Negotiating PSSs as Epistemological Objects:
An exercise in sociotechnical model development for planning support

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Combined Reviewer Feedback:

The authors proposal uses a framework based on Lehmann's work to analyse the design process of a PSS. However, at this stage the dimensions of the framework remain undiscussed and for this reason the relevance of applying Luhmanns ideas remains somewhat vague. It is therefore suggested to the authors to further elaborate on this framework and explain its relevance in the particular context of the study. Please, also make sure the paper directs sufficient attention to the link between the design of a PSS and the resulting urban design/planning process resulting in spatial outcomes, as the latter is the greater focus of this meeting.

Keywords: epistemological objects, complexity science, planning support systems, sociotechnical approach

Abstract

Planning support systems (PSSs) have been criticized for being fixed objects designed by system developers who lack adequate understandings of user needs and of the complexities involved in planning processes. Recent approaches to developing PSS models have included the end user – planners – to specify usability and functionality requirements, but these so-called sociotechnical approaches have yet to fully integrate the model development process into the planning process. During early-stage spatial planning, actors communicate their different meanings of planning system components to formulate planning problems before engaging in joint problem solving. In this study, we integrate PSS model development into the spatial planning process as an epistemological object whose meaning and utility are negotiated in a collaborative design process. To do so, we applied a systems approach derived from complexity principles to observe longitudinally how planners and developers negotiated the design of the PSS in a sociotechnical process within the context of the planning problem formulation task. As a part of the study, we invited system developers and PSS experts to collaborate with municipal planners in a collaborative planning problem formulation workshop series. We found that participants were able to formulate specific planning problems and we identified important contextual requirements for PSS integration into the planning process. We discuss the implications of these findings for the advancement of sociotechnical PSS development.

1. Introduction

Spatial planning is a social process that is inextricably linked to the complex socio-spatial systems it seeks to influence. The complexity of these systems originates from the myriad interactions of system actors with components of their environment. Recently, studies have begun to examine spatial planning and the design of urban spaces through the complexity lens (Portugali, 2012). Still, many questions remain unanswered regarding the nature of complexity in the spatial planning process. In early strategic stages of spatial planning, planners negotiate actor interests and influence in the context of environmental opportunities and limitations to formulate implementation strategies for a project (de Graaf and Dewulf, 2010).

This process consists of both *routine* or management- and analysis-based and *non-routine* or strategic (Batty, 1995) planning tasks that occur repetitively and are intertwined in a dynamic planning process (Vonk et al., 2007). Through this iterative design process, planners formulate, manage and analyze planning problems. Problem formulation involves both the structuring of the problem and defining of criteria for evaluating a solution, whereas problem management and analysis, known collectively as *problem solving*, involves the identification of a solution that satisfies these criteria (Zamenopoulus and Alexiou, 2012). The myriad possibilities generated by the complex interactions among actors as they communicate about the components in their planning environment muddle up these problem formulation and solving tasks. Potential undesirable consequences of inadequately formulated problems include the prolongation of the planning process and the generation of implementation strategies that do not fit the planning context.

This planning process, in complexity theory terms, is a dynamic social system comprised of planners who conduct communication interactions based on components in their shared environment (Luhmann, 1990). Early on in planning, these interactions form an iterative cycle of option creation and selection. Option creation is a necessary complexity-generating exercise predominantly, but not exclusively, associated with problem formulation. If planners do not find structured ways of making choices among possibilities, the planning system remains in a state of chaos. As Luhmann states, "well-defined systems make it possible…to live in the face of an extremely complex and contingent world and yet always have to choose from among only a small number of consciously controllable possibilities of behavior," (ibid, p. 53). Planners therefore rely on supportive methods and tools to progress the process of option creation and selection.

The most significant recent advancements in tools and methods available to planners have come from computer-based planning support. Planning support systems (PSSs) are a subset of information systems built upon geo-information technologies to support planners in specific planning tasks (Brail and Klosterman, 2001; Geertman and Stillwell, 2004; Harris, 1989; te Brömmelstroet and Bertolini, 2008). These tasks include exploration, representation, communication, analysis, prediction, prescription, design, implementation and monitoring (Batty, 1995; Geertman and Stillwell, 2004; Vonk et al., 2007). PSSs that have made the successful transition to practice typically support routine, yet complicated planning tasks associated with problem solving. This is because these descendants of geographic information systems (GIS) (Geertman, 2006; Harris, 1989) excel in processing complicated, generic datasets. These datasets represent an actual spatial system in a GIS environment to support tasks such as scenario building, spatial analysis and data modelling.

While these systems cope well with large, complicated datasets, they are less attuned to deal with system complexity. Planning systems may be complicated on account of their large number of components; however, complexity arises when the dependencies among components are of importance (Miller and Page, 2007). So far, PSSs have not been able to represent the complexity of actor interactions in a meaningful way. Consequently, disparity remains between the use of PSSs to support these interactions during problem formulation when compared to problem solving. According to a study by Vonk et al. (2007), out of 58 analyzed PSSs only one (1) system supported non-routine problem formulation while 55 systems supported routine problem-solving tasks. To reach their full potential, PSSs should be integrated to support the non-routine, strategic planning tasks that guide routine spatial planning tasks (Batty, 1995).

Some researchers attribute the failure to fully integrate PSSs into the structuring of non-routine tasks to a miscommunication among planners, system developers and other experts where agreement is lacking on the role of the PSS (Vonk and Geertman, 2008). Since conventionally system developers are not involved in the planning process, they are largely unaware of the rationale behind the choices made during the early planning stages. Consequently, the underlying PSS models they develop commonly reflect the strict technical rationality (Te Brömmelstroet and Schrijnen, 2010; Vonk and Geertman, 2008; Vonk, 2006) of the system development process rather than the collaborative rationality (Healey, 2010; Innes and Booher, 2010; Pelzer et al., 2013) of the planning process.

The failure of PSS design logic to transcend the technical development environment makes PSSs poorly adapted to the context of their use in ill-structured, non-routine planning tasks. Consequently, planners may mistrust the outcomes of PSS use because criteria for evaluating problem solutions are unknown, too abstract, or not relevant to the local context. If spatial planning and PSS model development occur in separation, the two processes are not likely to be compatible. The implications of this could be the inability to integrate a PSS into the planning process and consequently the failure of the PSS to support problem formulation during early-stage planning.

