed .

<#r.what> a gisop: ;
  <#associated_keyword> <#PositionKeyword> , <#QueryingKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:r.what .

<#r.what.color> a gisop: ;
  <#associated_keyword> <#ColorTableKeyword> , <#RasterKeyword> , <#QueryingKeyword> ;
  rdfs:seeAlso gmanuals:r.what.color .

  #####
  # r3.
  #####

<#r3.colors> a gisop: ;
  <#associated_keyword> <#ColorTableKeyword> , <#Raster3dKeyword> ;
  rdfs:seeAlso gmanuals:r3.colors .

<#r3.colors.out> a gisop: ;
  <#associated_keyword> <#ColorTableKeyword>, <#ExportKeyword> , <#Raster3dKeyword> ;
  rdfs:seeAlso gmanuals:r3.colors.out .

<#r3.cross.rast> a gisop: ;
  <#associated_keyword> <#ProfileKeyword> , <#VoxelKeyword> , <#Raster3dKeyword
```

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> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r3.cross.rast .

<#r3.flow> a gisop: ;
   <#associated_keyword> <#HydrologyKeyword> , <#VoxelKeyword> , <#Raster3dKeyw
ord> ;
   rdfs:seeAlso gmanuals:r3.flow .

<#r3.gradient> a gisop: ;
   <#associated_keyword> <#GradientKeyword> , <#VoxelKeyword> , <#Raster3dKeywor
d> ;
   rdfs:seeAlso gmanuals:r3.gradient .

<#r3.gwflow> a gisop: ;
   <#associated_keyword> <#GroundwaterFlowKeyword> , <#HydrologyKeyword> , <#Vo
xelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.gwflow .

<#r3.in.ascii> a gisop: ;
   <#associated_keyword> <#ASCIIkeyword> , <#ConversionKeyword> , <#ImportKeywor
d> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.in.ascii .

<#r3.in.bin> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#VoxelKeyword> , <#Raster3dKeyword
> ;
   rdfs:seeAlso gmanuals:r3.in.bin .

<#r3.in.lidar> a gisop: ;
   <#associated_keyword> <#3DrasterKeyword> , <#ImportKeyword> , <#LIDARkeyword
> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.in.lidar .

<#r3.in.v5d> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#VoxelKeyword> , <#Raster3dKeyword
> ;
   rdfs:seeAlso gmanuals:r3.in.v5d .
```

```
<#r3.in.xyz> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#LIDARkeyword> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.in.xyz .

<#r3.info> a gisop: ;
   <#associated_keyword> <#ExtentKeyword> , <#MetadataKeyword> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.info .

<#r3.mapcalc> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#Raster3dKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:r3.mapcalc .

<#r3.mask> a gisop: ;
   <#associated_keyword> <#MaskKeyword> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.mask .

<#r3.mkdspf> a gisop: ;
   <#associated_keyword> <#VoxelKeyword> , <#Raster3dKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:r3.mkdspf .

<#r3.neighbors> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#AlgebraKeyword> , <#FilterKeyword> , <#FocalStatisticsKeyword> , <#NeighborKeyword> , <#StatisticsKeyword> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.neighbors .

<#r3.null> a gisop: ;
   <#associated_keyword> <#NullDataKeyword> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.null .

<#r3.out.ascii> a gisop: ;
```

```
   <#associated_keyword> <#ASCIIkeyword>, <#ConversionKeyword>, <#ExportKeyword
> , <#VoxelKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.out.ascii .

<#r3.out.bin> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#VoxelKeyword> , <#Raster3dKeyword
> ;
   rdfs:seeAlso gmanuals:r3.out.bin .

<#r3.out.netcdf> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#NetCDFkeyword> , <#VoxelKeyword> ,
 <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.out.netcdf .

<#r3.out.v5d> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#VoxelKeyword> , <#Raster3dKeyword
> ;
   rdfs:seeAlso gmanuals:r3.out.v5d .

<#r3.out.vtk> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#VoxelKeyword> , <#VTKkeyword> , <#
Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.out.vtk .

<#r3.retile> a gisop: ;
   <#associated_keyword> <#TilingKeyword> , <#VoxelKeyword> , <#Raster3dKeyword>
;
   rdfs:seeAlso gmanuals:r3.retile .

<#r3.stats> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#VolumeKeyword> , <#VoxelKeyword
> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:r3.stats .

<#r3.support> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#VoxelKeyword> , <#Raster3dKeywo
rd> ;
```

```
  rdfs:seeAlso gmanuals:r3.support .

<#r3.timestamp> a gisop: ;
  <#associated_keyword> <#MetadataKeyword> , <#TimeKeyword> , <#TimestampKeyw
ord> , <#VoxelKeyword> , <#Raster3dKeyword> ;
  rdfs:seeAlso gmanuals:r3.timestamp .

<#r3.to.rast> a gisop: ;
  <#associated_keyword> <#RasterKeyword>, <#ConversionKeyword> , <#VoxelKeywor
d> , <#Raster3dKeyword> ;
  rdfs:seeAlso gmanuals:r3.to.rast .

<#r3.univar> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#UnivariateStatisticsKeyword> , <#Ra
ster3dKeyword> ;
  rdfs:seeAlso gmanuals:r3.univar .

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<#t.connect> a gisop: ;
  <#associated_keyword> <#MetadataKeyword> , <#SettingsKeyword> , <#TemporalKey
word> ;
  rdfs:seeAlso gmanuals:t.connect .

<#t.create> a gisop: ;
  <#associated_keyword> <#CreateKeyword> , <#MapManagementKeyword> , <#TimeKe
yword> , <#TemporalKeyword> ;
  rdfs:seeAlso gmanuals:t.create .

<#t.info> a gisop: ;
  <#associated_keyword> <#ExtentKeyword> , <#MetadataKeyword> , <#TimeKeyword>
, <#TemporalKeyword> ;
  rdfs:seeAlso gmanuals:t.info .

<#t.list> a gisop: ;
```

```
  <#associated_keyword> <#ListKeyword> , <#MapManagementKeyword> , <#TimeKey
word> , <#TemporalKeyword> ;
  rdfs:seeAlso gmanuals:t.list .

<#t.merge> a gisop: ;
  <#associated_keyword> <#MergeKeyword> , <#TimeKeyword> , <#TimeManagementK
eyword> , <#TemporalKeyword> ;
  rdfs:seeAlso gmanuals:t.merge .

<#t.rast.accdetect> a gisop: ;
  <#associated_keyword> <#AccumulationKeyword> , <#TimeKeyword> , <#TemporalKe
yword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.accdetect .

<#t.rast.accumulate> a gisop: ;
  <#associated_keyword> <#AccumulationKeyword> , <#TimeKeyword> , <#TemporalKe
yword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.accumulate .

<#t.rast.aggregate> a gisop: ;
  <#associated_keyword> <#AggregationKeyword> , <#TimeKeyword> , <#TemporalKey
word> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.aggregate .

<#t.rast.aggregate.ds> a gisop: ;
  <#associated_keyword> <#AggregationKeyword> , <#TimeKeyword> , <#TemporalKey
word> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.aggregate.ds .

<#t.rast.algebra> a gisop: ;
  <#associated_keyword> <#AlgebraKeyword> , <#TimeKeyword> , <#TemporalKeywor
d> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.algebra .

<#t.rast.colors> a gisop: ;
  <#associated_keyword> <#ColorTableKeyword> , <#TimeKeyword> , <#TemporalKeyw
