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Framing Spatial Decision Support Systems – A Multidisciplinary Perspective on Digital Decision Making in Spatial Planning

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1 ABSTRACT

Spatial planning must resolve increasingly complex land-use conflicts that arise from competing demands on land and space (Hersperger et al. 2015, p. 6, Danielzyk and Münter 2018, p. 1932). These divergent interests stem from heterogeneous stakeholder groups involved in spatial development processes, resulting in multidimensional planning concepts that must integrate socioeconomic, ecological, cultural, technical and ethical dimensions (Bottero et al. 2019, p. 1).

Ongoing digitalization in spatial planning (cf. van Winden and Carvalho 2017, p. 3; Pallagst et al. 2022) is accelerating the adoption of Spatial Decision Support Systems (SDSS), which promise not only faster but also more transparent and evidence-based decision-making within planning processes (Crossland et al. 1995, p. 226). Yet, despite their increasing relevance, SDSS remain insufficiently conceptualized with regard to their decision logic, technological architectures, and underlying data foundations. Ghattas (2018) suggested that further research is needed to better understand the various assessment tools available in sustainable spatial planning.

This contribution deals with the first integrative systematization of SDSS by linking theory on decision making in spatial planning with data and software engineering. Within the research project Ageing Smart – Designing Spaces Intelligently, researchers from various disciplines have collaboratively designed a classification framework through iterative workshops, in-depth research on theory and learnings from selected SDSS samples that merge theoretical insights from planning decision processes with perspectives on functionality, technology and data. This allows for a revised perspective and understanding, empowering researchers to better assess the significance and possibilities of digital tools in planning in the future.

Keywords: Spatial decision support systems, SDSS, decision making in spatial planning, stakeholder in spatial planning, data basis

2 INTRODUCTION

Spatial planning is engaged with coordinating different and often conflicting types of land uses to be allocated in a particular planning situation. From a governance perspective, it also operates as a public task being interdisciplinary, cross-section-oriented, and integrated in a multilevel system (Danielzyk and Münter 2018, p. 1932). It must be understood as a decision-making process. The development of space involves a multitude of different perspectives and concepts from various stakeholders and specialized disciplines, which means that the development and planning of space might be confronted with strong conflicts of interest and the planning solution can strongly vary (Pinson 2004, p. 509). To arrive at a decision that considers and balances the various interests, spatial planners use various intuitive as well as more analytical assessment methods (Scholles 2018, pp. 222-223).

The megatrend of digitalization as a global and multi-disciplinary phenomenon has also arrived in spatial planning (Van Winden and De Carvalho 2017, p. 3; Pallagst and Liggesmeyer 2022). On one hand, this creates challenges for spatial planning, and, on the other hand, it opens many new opportunities that have the potential to provide planners with new methods to improve planning tasks. One of these opportunities addresses the already mentioned complexity of the planning tasks and actors involved, which requires a reliable and comprehensible decision-making process. Digitalization is moving us to digital solutions such as a Spatial Decision Support System (SDSS). An SDSS is a tool to facilitate these day-to-day decisions by digital means (Sugumaran and Degroote 2010, p. 14). It combines different types of spatial and non-spatial data, performs analyses and visualizations, and can thus suggest possible solutions (Keenan and Jankowski 2019, p. 64). SDSS can make processes more efficient and enable decision-makers to make better decisions faster (Crossland et al. 1995, p. 226). One prerequisite for the efficient use of SDSS is the availability of qualitatively suitable data. Thus, the technologies, functionalities, and data types employed vary significantly. This, at times, also affects the type and quality of the benefits derived from a SDSS for spatial planning. Furthermore, it is crucial to distinguish which user groups are utilizing the program to discern whether it constitutes an expert tool or rather an application designed for a broader user base. However, practice shows that the term SDSS is not always easy to systemize and categorize.

To gain knowledge about the types of SDSS at hand in spatial planning and their application in practice as regards best practice examples, this contribution provides a suggestion for a classification of SDSS used in spatial planning. Various technical, data-related, and spatial planning-related aspects are applied to formulate different assessment criteria. The research on this topic emerged in connection with the interdisciplinary research project Ageing Smart – Designing Spaces Intelligently and it aims at developing a systematized research grid for comparative case studies in this field.The authors have provided a detailed description of the derivation of the classification model in Pauly et al. (2026) and, in Pauly et al. (2025), ventured an exploratory comparison of different SDSSs using the classification model as a methodological approach. The most important findings from this research are now compiled and described in this contribution.

When selecting the appropriate methodology for the investigations, the authors placed great emphasis on ensuring that the various areas of expertise could be utilized to the greatest possible extent due to the different professional backgrounds. However, when different scientific disciplines come together, conflicts can inevitably arise, e.g., with regard to methodological approaches, understanding of terms, and lines of argumentation. Therefore, iterative workshops were chosen as the core methodology for the research, in which the various perspectives on SDSS were shared and discussed without any predetermined conclusions. This allowed for a sharpening of conceptual understandings and the exploration of possibilities for developing a taxonomy-like model that would enable SDSS to be classified using categories that were as precisely defined as possible. In addition to the workshops, however, the research is also based on an in-depth investigation of existing theories, from which key content was compiled to help create the classification model for SDSS.