To bridge this gap between the two processes, researchers in recent years have developed PSS models by including input from users, typically planners, in a sociotechnical learning process (Te Brömmelstroet, 2010; Vonk and Ligtenberg, 2010). User input in the development process has brought improvements in the functionality and usability of PSSs (te Brömmelstroet and Bertolini, 2008; Vonk and Geertman, 2008; Vonk and Ligtenberg, 2010) for problem solving; however, these systems remain mostly absent from problem formulation. Without the involvement of the system developer during problem formulation, contextual knowledge and information about the planning environment may not be adequately represented in the PSS models used later in problem solving. Furthermore, important knowledge about the capabilities and limitations of PSSs would be absent from problem formulation.

We assume that if introduced to the spatial planning process at an early stage, the PSS model could serve to mediate between the system development and spatial planning knowledge domains. For a PSS model to succeed in this role, it must be capable of evolving, much like the planning processes it seeks to support. This is similar to the notion of epistemological objects, which "have an unfolding ontology and are constantly in flux" (Ewenstein and Whyte, 2009). As the epistemological PSS model evolves, new knowledge and issues are revealed. The aim of this article is to empirically analyze the role of PSSs as epistemological objects in crossing various types of knowledge boundaries to support collaborative, early-stage planning problem formulation and solving. To do so, we pose the following research questions: How do actors communicate about components in their environment during problem formulation and solving and how do these communication interactions change when PSS model development is introduced into the planning process?

This paper is divided into three parts. In the next section, we explain how PSS models that were developed using a sociotechnical approach fail to address contextual matters of complexity during problem formulation. We suggest a way forward for such models by introducing a theoretical framework to reduce system complexity into formulated problems that combines Luhmann's notion of communication with epistemological objects theory. Thereafter, we empirically explore how PSS model development alters the communication patterns of a sociotechnical design process in a spatial planning case study. Based on an in-depth discussion of this empirical exploration, we then propose how the negotiation of the PSS model might support may support early-stage problem formulation and solving in spatial planning.

2. Sociotechnical model development during problem formulation and solving

We have argued that to manage and analyze planning problems effectively, planners must clearly formulate these problems and the criteria for their evaluation. To formulate problems planners must find structured ways of reducing system complexity generated by their social interactions. While PSSs have demonstrated relative utility in supporting the routine management and analysis tasks involved in problem solving (for examples see Geertman and Stillwell, 2004), the application of PSSs to support non-routine problem-formulation tasks still lags begin. Herein lies a fundamental mismatch between what technologies can do and what is required of them socially (Ackerman, 2000). The following subsections describe previous attempts in the realm of sociotechnical PSS model development to resolve this mismatch and suggest an approach that supports problem formulation.

2.1 Sociotechnical PSS development

Conventionally, PSS models have been developed following a technology-driven systems engineering approach. Planners who adopted these tools were presented with a pre-programmed PSS suite designed independent of the planning task at hand. The system architecture likely included generic spatial analysis software elements, a visualization screen, self-closing polygons, an attribute database and interface hardware for finger touch or drag and drop functions (Vonk and Ligtenberg, 2010). Recent innovations invert this model so that the planning process, not the technology, drives PSS model development. These so-called sociotechnical PSS models involve the planner who specifies usability and functionality requirements for the PSS design (te Brömmelstroet and Bertolini, 2008; van Delden et al., 2011; Vonk and Ligtenberg, 2010; Vonk, 2006).

Vonk and Ligtenberg (2010) introduced a sociotechnical PSS model, which was collaboratively developed by a group of experts from planning-related fields. The planning tasks specified in the model were based on the Schetsschuit problem management and analysis method. These tasks included area exploration, visioning and designing. According to this method, the experts "discuss about planning problems and find supported solutions," (ibid, p.170). Working together in a workshop format, the planning experts and PSS developers collaboratively negotiated a PSS architecture of planning support workspaces. The workspaces included drawing and sketching sheets, a map library, navigable visualization screen and group support hardware that were selected and customized based on the emerging use needs of the spatial planning process.

Similarly, te Brömmelstroet and Schrijnen (2010) proposed and tested a mediated planning support process architecture that intertwined the PSS development process with the planning process. Their aim was to develop a mediating approach to integrate knowledge from transport and land use planning domains through a sociotechnical PSS development process. Similar to the Vonk and Ligtenberg study, planners, system developers, PSS experts and other experts engaged in a sociotechnical learning process where they shared diverse types of views and knowledge in a professional setting. A further characteristic common to both of these studies is the explicit statement of a spatial planning problem. This means that the forging of knowledge domains through sociotechnical PSS model development largely occurred during problem solving.

For projects undergoing early problem formulation, planning problems may be present but remain ill-defined (Rittel and Webber, 1973). This is because during problem formulation, attempts by planners to forge knowledge boundaries often generate complexity. As the planning system becomes overwhelmed with options, progress stagnates. Since the social system does not have the capacity to consider all components at a given time, actors must make choices. Social systems struggling to move planning forward must find methods and tools to support the meaningful selection of options that improve the fitness of the system.

Planning problems in an ill-defined state can only be supported to a limited extent by GIS (Harris, 1989) and other forms of visualization. Therefore, the role of planning support should also be to gather various sorts of knowledge, both spatial and non-spatial, to structure the planning problem (Couclelis, 1991; Geertman, 2006). According to Geertman, "spatial planning is a highly dynamic and inherently contextual and problem-oriented activity…non-spatial factors all play an important role in the spatial-planning practice," (ibid, p. 869). At the same time the visualization of both spatial and non-spatial data through a PSS has proven to provide a common language for collaboration (Al-Kodmany, 1999), which is particularly important during early planning stages. What and how knowledge should be communicated must be agreed upon by the actors involved. By looking at cases of spatial planning longitudinally, we may find evidence to ground the notion that PSSs models in an epistemological object state may help to structure these communication interactions during problem formulation.

