# Climate resilient spatial plans: Revised LADM climate adaptation profile

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**Key words**: land administration, ladm, subsurface data, climate adaptation, spatial planning.

**SUMMARY**

In 2022, the Netherlands introduced 'water and soil' guidance as key principle for Dutch spatial planning. This approach emphasizes water and soil considerations into planning processes, especially when addressing pressing climate challenges in the country, such as flooding, rising sea levels, and soil subsidence. However, its implementation has encountered significant obstacles, particularly in the areas of data accessibility, standardization, and interoperability. Despise their availability, geological and hydrological information is often specialized, fragmented into multiple sources, and overall still unused in spatial planning. To address these challenges, the Land Administration Domain Model (LADM) Part 5 climate adaptation profile was introduced in 2024 and incorporated as Annex C in the ISO 19152-5 standard. This specialization profile provides a structured framework to integrate subsurface and climate-related data into land administration systems, enabling planners to make informed decisions and share plan information to support climate adaptation. The initial profile received valuable feedback from spatial planners, who highlighted the need for better integration with external data sources, improved data traceability, and design flexibility. This paper presents a revised version of the LADM climate adaptation profile, incorporating key modifications to address the feedback and enhance its functionality. One significant update is the inclusion of external classes, facilitating integration with external data sources, such as geological and hydrological models, and climate projections. Additionally, the revised profile includes the LA_Source class to meet spatial planners' requests for data traceability. To demonstrate the revised LADM profile, real Dutch plan information is used. For instance, one case study demonstrates how the LADM profile facilitates subsurface assessment during the masterplan phase, by integrating groundwater data and geological models with land use plans. The examples highlight the profile's ability to bridge theoretical frameworks with practical implementation, supporting the Netherlands' 'water and soil' principle. In short, the revised LADM Part 5 climate adaptation profile strengthens Dutch efforts to achieve climate resilience by improving data integration, transparency, and decision-making. Its flexible and interoperable framework also holds promise for global adoption. As nations worldwide seek to balance spatial development with climate adaptation, the profile's standardized approach can inform international best practices.

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## 1. INTRODUCTION

In 2022, the Netherlands introduced 'water and soil guidance' as key principle for spatial planning (Harbers, 2022), particularly in the context of climate change. This is because climate resilience benefits from nature-based solutions, which are inspired by natural aspects such as geological and hydrological characteristics (European Commission 2025). For example, soil type impacts rainwater infiltration when addressing flooding. High-infiltration soils, like sandy types, are ideal for this purpose, while low-infiltration soils, such as clay, may require alternative solutions like artificial water storage (Deltares 2020). Moreover, understanding soil composition and groundwater dynamics is essential for sustainable decisions, influencing feasibility of construction and long-term land use (Volchko et al. 2020).

Consequently, the inclusion of subsurface considerations in spatial planning is increasingly emerging from planners and designers, driven by agendas such as the 'soil and water guidance' policy. This has significant implications for planning decisions and land administration. In this context, the Land Administration Domain Model (LADM) Part 5 climate adaptation profile was developed to support the inclusion of subsurface data and climate projections in climate-adaptive plan information. It provides a structured framework for integrating useful data into land administration systems, enabling planners to make informed decisions and share plan information to support climate adaptation.

The LADM climate adaptation profile, incorporated as Annex C in the ISO 19152-5 standard, received valuable feedback from spatial planners, who highlighted the need for better integration with external data sources, improved data traceability, and flexibility. This paper presents a revised version of the specialization profile, addressing the feedback received and enhancing its functionality. One significant update is the inclusion of external classes, facilitating integration with external data sources, such as geological and hydrological models and climate projections. Additionally, the LA_Source class meets spatial planners' requests for data traceability. The revised profile is flexible to different planning contexts, allowing planners to customize the profile to their specific needs, including in different countries. This allows the profile to be applied globally, ensuring its international relevance.

The paper is structured as follows: section 2 discusses the context of subsurface data in Dutch spatial planning, particularly in light of climate change. Section 3 presents the development of the LADM Part 5 climate adaptation profile, including feedback from planners. Section 4 discusses the revised profile, highlighting key modifications and how they address the feedback received. Section 5 explores practical applications of the revised profile, including case studies demonstrating its utility in real-world planning scenarios. Finally, Section 6 concludes the paper and section 7 suggests future research.