The next three sections of this article deal with the three different areas that were used to derive the classification model. First, we look at which decisions are made in spatial planning by which stakeholders and where SDSS can come into play. Next, we look at the various technologies and functionalities that are necessary to provide decision support and that can be found in SDSS. Finally, the third area examined is the topic of databases, which have a significant influence on the possibilities for decision support. The classification model resulting from the findings in the above areas is then presented and explained. The researchers' findings that need to be considered for the further development of the model are described.

3 DECISION MAKING IN SPATIAL PLANNING

3.1 Different interests and conflicts of land use

Based on the understanding that spatial planning is a public task that aims to coordinate different demands for the use of a defined space or land (Fürst und Mäding 2011, p. 11; Danielzyk und Münter 2018, p. 1932), the underlying consideration here is that the existence of a space or land is, by its very nature, also a problem. Spatial planning is therefore in the role of problem solver. Hersperger et al. (2015) specifies the problem mentioned and discusses a conflict that arises from the fact that land is a scarce resource. There are different perspectives on a defined land, which ensure that there are different ideas, proposals and claims as to what should happen to it and what function it should take on in the structure of the larger context, e.g. a city or a region. The resolution of this conflict is therefore described by Hersperger et al. (2015, p. 6) as conflict negotiation and thus also defines the goal of land use planning. It is further explained that planning processes therefore also mean conflict anticipation. From a governance perspective, however, it should be noted that planning processes, as the main action carried out in spatial planning, are interdisciplinary, cross-sectional and integrated into a multi-level system (Danielzyk und Münter 2018, 1932). This specifies the problem of the conflict of use and clarifies the dimension of the different perspectives from which the various interests emerge. According to Bottero et al. (2019, p. 1), these have their origin in various actors involved in planning processes, resulting in multidimensional concepts, e.g. from socio-economic, ecological, cultural, technical and ethical perspectives. Bottero et al. (2019) refers to the aforementioned problems in spatial development as decision problems. This makes it clear that spatial planning implies having to make decisions.

However, the observations on planning that coordinates and anticipates conflicts must be relativized to some extent by the fact that spatial planning and the associated governance structures are conceptualized differently in each country and are shaped by different planning cultures within the meaning of (Knieling und Othengrafen 2016). If one wants to compare these possible conceptualizations according to categories such as planning instruments, administrative levels, regulatory frameworks and their material content, one can speak of planning systems or models of spatial planning (Pallagst 2018, p. 1762; Dühr et al. 2010, p. 35). The understanding of spatial planning as a coordinator and conflict solver can be linked particularly well with the “Comprehensive Integrated” planning system category proposed by Dühr et al. (2010). However, it is clear that the other categories, especially “Land Use Management”, but also “Regional Economic” and “Urbanism”, are also based on the coordination of land use demands. Even in the countries mentioned by Pallagst (2018, p. 1768) of the Global South, in which spatial development is largely characterized by informal settlement activity, fundamental decisions on the use of a particular land must be the basis, even if there may not always be a balanced consideration of different interests. In general, it can therefore be said relatively universally that spatial planning as a public task deals with land use conflicts and considers and coordinates different interests in order to find solutions. The statement that spatial planning means that decisions are made about the development of an area can also be generalized.

3.2 Planning process

Planning processes depict the processes of coordinating, finding a solution and making a decision and how they interlock. In order to understand the handling of conflicts in spatial planning in depth, a planning process model must be used to operationalize the procedures (Hersperger et al. 2015, p. 7). Also models of planning processes are strongly conditioned by the prevailing planning system. Nevertheless, there are also general aspects that can be operationalized and in reality may have modifications in sequence or other details depending on the country. Hersperger et al. (2015, pp. 7-8) proposes the model of Steiner (2008) for this purpose. This has its origins in landscape planning, but is adapted slightly by Hersperger et al. (2015, pp.7-8) and applied to spatial planning processes in general.

Steiner (2008, pp. 10-11) proposes a process flow with eleven steps. The process starts with the first step, the identification of problems or opportunities, and is completed with the last step, the administration and monitoring of the final plan. After the second step, in which the goal is defined and established in order to address the problem, various steps follow in which inventories, analyses and detailed studies are carried out. Based on this, concrete concepts and options are developed, which then lead to the development of a first plan. This is followed by the citizen involvement step. The plan is then concretized through detailed designs and then implemented in step 10. It is noticeable that the various steps can occur in a different order in the reality of spatial planning depending on the planning system, which can even be regulated by law in some cases. One example of this is the citizen involvement. Hersperger et al. (2015, p. 8) have therefore placed public participation at the center, which makes it clear that on the one hand it is independent of the steps of the planning process and at the same time can be involved in all steps. Another important modification is that Hersperger et al. (2015, p. 8) turn the process into a cycle. This makes it clear that the administration and evaluation at the end of planning also identify problems and opportunities that initiate new planning. It is also made clear that conflict anticipation and conflict resolution are integral parts of the planning process.

