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# INTEGRATION OF CONTEXT-INFORMATION TO SUPPORT SPATIAL DECISION SYSTEMS

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**ABSTRACT**

Spatial decision making often requires the consideration of huge datasets from a great variety of sectors. For the achievement of decision that are accepted by as many actors as possible it is indispensable to consider all relevant fields, and contexts. However, if the goal of a project is ill defined or broadly scoped, it can be hard to identify all relevant actors and overview whether their different goals, perceptions and ideas of how a place, a landscape, a village or city should develop in the future, can be integrated. Actors recognize problems necessarily within their specific context. The idea of a holistic approach to decision making is to consider possibly all relevant contexts, in which a spatial problem is embedded. This should lead to qualitatively high and sustainable decisions because the ignorance of specific contextual information can lead to unsatisfying, in the worst case harmful results. The problem as such is not new, but this paper argues not from a perspective of human communication. It raises the question, whether *applications* can *support a holistic approach* in spatial decision making by extending decision systems with functionalities to integrate context-information automatically.

**KEYWORDS**

GIS, mobile GIS, context, integration, spatial decision support systems

## 1. INTRODUCTION

The abbreviation “GIS”, originally referring to “Geographic Information Systems”, has been used increasingly in the sense of “geographic Information Services” during the last decade. Services, however, support specific tasks in spatial decision making and play an important role in the field of desktop-, as well as mobile GIS. Chaining such services aiming at the support of users during the preparation of decisions is a challenge that will play a major role during the next years. Today, most spatial applications are embedded in multi-contextual frameworks. Spatial decision making requires often data that are related to different sectors, e. g. urban planning, agriculture, forestry, road and traffic infrastructure, water management, soil protection, etc. GIS in both senses, systems and services, are tools that own the ability to integrate information from different sectors in a suitable way. This, and the fact that the great appeal of GIS stems from their ability to integrate great quantities of information about the natural and human-made environment, and to provide a powerful repertoire of analytical tools to explore this data, makes GIS useful tools for decision making (Foote and Lynch 2015). A statement by Mount described the role of context adequately: “Context is an important aspect of any decision-making process. The constraints and opportunities surrounding decisions play causal roles in determining the outcomes of activities. In other words, context causes things to happen” (Mount 2013, p 1). The analysis of spatial data leads to new insights into spatial patterns. However, the selection of relevant data layers within the framework of a complex spatial problem setting relies still and only on human assessment and can be a challenging task. This is especially true if the problem is very complex, only semi-structured, ill-defined or broadly scoped (Mount 2013, Densham and Goodchild 1994). There are various risks occurring, among others the ignorance or insufficient consideration of relationships between sectors. Under- or overrepresentation of specific data layers is an additional risk and can result from a lacking knowledge about the overall problem or the conscious or unconscious non-observance of specific actors, and therefore context information.

Due to such risks, this paper focuses on the research question, if applications can assist users in identifying relevant contexts based on a problem-setting, aiming at integrating relevant context-information from different sectors comprehensively. Such a goal would require a formalization of both, the problem setting, and the sector-specific context information. Following, a brief review of context-aware research and developments will throw light onto existing approaches to deal with context information. A specific focus is on semantic heterogeneity of spatial data, a problem that still requires more intelligent solutions concerning information sharing and –integration. Some insights resulting from empirical studies are included to show the need for solutions referring to semantics. A use case is presented, aimed at the following goals:

- Presenting *multi-contextual decision making* as a prerequisite for a holistic approach to adequate problem solutions, respected by all relevant actors that are included in the decision-making process
- Presenting a very first assumption of how a technological approach could support the enablement of spatial applications to identify relevant context information automatically.
- Highlighting semantic problems that can occur during the context integration process.

Starting with a discussion of what holistic decision making means, an overview of research on context-sensitive systems and the special challenge of resolving semantic heterogeneity problems is presented. Following, the exemplary use-case is described. Finally, a suggestion is presented which may show a first step how to formalize context information, aiming at making it available for applications.