In this study, we explore the impact of PSS model development on early problem formulation and solving. As Figure 1 shows, we do so by adopting a complex systems theory approach. By understanding the planning process as a complex system we gain focus on the dynamic, component-based communication interactions of actors within a social system while viewing these interactions across the entire planning system. This social system we refer to consists of diverse planning professionals in a collaborative design team (CDT). The CDT acts as an expanded social system that includes not only planners but also PSS developers and experts who communicate about the components of their shared environment. These communication interactions introduce new components to the shared environment, whereby choices must be made that either activate or neutralize components in the environment. Contingent components are neutralized options that may be selected in future planning stages but have no influence in the current stage. In the context of this sociotechnical model development approach, we hypothesize that the introduction of a PSS model in an epistemological state provides necessary complexity-reducing structure to option selection, thereby supporting problem formulation. The fundamental concepts behind this hypothesis are further developed in the remainder of this section.

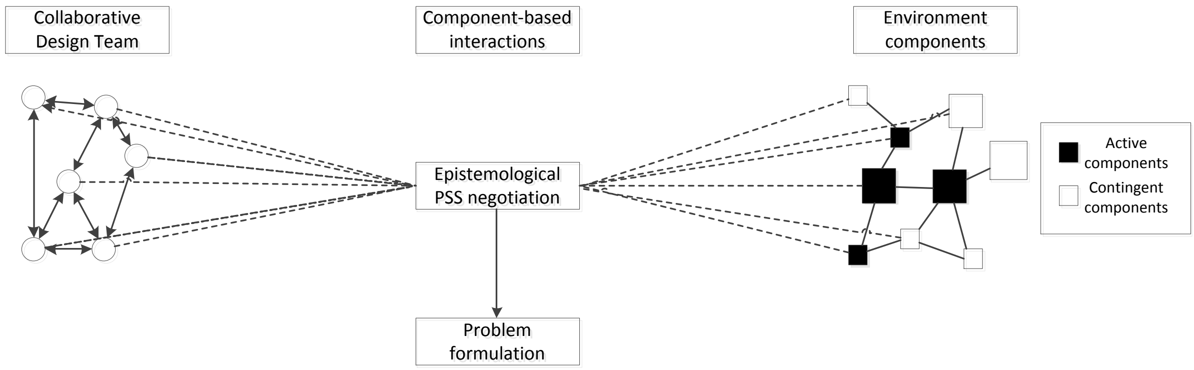

Figure 1 A Complex Systems View of Sociotechnical PSS model negotiation during problem formulation

2.2 Option creation and reduction in the planning system

The binding principles of all known systems are the dynamic interactions between components and the feedback loops that stabilize the process (von Bertalanffy, 1968). System components include a core social system of actors who exhibit agency while interacting with one another and with actors and objects present in their environment. According to Luhmann (1990), complexity refers to the myriad opportunities wherein these interactions occur at the cost of other possibilities. System complexity is often confused with complicatedness. Complicated systems contain a large number of free-standing components than can be analyzed through reduction and isolation (Miller and Page, 2007). Complex systems are more difficult to reduce because of the web of interactions among their component parts. According to Luhmann (1990), complexity has *material*, a *social* and a *temporal* dimensions. The material dimension of complexity refers to the distinction between a component as one thing and its negation as another. The social dimension is drawn from the accumulation of other perspectives pertaining to components along with one's own perspective through social interaction. The structure of the temporal dimension complicates the other two dimensions. To avoid overcomplicating the exploration of material and social dimensions one may simply assume that actors in the system share a synchronized space in time (ibid).

Social systems have a method to reduce complexity that is unique compared to other complex systems. What distinguishes social systems from other systems is that interactions center on communication, or the meaningful selection of information, its utterance and understanding by a recipient (Luhmann, 1990). This creates a selective relationship between the social system and its environment. Throughout the communication process actors makes choices that reduce possibilities thereby formulating discrete interactions out of "undifferentiated chaos" (Luhmann, 1995). Unselected environment components do not simply vanish. Rather, they are neutralized in the environment until chance brings them into view once more through what is called *contingency*. Therefore, contingency makes it possible to reduce complexity within the social system of actors while at the same time preserving complexity within the environment (ibid).

2.3 Component-based communication

The process of reducing undifferentiated chaos into discrete interactions in practice allows us to observe how actors collaboratively engage in option creation and reduction. By doing so, we gain a finer resolution on the interactions that theorists such as Luhmann conceptualize in their grand models of complex social systems. The interactions of interest in this study are the communications that occur within a social system, namely the CDT. The CDT is closed in terms of communication. This means that system actors communicate about, but not with, components in the environment. We refer to this as component-based communication. The purpose of component-based communication during problem formulation is to create and select options from the environment. When actors from different social systems interact, they introduce components but also boundaries that inhibit collaboration.

To overcome different types of boundaries when actors from different social systems interact, actors must communicate in multiple discursive forms. First, syntactic boundaries exist where a common syntax to ensure quality information exchange is lacking. According to Carlile (2002), systems theory (von Bertalanffy, 1968) introduces a significant boundary, namely between the social system and its environment. Even more dramatic are the boundaries that emerge when actors form novel links with objects or actors outside their own system. Not only must a new syntax for the newly formed system be established, but the new constellation of actors need to understand "these novel conditions or new knowledge that lies outside the current syntax used at the boundary", (Carlile, 2002).

Second, semantic boundaries are the continuation of syntactic boundaries once a common syntax has been established. Semantic differences create a barrier to productive collaboration. The task of knowledge building here is to learn about the underlying differences that create the boundary. The key is to communicate knowledge that is context-specific explicitly across the boundary (Carlile, 2002; Nonaka, 1994). The forms of communication used by actors in these processes are *dialogue* and *debate* (Forester, 2006). Through dialogue, actors seek to share knowledge to understand the other and through debate, actors subsequently seek to sort out facts or justifications for an argument (ibid, p. 4). Third, pragmatic boundaries exist between knowledge that is localized and problem dependent. Since actors face unique problem sets in their individual tasks, their knowledge is contextualized at the local level. To forge pragmatic boundaries, actors *negotiate*, which is Forester's third form of discursive communication. This negotiation of knowledge to form agreements upon a course of action reduces options in social systems, allowing the planning process to progress. Forging the boundary between these knowledge domains often requires the creation of transforming knowledge, or the processing of creating and validating new knowledge within and across functions (Carlile, 2002).

