A Process-Oriented Decision Support System for Sustainable Urban Development Strategies

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***Abstract*—Political decision-makers play a crucial role in shaping sustainable urban development strategies, yet they often face challenges, such as limited expertise, resources, and access to suitable Information Technology (IT) tools tailored to their needs. In this paper, we introduce a prototype of a decision support system explicitly designed to assist political decision-makers in formulating sustainable urban development strategies, thereby enhancing their capacity in urban planning. Developed collaboratively by urban planners, infrastructure engineers, experts of geoinformation systems and political decision-makers, this tool prioritizes simplicity and intuitiveness. It offers transparent procedures and easy access to expert knowledge, streamlining the decision-making process. By automatically retrieving data from a geographic information system and facilitating calculations, it minimizes time investment. Additionally, it embraces a comprehensive approach that considers diverse stakeholder perspectives. Finally, it enhances adaptability and scalability without requiring advanced IT skills. While the involvement of experts remains vital in crafting sustainable urban development strategies, this tool empowers political decision-makers with a clear understanding of the decision-making-process. Armed with this knowledge, they can engage more effectively with stakeholders, leading to informed, long-term decisions. Looking ahead, the integration of deep learning methods holds potential to further enhance the tool's effectiveness and efficiency.**

Keywords-urban planning; sustainable urban development strategies; digital guide for political decision-makers; decision support system for urban development strategies.

I. INTRODUCTION

Urban systems are growing rapidly all over the world. Forecasts assume that the size of cities will increase dramatically due to the pace of growth. According to a United Nations forecast, more than 66 percent of the world's population will live in urban areas by 2050 [1]. Such rapid urban development poses a challenge for spatial planning and requires integrative approaches to tackle the negative environmental, social and economic impacts of urban development [2]. This is why the concept of sustainable urban development has emerged. In addition to developing compact cities to reduce urban sprawl, other aspects of sustainability, such as environmental quality, social equity, economic viability, life satisfaction, precise urban planning, land use, infrastructure and energy management should be considered [1]. Managing a variety of purposes and striving for many different, often conflicting goals to meet the needs of different stakeholder are required. This poses significant challenges for political decision makers and urban planners. Although they are aware of the goals of sustainable urban development, they often do not know how to achieve these goals [3].

Moreover, the development of compact cities often meets with resistance and triggers public debate. The lack of public acceptance is therefore an important reason for slow pace of urban densification.

Political decision-makers are crucial actors in the development and implementation of sustainable urban development strategies, but they often lack expertise, have limited time, as well as human and financial resources. Furthermore, they do not have suitable IT support tools, as most tools are designed for experts [3].

This article presents a prototype decision support system aimed at assisting political decision-makers throughout the strategic phase of urban development projects. This system facilitates the process, enabling decision-makers to make and advocate for sustainable decisions with confidence, competence, and manageable effort.

This tool was developed in the context of urban planning in Switzerland to provide support for planning authorities in municipalities and cantons. Since the new revision of the Swiss Urban Planning Act, which was passed in 2014, the municipalities and cantons have also played a central role in sustainable urban development in Switzerland. The act requires that future urban development should primarily take place in existing building zones and that cantons and municipalities should be responsible for this. The paradigm shift presents the planning authorities with challenging tasks.

When developing the tool described in this paper, the following research objectives were defined: (1) A digital decision support tool should be realized that implements a transparent and process-oriented approach to accompany political decision-makers step by step in formulating sustainable urban development strategies. This tool should be simple to use, intuitive, not require much effort in collecting, recording and elaborating data. It should enable easy access to the required specialist knowledge, empowering political decision-makers with a clear understanding of the decision-making process. (2) A comprehensive catalog of criteria should be integrated into the tool, allowing the urban development scenarios to be assessed according to the most

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relevant perspectives and strategic goals. The latest should consider diverse urban contexts, including cities with different urban planning challenges. (3) Rules, i.e., heuristics and calculations for the systematic assessment of urban development scenarios should be modeled transparently, managed centrally and be easy to adapt without specific IT skills, as there are numerous local and cantonal differences in Switzerland. (4) The IT tool should be easy to adapt and scale with little or no IT knowledge if new process steps or thematic aspects are to be considered, as spatial planning is a constantly evolving discipline.