## 2. SUBSURFACE AND CLIMATE RESILIENT SPATIAL PLANNING

Effective climate adaptation involves nature-based solutions that often rely on subsurface and water information, such as soil types and groundwater levels (European Commission 2025, Deltares 2020). For this reason, soil and water considerations in spatial planning is increasingly emerging, pushed by related agendas like the Dutch 'soil and water guidance' (Harbers and Heijnen 2022). This section discusses the context of subsurface data in Dutch spatial planning, particularly in light of climate change impacts. It highlights the importance of subsurface characteristics and their implications for climate-adaptive design practices.

### 2.1 Spatial planning 'from the ground up'

The concept of 'water and soil guidance' (Harbers and Heijnen 2022) is not how the Netherlands has always approached planning decisions. Historically, Dutch spatial planning overlooked subsurface conditions, often developing urban expansions by placing a thick layer of sand on top of polders without considering long-term consequences. These areas today face water management and subsidence issues, and the artificial sand layer can be considered a biodiversity desert. Solving these issues requires understanding subsurface characteristics, such as soil types and water systems. The use of subsurface information as a basis is referred to as designing 'from the ground up'. This concept emphasizes subsurface information as an integral part of spatial planning rather than as an afterthought.

One example is PosadMaxwan's 2040 vision for a Dutch city center. In this project, subsurface information was used to guide decisions on where and how to develop new housing units. As a design choice, densification in this project was not the goal in itself but something that must align with the existing natural framework. Thus the water and soil system defined green blue structures, habitats, types of vegetation, location, and size of new buildings (PosadMaxwan 2023). Water and soil considerations can also be present in a masterplan, where land functions are defined. An example of this is the masterplan for Almere Pampus where subsurface data played a crucial role. The masterplan included about thirty thousand homes and all associated public and commercial facilities for healthcare, education, recreation, and daily shopping. Soil and water data guided decisions on the city's layout, especially regarding rainwater infiltration (Gemeente Almere and Rijksvastgoedbedrijf 2024) because certain soil types are naturally more capable of infiltrating rainwater (Deltares 2020).

Designing 'from the ground up' involves several key steps. The first one is gathering and analyzing data related to soil, groundwater, and underground infrastructure. This data can be obtained from various sources, such as geological surveys and local infrastructure databases. This data is then used to inform design decisions, ensuring that interventions are tailored to the specific subsurface conditions of the area. For example, planners may choose to implement permeable pavements in areas with sandy soil to enhance natural rainwater infiltration or reduce the size of underground interventions where needed, for example where there is a high concentration of cables or pipes. The following subsection discusses subsurface characteristics and their implications for spatial planning decisions.

### 2.2 Subsurface characteristics and climate-adaptive design

Nature-based spatial planning is considering natural aspects when making planning decisions (European Commission 2025). This includes natural subsurface considerations, such as geological and hyrological characteristics of an area. For example, planners must evaluate factors like soil load-bearing capacity to avoid subsidence. Or they may consider the permeability of the soil and groundwater levels to promote natural rainwater infiltration. These natural subsurface characteristics directly influence the feasibility and effectiveness of interventions, especially in the context of nature based climate resilience. There are also subsurface characteristics which are not natural but impact design decisions. In urban areas, subsurface infrastructures can limit the space for interventions. For example, in an area prone to waterlogging, the availability of underground space can guide designers when choosing between water roof collection or underground water storage.

Climate adaptation design must incorporate these subsurface characteristics to effectively address challenges like flooding and heat stress. In 2020, the Dutch ministry compiled a summary of twenty-five prevalent climate adaptation interventions (Rijksoverheid 2020) which were related to subsurface data needs (Kawasaki 2024). One of the main outcomes was the classification of subsurface data requirements into four categories, associated with four characteristics of soil, water and infrastructure. These categories are:

- **Groundwater Level:** Natural infiltration interventions depend on data regarding infiltration capacity. Infiltration capacity is higher when the highest groundwater level is less than seventy centimeters below surface level (Deltares 2020). Additionally, interventions related to additional water, such as waterways, or deep excavations, such as underground water storage, must consider the presence and levels of groundwater.
- **Spatial Claim:** The presence of subsurface natural or built elements, such as roots and cables, determine how much space is available for interventions. Thus, every intervention which involves adding subsurface elements, such as planting trees, must consider the presence of other subsurface elements. This is especially important in urban areas, where space is limited and subsurface infrastructure is dense.
- **Soil Type:** Soil type influences both infiltration capacity and the suitability for construction. Sandy soil facilitates infiltration, while clay and peat limit it and may affect building stability (Deltares 2020). This is particularly relevant for interventions like permeable pavements, which benefits from natural infilitrating soil conditions.
- **Geomechanics:** Refers to the load-bearing capacity of the ground, which influences construction material and method choices. This is particulalrly relevant for interventions that involve heavy construction, such as building new structures or modifying existing ones. Additionally, geomechanics is important when modifying the ground. For example, one of the twenty five interventions is the elevation of the ground, which is often done to prevent flooding. However, this requires knowledge of the load-bearing capacity of the ground to ensure that the elevation is feasible and safe.