3.3 Decisions within the planning process

From the considerations on planning processes and the task of spatial planning to resolve conflicts, conclusions can be drawn about the types of decisions that take place in spatial planning. In the planning processes proposed by Steiner (2008) and Hersperger et al. (2015), the initial point is the identification of problems and opportunities and the resulting planning objectives. Further on, after various studies and consideration of different aspects, there is then the point of creating planning concepts and a concrete design. This means that, particularly at the beginning of the process, attention is initially focused on the option to act and finally the decision to act on the basis of observations and monitoring with the identification step. Later, a decision must be made in order to define planning concepts and develop a concrete design. As planning can also change during the course of a process by taking other perspectives into account, the same type of decision also applies to the development of any preliminary planning alternatives.

In addition to the perspective of planning processes on decisions in spatial planning, the perspective of planning barriers can also be taken. For this purpose, the execution of planning must be understood as a creative act. However, the creative act of planning is limited by barriers (Schoen 2018, pp. 20-21). The planning system in Germany should serve as an example of this. Here, there are normative regulations with regard to planning limitations that are anchored in construction and planning law. These are the requirement of necessity ("Gebot der Erforderlichkeit"), the weighing-up for balancing requirement ("Abwägungsgebot") and the mandatory legal principles ("zwingende Rechtssätze") (Schoen 2018, pp. 21-22). The requirement of necessity states that planning must take place insofar as the circumstances make this necessary. It therefore describes the start of planning within the planning process. It is therefore the normative equivalent of the identification of problems and opportunities and the planning objectives formed from this as described by Steiner (2008) and Hersperger et al. (2015). The weighing-up for balancing requirement obliges planners to resolve the conflict arising from the different interests and to weigh up the various interests in a meaningful way. This is now the normative equivalent of Steiner's (2008) and Hersperger's et al. (2015) creation of planning concepts and a concrete design. This makes it clear that the two decision typologies already derived from the perspective of planning processes also arise from the perspective of planning barriers: The decision to act and the decision on a detailed design and planning alternatives.

In contrast, the third planning barrier from the example from Germany, the mandatory legal principles, is not a type of decision. Mandatory legal principles are about necessary knowledge of legally binding regulations that restrict the freedom of planners. Rather than a decision, it is therefore a type of consideration that can and must be one of many bases for deciding on a detailed design and planning alternatives. The other considerations proposed by Steiner (2008) and Hersperger et al. (2015) on which planning is based – in particular inventory, studies and citizen involvement – must therefore be extended to include consideration of legal barriers.

Further necessary additions result from the considerations on the influence of the planning culture context and from the fact that land use conflicts arise from different interests. In this respect, the consideration of the different interests of actors, the consideration of different technical interests and the consideration of existing norms and convictions must also be added.

In summary, it can be said that there are two core tyspes of decisions within planning processes that planners have to make: (1.) Decision to take action and (2.) decision about detailed design and planning alternatives.

At this point, however, it is important to note that this classification can only be considered a broad abstraction. Many different decisions made in spatial planning can be assigned to the categories mentioned above. The decision to act, for example, is accompanied by many questions that require a large number of proper sub-decisions: Should an intervention take place at a specific location? What are the objectives? Would it be worth the investment? Does the outcome compensate for the cost and effort? Decisions about detailed design and planning alternatives also raise procedural questions that require sub-decisions: Are there alternative locations, and what criteria are decisive in identifying the best location? What size, dimensions, scale, etc. are necessary? What exactly is the spatial distribution? In conceptual design projects, every single line sketched is ultimately also an independent decision.

However, when considering planning process models and planning barriers for derivation, it is not possible to achieve such a detailed breakdown and meaningful sorting of decision topologies. This would require independent in-depth basic research. However, since this article focuses on the systematization of SDSS, the authors have deliberately chosen to accept the abstraction based on two core decision types in planning processes.

The two decision typologies are framed by different considerations that serve as the basis for decision-making. Fig. 1 illustrates this approach.

The findings on the decision typologies within planning processes shape our understanding of which decisions can be supported by SDSS. At the same time, however, it must be made clear at this point that the two typologies of decisions considered only refer to the core of a planning process. Political decisions on planning, which are made by legislative bodies, for example, and can also be normatively demanded as part of spatial planning, are deliberately not considered. In addition, even after a planning process has been completed, decisions are made by potential stakeholders about whether or not to make use of the opportunities made possible by the planning. This makes it clear that our understanding of SDSS refers to a tool that addresses the core of spatial planning and its planning processes and probably mostly serves to support planners.