## 2. IMPROVING SPATIAL DECISION MAKING THROUGH FOSTERING A HOLISTIC APPROACH

Planning future developments in rural and urban landscapes requires the proper consideration of various information sources. Information comes from different sectors that follow their specific goals and which look on such landscapes from their specific perspectives. The perspectives, or views, of different sectors, such as urban planning, forestry, agriculture, water management, traffic infrastructure, construction and estate planning and many more, are closely tight to the specific contexts. Spatial decision support systems (SDSS) are therefore means to support the integration of data and information of such different sectors – or contexts – which is a complex and difficult task. GIS-supported SDSS are foreseen to integrate data layers from different sectors and sources in a suitable way. From a technical point of view this is not a problem as long the data layers are available in the same format and geolocated in a unique reference system. Another problem, however, is the integration of different data layers in terms of their content. Is it appropriate to integrate different data layers from diverse sectors without looking on the specific contexts in which the data were collected? This question will be investigated in more detail in the following parts.

SDSS are seen here close to a definition of Densham et al. (1996). They stated that SDSS have been developed to address ill-structured problems with spatial query, modeling, analysis, and display capabilities. Densham et al. identified a mismatch between the widespread single-user model of GIS and SDSS use and the group-based approach to decision-making that is often adopted when ill-structured problem-settings are addressed. The group-based approach relates to the need of considering different contexts for spatial decision making. Densham et al. came to the conclusion that SDSS-based spatial analysis and display methods must be expanded to encompass group decision-making processes, and new tools must be developed that will enable group members to generate, evaluate, and illustrate the strong and weak points of alternative scenarios and come to a consensus about how to proceed toward a decision. In such a sense, an SDSS can occur in various forms, aiming at helping decision makers in developing improved decisions (Gupta 2015). The authors found even more reasons for the necessity of such "group-based" approaches toward SDSS, e. g. the fact that complex spatial problems often have multiple, conflicting objectives for their solutions and that a solution, to be acceptable by all actors, must reconcile these conflicting goals. Many problems occurring in practice are still solved in a one-dimensional ("single-user") manner and they tend to solve them in a piecemeal way, instead of using an integrated approach.

There are various attempts aimed at improving SDSS. Many of them are still single-user focused, not taking into account multiple sectors adequately. In this paper, the idea of collaborative decision making supported by SDSS is coupled with the term of holistic decision making. 'Holistic' means to take into account most of the sectors that occur within the framework of a problem, instead of tackling them in a piecemeal way. Holistic problem-solving is hence the result of transdisciplinary cooperation of relevant actors (Odum and Barrett 2004; Velasquez-Manoff 2009). From a GIS perspective, holistic means that as many *relevant* datasets, and considerations of *different actors*, as possible are taken into account. This is illustrated in an extended version of a representation of a Spatial Decision Support System proposed by Dresser (2016) in figure 1.

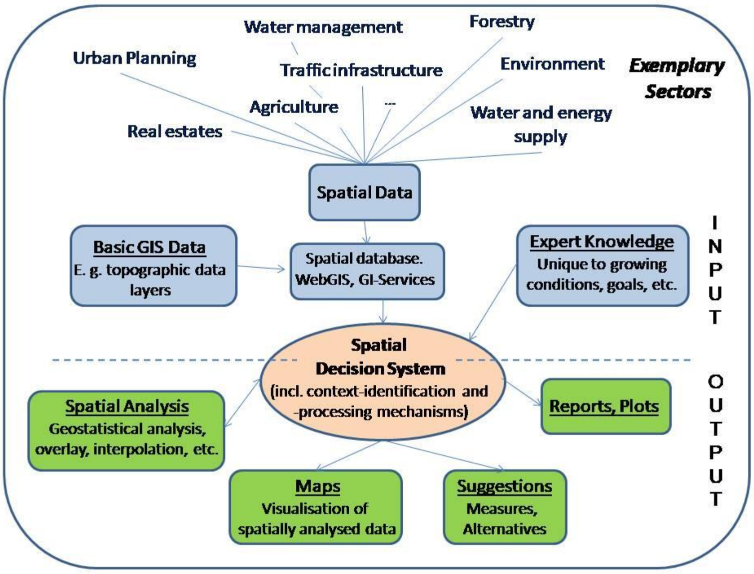


Figure 1. A Spatial Decision System and exemplary data sources from different sectors that must possibly be considered during the decision making process. The context-identification and –integration mechanisms refer to the proposed approach described in section 4
(Basics from Dresser 2016, modified and extended)

In computer science various approaches exist to integrate context information (see tables 2 and 3). Concerning *spatial* applications, context integration hasn't been dealt with comprehensively up to now. Whereas context-awareness has been identified as a property of mobile geo-applications, only few ideas have been published about how to achieve context integration in spatial decision making in general.