The remainder of this article is structured as follows. Section II discusses the theoretical framework and reviews the international literature with a particular focus on the four research questions. Section III describes the methodological approach used to develop the solution. Section IV explains the technical aspects of the developed solution. Section V critically discusses the results regarding the degree to which the objectives were achieved and points out possible future developments.

II. Related Work

The work described in this paper was inspired by decision support systems in spatial planning. These tools are particularly suited to understand the complex problems of spatial planning in urban areas [3], as they are used to explore weakly structured or unstructured problems characterized by many actors, many options and high uncertainty [4]. They make it possible to create different scenarios in which the objectives of urban development can be adjusted to balance different environmental, social and economic disadvantages and advantages. Furthermore, the analysis of potential positive and negative impacts supports long-term decisions [5], while the consideration of different perspectives promotes stakeholder interest and leadership [6].

The components of a decision support system are (1) a database, which contains georeferenced or non-georeferenced data, (2) a modeling component, which contains various models, such as simulation models, projection and analytical models, and (3) a user interface, which allows the user to easily interact with the system [7]. For solving problems, spatial planners can select the appropriate model, execute it by using the data in the database and use the results coming from the decision support system as a basis for decision-making [7].

The selection of models, suitable data, or the interpretation of results from a decision support system can often pose challenges. Therefore, integrating expert systems presents an interesting solution [8].

Expert systems are computer-based systems that make it possible to access the extensive specialist knowledge of experts in a particular field to solve complex problems and support well-founded decision-making processes. In the context of spatial planning, they can integrate rules, heuristics and experiences of urban planners to help diagnose problems, evaluate options and recommend actions [7][8].

Theories, rules of thumb, estimates and computational methods of experts are included in the knowledge base of the expert systems. The set of rules to manipulate the information of the basic knowledge to generate recommendations is called control system. This is distinct from the basic knowledge so that both systems can be expanded and adapted as required without causing substantial changes to the computer program. The rules in the control system are generally defined in the form of if-then-else statements [7] and their adaptation generally requires programming knowledge.

Given the emphasis on facilitating the creation of sustainable urban development scenarios, integrating expert systems into decision support systems has been explored with keen interest, aiming to ensure easy accessibility to expert knowledge.

Decision support systems have continuously evolved over the years to include more and more advanced technologies. Despite this modernization, however, they still present gaps that result in an obstacle to the use of these tools [3]. These tools are typically very specific, require specialist knowledge to operate, are time-consuming, complex, less intuitive and not scalable [3]. Furthermore, their integration is insufficient [9] to foster a holistic view, a crucial element for sustainable urban development.

In addition, users may struggle to determine which tool is best suited for a given problem [3], as there are many decision support systems for various urban planning problems.

In general, decision support systems focus on the design and evaluation of possible urban solutions, but only a few focus on the decision-making process itself. [10]. According to reference [8], decision-making processes for sustainable urban development require structure and flexible guidance, to support argumentation and communication between stakeholders.

Although there have been attempts to formally model the decision-making processes in spatial planning [11], no relevant work could be found in the literature that systematically implements this approach. Only one paper was found in which a workflow management system was developed on top of a geoinformation system to provide spatial decision support by incorporating environmental data [12].

III. Methodology

For the development of the tool, the Design Science Methodology [13] was employed, which aims to create an artifact to solve a problem and analyze its performance. This methodology consists of three cycles: (1) the relevance cycle, (2) the rigor cycle and (3) the design cycle. The relevance cycle establishes the application context, determines the requirements for the artifact and defines the criteria for its success. In the rigor cycle, existing knowledge and theory is used to influence the design process and expand the knowledge base. In the design cycle, the artifact is designed, evaluated and, if the criteria are met, released into practice.

A. *Rigor cycles*

To develop the tool, experts and user representatives including urban planners, infrastructure engineers, experts of geoinformation systems and political decision-makers were identified. Through workshops and semi-structured interviews, based on a participatory human-centered design approach, functional and non-functional requirements for the

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tool were developed. These requirements were specified based on test areas with different urban contexts. Evaluation criteria were defined together with the participants. Expert knowledge for the creation and evaluation of urban development scenarios was identified through literature research, as well as workshops and interviews, and then modeled in traditional knowledge representation formats.