## 3. LADM CLIMATE ADAPTATION PROFILE DEVELOPMENT

The LADM climate adaptation profile aims to provide a structured framework for integrating subsurface data and climate projections into land administration systems, enabling planners to make informed decisions and share plan information to support climate adaptation. Its development was driven by the needs and benefits of integrating subsurface data into spatial planning, particularly in the context of climate resilience. The profile was included in Annex C of the ISO 19152-5 standard, and received valuable feedback from spatial planners and LADM experts. This section discusses the development of the LADM Part 5 climate adaptation profile, including the key phases of its development and the feedback received.

### 3.1 LADM climate adaptation profile development phases

The development of the LADM Part 5 climate adaptation profile consisted of three key steps: scope definition, profile creation, and testing. This three-phase approcah is based on the methodology for developing LADM country profiles, as described by Kalogianni et al. (2021). A potential approach for the develoment of a LADM Part 5 profile is to start with the analysis of requirements from national legislation, followed by conceptual modelling (Radulovic et al. 2019). Thus the profile development started with the study of different climate adaptation design guidelines and policies. From this study, subsurface data needs were identified, leading to the development of a conceptual model that outlined key subsurface characteristics and their implications for spatial planning decisions. This foundation ensures that the LADM profile addresses the specific needs of integrating subsurface data into climate resilient land administration.
The second phase, creation, included the mapping of LADM classes and UML modelling. The detailed research of these two first phases was published as a Masters' thesis (Kawasaki 2024). The first version of the LADM Part 5 climate adaptation profile was presented at the FIG LADM Workshop 2024, where it received valuable feedback from LADM experts. Subsequently, stakeholders were involved. Their feedback highlighted the need for better integration with external data sources, improved data traceability, and maintaining flexibility in the profile design. Based on this feedback, the profile was revised to include external classes for data integration and the LA_Source class for data traceability. The revised profile was then validated and incorporated in Annex C of ISO 19152-5. Additonally, a paper presented the results from the interviews conducted with urban planners and the overall use of LADM for integrating subsurface data into climate-adaptive urban design practices (Kawasaki et al. 2025).
In the testing phase, plan information from Almere (Netherlands) was used for a first implementation of the LADM Part 5 profile. This consisted of an instance level diagram, showcasing the association between a particular planned area and the external sources of subsurface data and climate projections through the use of LADM Part 5 climate adaptation profile classes. The current paper continues the testing phase, presenting the revised profile and a second implementation. This implementation showcase the integration of Dutch geological models in 3D LA systems. This second implementation aims to demonstrate the profile's utility in integrating subsurface data into 3D digital twins.