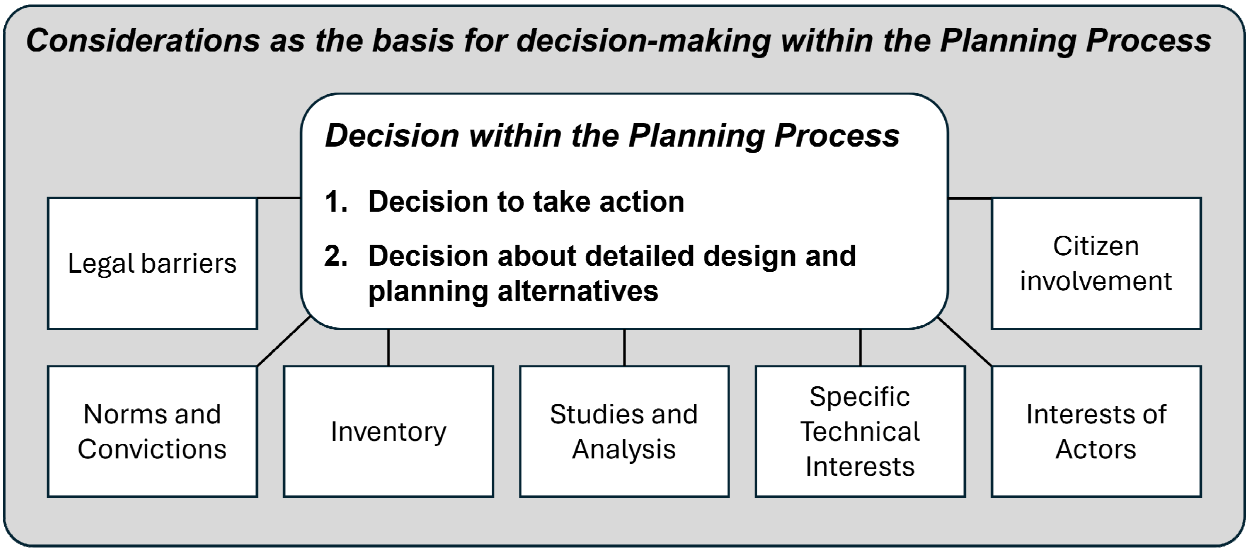

Fig. 1: Decision Typologies in Spatial Planning (translated from Pauly et al. 2026, p. 263)

3.4 Stakeholder in Spatial Planning

When focusing purely on the actors involved in planning processes, it becomes clear that the aforementioned differing interests originate from them, are rooted in them, and are articulated by them. Since planning processes require a solution, but differing interests clash, some form of cooperation is inevitable. The various participants have relationships with each other that are defined by conflict. During cooperation, relationships can be positively influenced if authentic dialogue takes place (Innes and Booher 2010, p. 37). This makes it clear that there must be certain factors, such as specific participation and moderation formats, that enable the best possible compromise to be reached. Ultimately, however, it remains the task of spatial planners to coordinate and weigh up conflicting demands. A decision is then made on the basis of intuitive and analytical evaluation methods (Scholles 2018, pp. 222–223). In order to gain a better understanding of the various actors involved in planning processes, two studies were examined which, for the purposes of their investigations, provide an overview of those involved in planning and their interconnections.

Hölzl and Nuissl (2014) examine urban governance structures in Santiago de Chile and divide the stakeholders into public, private, and civil society groups. They assign influence indices to these groups to illustrate their importance for urban governance. In the public sector, the authors name the responsible ministry, municipalities, the central government with other relevant ministries, regional secretariats, and the regional government. In the private sector, real estate developers, infrastructure companies, the Chilean Chamber of Construction, and other private stakeholders are named. In the civil society sector, individual politicians and universities are mentioned in addition to citizens. The allocation of the influence index is irrelevant at this point, as the influence and role of the various stakeholders can vary greatly depending on the context of the country under consideration. This also applies in part to the allocation of individual stakeholders to the categories proposed by the authors.

Källström and Smith (2023) scientifically accompanied the planning process for regional planning in a Swedish county through several workshops and other events and conducted qualitative interviews. The authors list the actors involved and divide them into ‘internal’, ‘primary’ and ‘secondary’ stakeholders, as well as citizens as a further group of actors. The ‘internal’ stakeholders include a ‘county politician’, the chair of the ‘regional development committee’, the regional planning manager, the project manager, the project team, and the chairs of the thematic working groups. The ‘primary’ stakeholders are listed as the municipality politicians, the members of the ‘regional planning council’, the managers of a municipal association, and the ‘public officials’ of the participating municipalities. National authorities and other secondary participants are listed as ‘secondary’ stakeholders. The group of citizens is not further subdivided.

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It should also be noted in this example that the proposed structure is strongly influenced by the given context. However, sorting according to the degree of participation in the process can be very useful, as it allows the role of stakeholders in the planning process to be better classified.

Public/Private: **Spatial planner / Project manager**	*internal*	*Strategic core decisions*
Public Sector: **Executive and legislative bodies with decision-making power**	*primary*	*Political decisions*
Public Sector: **Other by planning activity affected executive and legislative bodies**	*secondary*	*Expression of interest (/vetos)*
Private Sector: **Real estate/Private individual developer and others**		*Economical decisions*
Private Sector: **By planning activity affected organizations and companies**		*Expression of interest (/vetos)*
Civil Society: **Citizens**		*Participation*
Civil Society *(can be additionally public or private sector as well)*: **Universities and other driving forces**		*Participation and expertise*

Fig. 2: Stakeholder within Spatial Planning and their types of decisions (translated from Pauly et al. 2026, p. 265)

These considerations were taken up and resulted in a proposal for the classification of stakeholders in spatial planning (see Fig. 2). A distinction is made between 'internal', 'primary' and 'secondary' actors. These categories define the degree of participation in the planning process. The right-hand column shows the decision typologies. It is clear that the core decisions in spatial planning – the decision to act and the decision on specific planning content – are mainly made by the top group of actors. This underlines our understanding of an SDSS as a support system for planners. However, it is also obvious that planners' decisions can be accompanied by other types of decisions from the primary and secondary stakeholder groups in the planning process. This makes it necessary to also classify an SDSS based on the decisive stakeholder group.