## 3. CONTEXT-RELATED RESEARCH

A question that was asked by Dey and Abowd many years ago seems to be still relevant today: "How do we as application developers provide the context to the computers, or make those applications aware and responsive to the full context of human-computer interaction?" (Dey & Abowd 2000, p. 2). Aiming at apporaching an answer with a *focus on geo-applications*, the following issues will be analyzed:

- Which context types and which context representations do exist?
- Are there approaches for context information integration and –processing existing?
- Which opportunities occur to use context-integration approaches in spatial applications?

## 3.1 General Context Types

In computer science it has been understood that developing context-aware applications should be supported by adequate context information modeling and reasoning techniques. The aims of such techniques are to reduce the complexity of context-aware applications and improve their maintainability and evolvability (Bettini et al. 2010). In table 1 basic context types are specified, taking into account results from (Sagl et al. 2015, Topcu 2010, Bettini et al. 2010, Hong et al. 2009). Whereas these authors discuss context aware systems in general, this paper focuses on the need of *context integration in spatial applications*. Therefore, table 1 includes an example related to a mobile geo-application that is used for data collection purposes, namely an app aimed at acquiring road specific information.

Table 1. Basic context types

| **Context type** | **Brief description** | **Example: Data collection app for road information** |
|---|---|---|
| **Computer-specific context** | The device including its properties, as well as the data network | Employee has a smartphone incl. GPS-receiver and digital maps; sporadic Internet connection |
| **User-context** | Personal data, preferences, individual goals | Employee is well trained in mobile apps; goal is to collect road specific information |
| **Physical context** | Location, temperature and further weather conditions, other facts and circumstances close to the current location | Start- and goal point and the track on which data will be collected are fixed; weather conditions and possibly specific conditions and needs to be considered |
| **Temporal context** | Current date and time, planning period | Start time and duration of data collection; physical properties of the employee and weather conditions |
| **Social context** | Near Groups or individuals | Other data collectors spatially close? Have citizens delivered road information which can be integrated? |

## 3.2 Surveys

There have been different reviews of context-aware systems during the foregoing years (e. g. Hase and Vaidya 2013, Truong and Dustdar 2009, Hong et al. 2009). Publications in the field of pervasive and ubiquitous computing are prone to consider context information (e. g. Ou et al. 2006). Carvalho and da Silva (2012) pointed out that „The purpose of software is to help people to perform their activities and fulfill their objectives. In this regard, the human-software relationship could be enhanced if software could adapt to changes automatically during its utilization". Chen and Kotz (2005) surveyed the literature related to mobile systems. The following overview (table 2) provides information gathered from various papers.

Table 2. Methodologies and technologies to integrate context information into computer applications

| Method | Brief description | Authors / Source |
|---|---|---|
| **Proximate selection approach** | The focus is on the user interface: Objects are related with other objects which are spatially „close“ to them | Schilit et al. 1994 |
| **Automatic contextual reconfiguration approach** | New components replace existing, if the context changes (then a reconfiguration of the system is carried out). | Kwon (2006) |
| **Context-triggered actions** | If the user gets into a new situation or if new data play a role, the system adapts using if-then-rules. | Chen & Kotz (2005) |
| **Extending standard context models** | An extension for a standard context model | Wieland et al. (2011); Sagl et al. (2015) |
| **Ontological context-integration** | The adaptation of a system to different users through context-related ontologies. | Gruber (1995); Wang et al. 2004); Welty (2010); Topcu (2011); Pundt (2012) |

Another survey is from Baldauf et al (2007). Here, different approaches which are aimed at the integration of context information are mentioned (Baldauf et al, 2007; see also Kokinov et al., 2007). Later, Hong et al. (2009) presented a detailed literature review of context-aware systems (table 3).

