Machine Learning Approaches for Designing Sustainable Planning Regulations

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1 ABSTRACT

Quantitative and qualitative assessment is essential for identifying levers for sustainable development processes and the impact of planning decisions. Small and medium-sized municipalities in particular struggle with a lack of resources and expertise in the creation and preparation of strategic, forward-looking decision-making bases. AI promises to help automate some of these processes, create a data base and provide planning support that will save time and money in the longrun.

This paperillustrates the possibilities of Machine learning (ML) approaches to evaluate quantitative data for qualitative outcomes within planning and decision processes. Furthermore, it provides a basis for discussing possible implications for planning practice based on ML approaches dealing with the impact prediction of planning regulations. In which planning steps and processes can the use of ML bring added value? Which questions can be answered and which prerequisites need to be created? How reliable are results and what can be derived from them?

In answering those questions, a special focus will be placed on the needs of small and medium-sizedmunicipalities. The use of the technologies in early planning phases will be analysed, to allow assessment for holistic sustainable developments., in terms of environmental, economic, social and design aspects.

ML approaches enable impact prediction based on impact assessment of past regulatory frameworks. Within planning processes, ML-based analysis and predictions allow informed decisions to be made that have analysed future effects and interactions and take holistic considerations into account. AI and big data make it possible to tap into ‘new data sources’ with a view to evaluating and predicting future developments, with the aim of making more resilient planning decisions. This changes the role of planning, as it is all the more required to help interpret the data and draw the right conclusions for future measures and solutions.

Keywords: small and medium-sized municipalities, decision support, planning regulations, machine learning, planning

2 INTRODUCTION: AI METHODS IN SPATIAL PLANNING

2.1 Premise and Research Question

There are already numerous international AI and ML applications across various thematic areas and stages of planning processes. The “Akademie für Raumentwicklung in der Leibniz-Gemeinschaft” (ARL) recommends that public administration and planning make sustainable use of AI in spatial development for the common good.(ARL, 2024)

However, for many small and medium-sized municipalities in Austria, practical implementation remains challenging due to limited competencies and resources. These municipalities, in particular, face difficulties in acquiring the necessary expertise and resources to develop and prepare strategic, future-oriented decision-making frameworks.

This leads to the key question for this paper. What possibilities does AI offer to help small and medium-sized municipalities to formulate and adopt sustainable planning regulations? Where can interfaces for the use of AI be identified in the area of local spatial planning instruments (ÖEK, FWP, BPL) that bring comprehensible added value for municipalities?

2.2 Literature Review

Remote sensing data is crucial for ML applications in spatial planning. Satellite imagery time series aid in segmenting and classifying objects like roads, buildings, and vegetation (Dornaika et al., 2016; Shorter & Kasparis, 2009; Zhou & Chang, 2021). These methods also enhance urban zone classification (Chen et al., 2021). Model accuracy depends on annotated datasets, created automatically (Karila et al., 2023) or manually (González-Collazo et al., 2023). When available, pre-existing vectorized datasets with rich attributes are preferred, but ML methods can help fill gaps where structured data is lacking.

Nagappan and Daud (2021) highlight that while ML has advanced in detecting land-use and land-cover patterns from various data sources and temporal analyses, it seldom considers their correlation with planning regulations.

In their study on possible applications of AI in urban planning (2025), Otengrafen et al. identified five different types of AI: Analytical, Functional, Textual, Visual and Interactive AI. They present their possible applications of AI in a matrix along the 5 planning phases according to Diller et al. 2017: See Figure 1.