4 TECHNOLOGIES AND FUNCTIONALITIES USED IN SDSS

In addition to looking at SDSS from the perspective of spatial planning and which decisions are made by whom, it is also important to examine the underlying technologies that can result in different functionalities and represent another dimension for classifying SDSS.

In general, available data can be used in various ways in spatial planning. This includes different types of data and also different data sources (sensors, statistical data, etc.). It is obvious that the origin and frequency of data collection have therefore a massive impact on meaningful technologies.

From statistical data to Information and Communication Technologie (ICT) to big data applications, there are dozens of digital concepts and tools that could be considered. For the purpose of decision-making, however, real-time data can be disregarded, as only longer planning horizons are considered in spatial planning.

Other aspects that should be taken into account are the digital skills of planners and their digital environment. End users should have at least basic digital skills, and the underlying digital infrastructure should be provided. Another aspect is certainly the question of how often a digital tool is used. Since this is not static, usage would have to be tracked over time. Since such data is usually not available, this point is not taken into account here. Finally, it could be relevant to what extent end users were involved in the development of the tool. However, this is not easy to determine, which is why it is neglected in the following.

When talking about technology here, a distinction must be made between software and hardware. Since hardware usually plays a subordinate role from the user's point of view, the following analysis focuses on the software aspects of SDSS, whereby the following points can be used to classify SDSS:

Application type	Examples of application types can be smartphone apps, desktop apps or a web-based system. As the questions for spatial planning are usually complex, we assume it is very likely to have tools on a desktop PC, laptop, or maybe tablet PC.
Code ownership	The question if a tool is an open-source product is important. Sometimes, even the programming language (and which libraries are used) can have a massive impact on the usage of the tool. Obviously, an open-source tool usually has a larger community for development and extensions of the tool.
Extendibility	Usually, a new tool is not developed from scratch, that means existing tools or building blocks are taken and extended. From a spatial planning perspective, it might be interesting to discuss the extendibility of the tool. New features might be desired so the question is if they can be added to an existing tool might be of interest.
GUI design	The tool can contain different information in form of text, tables, graphs, and maps. The style and complexity of the tool (number of tables, charts, …) can vary and might be of interest for a comparison.
Interactivity	For a tool, you need to consider if the user can interact with the tool. In other words, the question is if the tool only displays values, tables and charts or if the city planner can set different values as input to obtain different results. Hence, we can classify the tool in interactive tools and static tools.
Analysis	We can group the different analysis methods in terms of classical machine learning methods, wich can be sub-goruped in a) supervised learning, b) unsupervised learning or c) semi-supervised learning. More details and more examples in the context of resilience of interdependent critical infrastructure systems can be found in (Alkhaleel, 2024, p. 3-6). In supervised learning, you usually have labelled data, meaning each dataset has a pre-defined output and the goal is to find an accurate prediction of new data, based on the data labels of known data. In other words, supervised learning usually covers aspects like classification, prediction, or regression. Most important examples are image classifier or prediction tasks (e.g. weather forecast or stock market prices). Typical algorithms are for example decision trees, support vector machines, different regression techniques or artificial neural networks. It should be mentioned that a simple statistical regression is a very basic but supervised learning technique. Unsupervised learning has, in comparison to supervised learning, no labels. In other words, you try to find patterns or structures in the data. The most prominent task is clustering where data points are put into clusters based on their similarities. An example for an unsupervised learning application would be the clustering of people according to their web surfing behaviour, to provide individual advertising. Typical algorithms are K-means clustering or dimensionality reduction techniques like principal component analysis. Semi-supervised learning is a mixture of supervised and unsupervised learning: the labels of the data are only available for parts or a subset of the data. In this case, special generative methods create artificial labels which can be used to adjust the machine learning model.

Tab. 1: Categories to classify technologies used in SDSS in terms of software aspects, own representation

5 DATABASE USED IN SDSS

The quality of the output and results of an SDSS is strongly determined by the quality of the underlying data, whether used directly or through models derived from it. The data should adequately represent and model the addressed spatial problem and contextual factors in such a way that the SDSS can make effective use of all relevant information to achieve optimal results. Understanding the underlying database is therefore a central aspect of classifying an SDSS. Data can be evaluated and categorized according to various criteria, including content domain, publisher, and technical aspects (Van Nuffelen 2024). Depending on the investigator and use case, different aspects may be given more weight. Such assessments can be carried out at varying level of detail; however, this degree of granularity is beyond the scope of this report. The choice of data-relevant dimensions for classifying an SDSS involves balancing the aim of a simple and clearly comprehensible classification structure against the inherent complexity of data and metadata, especially in a broad and multifaceted application domain such as planning.

5.1 Transparency

Is there a website, manual or similar source that provides information on the data used in the SDSS? In the absence of such documentation, it might be difficult to answer most of the following questions correctly.