B. *Relevance cycles*

To develop the knowledge base, the approach utilized was based on the results of workshops, expert interviews, and an extensive literature review on decision support systems (see Section II). Additionally, extensive literature reviews were carried out on the following topics to identify useful theories, concepts, and technologies aimed at achieving the research objectives:

- Business process management concepts to design a digital guide that supports users in formulating sustainable urban development strategies.
- WorkFlow Management Systems (WFMS) for the implementation of the digital guide in a simple and flexible way.
- Theories and concepts to building a system of targets and metrics to assess sustainable urban development scenarios.
- Methods for modeling rules using an easy-to-learn language and centralized management of these rules in a user-friendly system.
- Low-code technologies to minimize the time required for programming.

a) *Definition and modeling of business processes*

For the design of the digital guide, inspiration stemmed from the idea that the process to formulate sustainable urban development strategies can be considered as a business process, consisting of a series of activities to achieve goals [14]. Therefore, business process management methods were employed to first identify the steps involved in formulating urban development strategies, and then to graphically model them, ensuring transparency and clarity [15].

Contrary to a deterministic model, findings from workshops with experts revealed that, while certain steps of the digital guide are essential, others can be optional or less precise. Creating a detailed process model using formal languages, such as Business Process Model and Notation (BPMN), was considered too restrictive, so we modeled the digital guide as a sequence of phases.

The identification of the process steps for strategy development was inspired by the work [11], which describes a metamodel for the spatial planning process. The presented process has a linear execution path over five main steps, organized as an iterative and cyclical process with several feedback transitions. This cyclical pattern facilitates and allows adjustments to the changes and insights arising during the process itself [11].

b) *Workflow management systems*

Once modeled, processes require effective execution and control, for which technical support is essential. WFMS play a central role in this regard. They have the characteristics of being able to react to changes in processes without program modifications [16], based on parts that can be reused, and are therefore highly adaptable.

Different types of WFMS exist. Form-oriented WFMS have been utilized [17] for implementing each process step of the digital guide. These are mostly used to read and display the content of database tables and are designed to be easily reused and customized, practically without programming knowledge [16].

c) *Balanced Scorecard*

The Balanced Scorecard (BSC) is a proven method for measuring and evaluating performance and progress in various organizational areas [18]. It offers a holistic, target- and Key Performance Indicator (KPI)-focused, balanced, and strategically oriented approach.

The BSC takes a holistic approach by considering multiple perspectives. It is goal- and KPI-oriented because it combines clear goals with specific performance indicators. It ensures that the assessment provides a balanced and comprehensive view. It is strategy-oriented, as the targets are derived directly from the strategy.

The decision to employ this method in assessing sustainable urban development scenarios was driven by the necessity for a comprehensive, balanced, and strategy-compliant system of targets and key figures. Furthermore, the definition of indicators for evaluating such scenarios was influenced by the findings of the ANANAS research project [19].

d) *Modeling of decision rules*

The key metrics for evaluating urban development scenarios should be determined using well-defined rules. These rules should not only be transparent and comprehensible for users but also adaptable or expandable if necessary. To achieve this, the rules must be described in a language that is both easily understandable and formal, allowing for straightforward conversion into a machine-interpretable format. The Decision Model and Notation (DMN) meets these requirements. It is a modeling language designed for the formal specification of decision logics and rules [20]. DMN allows for the representation of these logics through easily understandable graphical models. Elements such as decision diagrams and tables are used to formally describe decision rules and logics. Models created in this way can be applied in various contexts to formalize and automate decision-making processes. DMN thus provides a standardized language for communicating and exchanging decision logic [21].

e) *Low-code technologies*

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Low-code technologies were used to develop the digital guide and the system for interpreting the rules created with DMN. This term covers methods and platforms that enable the development of applications with the help of prefabricated software modules without the need for extensive handwritten lines of code [22]. For development, the modules are selected with the help of a visual user interface and configured as required. The corresponding low-code platforms also offer powerful drag-and-drop functionalities, integrated databases and automation tools to speed up the development process. This not only enables faster development, but also means that less software development expertise is required [23].

The use of low-code technologies lent itself to the development of the digital guide because it allowed a prototype to be developed quickly, results from workshops could be visualized quickly, sometimes even 'on the fly', and the time required to develop the complete prototype remained within a manageable framework.