Table 3. Layers of context and related approaches (Hong et al (2009); Baldauf et al., (2007); and others)

| **Layer** (classification framework) | **Approaches** | **Goal** |
|---|---|---|
| **User-Infra-structure (incl. direct sensor access)** | Mobility is at its core the essence of context-awareness. The dynamic environment sets special requirements for usability and acceptance of context-aware systems. Clients gather context information directly from sensors. | Optimizing usability of context-aware systems, focusing on the GUI. |
| **Application** | • Computing device to operate independently of human control (customizable by user context and preference)<br>• Systems that not only handle a current task, situation and action but also anticipate future behavior<br>• Systems that recognize each other at a certain distance because proximal devices are important factors to offer appropriate services to users<br>• Applications that provide a rich set of capabilities and services to the nomad moving from place to place in a transparent form | Supporting users in many different situations and smart environments such as home, hospital, museums, shops, etc. These applications include, among others, decision support systems, and web services. |

| | | |
|---|---|---|
| **Middle-ware Infrastructure (incl. networked services)** | • Mobile agents (emerge as technology suitable to develop context-aware systems)<br>• Reflective middleware (possesses the unique ability to model itself through self-representation)<br>• Methods of encapsulation used to separate e.g. business logic and graphical user interfaces<br>• Metadata based middleware (facilities perform binding management actions based on metadata and context and locations visibility) | Allowing agents to acquire contextual information easily, reason about it using different logics and then adapt themselves to changing contexts. |
| **Network Infra-structure** | Internet protocol, handoff management, sensing, network requirements, network implementation | Dynamic adaptation to changes in contexts. |
| **Context server** | Introducing an access managing remote component and thus permitting multiple clients access to remote data sources. | Usage of a context server to relieve clients of resource intensive operations. |
| **Concept & Research** | • Designing and modeling algorithm, message bus encoded by XML, role and communication methods of agents<br>• Increasing accuracy and efficiency of algorithm for extracting context<br>• Development of algorithms to recommend appropriate service considering the user context | Develop theories and foundations to construct context-aware systems |

Aiming at answering the question, whether context-awareness is only a matter of mobile geo-applications or if it is relevant for SDSS in general, section 4 introduces a conceptual approach.

# 4. APPROACHING CONTEXT-INFORMATION INTEGRATION

Context information is related to a specific sector, such as water management, forestry, agriculture, urban planning, traffic infrastructure, or tourism. An application that considers different, relevant contexts needs access to descriptions of potentially *relevant* context models. A formalized description of the data acquired and stored by single sectors would lead to a sector-specific meta model. Such a meta model could be implemented using, for instance, textual tags in XML. If different sectors provide meta models, these can be compared automatically. The comparison can lead to the identification of equal or similar tags in the XML descriptions. If such identities, or similarities, are detected this hints on potential relationships between different contexts, or sectors. A problem-setting, however, could also be formalized in a tag-based manner and analysed together with the meta models. Equalities between the problem-setting and sector-specific meta models would either represent relationships between the problem, and possibly concerned sectors. The component that compares the XML models should work on a syntactical, and a semantic basis. If syntactically equal terms are identified, this is a hint on a contextual relationship between sectors, and/or between the problem-setting and sectors. The claim is that all sectors that show any such relationships should be considered when decisions within the framework of the spatial problem are made. However, the problem of data heterogeneity results mainly from its semantics. Different sectors use equal or similar terms to describe different concepts. This issue is highlighted briefly in the next sections, thus referring to some empirical results obtained in a study presented by Pundt (2012).