ord> , <#RasterKeyword> ;
```

```
  rdfs:seeAlso gmanuals:t.rast.colors .

<#t.rast.contour> a gisop: ;
  <#associated_keyword> <#ContourKeyword> , <#TimeKeyword> , <#TemporalKeywor
d> , <#RasterKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.contour .

<#t.rast.export> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#TimeKeyword> , <#TemporalKeyword
> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.export .

<#t.rast.extract> a gisop: ;
  <#associated_keyword> <#ExtractKeyword> , <#TimeKeyword> , <#TemporalKeyword
> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.extract .

<#t.rast.gapfill> a gisop: ;
  <#associated_keyword> <#InterpolationKeyword> , <#TimeKeyword> , <#TemporalKe
yword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.gapfill .

<#t.rast.import> a gisop: ;
  <#associated_keyword> <#ImportKeyword> , <#TimeKeyword> , <#TemporalKeyword
> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.import .

<#t.rast.list> a gisop: ;
  <#associated_keyword> <#ListKeyword> , <#MapManagementKeyword> , <#TimeKey
word> , <#TemporalKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.list .

<#t.rast.mapcalc> a gisop: ;
  <#associated_keyword> <#AlgebraKeyword> , <#TimeKeyword> , <#TemporalKeywor
d> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:t.rast.mapcalc .
```

```
<#t.rast.neighbors> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#TimeKeyword> , <#TemporalKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.neighbors .

<#t.rast.out.vtk> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#TimeKeyword> , <#VTKkeyword> , <#TemporalKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.out.vtk .

<#t.rast.series> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#SeriesKeyword> , <#TimeKeyword> , <#TemporalKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.series .

<#t.rast.to.rast3> a gisop: ;
   <#associated_keyword> <#Raster3dKeyword>, <#ConversionKeyword> , <#TimeKeyword> , <#VoxelKeyword> , <#TemporalKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.to.rast3 .

<#t.rast.to.vect> a gisop: ;
   <#associated_keyword> <#ConversionKeyword> , <#TimeKeyword> , <#TemporalKeyword> , <#RasterKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.to.vect .

<#t.rast.univar> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#TimeKeyword> , <#TemporalKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.univar .

<#t.rast.what> a gisop: ;
   <#associated_keyword> <#SamplingKeyword> , <#TimeKeyword> , <#TemporalKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:t.rast.what .

<#t.rast3d.algebra> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#TimeKeyword> , <#VoxelKeyword> ,
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<#TemporalKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:t.rast3d.algebra .

<#t.rast3d.extract> a gisop: ;
   <#associated_keyword> <#ExtractKeyword> , <#TimeKeyword> , <#VoxelKeyword> , <
#TemporalKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:t.rast3d.extract .

<#t.rast3d.list> a gisop: ;
   <#associated_keyword> <#ListKeyword> , <#MapManagementKeyword> , <#TimeKey
word> , <#VoxelKeyword> , <#TemporalKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:t.rast3d.list .

<#t.rast3d.mapcalc> a gisop: ;
   <#associated_keyword> <#AlgebraKeyword> , <#TimeKeyword> , <#VoxelKeyword> ,
<#TemporalKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:t.rast3d.mapcalc .

<#t.rast3d.univar> a gisop: ;
   <#associated_keyword> <#StatisticsKeyword> , <#TimeKeyword> , <#VoxelKeyword> ,
 <#TemporalKeyword> , <#Raster3dKeyword> ;
   rdfs:seeAlso gmanuals:t.rast3d.univar .

<#t.register> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#RegisterKeyword> , <#Time
Keyword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:t.register .

<#t.remove> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#RemoveKeyword> , <#Time
Keyword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:t.remove .

<#t.rename> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#RenameKeyword> , <#Time
Keyword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:t.rename .
```

```
<#t.sample> a gisop: ;
   <#associated_keyword> <#SamplingKeyword> , <#TimeKeyword> , <#TemporalKeywo
rd> ;
   rdfs:seeAlso gmanuals:t.sample .

<#t.select> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#TimeKeyword> , <#TemporalKeywo
rd> ;
   rdfs:seeAlso gmanuals:t.select .

<#t.shift> a gisop: ;
   <#associated_keyword> <#ShiftKeyword> , <#TimeKeyword> , <#TimeManagementKe
yword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:t.shift .

<#t.snap> a gisop: ;
   <#associated_keyword> <#SnappingKeyword> , <#TimeKeyword> , <#TimeManageme
ntKeyword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:t.snap .

<#t.support> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#TimeKeyword> , <#TemporalKeywo
rd> ;
   rdfs:seeAlso gmanuals:t.support .

<#t.topology> a gisop: ;
   <#associated_keyword> <#TimeKeyword> , <#TopologyKeyword> , <#TemporalKeywo
rd> ;
   rdfs:seeAlso gmanuals:t.topology .

<#t.unregister> a gisop: ;
   <#associated_keyword> <#MapManagementKeyword> , <#TimeKeyword> , <#Unregist
erKeyword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:t.unregister .

<#t.vect.algebra> a gisop: ;
```

```
  <#associated_keyword> <#AlgebraKeyword> , <#TimeKeyword> , <#TemporalKeywor
d> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.algebra .

<#t.vect.db.select> a gisop: ;
  <#associated_keyword> <#AttributeTableKeyword> , <#SelectKeyword> , <#TimeKeyw
ord> , <#TemporalKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.db.select .

<#t.vect.export> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#TimeKeyword> , <#TemporalKeyword
> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.export .

<#t.vect.extract> a gisop: ;
  <#associated_keyword> <#ExtractKeyword> , <#TimeKeyword> , <#TemporalKeyword
> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.extract .

<#t.vect.import> a gisop: ;
  <#associated_keyword> <#ImportKeyword> , <#TimeKeyword> , <#TemporalKeyword
> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.import .

<#t.vect.list> a gisop: ;
  <#associated_keyword> <#ListKeyword> , <#MapManagementKeyword> , <#TimeKey
word> , <#TemporalKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.list .

<#t.vect.observe.strds> a gisop: ;
  <#associated_keyword> <#SamplingKeyword> , <#TimeKeyword> , <#TemporalKeywo
rd> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.observe.strds .

<#t.vect.univar> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#TimeKeyword> , <#TemporalKeywo
rd> , <#VectorKeyword> ;
```