C. Design cycle

In the design cycle, the prototype of the decision support system was developed according to the requirements and evaluated in field tests using the defined test areas. Continuous iterations were carried out to refine and adapt the prototype. This involved optimizing the user interface to enhance user-friendliness, adapting the process steps for formulating sustainable urban development strategies, and refining the system of key figures and associated calculations.

For evaluating the prototype, the users had to assess the following criteria on a scale from 1 (very bad) to 6 (very good): user-friendliness, transparency, time-saving in collecting and analyzing data, accuracy of scenario assessments and easy adaptability and scalability of the tool.

IV. RESULTS

The developed solution comprises the following components:

- A digital guideline that enables the process-oriented recording and assessment of urban development scenarios.
- A system of targets and metrics integrated into the digital guide that enables a holistic, balanced and strategy-conform assessment of the scenarios.
- A separate ‘set of rules’ that communicates with the digital guide via an interface. It allows the modeling and execution of rules for the calculation of key figures in a formal and simple standard language.
- A geoinformation system that is linked to the digital guide and enables the georeferenced recording of the scenarios on the one hand and the visualization of the calculated key figures (e.g., visualization of land density) on the other.

The combination of the various software components is shown in Figure 1.

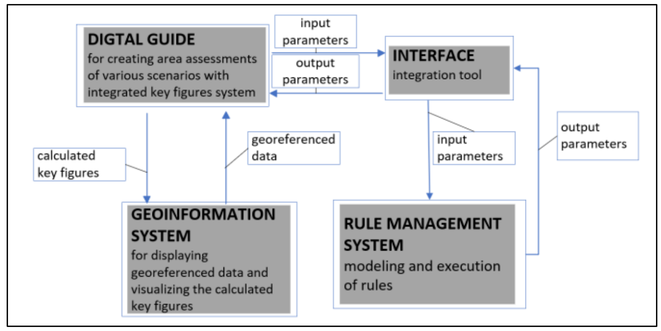

Figure 1. Interaction of the various software components.

A. The digital guide

The prototype was developed as a web-based application, utilizing the Microsoft PowerApps low-code platform [24]. Similar to a digital guide, it leads users through the process, which consists of seven main steps: Step 1: ‘Selection of the project-specific development goals’; Step 2: ‘Recording the current scenario’; Step 3: ‘Evaluation of the current scenario’; Step 4: ‘Selecting a scenario’; Step 5: ‘Building scenarios’; Step 6: ‘Evaluation of scenarios’; Step 7: ‘Comparison of scenarios’, with further sub-steps as shown in Figure 2. Each process step can be carried out for each of the six defined topic areas: Topic Area 1: ‘Settlement’; Topic Area 2: ‘Landscape’; Topic Area 3: ‘Traffic’; Topic Area 4: ‘Supply’; Topic Area 5: ‘Building Opportunities’; Topic Area 6: ‘Finance’, with the respective sub-topic areas of urban development. The process steps in the created prototype are therefore navigated horizontally, while the topic areas are arranged vertically.

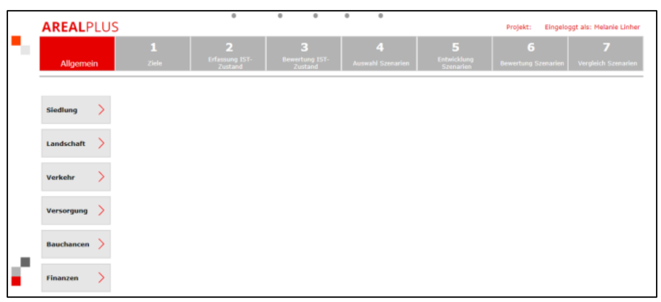

Figure 2. Process flow with the seven main steps and the six topic areas.

Figure 3 shows an example to illustrate the use of the guide, in which step 1, ‘Objectives’ (‘Ziele’), is shown for the topic area ‘Settlement’ (‘Siedlung’) and the sub-topic area ‘Land and building potential’ (‘Fläche und Flächenpotential’).