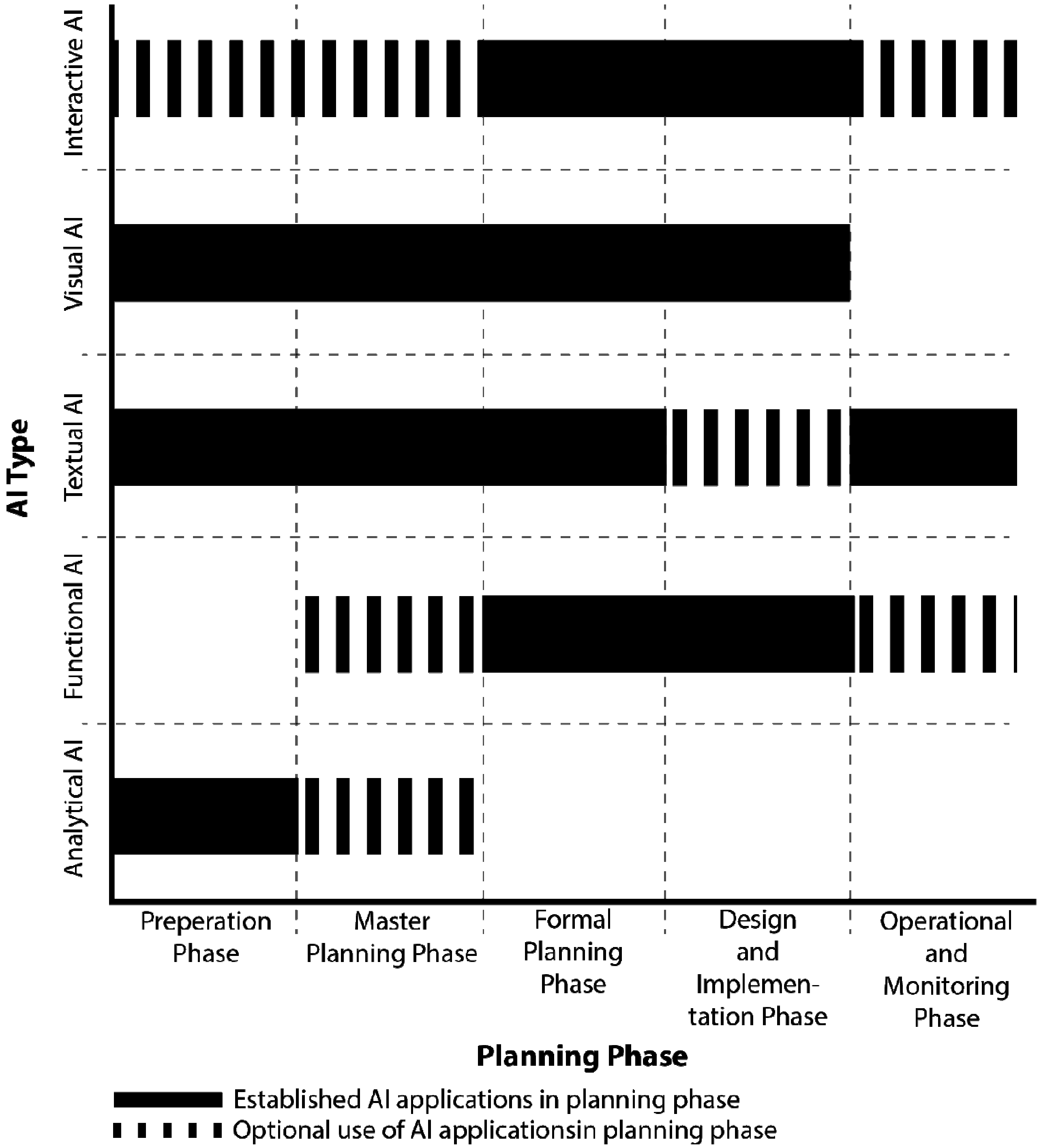

Fig 1: Use of AI Tools in different planning phases. A proposal by Othengrafen et al. 2025 for “the use of AI tools related to urban planning in different planning phases”. Source: Own illustration based on Othengrafen et al. (2025).

Rural areas, in particular, face critical challenges that demand planning support tools capable of accurately estimating the outcomes of decisions and their complex interactions. As the need for sustainable development becomes increasingly urgent, robust methods leveraging ML can offer insights into soil quality, land-use changes, and the role of natural structures as nature-based solutions (NBS). The method by Forster et al. (2025) plays an interesting role in this context and will be examined in more detail in this paper. Forster et al. investigate how existing planning regulations have influenced the spatial distribution of land use, with a particular focus on green spaces in settlement areas. To achieve this, a finely structured analysis of current land distributions and their underlying planning regulations is conducted. Based on this analysis, a test dataset is created for a machine learning model. This model aims to predict the impact of "new" planning regulations on soil sealing and land distribution patterns (Forster et al., 2025). In Othengrafen's classification, this form of AI application would be characterized as "Functional AI."

2.3 Main Planning Processes in Municipalities in Austria

Local spatial planning in Austria is based on three central planning instruments: the local development concept, the zoning plan and the development plan. A good overview of the instruments is provided by Stöglehner (2023). Here is a brief summary:

The local development concept (ÖEK) is the strategic guiding document of a municipality and defines the long-term development goals for the next ten to fifteen years. It is not directly legally binding for citizens, but serves as a basis for further planning. The concept defines which areas are earmarked for settlements, commerce, transport infrastructure or nature conservation and is based on sustainable and functional development principles.

The zoning plan (FWP) is a binding instrument that regulates the use of all land in the municipal area. It divides the entire municipal area into various zoning categories, including building land, transport areas and grassland. The zoning plan must be based on the specifications of the local development concept and can only be amended by a municipal council resolution. The federal state is the supervisory authority and monitors the legal status of the plans, but has no authority to shape their content.

Finally, the development plan (BP) regulates the specific structural use of individual plots or sub-areas within the building land. It determines, for example, how high and in what way buildings may be erected, where building lines run or which design specifications must be adhered to. The development plan is directly legally binding for property owners and ensures that construction projects are in line with the overarching plans of the municipality.