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  rdfs:seeAlso gmanuals:t.vect.univar .

<#t.vect.what.strds> a gisop: ;
  <#associated_keyword> <#SamplingKeyword> , <#TimeKeyword> , <#TemporalKeywo
rd> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:t.vect.what.strds .

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<#test.r3flow> a gisop: ;
  <#associated_keyword> <#HydrologyKeyword> , <#VoxelKeyword> , <#Raster3dKeyw
ord> ;
  rdfs:seeAlso gmanuals:test.r3flow .

<#test.raster3d.lib> a gisop: ;
  <#associated_keyword> <#TestKeyword> , <#Raster3dKeyword> ;
  rdfs:seeAlso gmanuals:test.raster3d.lib .

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<#v.buffer> a gisop: ;
  <#associated_keyword> <#AreaKeyword> , <#BufferKeyword> , <#CircleKeyword> , <#
GeometryKeyword> , <#GrowKeyword> , <#LineKeyword> , <#ShrinkKeyword> , <#Vect
orKeyword> ;
  rdfs:seeAlso gmanuals:v.buffer .

<#v.build> a gisop: ;
  <#associated_keyword> <#GeometryKeyword> , <#TopologyKeyword> , <#VectorKeyw
ord> ;
  rdfs:seeAlso gmanuals:v.build .

<#v.build.all> a gisop: ;
  <#associated_keyword> <#TopologyKeyword> , <#VectorKeyword> ;
```

```
    rdfs:seeAlso gmanuals:v.build.all .

<#v.build.polylines> a gisop: ;
    <#associated_keyword> <#GeometryKeyword> , <#LineKeyword> , <#TopologyKeywor
d> , <#VertexKeyword> , <#VectorKeyword> , <#NodeKeyword> ;
    rdfs:seeAlso gmanuals:v.build.polylines .

<#v.category> a gisop: ;
    <#associated_keyword> <#CategoryKeyword> , <#LayerKeyword> , <#VectorKeyword
> ;
    rdfs:seeAlso gmanuals:v.category .

<#v.centroids> a gisop: ;
    <#associated_keyword> <#AreaKeyword> , <#CentroidKeyword> , <#VectorKeyword> ;
    rdfs:seeAlso gmanuals:v.centroids .