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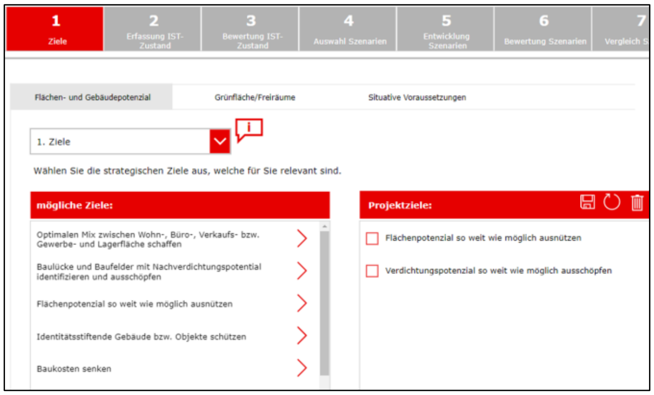

Figure 3. Step 1: Selection of the project-specific development goals.

Specifically, the user selects from a list of possible urban development goals ('mögliche Ziele') on the left-hand side, the specific goals 'utilize space potential as far as possible' ('Flächenpotenzial so weit wie möglich ausnutzen') and 'utilize densification potential as far as possible' ('Verdichtungspotential so weit wie möglich ausnutzen'). The selected goals for the analyzed test area are listed then on the right-hand side.

In sub-step 2, 'Key Figures' ('Kennzahlen'), which is represented in Figure 4, a list of possible key figures for quantifying the objectives chosen in the previous step is available for selection. In the specific case, the user selects the key figures 'land utilization rate of zone WG3' ('Ausnützungsziffer WG3'), where 'WG3' means 'residential zone with three full stores', 'land density' ('Dichte'), 'degree of land utilization' ('Flächenausnützungsgrad'), and 'degree of land densification' ('Verdichtungsgrad'). After the key figures have been selected, the target, minimum and maximum values should be defined on the right-hand side.

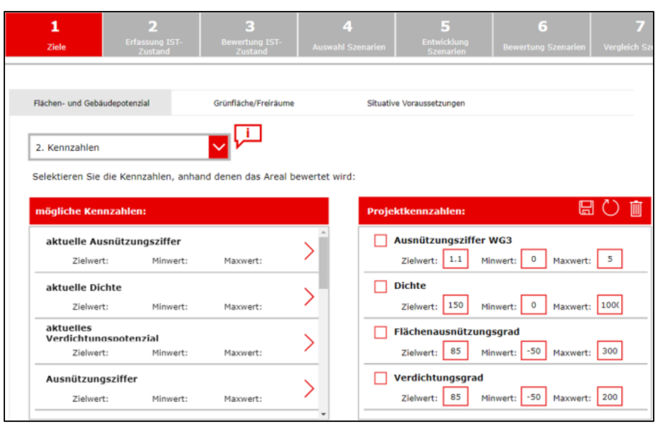

Figure 4. Step 1: Selection of the project-specific key figures.

In step 2, 'Recording the current scenario' ('Erfassung IST-Zustand'), land and building data, if available, should be obtained automatically from the geoinformation system (see Figure 5).

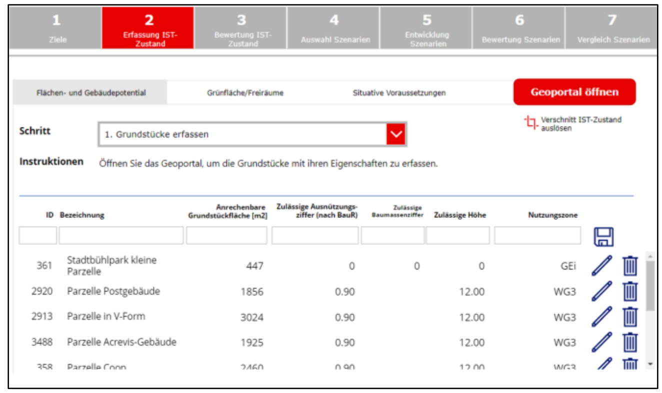

Figure 5. Step 2: Recording the current status (land parcel and buildings attributes).