When collaborating, planners engage in complexity-building dialogue and the sorting out of facts through debate. Both forms of communication are considered instrumental for the creation and subsequent selection of options. However, without the introduction of tools and methods to structure the processing of options from the environment, the social system can become overwhelmed. Quite commonly systems of planners find themselves caught in a cycle of option creation and selection without establishing pragmatic steps forward in the planning process. To move spatial planning forward, planners must not only discuss and debate, but also negotiate their meanings of components to formulate new knowledge.

Whenever two or more social systems merge into a newly formed social system, the actors must engage in all three types of component-based communication. During collaboration, for example, new actors must be introduced to the ongoing discourse and the discourse itself may have to adapt as well (Luhmann, 1990). This implies not only the coordination of domain-specific knowledge but also the creation on new knowledge. The coordination, development and learning of knowledge from different systems is an important function of epistemological objects (Ewenstein and Whyte, 2009). These objects serve a boundary-crossing role when new social systems are created during collaboration. Objects in an epistemic state are "abstract in nature: they are the objects of inquiry and pursuit. Hence, they are characterized by lack and incompleteness." (ibid, p.9). Because these objects are inherently incomplete, they may help to set the rules, common frames of reference and shared archives (Star and Griesemer, 1989) that enable productive collaboration. The following section explores these theoretical concepts in a practical case study.

3. Research Setting and Method

To understand how negotiating an epistemological PSS model can impact problem formulation and solving, we conducted a longitudinal case study of a spatial planning project over the duration of approximately two years. The case study involved the formulation of plans to expand an industrial terrain across the border between Germany and the Netherlands. The case study was selected from among several spatial planning projects currently being researched by the authors. To conduct the research, the authors collaborated with commercial product developers in a consortium to create holistic planning support methods and instruments. The case study was selected based on the early-stage problem formulation dilemmas its planners faced and since the planning issues they dealt with were both spatial and non-spatial in nature.

3.1 Data collection and analysis

While collecting data, we were particularly interested in how the act of negotiating a PSS model led to emergent forms of communication. Specifically, we wanted to observe the reduction of environment options to discrete interactions (Luhmann, 1995). We, thereby, sought (1) to reconstruct the social planning system of the case study based on communication interactions and (2) to analyze the negotiation of a PSS model during planning problem formulation discussions. We used multiple methods to collect qualitative data following an ethnographic-action research methodology. According to this methodology, researchers and planners engage in an iterative cycle of active participant observation, problem identification, and planning support development and implementation (Hartmann et al., 2009).

Due to the grounded nature of this methodology, data collection was purposefully non-linear. It was driven by the emergent opportunities of the case study rather than by a structured research design. To begin, we participated in and observed project meetings to identify the work routines of planners in a group setting. Once we had identified a need for planning support, we designed a sociotechnical PSS development workshop intervention. When the workshop outcomes revealed a need for deeper understandings of the planning system, we conducted semi-structured interactive discussions with the planners. These discussions contrasted with traditional interview methods since the interests, knowledge and opinions of the interviewer are known (Healey, 2007). To support these methods, we iteratively reviewed project documents and meeting outcomes. By triangulating multiple qualitative data sources (Yin, 2003), we were able to develop richer interpretations of the component-based communications.

Given the design nature of both the problem formulation and solving, and the PSS model development tasks, we adopted a systems-based approach for data analysis. This allowed us to study how actors within the CDT negotiated the epistemological PSS model through discursive communication about environmental components. To build a case for option creation and the need to make choices among options, we conducted both communication and complexity data analyses. First, to perform the communication analysis we relied on Forester's (2006) three types of communication interactions: dialogue, debate and negotiation. Second, to conduct the complexity analysis, we relied on complex systems theory (Luhmann, 1990, 1995) to reconstruct the planning system. This provided us a holistic systems view of the planning process to better interpret the discrete communication interactions of actors in processes of option creation and selection. To explore the question of how PSS model development alters communication in spatial planning, we compared the communication interactions documented during the retrospective discussions with planners to the interactions collected during the case study workshops. With this, we were able to distinguish between active components involved in communication interactions and contingent components identified by one or more actors but that were not involved in the observed communications.

3.2 Case description: Cross-border industrial terrain expansion

The case followed in this study involved the expansion of an existing industrial terrain across the border between Germany and the Netherlands. In 2009, two neighboring German and Dutch municipalities signed a memorandum of understanding to collaboratively expand an industrial terrain situated approx. 1km southwest of the German municipality and about 500m from the border. The 120 ha. terrain is a major employer for the German municipality that generates 41 % of the city's renewable energy. The Dutch municipality proposed the collaboration to its German counterpart for two reasons: (1) to construct an industrial terrain without infringing on a regional anti-competition agreement with neighboring municipalities in the Netherlands and (2) to protect the integrity of the natural landscape surrounding the municipality by first expanding the existing terrain on the German side. Both municipalities considered the opportunity for cross-border collaboration and trade strong selling points.

In 2011, the consortium of PSS developers and researchers was invited by the project planners to collaboratively develop a PSS model. Through a sociotechnical approach, the consortium members were introduced as actors in a now extended social system, the CDT. The CDT represented an expanded social system that negotiated the PSS model in relation to environment components iteratively through option creation and reduction. The CDT consisted of three main expert roles derived from specific knowledge domains– the planner, the system developer and PSS expert (Vonk and Geertman, 2008; Vonk et al., 2007). This classification according to roles allowed the CDT participants to switch and share roles. The planners contributed knowledge of the project-specific problem context. The system developers possessed knowledge primarily in the domain of PSS technology. And, the PSS experts used theoretical knowledge about planning, PSS technologies and collaborative design practices to guide the model development process. For example, in the workshops the researchers often played the dual roles of PSS expert to direct the workshop according to general planning process knowledge and of system developer to communicate the limitations of the PSS technology.