5.2 Implicit data

Implicit data refers to information that is not explicitly stated or directly provided. Does the system use statistical parameters that have been derived from data or does it employ AI models that have been trained on training data?

5.3 Domains

Demography and socioeconomics	This data might include population statistics (e.g. age distribution and gender ratio), household data, and employment statistics.
Land use and spatial planning	This includes official planning documents, including development plans, land-use plans and zoning plans.
Infrastructure and supply	These datasets include utility network information such as electricity grids, water supply networks, and gas pipelines, service data like maintenance records and outage reports, and transportation infrastructure data.
Transportation and mobility	Relevant data may include traffic flow information such as vehicle counts and congestion levels, public transport data including bus and train schedules, as well as user mobility data such as bicycle-sharing and car-sharing usage patterns and pedestrian counts. This can be considered dynamical information about the usage of infrastructure.
Environment and climate	This domain covers data on air quality, weather data including temperature, precipitation, and humidity, and information on green spaces like the locations and sizes of parks and urban forests.
Health and safety	This domain includes health statistics such as disease incidence rates and hospital admissions, safety data like crime rates and emergency response times, and health service accessibility.
Economy	Economic data might encompass business information such as the number of businesses and types of industries and employment data including job vacancies and wage levels.
Education and culture	Relevant data include school data such as enrollment numbers and graduation rates, information on cultural institutions like museums and theaters, and data on cultural events.
Housing	Housing data can include information on housing stock such as the number and types of housing units and occupancy rates, real estate data like property values and rental prices, and assessments of housing conditions including the age of buildings and renovation needs.
Public services	This domain involves data on the location and availability of public facilities such as hospitals, schools, and libraries.

Tab. 2: Different possible domains of data used in SDSS, own representation

5.4 Data types

The term ‘data type’ is used here to provide a technical overview of the data used without delving into the details of specific data formats. While satellite data, for instance, also falls within the scope of geodata, this type of classification specifically highlights special cases that are of particular relevance for an SDSS investigation.

Geodata	Various spatial structures are used in SDSS. Those contain administrative regions like federal states, municipal borders and districts. Relevant points of interest might be doctors or schools. Detailed maps of infrastructure such as roads and supply lines might also be included.
Sensor data	Air quality, noise and temperature sensors are among the most used sensors in cities. There are also sensors in public transportation and to control traffic.
Remote sensing data	This includes LIDAR data, satellite images, radar data and aerial imagery.
Statistical data	All qualitative and quantitative information that is collected und saved in a structured way like census data.
Images and videos	This could contain surveillance footage, aerial imagery and photographs of public spaces.
Text documents	Any kind of accompanying documents like protocols or documentations
User generated content	This refers to any form of content – text, images, videos, reviews, and other forms of media – that is created and shared by individuals rather than by professional content creators or organizations. This content is typically made publicly available through online platforms, social media, websites, and other digital channels.

Tab. 3: Different possible data types used in SDSS, own representation

5.5 Origin, openness and legal matters

The license under which a data set is made available defines the terms and conditions for its use, sharing, modification and redistribution. Of particular interest is whether the data is openly accessible and therefore freely usable. On the other hand, it must be considered separately whether sensitive data is being used that warrants special protection.

5.6 Timeliness

For some applications, the quality of the results depends on the timeliness of the data used. Are regular updates available, or are there options to update the data? Additionally, is real-time data being used?

5.7 Linking, integrationand export

Of interest is to determine whether users are able to upload or input their own data. Additionally, the availability of interfaces, such as connections to open data portals or other applications, that facilitate data integration is a relevant consideration. Moreover, it is crucial to ascertain whether the system supports the export of results or provides direct connections to other tools for further use of the results.

6 RESULTS

6.1 Classification model for SDSS

Based on the above, a classification according to three overarching categories of indicators is proposed:

(1) Type of decision

(2) Technology an functionalities used

(3) Data basis

The three higher-level categories contain indicators that describe the central characteristics of an SDSS. However, the indicators differ in terms of their response modality. Based on an application to be examined that is classified as an SDSS, the indicators require a binary, descriptive, or nominal response. An example of a bionary indicator is the decision to act, which can be classified as either given/applicable or not given/not applicable. In contrast, the indicator analysis is a descriptive modality, since no choice from predefined categories would be conceivable here, but rather a case-by-case description is required. The situation is different with the nominal modality, where it is expected that an assignment to a predefined selection of categories is possible. An example of this is the data type indicator.

Regardless of the response modality, however, the indicators serve taxonomic-like purposes, enabling SDSS to be classified. For the sake of better understanding and content-related organization, however, we recommend following the order of the three superordinate categories.

The following figure combines the most important findings on the classification of SDSS in spatial planning.