<#v.class> a gisop: ;
    <#associated_keyword> <#AttributeTableKeyword> , <#ClassificationKeyword> , <#Sta
tisticsKeyword> , <#VectorKeyword> ;
    rdfs:seeAlso gmanuals:v.class .

<#v.clean> a gisop: ;
    <#associated_keyword> <#GeometryKeyword> , <#SnappingKeyword> , <#TopologyKe
yword> , <#VectorKeyword> ;
    rdfs:seeAlso gmanuals:v.clean .

<#v.cluster> a gisop: ;
    <#associated_keyword> <#ClumpKeyword> , <#ClusterKeyword> , <#Level1Keyword>
, <#PointCloudKeyword> , <#VectorKeyword> ;
    rdfs:seeAlso gmanuals:v.cluster .

<#v.colors> a gisop: ;
    <#associated_keyword> <#ColorTableKeyword> , <#VectorKeyword> ;
    rdfs:seeAlso gmanuals:v.colors .

<#v.colors.out> a gisop: ;
    <#associated_keyword> <#ColorTableKeyword> , <#ExportKeyword> , <#VectorKeywo
```

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rd> ;
   rdfs:seeAlso gmanuals:v.colors.out .

<#v.db.addcolumn> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
   rdfs:seeAlso gmanuals:v.db.addcolumn .

<#v.db.addtable> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
   rdfs:seeAlso gmanuals:v.db.addtable .

<#v.db.connect> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#LayerKeyword> , <#VectorKey
word> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.db.connect .

<#v.db.dropcolumn> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
   rdfs:seeAlso gmanuals:v.db.dropcolumn .

<#v.db.droprow> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
   rdfs:seeAlso gmanuals:v.db.droprow .

<#v.db.droptable> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
   rdfs:seeAlso gmanuals:v.db.droptable .

<#v.db.join> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
   rdfs:seeAlso gmanuals:v.db.join .
```

```
<#v.db.reconnect.all> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.db.reconnect.all .

<#v.db.renamecolumn> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.db.renamecolumn .

<#v.db.select> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#SQLkeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.db.select .

<#v.db.univar> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#StatisticsKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.db.univar .

<#v.db.update> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.db.update .

<#v.decimate> a gisop: ;
   <#associated_keyword> <#DecimationKeyword> , <#ExtractKeyword> , <#GeneralizationKeyword> , <#Level1Keyword> , <#LIDARkeyword> , <#PointsKeyword> , <#SelectKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.decimate .

<#v.delaunay> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#TriangulationKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.delaunay .
```

```
<#v.dissolve> a gisop: ;
   <#associated_keyword> <#AreaKeyword> , <#DissolveKeyword> , <#LineKeyword> , <
#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.dissolve .

<#v.distance> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#DistanceKeyword> , <#VectorK
eyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.distance .

<#v.drape> a gisop: ;
   <#associated_keyword> <#3Dkeyword> , <#GeometryKeyword> , <#SamplingKeyword
> , <#SurfaceInformationKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.drape .

<#v.edit> a gisop: ;
   <#associated_keyword> <#EditingKeyword> , <#GeometryKeyword> , <#Level1Keywor
d> , <#LineKeyword> , <#NodeKeyword> , <#PointKeyword> , <#VertexKeyword> , <#Ve
ctorKeyword> ;
   rdfs:seeAlso gmanuals:v.edit .

<#v.external> a gisop: ;
   <#associated_keyword> <#ExternalKeyword> , <#ImportKeyword> , <#Level1Keyword
> , <#OGRkeyword> , <#PostGISkeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.external .

<#v.external.out> a gisop: ;
   <#associated_keyword> <#ExportKeyword> , <#ExternalKeyword> , <#OGRkeyword> ,
<#OutputKeyword> , <#PostGISkeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.external.out .

<#v.extract> a gisop: ;
   <#associated_keyword> <#DissolveKeyword> , <#ExtractKeyword> , <#RandomKeywo
rd> , <#SelectKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.extract .

<#v.extrude> a gisop: ;
```

```
  <#associated_keyword> <#GeometryKeyword> , <#3Dkeyword> , <#SamplingKeyword
> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.extrude .

<#v.generalize> a gisop: ;
  <#associated_keyword> <#DisplacementKeyword> , <#GeneralizationKeyword> , <#Si
mplificationKeyword> , <#NetworkGeneralizationKeyword> , <#SmoothingKeyword> , <#
VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.generalize .

<#v.hull> a gisop: ;
  <#associated_keyword> <#3Dkeyword> , <#GeometryKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.hull .

<#v.import> a gisop: ;
  <#associated_keyword> <#ImportKeyword> , <#ProjectionKeyword> , <#VectorKeywo
rd> ;
  rdfs:seeAlso gmanuals:v.import .

<#v.in.ascii> a gisop: ;
  <#associated_keyword> <#ASCIIkeyword> , <#ImportKeyword>, <#Level1Keyword> , <
#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.in.ascii .

<#v.in.db> a gisop: ;
  <#associated_keyword> <#ImportKeyword> , <#PointsKeyword> , <#VectorKeyword> ,
 <#DatabaseKeyword> ;
  rdfs:seeAlso gmanuals:v.in.db .

<#v.in.dxf> a gisop: ;
  <#associated_keyword> <#DXFkeyword> , <#ImportKeyword> , <#Level1Keyword> , <
#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.in.dxf .

<#v.in.e00> a gisop: ;
  <#associated_keyword> <#E00keyword> , <#ImportKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.in.e00 .
```

```
<#v.in.geonames> a gisop: ;