The spatial planning laws of the federal provinces stipulate how local development concepts, zoning plans and development plans must be drawn up, amended and approved. Supervision of the municipalities is also the responsibility of the federal provinces, which ensure that municipal spatial planning is in line with overarching provincial objectives. Together, these three instruments form a graduated planning structure that ranges from strategic development and large-scale utilisation allocation to detailed building specifications.

Small and medium-sized municipalities in Austria face several challenges in spatial planning. They often lack financial resources and expert staff, requiring external planners. Coordination with authorities, neighboring municipalities, and citizens can be time-consuming, especially for zoning plan changes. While some municipalities struggle with depopulation and vacant buildings, others must rapidly develop residential and commercial areas. Conflicts often arise between economic development and environmental protection. Many municipalities rely on investors, which can hinder sustainable planning. Stricter environmental regulations and climate protection measures pose additional demands for future-oriented spatial planning.

Although the three instruments have different focal points, time horizons and spatial scales, they are subject to ‘similar’ processes in terms of content, which can essentially be divided into these (very simplified) phases:

(1) Inventory and problem analysis

(2) Design phase

(3) Determining a decision and finalising the design

(4) (Public) Review phase

(5) Approval and enactment of the planning resolution

We now examine the application case proposed by Forster for further research questions. We primarily place the applications of such an "impact prediction tool" in the (iterative) design phase (2.). However, the necessary data collection and processing are certainly also part of the inventory (1.).

3 PREDICTING THE IMPACTS OF PLANNING REGULATIONS

As already outlined in Section 2, Forster et al. (2025) demonstrated how ML models can be used to generate concrete predictions, for example, regarding soil sealing rates or the distribution of specific land types. The training data consists of detailed land use analyses combined with existing planning and zoning regulations. However, the practical application of this approach is still pending. Figure 2 illustrates the basic concept behind the demonstration example. The correct classification of areas and spatial objects is crucial for this type of supervised machine learning. In Austria, numerous attributed vector datasets are already available for similar types of research questions. However, the quality of these attributes, particularly in terms of completeness and accuracy, still has room for improvement.