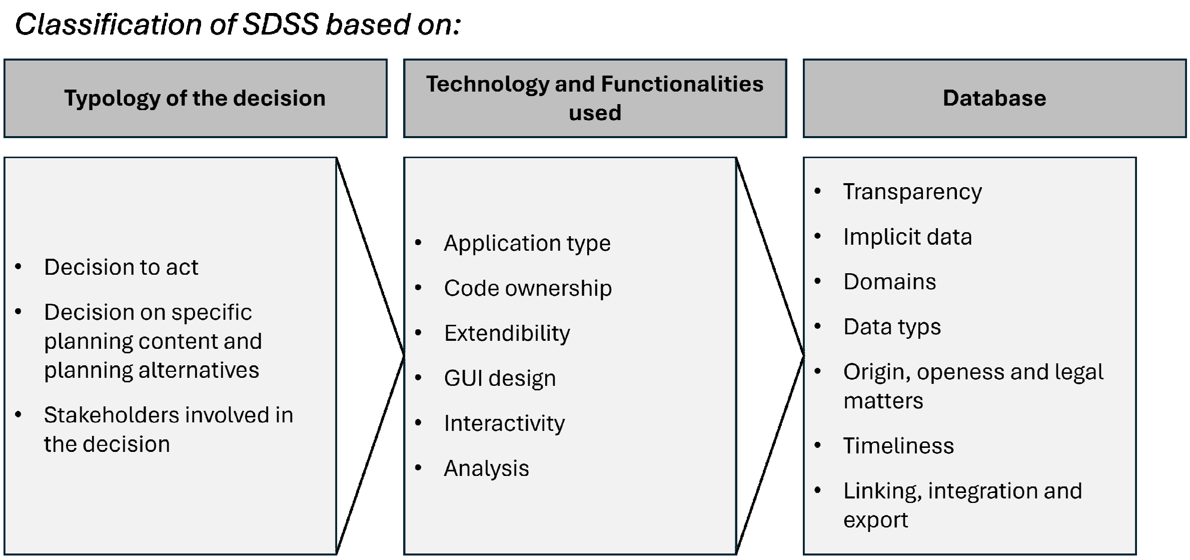

Fig. 3: SDSS-classifying indicators (translated from Pauly et al. 2026, p. 273)

The typology of decisions provides information about which specific decisions are made. Based on the authors' research, these are core decisions within planning processes. On the one hand, the use of SDSS can make users aware of planning needs that were previously unknown. This can lead to the decision to take action. On the other hand, the decision to take action may already have been made as a starting point. In this case, SDSS can make it easier to make decisions about specific planning content and planning alternatives. Furthermore, the group of actors who are supported in their decision-making is another important feature of SDSS. Although it has already been made clear that the core decisions are actually only made by internal actors, political decisions by primary actors could also play a role, for example, if applicable in a given application.

The technologies and functionalities used in SDSS represent a further step toward classification. SDSS can differ in terms of their type of application, code ownership, expandability, GUI design, interaction, and analysis options.

As a final step, classification according to the database is proposed. The database is so important in SDSS because it provides the basis for all functionalities. The quality of the entire SDSS also depends on the quality of the data. In terms of the database, SDSS can differ in terms of data transparency, implicitness, domains, data types, origin, openness, legal aspects, data currency, and data linking, integration, and export.

6.2 First attempts of an application

In Pauly et al. (2025), the authors conducted a study in which they tested the classification model as a method for comparing four selected SDSS. The aim was, on the one hand, to validate the defined indicators and, on the other hand, to identify initial patterns that could indicate certain regularities in SDSS. When selecting the four SDSSs to be compared, care was taken to ensure that they differed from each other as much as possible, particularly in terms of their basic usage concept, in order to enable a differentiated analysis. So, the four SDSS were deliberately selected for their heterogeneity in application domain and methodological approach.These are described in the following paragraphs.

Urbanist AI was developed by two private companies that combine expertise in the fields of software development and spatial development. The basic idea behind Urbanist AI is to highlight alternative design options, particularly for public spaces, thereby identifying areas where action is needed, which can ultimately support decision-making. To this end, the software generates images of the space using AI technology (Toretei S.R.L., SPINUNIT Lab OY, SPINUNIT OÜ, n.d.).

Daviplan was developed by the company Gertz Gutsche Rümenapp Stadtentwicklung und Mobilität. The application was commissioned and provided by the Federal Institute for Research on Building, Urban Affairs, and Spatial Development (BBSR) and the Federal Ministry of the Interior in Germany. The idea behind Daviplan is to analyse the location and supply structures of public services using map-based visualizations, thereby providing targeted support for spatial development decisions (Gertz Gutsche Rümenapp Stadtentwicklung und Mobilität GbR, n.d.; Gertz Gutsche Rümenapp Stadtentwicklung und Mobilität GbR and BBSR, 2023).

Maptionnaire was originally developed in the academic sector, which ultimately led to the founding of a private company (Mapita Oy, n.d). The developers themselves describe Maptionnaire as a geographic information system (GIS) for public participation. The basic idea is to allow the population to generate data on specific topics in which they are involved, which can then be used by planners. This highlights areas where action is needed, which can serve as a decision-making support for those responsible (Mapita Oy, n.d.b).

HEC-RAS was developed by the Hydrologic Engineering Center, part of the United States Army Corps of Engineers. However, the application is also made available for civilian use. The software calculates water flows and visualizes them for flood scenarios (USACE Hydrologic Engineering Center, n.d.).