   <#associated_keyword> <#GazetteerKeyword> , <#ImportKeyword> , <#VectorKeywor
d> ;
   rdfs:seeAlso gmanuals:v.in.geonames .

<#v.in.lidar> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#Level1Keyword> , <#LIDARkeyword> ,
 <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.in.lidar .

<#v.in.lines> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#LineKeyword> , <#PointKeyword> , <#
VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.in.lines .

<#v.in.mapgen> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.in.mapgen .

<#v.in.ogr> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#OGRkeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.in.ogr .

<#v.in.region> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.in.region .

<#v.in.wfs> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#OGCwebServicesKeyword> , <#Vector
Keyword> ;
   rdfs:seeAlso gmanuals:v.in.wfs .

<#v.info> a gisop: ;
   <#associated_keyword> <#AttributeColumnsKeyword> , <#ExtentKeyword> , <#Histor
yKeyword> , <#Level1Keyword> , <#MetadataKeyword> , <#TopologyKeyword> , <#Vect
orKeyword> ;
```

```
  rdfs:seeAlso gmanuals:v.info .

<#v.kcv> a gisop: ;
  <#associated_keyword> <#PointPatternKeyword> , <#PointsKeyword> , <#StatisticsKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.kcv .

<#v.kernel> a gisop: ;
  <#associated_keyword> <#HeatmapKeyword> , <#HotspotKeyword> , <#KernelDensityKeyword> , <#PointDensityKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.kernel .

<#v.label> a gisop: ;
  <#associated_keyword> <#PaintLabelsKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.label .

<#v.lidar.correction> a gisop: ;
  <#associated_keyword> <#LIDARkeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.lidar.correction .

<#v.lidar.edgedetection> a gisop: ;
  <#associated_keyword> <#EdgesKeyword> , <#LIDARkeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.lidar.edgedetection .

<#v.lidar.growing> a gisop: ;
  <#associated_keyword> <#LIDARkeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.lidar.growing .

<#v.lrs.create> a gisop: ;
  <#associated_keyword> <#LinearReferenceSystemKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.lrs.create.

<#v.lrs.label> a gisop: ;
  <#associated_keyword> <#LinearReferenceSystemKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.lrs.label.
```

```
<#v.lrs.segment> a gisop: ;
   <#associated_keyword> <#LinearReferenceSystemKeyword> , <#NetworkKeyword> , <
#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.lrs.segment.

<#v.lrs.where> a gisop: ;
   <#associated_keyword> <#LinearReferenceSystemKeyword> , <#NetworkKeyword> , <
#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.lrs.where.

<#v.mkgrid> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#GridKeyword> , <#HexagonKeywor
d> , <#PointPatternKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.mkgrid .

<#v.neighbors> a gisop: ;
   <#associated_keyword> <#AggregationKeyword> , <#AlgebraKeyword> , <#StatisticsK
eyword> , <#VectorKeyword> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:v.neighbors .

<#v.net> a gisop: ;
   <#associated_keyword> <#NetworkMaintenanceKeyword> , <#VectorKeyword> , <#Ne
tworkKeyword> ;
   rdfs:seeAlso gmanuals:v.net.html .

<#v.net.alloc> a gisop: ;
   <#associated_keyword> <#CostAllocationKeyword> , <#NetworkKeyword> , <#VectorK
eyword> ;
   rdfs:seeAlso gmanuals:v.net.alloc .

<#v.net.allpairs> a gisop: ;
   <#associated_keyword> <#NetworkKeyword> , <#ShortestPathKeyword> , <#VectorKe
yword> ;
   rdfs:seeAlso gmanuals:v.net.allpairs .

<#v.net.bridge> a gisop: ;
```

```
  <#associated_keyword> <#ArticulationPointsKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.bridge .

<#v.net.centrality> a gisop: ;
  <#associated_keyword> <#CentralityMeasuresKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.centrality .

<#v.net.components> a gisop: ;
  <#associated_keyword> <#ComponentsKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.components .

<#v.net.connectivity> a gisop: ;
  <#associated_keyword> <#ConnectivityKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.connectivity .

<#v.net.distance> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#ShortestPathKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.distance .

<#v.net.flow> a gisop: ;
  <#associated_keyword> <#FlowKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.flow .

<#v.net.iso> a gisop: ;
  <#associated_keyword> <#IsolinesKeyword> , <#NetworkKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.iso .

<#v.net.path> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#ShortestPathKeyword> , <#VectorKeyword> ;
```

```
  rdfs:seeAlso gmanuals:v.net.path .

<#v.net.salesman> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#SalesmanKeyword> , <#VectorKeyw
ord> ;
  rdfs:seeAlso gmanuals:v.net.salesman .

<#v.net.spanningtree> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#SpanningTreeKeyword> , <#VectorK
eyword> ;
  rdfs:seeAlso gmanuals:v.net.spanningtree .

<#v.net.steiner> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#SteinerTreeKeyword> , <#VectorKey
word> ;
  rdfs:seeAlso gmanuals:v.net.steiner .

<#v.net.timetable> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#ShortestPathKeyword> , <#VectorKe
yword> ;
  rdfs:seeAlso gmanuals:v.net.timetable .

<#v.net.visibility> a gisop: ;
  <#associated_keyword> <#NetworkKeyword> , <#ShortestPathKeyword> , <#Visibility
Keyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.net.visibility .

<#v.normal> a gisop: ;
  <#associated_keyword> <#PointPatternKeyword> , <#PointsKeyword> , <#StatisticsKe
yword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.normal .

<#v.out.ascii> a gisop: ;
  <#associated_keyword> <#ASCIIkeyword> , <#ExportKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.ascii .

<#v.out.dxf> a gisop: ;
```

```
  <#associated_keyword> <#DXFkeyword> , <#ExportKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.dxf .

<#v.out.lidar> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#LIDARkeyword> , <#PointsKeyword> ,
<#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.lidar .

<#v.out.ogr> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#OGRkeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.ogr .

<#v.out.postgis> a gisop: ;
  <#associated_keyword> <#3Dkeyword> , <#ExportKeyword> , <#PostGISkeyword> , <#
SimpleFeaturesKeyword> , <#TopologyKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.postgis .

<#v.out.pov> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.pov .

<#v.out.svg> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.svg .

<#v.out.vtk> a gisop: ;
  <#associated_keyword> <#ExportKeyword> , <#VTKkeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.out.vtk .

<#v.outlier> a gisop: ;
  <#associated_keyword> <#ExtractKeyword> , <#FilterKeyword> , <#LIDARkeyword> ,
<#SelectKeyword> , <#StatisticsKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.outlier .

<#v.overlay> a gisop: ;
  <#associated_keyword> <#ClipKeyword> , <#DifferenceKeyword> , <#GeometryKeywo
rd> , <#IntersectionKeyword> , <#SpatialQueryKeyword> , <#UnionKeyword> , <#Vector
```

```
Keyword> ;
   rdfs:seeAlso gmanuals:v.overlay .

<#v.pack> a gisop: ;
   <#associated_keyword> <#CopyingKeyword> , <#ExportKeyword> , <#VectorKeyword
> ;
   rdfs:seeAlso gmanuals:v.pack .

<#v.parallel> a gisop: ;
   <#associated_keyword> <#BufferKeyword> , <#GeometryKeyword> , <#LineKeyword>
, <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.parallel .

<#v.patch> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#Level1Keyword> , <#VectorKeywor
d> ;
   rdfs:seeAlso gmanuals:v.patch .

<#v.perturb> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#Level1Keyword> , <#PointPatternK
eyword> , <#RandomKeyword> , <#StatisticsKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.perturb .

<#v.proj> a gisop: ;
   <#associated_keyword> <#ImportKeyword> , <#ProjectionKeyword> , <#Transformati
onKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.proj .

<#v.qcount> a gisop: ;
   <#associated_keyword> <#PointPatternKeyword> , <#StatisticsKeyword> ,<#VectorKe
yword> ;
   rdfs:seeAlso gmanuals:v.qcount .

<#v.random> a gisop: ;
   <#associated_keyword> <#Level1Keyword> , <#PointPatternKeyword> , <#RandomKe
yword> , <#SamplingKeyword> , <#StatisticsKeyword> , <#StratifiedRandomSamplingKe
yword> , <#VectorKeyword> ;
```

```
  rdfs:seeAlso gmanuals:v.random .

<#v.rast.stats> a gisop: ;
  <#associated_keyword> <#QueryingKeyword> , <#SamplingKeyword> , <#StatisticsKeyword> , <#UnivariateStatisticsKeyword> , <#ZonalStatisticsKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.rast.stats .

<#v.reclass> a gisop: ;
  <#associated_keyword> <#AttributesKeyword> , <#ReclassificationKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.reclass .

<#v.rectify> a gisop: ;
  <#associated_keyword> <#Level1Keyword> , <#RectifyKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.rectify .

<#v.report> a gisop: ;
  <#associated_keyword> <#StatisticsKeyword> , <#VectorKeyword> , <#GeometryKeyword> ;
  rdfs:seeAlso gmanuals:v.report .

<#v.sample> a gisop: ;
  <#associated_keyword> <#SamplingKeyword> , <#VectorKeyword> , <#RasterKeyword> ;
  rdfs:seeAlso gmanuals:v.sample .

<#v.segment> a gisop: ;
  <#associated_keyword> <#GeometryKeyword> , <#NodeKeyword> , <#PointKeyword> , <#SegmentKeyword> , <#VertexKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.segment .

<#v.select> a gisop: ;
  <#associated_keyword> <#GeometryKeyword> , <#SpatialQueryKeyword> , <#VectorKeyword> ;
  rdfs:seeAlso gmanuals:v.select .
```

```
<#v.split> a gisop: ;
   <#associated_keyword> <#DensificationKeyword> , <#GeometryKeyword> , <#NodeKe
yword> , <#SegmentKeyword> , <#VertexKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.split .

<#v.support> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.support .

<#v.surf.bspline> a gisop: ;
   <#associated_keyword> <#InterpolationKeyword> , <#LIDARkeyword> , <#SurfaceKey
word> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.surf.bspline .

<#v.surf.idw> a gisop: ;
   <#associated_keyword> <#IDWkeyword> , <#InterpolationKeyword> , <#SurfaceKeyw
ord> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.surf.idw .

<#v.surf.rst> a gisop: ;
   <#associated_keyword> <#3Dkeyword> , <#InterpolationKeyword> , <#SurfaceKeywor
d> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.surf.rst .

<#v.timestamp> a gisop: ;
   <#associated_keyword> <#MetadataKeyword> , <#TimeKeyword> , <#TimestampKeyw
ord> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.timestamp .

<#v.to.3d> a gisop: ;
   <#associated_keyword> <#3Dkeyword> , <#GeometryKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.to.3d .

<#v.to.db> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#VectorKeyword> , <#Database
Keyword> ;
```