## 4.1 Data Semantics are Contextual

The different sectors are using terms and concepts that refer to their specific perspective, or context. However, this leads to semantic differences. Same terms can have different semantics which provides problems for an automatic identification of the "correct" terms, or concepts within the framework of a specific application. This is true for many terms, but starts with very basic concepts. The varying concepts of a "point" is one example. An adequate geometrical and topological representation of a point, and point-based networks (as, for instance, traffic or stream networks), is dependent from the context of the sector, or community, that uses it. One specific representation may satisfy the requirements of one community, which does not necessarily mean that it fits those of another. Even the quantity and density of points to be considered in a graph, depends from the purpose the network is used for. This is especially true for the semantic information linked to each point. Apart from universal information, such as the coordinates, height, and topological characteristics, the semantic information is highly context dependent. This means that a point in one application may be represented by x, y- coordinates, and a name, whereas it might be represented by coordinates, a name and several further descriptive attributes (including their proper description) in another (referring to the following example in sections 4.2 and 4.3 a "point" could be, for example, and "urban tree" in one sector, and a "road tree" in another). Attributes to describe such points more in detail, are expressed using words which are part of a vocabulary of a specific sector. The semantics of the words, used to express what a point means in an application, is only interpretable if the context is known, in which the term is used. Apart from the various meanings of the term itself (see Table 4 as an example), a point may be a concrete spatial object (house, road junction, tree) or a POI. But what does POI mean in an application context? In one application it can be POI representing accommodation opportunities, in another it can be historical buildings, and in a third the POI may be doctors' offices and hospitals, due to each underlying application and the special interest of users.

Table 4. Varying meanings of the noun, and verb, “point”

| | Meaning | Examples | Spatial relevance? |
|---|---|---|---|
| **Noun “point”** | A geometric element that has position but no extension | “a point is defined by its coordinates” | Yes |
| | The precise location of something; a spatially limited location | “she walked to a point where she could survey the whole street” | Yes |
| | Brief version of the essential meaning of something | To “get to the point" | No |
| | An instant of time | “at that point I had to leave” | No |
| | The dot at the left of a decimal fraction | | Yes/No |
| | Indicate a place, direction, person, or thing; either spatially or figuratively | “this is the point where we can live happily” | Yes |
| **Verb “point”** | Direct the course; determine the direction of travelling | “he pointed toward the castle” | Yes |
| | Be a signal for or a symptom of | “her behaviour points to a severe neurosis” | No |
| | Sail close to the wind | “they pointed Northwest” | Yes |

The examples underpin that semantics, are not universal in many cases, but tight to a specific context. A point object, enriched by more information referring to a specific application, is distinguishable from another concerning its meaning, not necessarily its location (Florczyk et al. (2010). It needs technologies that solve such semantic problems or even help to deal with them. But there are some progressive steps in this direction. Semantic similarities, for instance, can be detected grounded on appropriate published algorithms (e. g. UMBCSim 2016, Rus et al. 2013).

## 4.2 Identifying Contextual Relationships between Two Sectors: “Road infrastructure” and “Environment”, a Case Study

To avoid criticism about decisions, often uttered after the decisions have been implemented (e. g. criticisms on ‚incompleteness‘ of problem solutions, ‚overemphasis‘ of specific aspects, ‘ignorance’ of certain actors or lacking ‚sustainability‘), the identification of potentially relevant contexts within a spatial problem-setting could help to make more comprehensive, and therefore better decisions.

The exemplary scenario is as follows: in urban planning, road infrastructure and green areas (lawns, parks, green corridors along roads, etc.) play an important role. Particular urban management purposes may require the collection of data about road conditions, as well as information about the vitality of trees along the roads. Data collection is mostly done using GPS-supported, mobile geo-applications. The data is stored using GIS. Of course, such data are collected primarily for usage within a single sector. But once digitized, such data could be relevant for different other applications as well.

Two mobile apps are supposed, an app to collect road data, and another app to acquire information about urban vegetation. Such tasks are often carried out by different administrational units.

However, the data, collected using the mobile GI apps, is potentially interesting in many different contexts. To make this more explicit, the following table considers a road infrastructure (or traffic-) department and an environmental department. The table shows sector-specific issues and, additionally, it hints on contexts in which other sectors the data could play a role as well. The use-case serves only as a theoretical framework, and table 5 raises some issues to demonstrate the goal of making the "SDSS" context-aware. To achieve this, it needs to be expanded by a functionality that, in a first step, tries to identify all relevant contexts within the framework of the underlying problem-setting. This is envisaged using the formalized meta models.