At the time of introduction to the project, the planners were meeting regularly but remained too long in a cycle of dialogue and debate without a clear structure for reducing system complexity. In the project much of the complexity-reducing structure remained archived in the minds of the planners and in a preliminary vision document. This reinforced a pragmatic boundary between the planners and the consortium members. Therefore, the consortium sought a more interactive approach to create and select system options. They suggested a series of sketching planning workshops based on the formulation of explicit planning objectives and indicators for scenario evaluation. The consortium thought that the introduction of the epistemological PSS model might help planners to move beyond the dialogue and debate cycle and into the creation of new knowledge through negotiation. This sociotechnical exercise is described below.

Negotiating the PSS model: A sketch planning workshop exercise

In Section 2.1 we explained that most sociotechnical approaches imbed the PSS development process in problem management and analysis tasks once planning problems have been formulated. These PSS models often do not explicitly state questions that bridge problem formulation and problem solving such as how do datasets used for spatial analysis reflect stakeholder interests? To expand the sociotechnical approach to support non-routine problem-formulation tasks, we attempted to imbed the PSS model development process deeper in the planning context (Te Brömmelstroet and Schrijnen, 2010). We thereby sought to observe examples of dialogue, debate and negotiations communications within the CDT. To begin, the planners conducted stakeholder analysis dialogue exercise to identify stakeholder interests. After this, the planners debated these interests and consolidated them into four strategic objectives:

- Develop a cross-border industrial terrain based on renewable energy production and distribution
- Promote cross-border knowledge exchange between German and Dutch companies
- Minimize the barriers between the two markets and attract global business
- Improve the transport connection to the industrial terrain

Together with the planners, the consortium members engaged in collective dialogue to create a long list of possible component relations underlying the satisfactory spatial outcomes of these objectives and the list was later reduced to five (5) possibilities for each scenario. Thereafter, the CDT conducted a sketch planning exercise, which allowed planners to quickly describe relationships (Hopkins, 1999) between the possibilities in spatial terms. Planners were provided printed maps of the industrial terrain and pens so that they could use familiar tools for sketching these relationships. In two rounds, teams of two planners sketched a possible physical solution maximizing one of the main objectives. In total, eight different sketched scenarios were developed representing two physical solutions for each of the objectives.

Due to the time-consuming nature of the work, the consortium developed spatial analysis indicators and planning parameters between workshops. First, based on the planners' sketches of terrain buildings, the consortium chose to set planning parameters based on buildings and industry categories. Second, the consortium derived indicator calculation algorithms based on the four strategic objectives. Calculations for the German and Dutch market values and renewable energy production were generated based on economic industry indexes. Furthermore, an input-output matrix based on industry classifications (Blin and Cohen, 1977) was used to calculate knowledge exchange among industries.

Figure 2 Terrain expansion sketch planning exercise (*left*); a consortium member introduces planners to the spatial analysis software (*middle)*; expansion scenario with assessment indicators (*right*)

At the opening of the second workshop, a debate emerged over the assessment indicators followed by a dialogue that expanded the industry function parameters that the consortium developed between workshops. With these, the CDT then conducted a second sketch planning exercise to balance and maximize the strategic objectives. Participants selected buildings and their industry category and two plans were selected for an analysis of strengths, weaknesses, opportunities and threats (SWOT) from the perspective of an important stakeholder. This allowed participants to test the sensitivity of the parameters and indicators. Subsequently, the parameters and indicators were entered into a spatial analysis program prototype developed by the consortium. Access to the tool was provided to the planners as a web-based application. Figure 2 shows (1) consortium members observing as planners debate the relationships between system components in the sketch planning exercise, (2) the translation of these sketched scenarios into a GIS environment with collaborative analysis functions and (3) an example of a collaboratively developed expansion scenario in the spatial analysis software.

At the end of the workshop series, the PSS experts conducted separate feedback discussions both with the planners and the system developers to assess the utility of the workshop design and outcomes. According to their responses, opinions were somewhat split between the groups regarding the workshop outcomes. System developers expressed that the workshops provided structure to an otherwise chaotic planning process. They considered the ability of planners to explicitly state and evaluate strategic objectives based on stakeholder interests an indication of workshop success. Additionally, the consortium was able to develop indicator metrics in a GIS environment, which the planners could use in the further specification of and experimentation with expansion scenarios.

Overall, the planners were likewise satisfied with the workshop process format; however, they were dissatisfied with the workshop outcomes. Statements such as, "indicators did not represent our local situation" and "the placing of specific industries into certain spatial locations came too early in our process" most likely indicated shortcomings in the workshop format. Since the workshop process was auxiliary to the ongoing planning process, consortium members may have lacked sufficient opportunity to explore the planning system into which the PSS would be integrated. Therefore, the PSS experts decided to conduct retrospective interactive discussions with each of the planners in hopes of identifying component interactions in the actual planning process that would be critical to problem formulation and solving.

Revealing system complexity through retrospective interactive discussions

Interactive discussions conducted individually with the six planners revealed a significantly more complex planning system than what was observable during the workshops. In total, the planners mentioned 116 unique components that constitute the planning system of the industrial terrain expansion project, see Figure 3. We observed the material complexity generated as planners introduced new components. Collectively, the planners mentioned 22 different stakeholders and actors beyond their social planning system, 14 different policy artifacts that represented different policy frameworks of the Dutch and German municipalities, and 26 different issues relevant to the planning process. Therefore, unsurprisingly, 13 different project goals were identified from the interactive discussions with the planners compared to the three (3) strategic objectives that the same group of planners formulated during the workshop interventions. Additionally, when planners spoke of the same components they sometimes had different perceptions, which introduced social complexity to the system.