rdfs:seeAlso gmanuals:v.to.db .

<#v.to.lines> a gisop: ;
<#associated_keyword> <#AreaKeyword> , <#GeometryKeyword> , <#LineKeyword> , <#PointKeyword> , <#VectorKeyword> ;
rdfs:seeAlso gmanuals:v.to.lines .

<#v.to.points> a gisop: ;
<#associated_keyword> <#3Dkeyword> , <#GeometryKeyword> , <#LineKeyword> , <#NodeKeyword> , <#PointKeyword> , <#VertexKeyword> , <#VectorKeyword> ;
rdfs:seeAlso gmanuals:v.to.points .

<#v.to.rast> a gisop: ;
<#associated_keyword> <#ConversionKeyword> , <#RasterizationKeyword> , <#VectorKeyword> , <#RasterKeyword> ;
rdfs:seeAlso gmanuals:v.to.rast .

<#v.to.rast3> a gisop: ;
<#associated_keyword> <#ConversionKeyword> , <#VoxelKeyword> , <#VectorKeyword> ;
rdfs:seeAlso gmanuals:v.to.rast3 .

<#v.transform> a gisop: ;
<#associated_keyword> <#GeometryKeyword> , <#GCPkeyword> , <#TransformationKeyword> , <#VectorKeyword> ;
rdfs:seeAlso gmanuals:v.transform .

<#v.type> a gisop: ;
<#associated_keyword> <#AreaKeyword> , <#EditingKeyword> , <#GeometryKeyword> , <#LineKeyword> , <#PointKeyword> , <#VectorKeyword> ;
rdfs:seeAlso gmanuals:v.type .

<#v.univar> a gisop: ;
<#associated_keyword> <#AttributeTableKeyword> , <#GeometryKeyword> , <#StatisticsKeyword> , <#UnivariateStatisticsKeyword> , <#VectorKeyword> ;
rdfs:seeAlso gmanuals:v.univar .

```
<#v.unpack> a gisop: ;
   <#associated_keyword> <#CopyingKeyword> , <#ImportKeyword> , <#VectorKeyword
> ;
   rdfs:seeAlso gmanuals:v.unpack .

<#v.vect.stats> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#UnivariateStatisticsKeyword> ,
<#ZonalStatisticsKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.vect.stats .

<#v.vol.rst> a gisop: ;
   <#associated_keyword> <#InterpolationKeyword> , <#RSTkeyword> , <#SurfaceKeywo
rd> , <#VoxelKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.vol.rst .

<#v.voronoi> a gisop: ;
   <#associated_keyword> <#GeometryKeyword> , <#SkeletonKeyword> , <#Triangulatio
nKeyword> , <#VectorKeyword> ;
   rdfs:seeAlso gmanuals:v.voronoi .

<#v.what> a gisop: ;
   <#associated_keyword> <#PositionKeyword> , <#QueryingKeyword> , <#VectorKeywo
rd> ;
   rdfs:seeAlso gmanuals:v.what .

<#v.what.rast> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#PositionKeyword> , <#Queryin
gKeyword> , <#SamplingKeyword> , <#SurfaceInformationKeyword> , <#VectorKeyword
> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:v.what.rast .

<#v.what.rast3> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#PositionKeyword> , <#Queryin
gKeyword> , <#SamplingKeyword> , <#SurfaceInformationKeyword> , <#VectorKeyword
> , <#RasterKeyword> ;
   rdfs:seeAlso gmanuals:v.what.rast3 .
```

```
<#v.what.strds> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#PositionKeyword> , <#QueryingKeyword> , <#SamplingKeyword> , <#TimeKeyword> , <#VectorKeyword> , <#TemporalKeyword> ;
   rdfs:seeAlso gmanuals:v.what.strds .

<#v.what.vect> a gisop: ;
   <#associated_keyword> <#AttributeTableKeyword> , <#PositionKeyword> , <#QueryingKeyword> , <#SamplingKeyword> , <#VectorKeyword> , <#DatabaseKeyword> ;
   rdfs:seeAlso gmanuals:v.what.vect .

   #####
   # w
   #####

<#wxpyimgview> a gisop: ;
   <#associated_keyword> <#GraphicsKeyword> , <#RasterKeyword> , <#DisplayKeyword> ;
   rdfs:seeAlso gmanuals:wxpyimgview .
```

ANNEX

FORESIGHT AND PLANNING

The similarity of foresight with urban planning lies in the nature of both their object of interest and their process – open and complex. Regarding the object of interest, and in an analogy to Steinitz' (2012 [135]) framework of Geodesign, foresight experts are called to describe system structures ("representation" and "process" models), identify critical issues ("evaluation"), find paths of change ("change"), and play out alternative futures ("impact"), all built up around decision-making ("decision" model). On the other hand, regarding the two planning schemes from the process point of view, foresight's mode of unfolding presents similarities to Steinitz' (2012 [135]) Geodesign framework. In fact, it appears that EFFLA's (2012 [31]) proposal is a cyclic arrangement of phases comparable to the iterations of Steinitz' scheme (Figure 8.1).