Table 5. Contexts that are potentially relevant a) for mobile mapping apps and b) for urban planning purposes in general

<table>
<tr><th colspan="2">Specific contexts, potentially relevant for the mobile apps</th></tr>
<tr><td>Sector: Road infrastructure;<br>Using: "Road Infrastructure Mapping App"</td><td>Sector: Environment;<br>Using: "Urban Vegetation Mapping App"</td></tr>
<tr><td>• requirements of passengers<br>• requirements of cyclists<br>• harmonization of pavement of roads with noise minimization demands<br>• integration of road improvement and historical, as well as aesthetical aspects</td><td>• Influences of pavement and road infrastructure elements on the vitality of road trees<br>• Influences of road improvement on water provision for road vegetation<br>• Limiting effects of road trees on traffic (e. g. visibility of traffic signs)<br>• Selection of suitable species for road vegetation in case of tree replacement<br>• Consideration of legal aspects concerning cutting and replacing of road trees<br>• Consideration of urban-aesthetical aspects</td></tr>
<tr><th colspan="2">Other contexts, potentially identified by the SDSS (which must be expanded by formal descriptions aiming at accessing sector specific meta models and identifying dependencies between the problem, and relevant sectors)</th></tr>
<tr><td colspan="2">• Traffic security context (e. g. road trees may affect traffic security aspects)<br>• Environmental context (e. g. role of road trees for urban microclimate)<br>• Urban aesthetics context (e. g. coincidence of the improved road, and road vegetation, concerning the aesthetical urban picture that is envisaged)<br>• Urban development context (e. g., consideration of underground engineering; telecommunication measures (hauling of pipes, wires, etc.) during the renewal of roads and the planting of new trees)<br>• Political context (e. g. integrated urban development plan)<br>• Economic context (e. g. improvement of overall urban traffic infrastructure)<br>• Climate Change adaptation context (e.g. consideration of climate protection ($CO_2$-reduction) and climate adaptation (generation of shadow through trees))<br>• Citizens participation context (1) (e. g. requirements of elderly people, children, handicapped people)<br>• Citizens participation context (2) (e. g. resistance against planned road- and vegetation modifications)</td></tr>
</table>

The challenge is to consider multi-contextuality *not only on the human level* but on the *level of geo-software* that supports communication and data sharing needs.

## 4.3 A First Step toward Formalization of Meta Models

Neither table 3, nor figure 4 substantiate a claim that they are complete. They indicate exemplarily that multi-contextuality is a crucial prerequisite for proper and comprehensive spatial decision-making. „The association between Web-Services [or geo-applications] and context is not easy to achieve because the adequate mechanisms are not offered to developers in order to support the description and representation of context-related information and its later utilization (…).” (Carvalho & da Silva 2012, p 63). The claim is that technology can contribute to improve spatial decision-making quality through the application of techniques to integrate context information, thus supporting a holistic approach.

A prerequisite for the suggested approach is the description of context-specific meta models. There are XML derivates which own the capabilities for formalizing textual descriptions, e. g. RDF and/or OWL. RDF gains popularity for its ability to manage semi-structured data without a predefined database schema and therefore suitable for meta-model descriptions (Brodt et el. 2011). The difference between such a meta-model, and an ontology, for which formalization in RDF/OWL is possible, can be scrutinized. Ontology-based spatial models, however, have been considered as useful in many publications (e. g. Gruber 1995, Bolchini et al. 2006, Klien et al. 2006, Ou et al., 2006, Kuhn et al. 2007, Obrst et al. 2010, Pundt 2012).

The following figure presents the proposed interplay of the formal models under the assumption that the SDSS was expanded with a formal description of the problem setting, e. g. within the framework of an “urban road improvement project”. Based on the underlying models, two specific contexts are identified as being *relevant*. Whereas information on the age of trees can be found in one sector-specific model (Sector: “Road Infrastructure”), the question could come up, how the vitality of old trees looks like. This information is available in another context-model (Sector: “Environment”). In such a way, both pieces of information can be provided to the decision makers through the context integration procedure. The information can afterwards be taken into account in the decision making process, thus avoiding wrong decisions, e. g. cutting of road trees only due to their age, even if they are still quite healthy.