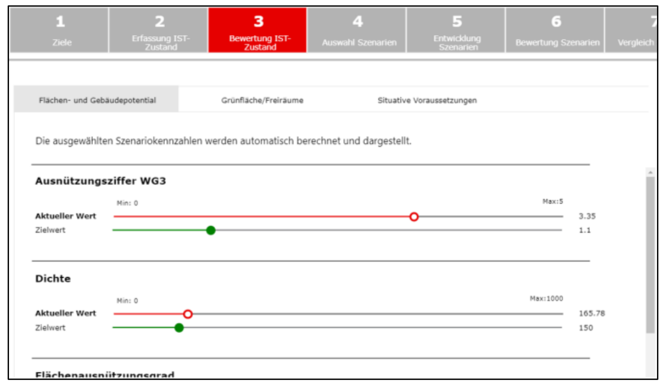

Figure 6. Step 3: Evaluation of the current scenario, with automatic calculation of the key figures 'land utilization rate WG3' and 'land density'.

In step 3, 'Evaluation of the current scenario' ('Bewertung IST-Zustand'), the selected key figures for the current scenario are automatically calculated for the analyzed test area, as illustrated in Figure 6. They are compared with the target value defined in step 1, 'Objective', and sub-step 2, 'Key Figures', allowing for immediate visualization of the effects associated with the created development scenario. This is especially useful when considering the perspectives of the stakeholder involved.

In step 4, 'Selecting a scenario', the user selects the scenario to be considered. The digital forms of step 5, 'Building scenarios' ('Auswahl Szenario'), are similar to those of step 2, 'Recording the current scenario'. Possible scenarios are created directly in the geoinformation system (as explained in sub-section D), and georeferenced information, such as the land area and the green area, is automatically transferred into the digital guide.

In step 6, 'Evaluation of scenarios' ('Bewertung Szenarien'), the key figures selected in step 1, 'Objectives', are automatically determined based on the modified properties of the respective scenario, similar to step 3, 'Evaluation of the current scenario'. In step 7, 'Comparison of scenarios' ('Vergleich Szenarien'), the calculated key figures for each recorded scenario are displayed side by side, as is shown in Figure 7.

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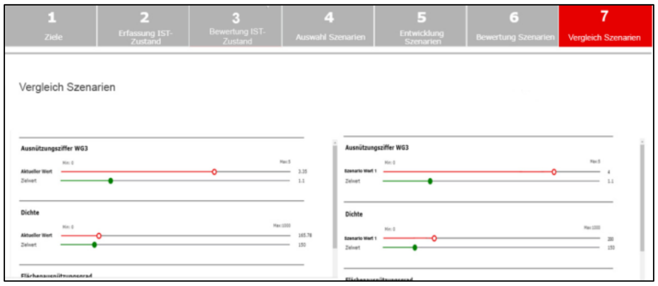

Figure 7. Step 7: Comparison of scenarios.

The digital guide is designed so that the digital forms have the same repetitive structure for each process step and topic area. Basically, three principal functions can be identified in the process of creating a scenario: (1) the recording of geo- or non-georeferenced data for each object related to the analyzed test area (e. g., the recording of the land area for each land parcel of the test area), (2) the calculation of the selected key figures for each object (e.g., the calculation of the land density of each land parcel of the test area), and (3) the calculation of key figures consolidated to the entire analyzed test area (e.g., the land density of the entire test area).

As a prototype version, the digital guide was designed to be as easily adaptable and modular as possible. This means that new topic areas, sub-topic areas, objectives, key figures, and objects, such as buildings and roads, can be easily added with the corresponding information and key figures.

B. *Target and indicator system for the systematic assessment of scenarios*

An important component of the digital guideline is a system of targets and indicators for a holistic and balanced assessment of the generated urban development scenarios. The perspectives of the target and indicator system correspond to the topic areas of the vertical navigation of the digital guide, as shown in Figure 8.

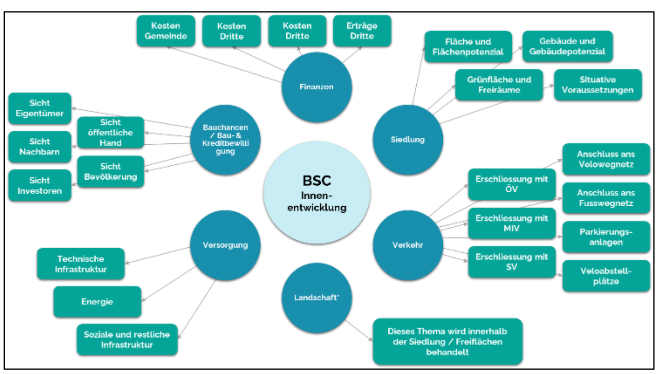

Figure 8. Target system for a holistic and balanced evaluation of scenarios.