The first phase, strategic intelligence gathering, has a clear correspondence to Geodesign's first iteration, as they both deal with a general acquaintance with the system(s) of interest. The second foresight phase, sense-making, is a more in-depth analysis of the system(s), as well as vision building. The former is a target of Steinitz' third iteration, while the latter can be more evidently mapped to the second iteration, which caters for study method specifications, based indeed on a vision created from the decision model. In foresight, this emphasis on the decision model is considered in the phase of policy priority selection and as such has a correspondence with the second iteration. This phase includes, however, the whole decision making process, which is equally pertinent to the third iteration, as well. Foresight comes with the addition of a fourth stage: that of policy implementation design. In urban planning this would correspond to the implementation design of plan alternatives, which is out of scope for Geodesign.

Further to the above, somewhat coarse, mapping between the two processes, a very important property that they share is that neither should be interpreted rigidly. Their frames are recursive, supporting more than one passage through each phase, either at their entirety or bypassing parts of them as needs call for, while feedback consists a crucial element. In this way, they provide for flexibility and adaptation to an ever-changing context, multiple needs, and a plethora of participants. The correspondence, therefore, of the urban planning process with that of foresight lies in their complex, dynamic and participative character.

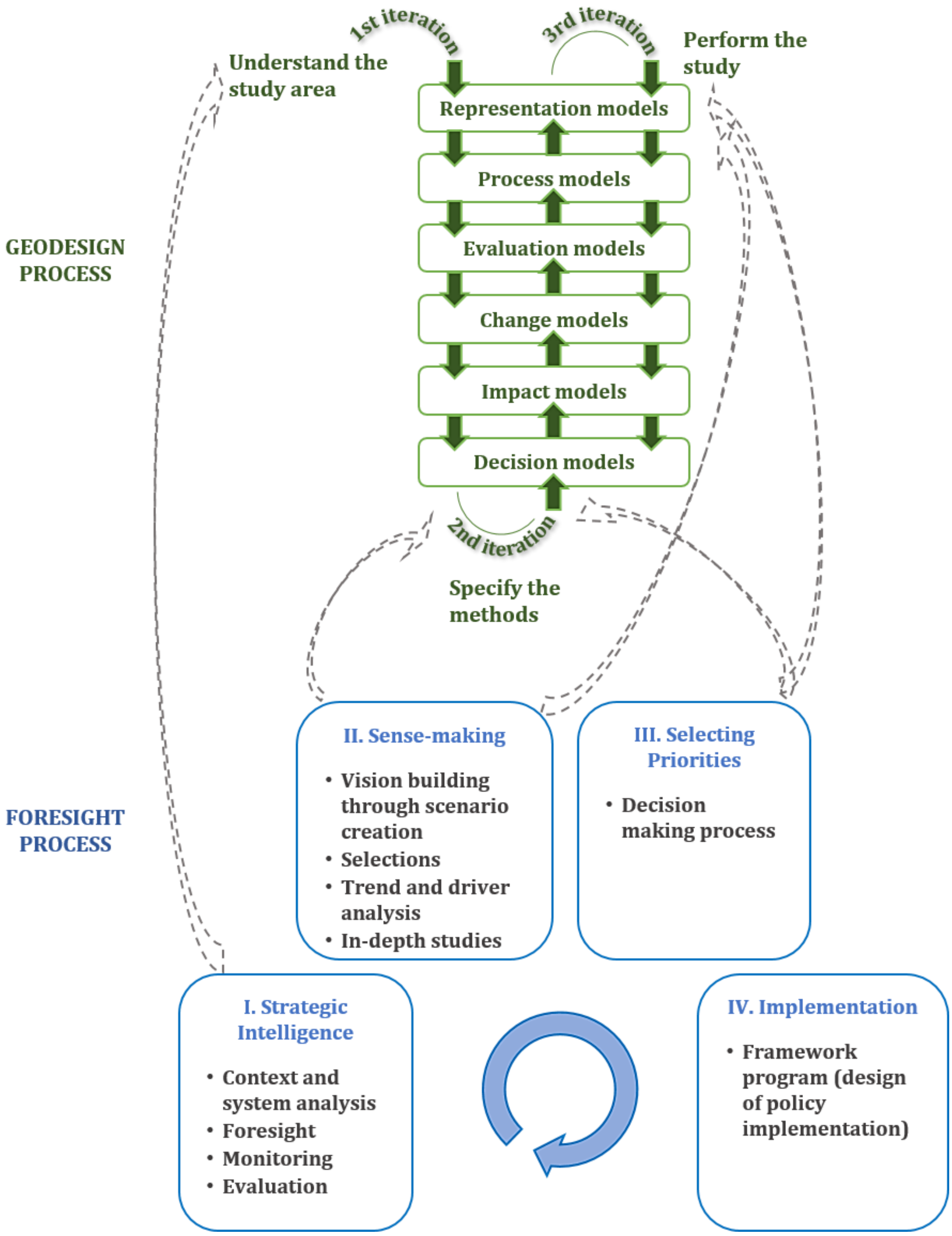

Figure 8.1: Correspondence between Steinitz' (2012 [135]) Geodesign framework for urban planning and EFFLA's (2012 [31]) framework for strategy and policy foresight in Europe.