Concerning the formal representation, in a first step not XML (or RDF/OWL) has been used, but N-triples. This is a line-based, plain text format, capable of storing and transmitting data. It relies on the components subject, predicate, object and in such a way it provides a means to represent spatial features. A basic format of an n-triple is as follows (W3C 2014):

```
<http://one.example/subject1> <http://one.example/predicate1>
<http://one.example/object1> .
_:subject1 <http://an.example/predicate1> "object1" .
_:subject2 <http://an.example/predicate2> "object2" .
```

According to this basic structure, the following figure represents an example in that two meta-models represent the context-specific description using n-triples. The triples are applied to find corresponding contexts, hinting on their relevance within the framework of the decision making process.

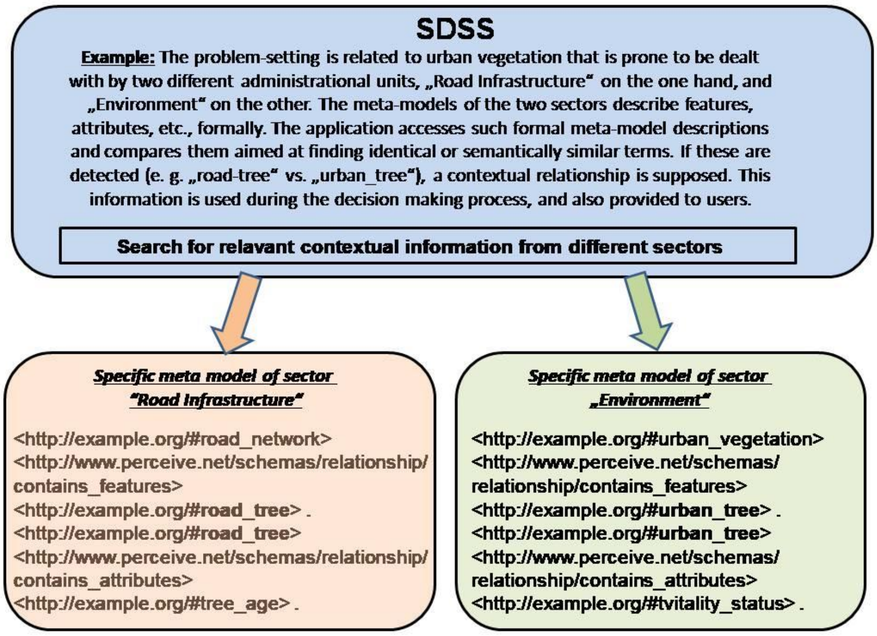


Figure 2. A spatial decision system (SDSS) can handle specific meta-models using n-triple-based formalization. The aim is to identify contextual relationships between different sectors

The figure shows only a very first idea of how to approach context integration in SDSS. Further studies should be carried out to investigate if such an approach is vital, and could be combined with solutions that have been mentioned in tables 2 and 3.

## 5. CONCLUSIONS

Spatial decision support systems (SDSS) should be completed by components that enable the system to identify and possibly integrate relevant contextual information from different sectors. This capability would support a holistic approach in decision making, thus aiming at considering as many relevant contexts as possible. The *application-steered identification* of relevant context information, and *its provision* would support decision making especially in complex, multi-dimensional problem settings.

Extracting information from different representations, e. g. meta models as mentioned before, is a tough task to do. However, the growing need for more transdisciplinarity and cross-sector thinking in spatial decision making, require action for more substantial, sector-wise formal context representations. If they exist, applications would be enabled to identify relationships and dependencies between different contexts which would contribute to more sustainable decisions.

In this paper, related work has been investigated critically; a use case has been defined to make the problem more transparent, and an idea to formalize context information is presented.

A next step should be to implement the exemplary use case and to test if the approach supports the goals defined previously.

However, the overall aim of making SDSS context-aware is to minimize the danger of producing deficient, ignorant or wrong decisions. Such support would also avoid workflows that are carried out uniquely, sector-specific ("piecemeal"), instead of integrative.

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