The indicators, which correspond to the key figures listed in step 1, ‘Objectives’, and sub-step 2, ‘Key Figures’, of the digital guide, are generally quantitative indicators. For example, for the topic area 'Settlement' and the sub-topic area 'Area and Area potential', key figures, such as ‘land utilization rate’, ‘land density’, ‘degree of land utilization’ and ‘degree of land densification’ are calculated. However, qualitative key figures are also included, such as the assessment of the risk of objection for the topic area ‘Building Opportunities’ (‘Bauchancen’) and the sub-topic area 'Interest of Neighbors' (‘Sicht Nachbarn’), where a subjective assessment on a scale of 1 to 5 is required.

C. *Rules for evaluating the scenarios*

The key figures for assessing the scenarios according to the selected objectives are calculated automatically within the digital guide. To formalize and simplify the rules for these automatic calculations, the standard language Decision Modeling and Notation (DMN) was utilized. These rules are modeled and executed within a separate low-code application called ‘The Universal Process Orchestrator’ on the Camunda platform [25], which then communicates with the digital guide via an interface.

Figure 9 illustrates the DMN model for calculating the key figure 'number of inhabitants and employees' (represented by the rectangle 'EW_and_BF').

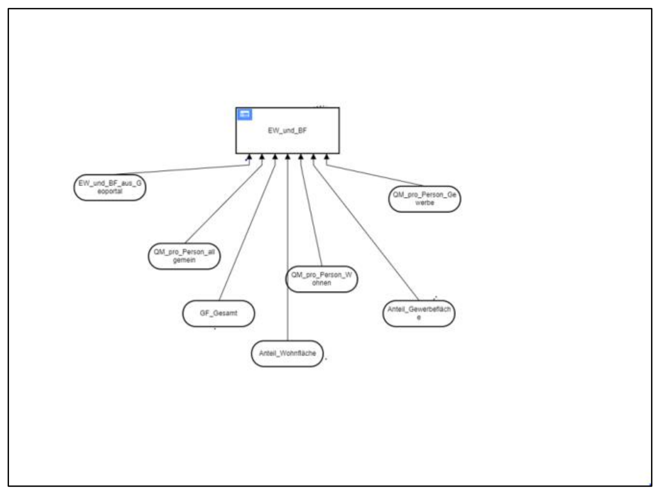

Figure 9. DMN model for the key figure 'Number of inhabitants and employees'.

This key figure depends on various input parameters, which are contained in ovals within the model. The relationships between the input parameters are then defined within a simple decision table.

D. *Geoinformation system for the georeferenced recording of scenarios*

Another important component of the system is the integration of the digital guide with a geoinformation system of GEOINFO [26], enabling the easy and intuitive creation of various urban development scenarios with georeferenced data. Specific aspects for each scenario can be specified using a set of user levels, which are selectable on the left-hand side. For instance, within the 'Settlement' user level, green areas or buildings can be created, while new roads can be recorded within the 'Supply' user level, as depicted in Figure 10.

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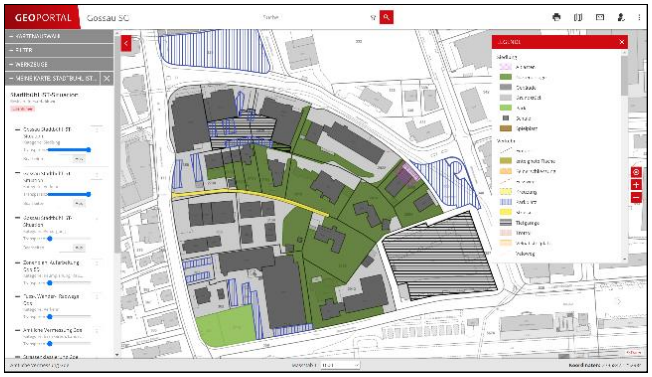

Figure 10. Snap shot of the geoinformation system: user levels ‘Settlement’ and ‘Supply’ for the considered test area.