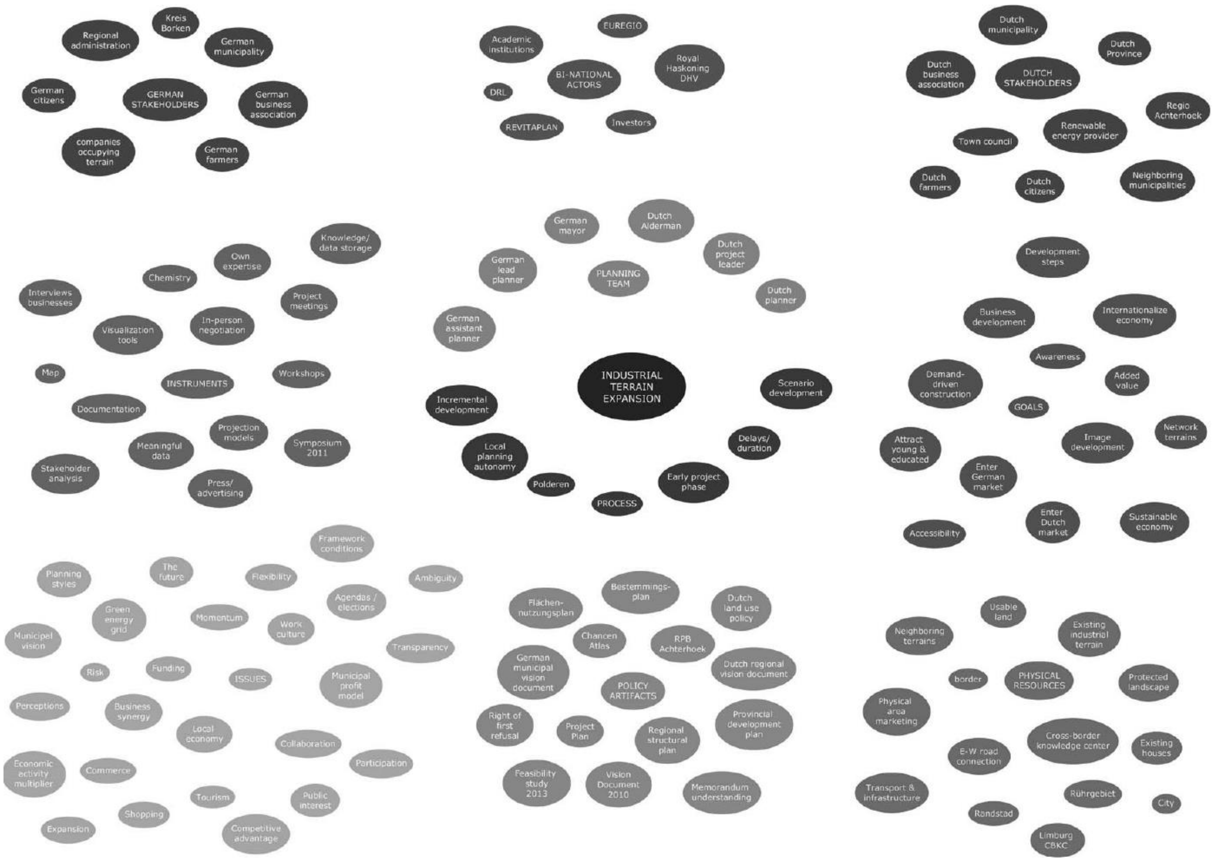

Figure 3 Mapping of case study system components

4. Evaluation

During our field research we were confronted with the need to support planners in reducing system complexity by making choices to support planning formulation. In this section we evaluate efforts to better understand this support need empirically. The section begins with the evaluation of component-based communications that occurred within the context of the broader planning process and continue by evaluating the component-based communications that occurred during the PSS model development workshops.

4.1 Complexity-generating dialogue and debate communications

The interactive discussions we conducted revealed a long and intensive process of dialogue and debate to forge syntactic and semantic boundaries within the social system. Since collaboration between the municipalities was unprecedented, these boundaries were initially profound. Table 1 shows the cyclical nature of the dialogue and debate processes. Not only were the planners confronted with the syntactic boundary of two different languages, but they also had to overcome semantic boundaries. For example, the terms "project" and "land use plan" held significantly different meanings in the two local contexts. First, the different meanings of project carried implications for the constellation of the social planning system. While industrial terrain expansion was officially recognized as a project by the Dutch municipality and subsequently assigned a project leader, planner and supervising alderman, the German municipality perceived the expansion as another task related to the municipal goal of economic growth in the industrial sector. The German municipality planners forged a semantic barrier by referring to the collaboration as a project; however, their involvement remains predominantly task based. Second, the planners were confronted with different meanings of land use plan and the respective policy implications of the plan in their countries. The German municipality's land use plan (*Flächennutzungsplan*) is comparatively more flexible and suitable for the incremental expansion of the industrial terrain, while the Dutch municipality's land use plan (*Bestemmingsplan*) is more rigid requiring regional approval for any changes. Dialogue and debate over the differences of the two land use plans added new options to the planning environment.

Table 1 Component-based interaction types prior to PSS model development

Component-based interaction	Dialogue	Debate	Negotiation
Planners communicate in two languages, each in his/her native tongue	x		
German municipality adopts Dutch municipality's reference to the "project" although generally their job descriptions are not based on projects		x	
Identification of differences in policy frameworks: The regulatory frameworks and contents of land use plans (LUP) differ making collaboration difficult	x		
Planners prefer to adopt German municipality's strategy to extend the existing terrain since German municipality's LUP is conducive to incremental development		x	
Municipal profit models-taxation based on selling of land vs. trade tax	x		
Planners also prefer to extend the existing terrain since German municipality's commercial taxes are based on the renting of land		x	
Local and regional economy ·German municipality strong in industry ·Dutch municipality anti-competition agreement ·Cross-border trade in tourism, shopping but not commerce	x		
Identification of: · baseline situations in each municipality	x		
Vision formulation based on baseline situations: ·Sustainability ·Cross-border character ·Spatial aspects		x	
Consolidation of baseline components strengths, weakness and goals			x

Additionally, components of the local economies such as the German municipality's comparatively favorable trade tax (*Gewerbesteuer*) and land use regulations and its existing industrial terrain were identified and debated to identify favorable expansion alternatives. Two Masters students formulated these alternatives into development recommendations in a preliminary vision document. However, these communication interactions did not produce the necessary structure to operationalize this early strategic vision. Taking into account these finding of the planning process, it becomes apparent that system complexity may have played a significant role in the planners' inability to operationalize a set of clearly formulated problems in the first years of the project.