Now a short summery of the outcomes of the comparison will be given: With regard to the decision-making criteria, it was found that all four applications fundamentally support the decision to act by highlighting deficiencies in the current situation. While Daviplan, Maptionnaire, and HEC-RAS point out these deficiencies directly, UrbanistAI does so more indirectly through idealized representations that do not necessarily correspond to real planning conditions.Daviplan and HEC-RAS in particular provide support for decisions on specific planning content and alternatives, as scenarios are a central component of these applications. Depending on how it is used, Maptionnaire can be used both for pure deficit assessment and for evaluating planning options. UrbanistAI, on the other hand, is primarily used to visualize imaginary possibilities and does not support realistic planning decisions.All applications are primarily aimed at internal, strategic decisions by spatial planners. Daviplan is more suited to supra-local planning, while HEC-RAS is typically used in specialist planning. In addition, all tools can support political decision-making processes. Maptionnaire plays a special role here, as it involves residents who do not make decisions themselves, but support planning considerations through their input.

In terms of technology and functionality, the applications differ in their technical implementation and accessibility. While HEC-RAS must be installed as a desktop application, UrbanistAI, Daviplan, and Maptionnaire are browser-based, with Daviplan requiring a one-time Docker installation. The licensing model also varies: UrbanistAI and Maptionnaire require a license, HEC-RAS is free of charge, and Daviplan is available as open-source software, which is the only application that allows for extensibility. All tools offer cartographic visualizations. In addition, UrbanistAI displays generated images, Daviplan displays tables and diagrams, and HEC-RAS additionally displays hydrological parameters such as water flows or elevation profiles. The interaction options range from importing your own photos (UrbanistAI) to integrating POIs for accessibility analysis (Daviplan), creating participation questionnaires (Maptionnaire), and parameterizing complex water flow models (HEC-RAS). Methodologically, UrbanistAI uses generative AI, Daviplan uses accessibility models and forecasts, Maptionnaire primarily uses cartographic visualization of user-generated data, and HEC-RAS uses simulation-based hydrological models.

In the area of databases, transparency was examined first. Only limited information is available for UrbanistAI and Maptionnaire, as no detailed documentation is available. In contrast, Daviplan and HEC-RAS offer comprehensive manuals that provide insights into the data used and model assumptions. UrbanistAI does not disclose any information on the training or background data for its AI, andMaptionnairesimilarly does not allow any statements on this subject. Daviplanoperates without implicit data assumptions, whereasHEC-RAS is based on a water flow model with corresponding assumptions. In terms of content, the applications cover different domains, including land use, environment, infrastructure, demographics, mobility, and health, Maptionnaire poteappears capable to integrate all urban topics. All SDSSs utilize with geodata; in addition, photographs and texts (UrbanistAI), statistical data (Daviplan), user-generated content (Maptionnaire), and model-based hydrological data (HEC-RAS) are used. Users can import their own data into all applications. However, statements regarding openness, timeliness, and data protection aspects remain largely unclear, with the exception of Daviplan, which partially relies on openly accessible official statistical data.

6.3 Outlook

The comparison of the four SDSS UrbanistAI, Daviplan, Maptionnaire, and HEC-RAS reveals the diversity of possibilities offered by data-based decision support in spatial planning. It became clear that SDSS are difficult to conceptualize in a general understanding due to this heterogeneity. One reason for this is that their possible applications differ greatly from one another. Applying the SDSS typology clearly shows where the differences lie and how they influence its use as a spatial planning tool.

Since existing SDSSs are found in very different contexts, it is necessary to use a methodology that enables comparative analysis and maps the core characteristics. In this respect, it can be said that the classification approach proposed here offers a good opportunity to gain a better understanding of SDSSs.

Exploring further classification options could expand this understanding even further. For example, the introduction of defined SDSS subject areas would be conceivable. In addition, the development of maturity criteria could add an evaluation level to the typology.

It is striking that for some criteria, such as the ‘openness’ or ‘legal aspects’ of the database, no statement could be made for all or a majority of the applications examined due to a lack of information. This could be due to the selection of the four SDSS and must be critically examined. In further investigation, an expansion of the methodology, in particular through qualitative interviews with the developers, would be conceivable.

All in all, the contribution shows that research into the classification of SDSS helps to better understand their growing importance for spatial planning. New digital tools are increasingly being used in the context of spatial planning, leading to changes in the working methods of spatial planners. Data-based decision support systems are designed to make them more efficient and have the potential to contribute to better and faster decisions in spatial planning, thereby supporting the planning process.

We could learn, that SDSS mediate spatial thinking by structuring how geographic information is represented, analyzed, and visualized. Importantly, SDSS do not introduce fundamentally new types of spatial decisions; rather, they operationalize and support existing decision-making processes by structuring complex spatial information and, in some cases, lowering the threshold for non-specialist users to engage with spatial decisions making. Research on the classification of SDSS promotes understanding in this area.

The purpose of this contribution is to provide a framework for future research into questions surrounding the potential, benefits, and possible areas of application of emerging digital tools designed to support decision-making in spatial planning. Comparative case study analyses using the framework proposed here appear to be suitable for this purpose.

The findings on decision typologies in spatial planning processes should be understood as a by-product of this contribution. The authors see this as a worthwhile starting point for conducting in-depth basic research in order to better conceptualize decision typologies in the future.

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