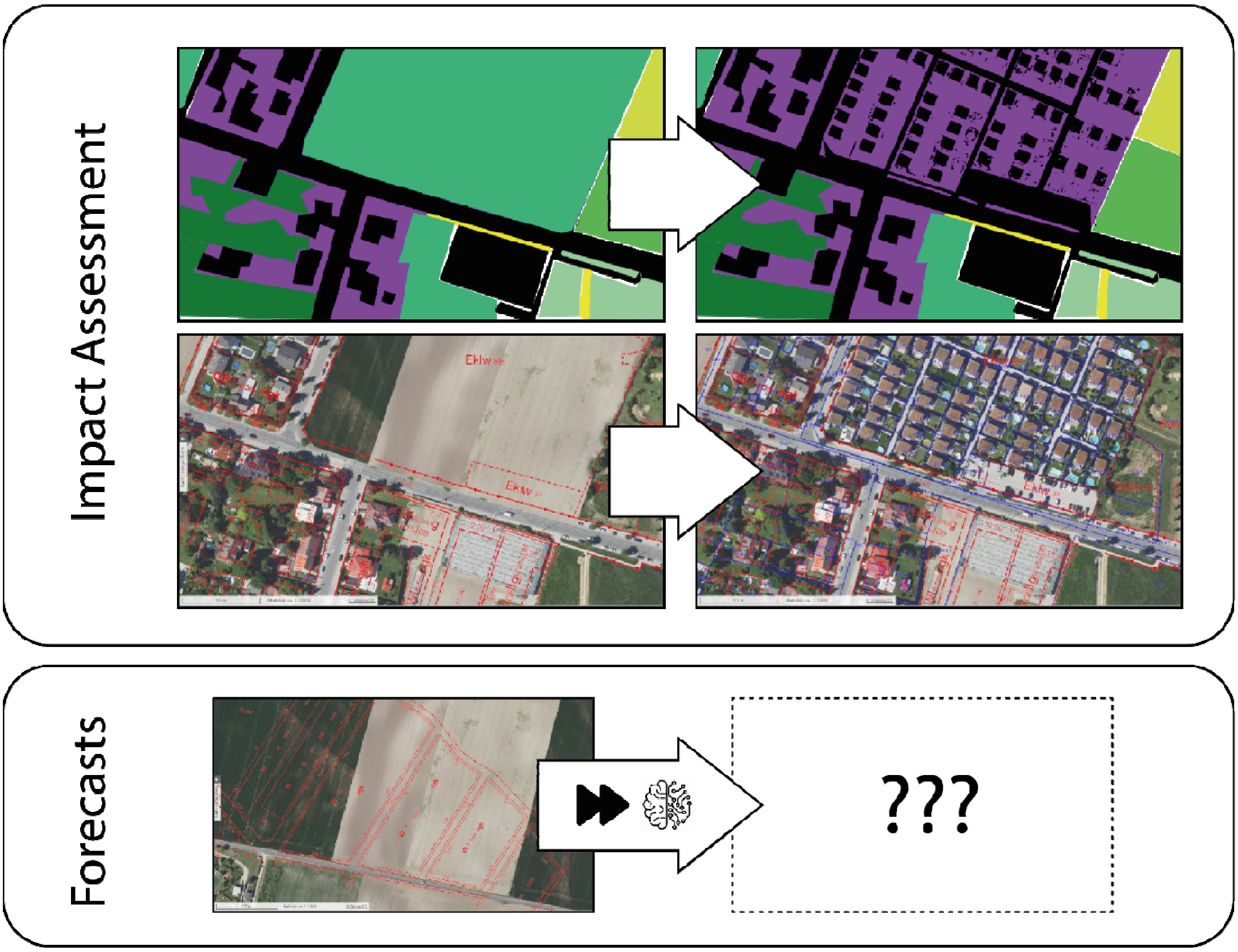

Fig 2: Schema of methodological concept of impact assessment and forecasts of planning decision using ML models as proposed by Forster et al, (2025), own illustration.

The following two examples illustrate the issues addressed in the impact assessment:

1. Impact of zoning changes on specific land uses and distributions (paved areas, green areas, development areas). Analysis of the development of existing dedicated areas, derivation of characteristic values, historical analysis of building files with regard to the time of dedication or time of development. Application: Compare the impact of the dedication of different areas/land use categories on the land balances.

2. The impact of building regulations: Similar to land use planning, ML models can be used to test and predict specific indicators. However, it is important to ensure that the classification of existing data is as accurate and correct as possible and that previous planning decisions are processed as fully as possible. As shown in Figure 2 above, the 'before' situation is recorded in the training data and the areas are evaluated

qualitatively and quantitatively. The same process is carried out for the 'after' situation. These data form the 'ground truth' or the basis of the ML dataset. These data are used to train ML models. As new planning variants emerge, they can be analysed with the ML models to predict which 'after' situations will result from the plans.

These planning games only make sense if concrete actions and checklists for planning are generated from these historical trends and findings.

Large cities such as Vienna are already working on accelerating and improving certain planning procedures using algorithm-supported processes based on digitally available building regulations. In the future, submission documents for building projects will be subject to automated checks.

In order to transfer such methods into planning practice, it is important that planning regulations are also mapped in digital, geocoded data formats (2D and 3D) in the future to enable computer-aided evaluations. When transforming existing regulations and data, AI can help to derive processable data from historical datasets in a variety of formats by implementing textual and verbal planning regulations in digital geometries. This could be implemented in a process chain involving different types of AI (analytical, textual, functional). However, the processing for a single small or medium sized municipality is rather difficult due to the small number of cases and the amount of data. In this case, an inter-municipal association or, better still, a national initiative would be more appropriate to achieve more reliable results.

4 DISCUSSION & OUTLOOK

The use of these specific algorithms for impact prediction appears to be technically feasible across all three instruments of local spatial planning for the early detection of effects and interactions. The most promising application seems to be in the area of zoning regulations, as each developed property in Austria represents a potential entry for a test dataset. Predictions regarding land-use changes based on modifications to the local development concept (ÖEK) are likely to be less meaningful due to the limited number of cases available in the training data.

The use of other AI types (see Othengrafen) in the many other areas of spatial planning can be made efficient and useful for municipalities even without large quantities of high-quality data. ML approaches enable impact prediction based on impact assessment of past regulatory frameworks. Within planning processes, ML-based analysis and predictions allow informed decisions to be made that have analysed future effects and interactions and take holistic considerations into account.

The new automatable, machine-assisted capabilities require a reconsideration of rigid, linear planning processes, where temporal aspects and dynamics are only limitedly considered in the evaluation of planning options. Simulating planning variants and scenarios presents a great opportunity to make more sustainable and future-oriented decisions. Engaging with this topic both conceptually and on a data level leads to the following positive outcomes:

(1) Quantitative and qualitative "land inventory" for the municipalities. That data can act as a future planning basis.

(2) The process creates reliable data on the impact of planning regulations on the future quality of land and the environmental impact and climate resilience

(3) The process fosters reflection processes on previous planning

(4) And supports a transfer of expertise for climate-resilient planning to the decisions makers and involved stakeholders.

It definitely changes the role of planning, as it is all the more required to help interpret the data and draw the right conclusions for future measures and solutions. Therefore, the ARL's recommendations for action, particularly in the area of capacity building and cooperation, should be implemented at least across municipalities, ideally across federal states or even nationwide.

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