4.2 The structuring of problem formulation through PSS model negotiation

Table 2 summarizes the different component-based communication interaction types identified during the PSS model development workshops. We can see that the negotiating principles introduced through PSS model development apparently had a structuring impact on the planning process into rough steps.

Table 2 Component-based communication types according to approach steps during PSS model development

Discrete component-based communications	Dialogue	Debate	Negotiation
STEP1: Identification of stakeholders and interests	x		
STEP 2a: Formulation of four objectives based on long list of interests		x	
STEP 2b: Longlist of component relations underlying spatial outcomes of objectives	x		
STEP2c: Reduction of longlist to possibilities for each scenario		x	
STEP 3: Creation of 8 sketched solutions emphasizing different objectives		x	
STEP 4a: Reduction of sketched solutions into spatial parameters – building and functions			x
STEP 4b: Reduction of sketched solutions and into indicator algorithms			x
STEP 4c: Identification of more industrial function parameters	x		
STEP 2d: Elimination of improved transport objective			x
STEP 5a: Second round of solution sketching and selection of top two scenarios		x	
STEP 5b: SWOT scenario analysis to test parameters and indicators			x
STEP 5c: Not conducted. Evaluation of spatial analysis tool			x

During the stakeholder analysis, objective setting, and scenario sketching (Steps 1-3), planners remained in the dialogue and debate interaction cycle. These communication interactions introduced the consortium members to the active components and relationships among environment components underlying the strategic objectives. This allowed the consortium members to become acquainted with the planning problem before introducing the requirements and limitations of the PSS. When confronted by the input needs of the epistemological PSS model, the planners were compelled to negotiate with the consortium members to reduce options into spatial parameters and quantifiable indicators for scenario assessment (Steps 4a-4b). The identification of more industrial function parameters in Step 4c shows that there is no clear temporal delineation where dialogue and debate end in a process and negotiation begins. Nonetheless, the need to reduce options into inputs that can be operationalized in a PSS environment shows how negotiations with the consortium helped planners to move beyond the iterative option creation and selection cycle and towards implementation and evaluation.

Steps 4a-5c indicate that these process-driving steps are more commonly achieved through negotiation communications. For example, during the workshops the consortium realized that the planners' debate over the objective to improve the transport connection was inhibiting progress. A PSS expert, therefore, negotiated with the planners to neutralize the objective. Since the decision to improve roadway infrastructure fell under regional decision-making jurisdiction, the CDT decided to make the roadway objective a contingent option. The option to neutralize the transport objective still permits planners to reactivate the objective at a later stage without jeopardizing the planning process in its current stage. This negotiation showed how the expert's focus on process supported the forward motion of the exercise. These collective findings suggest a method to structure collaborative planning option creation and selection. However, feedback received from planners pertaining to the utility of the assessment indicators and later spatial modeling steps suggest a further need for knowledge of the planning context. Based on these findings, we have constructed the sociotechnical model below.

4.3 A sociotechnical PSS model to support problem formulation

The findings from both the theoretical and empirical research conducted in this study have culminated in a conceptual sociotechnical PSS model that advances the Vonk and Ligtenberg (2010) model. Figure 4 introduces this conceptual sociotechnical PSS model that is driven by the context of the problem formulation and solving tasks. The model depicts the PSS architecture comprised of both problem formulation and problem solving tasks, and their component steps. The tasks included in this model can and should be customized to the ongoing planning process of a project. The tasks we included in the model for the case included analyzing stakeholders, setting objectives based on stakeholder interests, developing terrain expansion scenarios, establishing scenario assessment criteria and finally evaluating the developed scenarios.