A legend on the right-hand side helps identify which aspect (e.g., streets or green areas) is represented by each color or symbol. The georeferenced data entered in this manner can then be automatically imported into the digital guide for the corresponding topic area and sub-topic area.

Additionally, once key figures (such as 'land density') have been calculated in steps 3 and 6 of the digital guide, they can be displayed in the geoinformation system for each land parcel within the test area under consideration, as illustrated in Figure 11.

Figure 11. Different shades of green represent the land density of each land parcel within the test area under consideration.

V. Conclusion and Future Work

The primary research question addressed in this paper examines the feasibility of a digital expert decision support system, designed to aid political decision-makers, in formulating and evaluating sustainable urban development scenarios. The objective was to implement a transparent and procedural approach to help the user step by step. Additionally, the tool was intended to be user-friendly, intuitive, and require minimal time for data collection, recording, and analysis.

The objectives associated with the primary research question have been successfully achieved.

The developed tool is user-friendly and intuitive, owing to its process-oriented approach and integration with the geoinformation system interface. This interface facilitates the straightforward creation of georeferenced scenarios and the automatic retrieval of associated georeferenced data. Key figures are also automatically calculated through integration with the rule system, reducing the need for extensive data preparation and analysis. Moreover, the presentation of scenario evaluation results against predefined objectives is clear and intuitive.

The implemented decision support system provides political decision-makers with a tool to comprehend the creation and evaluation of sustainable urban development scenarios in a transparent and systematic manner. This enables them to engage in competent and professional discussions with the involved experts and stakeholders. However, the tool cannot replace the creative process required to generate scenarios. Therefore, the development of sustainable and plausible scenarios still requires the involvement of experts.

The second research question, which related to the integration of a comprehensive catalog of criteria for assessing urban development scenarios according to the most relevant perspectives and strategic goals considering different urban contexts, has also been fully answered. According to project participants, this holistic approach to evaluating urban development scenarios, coupled with real-time visualization of their impacts, will expedite the decision-making process.

The third research question examined how rules, heuristics, and calculations for the assessment of the scenarios can be transparently modeled, centrally managed and executed. This question was fully answered by modeling the calculations using the standard DML language and executing them in a dedicated tool developed specifically for this purpose.

The fourth research question focused on the ease of adaptation and scalability of the IT tool, allowing for the incorporation of additional process steps, thematic aspects, or assessment criteria without requiring extensive IT knowledge. This question was positively addressed through the utilization of low-code technologies, employing both the Camunda software for managing and executing rules and the PowerApps software from Microsoft 365 for the digital guide. Furthermore, significant flexibility was ensured by applying concepts from workflow management software, which rely on reusable forms that can be easily customized.

As a final consideration in relation to the achievement of the project's goals, it is worth mentioning that all the criteria for evaluating the tool prototype, that are listed in section III and subsection C have been met more than satisfactorily by the users.

In summary, the unique value of the prototype tool described in this article lies in its integration of several advanced technologies and methodologies. Unlike existing decision support systems, our prototype offers an intuitive, user-friendly, and time-saving operation, combined with a process-based and transparent approach to the creation and holistic evaluation of urban development scenarios. Furthermore, the specific combination of geoinformation systems with expert systems and low-code platforms is unprecedented, providing a more robust, scalable, and flexible solution.

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Drawing from the experiences gained through the development and storage of scenarios, the tool could be further optimized in the future by integrating deep learning methods to provide powerful support in the planning and implementation of sustainable urban developments. Deep learning algorithms are distinguished by their ability to automatically extract relevant features from data [27]. By leveraging these algorithms, along with extensive data analyses and empirical values, the tool could automatically suggest targets and target values for a selected urban area, identify areas with similar characteristics, and generate indications for the development of plausible scenarios. Furthermore, once implemented in reality, scenarios could be subsequently recorded and estimated values could be continually refined, allowing for further optimization.

This combination of traditional estimation methods with the advanced analysis capabilities of deep learning would enable the tool to fully realize its potential. To enhance the tool while maintaining its simplicity and user-friendliness, it is crucial to assess whether integrating deep learning techniques aligns with one of the system's original design objectives: adapting and scaling the tool with little or no IT knowledge.

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