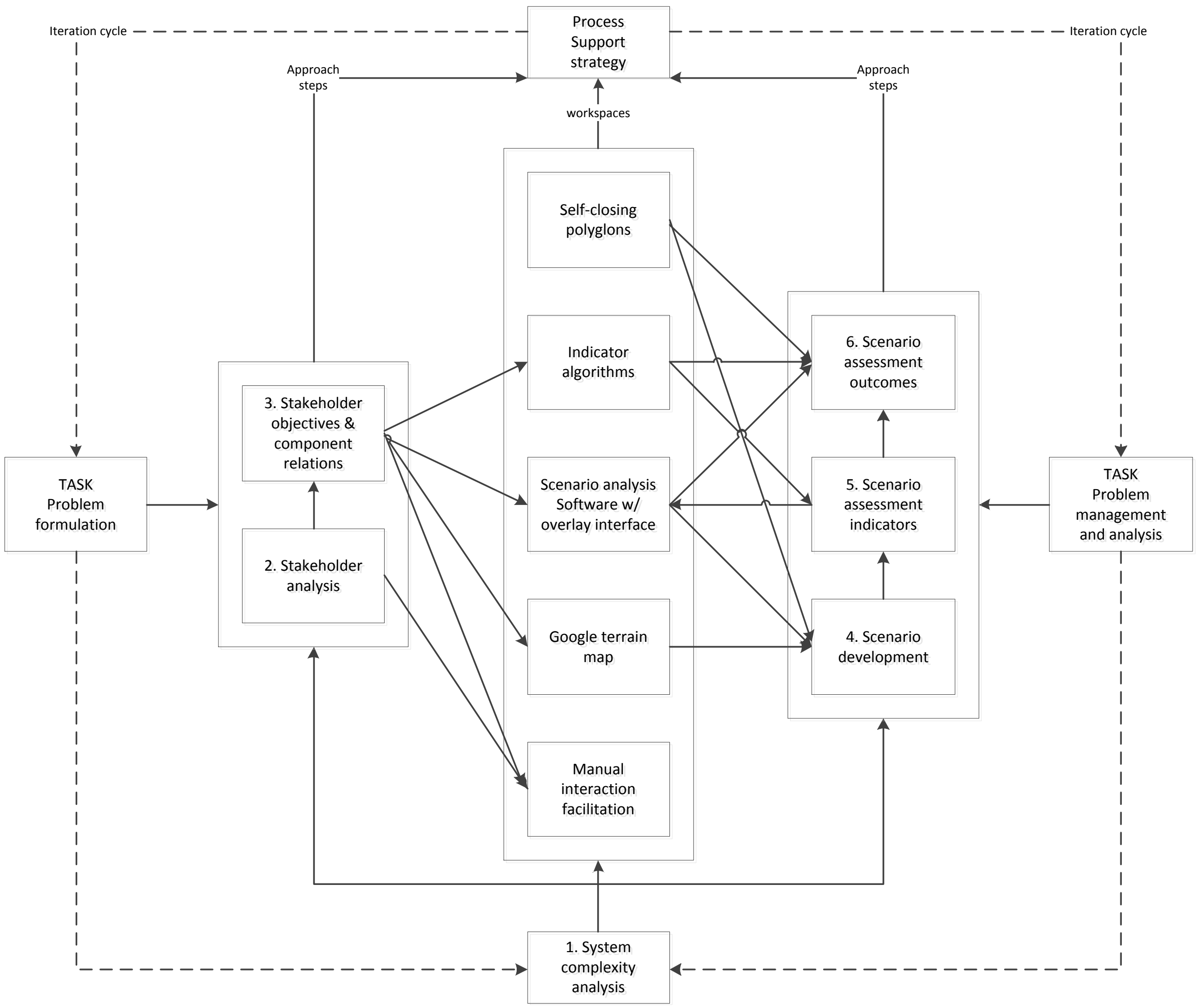

Figure 4 Conceptual context-driven sociotechnical PSS model, adapted from (Vonk and Ligtenberg, 2010)

The proposed model advances the Vonk and Ligtenberg model in three ways. First, it integrates PSS model development into problem formulation to support the creation and selection of options, whereas previous PSS development models have been integrated into the management and analysis of planning problems. The inclusion of problem formulation steps refines the PSS model to include analyses that are both spatial and non-spatial in nature. Stakeholder analysis, for example, is a primarily non-spatial analysis method conducted during problem formulation. However, the outcomes of this early exercise provide important input for the creation of spatial scenarios and the indicators used to assess them, which are problem management and analysis steps. The directional arrows in Figure 4 indicate the relational influence between the planning approach steps and PSS workspaces.

Second, the proposed model bridges the gap between problem formulation and problem solving by structuring the problem formulation task into concrete inputs for the PSS and by providing the basis for developing customized workspaces for problem management and analysis. Regarding the former, the model introduces the structured selection of system components and their translation into objectives that can be explored spatially and used to create quantifiable scenario assessment indicators. Regarding the latter, the model supports the development and assessment of spatial scenarios not only by providing objective-based indicators but also by converting practitioner manual sketches of component relations into spatial parameters used by the planners in a more complicated GIS environment. Third, the outcome of integrating PSS system development into the planning process suggests a PSS development framework that is more method than model. Furthermore, the steps in this method should be reiterated for each new context (Te Brömmelstroet and Schrijnen, 2010) and for each specific stage in the planning process.

5. Conclusions and Discussion

Although the notion of a generally applicable PSS model may seem contradictory to the context-specific nature of planning (Saarloos et al., 2008), we believe that the findings from this research are worthy of further testing in other contexts. The context-specific nature of PSS models stresses the importance not only of user involvement in the PSS model development process, but also the necessity to integrate the design process into the context of the planning process itself. In this study, we were able to show that the negotiation of the PSS model during problem formulation did result in the reduction of options into measurable objectives. However, feedback received from planners about the workshop intervention indicates a need for methods that integrate the sociotechnical PSS development process still deeper into the planning process.

To achieve PSS integration that leads to PSS adoption in practices requires further research. Accounting for the unique conditions of each case that are central to the understanding of an observed phenomenon will be important during future validation of a context-based model for PSS development. We believe that the inclusion of system complexity analysis in the proposed PSS development model provides a first step in that direction, (see Step 1 of Figure 4). The sociotechnical model development exercise conducted in this study showed us that there are limits to the degree that "outsiders" can push a planning process. Therefore, we suggest that PSS experts and system developers also create a debate with planners over the appropriate process steps to include in the model.

Because of the nature of complexity in social systems, complexity theory does not provide sufficient analytical methods to understand the different types of communications that occur during option creation and selection. Complexity reduction is best done through system observations of component selection. Being confronted by this situation in this study prompted us to experiment with an analytical framework that combines complexity theory with the notion of epistemological objects. Future attempts to apply complexity theory to the field of planning would benefit from direct field observation of epistemological objects used in communication interactions.

Previous works have claimed that users need PSSs that contain “just enough” sophistication to help them solve a problem (Lee, 1973; te Brömmelstroet and Bertolini, 2008). Anything additional to that only serves to add undesirable complicatedness to the planning system. In addition, we have found repeatedly in this and in other studies that the limitations of the introduced technologies sometimes stimulate the most meaningful discussions. In this study, the incompleteness of the PSS as an epistemological object offered the flexibility for users to revise indicators and parameters for problem solving and for developers to adapt support methods to the planning process. This is possibly the strongest argument for introducing PSS models in an epistemological state during the problem formulation stage of planning. PSSs in a fixed state lack this flexibility and are therefore better suited for problem solving. Geertman (2007) similarly distinguishes between communication and analysis PSSs. This distinction in purpose between PSS types should be made explicit to planners to avoid misunderstandings about the potential outcomes of system use. At the same time, we suggest further research into the transformation of epistemological PSSs into fixed, boundary object PSSs that may provide a single tool for divergent uses during the later analysis and evaluation stages of planning.

A further limitation to the study was that by integrating the PSS model development into early planning stages, it was not possible to show a direct link between problem formulation and spatial outcomes. Doing so would have required a much longer following of the case study than was possible within the scope of this research. However, it can be assumed that future spatial outcomes will be of higher quality if planners receive support in identifying and communicating about planning system components and subsequently making choices. Recent substance to this claim arrived with the explicit statement of the strategic objectives first developed in the workshops in the official project vision document published in 2013. We would prefer, however, to see planning outcomes such as these not only archived in project reports, but also made amendable and accessible in PSS environments.

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