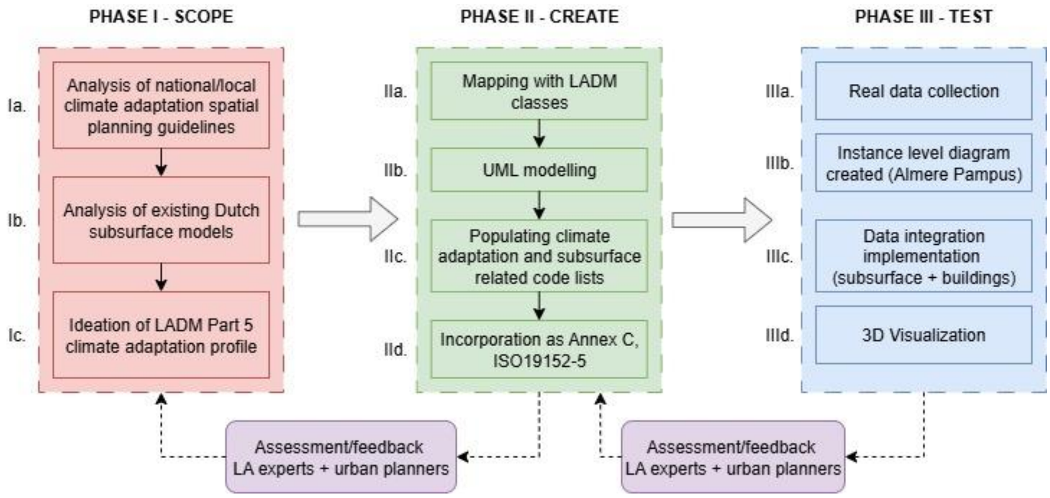


**Figure 1.** Development of LADM climate adaptation profile, adapted from Kalogianni et al. (2021)

### 3.2 LADM climate adaptation profile evaluation

Literature shows that involving stakeholders in the process of the LADM profile design, development and implementation is crucial for the acceptance of results (Kalogianni et al. 2021). For this reason, spatial planners were involved in the development of the LADM Part 5 climate adaptation profile. During interviews conducted with planners from two Dutch urban design offices in 2024, the challenges on integrating subsurface into spatial planning were described and feedback on the LADM climate adaptation profile was given. The integral results of these interviews are published in a separate paper (Kawasaki et al. 2025). The feedback received was crucial for the the revised profile, therefore a summary of key findings is presented.

The first theme that emerged was the need for better integration with external data sources, such as geological and hydrological models, and climate projections. The interviewees expressed a desire for a more structured approach to integrate these sources, facilitating their use. This is because while existing platforms provide valuable data, designers must still combine multiple sources to obtain comprehensive subsurface information. In this context, designers expressed that 'the idea of interlinking things together is very useful' (Kawasaki et al. 2025). The revised profile's external classes is designed to facilitate this data integration.

Secondly, the importance of data traceability emerged. Designers emphasized that while exact values are important, understanding the source of the data is equally critical for decision-making. Interviewed designers defined that 'in plan information, that would mean adding the source of this data inside of a database' (Kawasaki et al. 2025). This feedback aligns with the capabilities of the revised profile through the use of LA_Source class, which enables the storage of any kind of source information, ensuring traceability of data within the Spatial Information Infrastructure (SII) or Spatial Data Infrastructure (SDI) (Lemmen 2015). This functionality allows urban planners to trace the origins of the data, verify its accuracy, and assess its relevance, fostering confidence in informed decisions.

The third key theme from the feedback was the need for flexibility. The interviewees expressed a desire for an adaptable framework that could be tailored to specific planning needs, allowing for customization based on local conditions and project requirements. This feedback aligns with the LADM Part 5 profile's design principles. The profile is designed to be customizable, by for example adding new external sources or extending CodeLists, while maintaining a structured approach to data integration and plan information exchange.

## 4 REVISED LADM CLIMATE ADAPTATION PROFILE

The LADM Part 5 climate adaptation profile was introduced in 2024. Subsequently, the profile was tested and received feedback from spatial planners which led to the profile's revision. The following subsections provide a detailed description of the revised profile, including its core LADM Part 5 structure, key classes, and how it addresses the received feedback. The revised profile is shown in figure 2. Key modifications are:

– Inclusion of **external classes** to facilitate integration with external data sources, such as geological and hydrological models, and climate projections. Initially the profile only included classes for subsurface and climate related data, but the feedback highlighted the need for better integration with external data sources.
– Association of the **LA_Source** class to external classes to meet spatial planners' requests for data traceability. This class allows planners to track the origin and lineage of plan information, but also external sources, enhancing traceability.
– Attention to mantain certain **flexibility** to accommodate diverse planning contexts and requirements, as requested by planners. The revised profile is designed to stay adaptable to different planning contexts, allowing planners to customize the profile to their specific needs.

### 4.1 LADM Part 5 as core structure

The Spatial Plan Information Package (LADM Part 5) extends core LADM classes from the Party, Administrative, and Spatial Units packages, incorporating boundary faces, boundary face strings, and spatial units, and introduces new classes, SP_PlanGroup, SP_PlanUnitGroup, SP_PlanBlock, SP_PlanUnit, and SP_Permit, to model zoning, planned land use, and associated Rights, Restrictions, and Responsibilities (RRRs) (Indrajit et al. 2020, ISO 2024a). The LADM Part 5 climate adaptation profile is based on the fundamental idea that a structured framework for sharing plan information, such as LADM Part 5, can also enhance the national and international creation and exchange of climate resilient plan information.

For this purpose, the specialized profile for climate adaptation (CLIMA) inherits the attributes of the LADM Part 5 classes while integrating additional attributes tailored for climate adaptation design and external classes related to identified data needs. This generic profile thus refines LADM Part 5 for a specific scope, climate adaptation, which has global relevance. This is the main reason for presenting a generic profile instead of only a country-specific one, allowing it to serve as a basis in different countries.

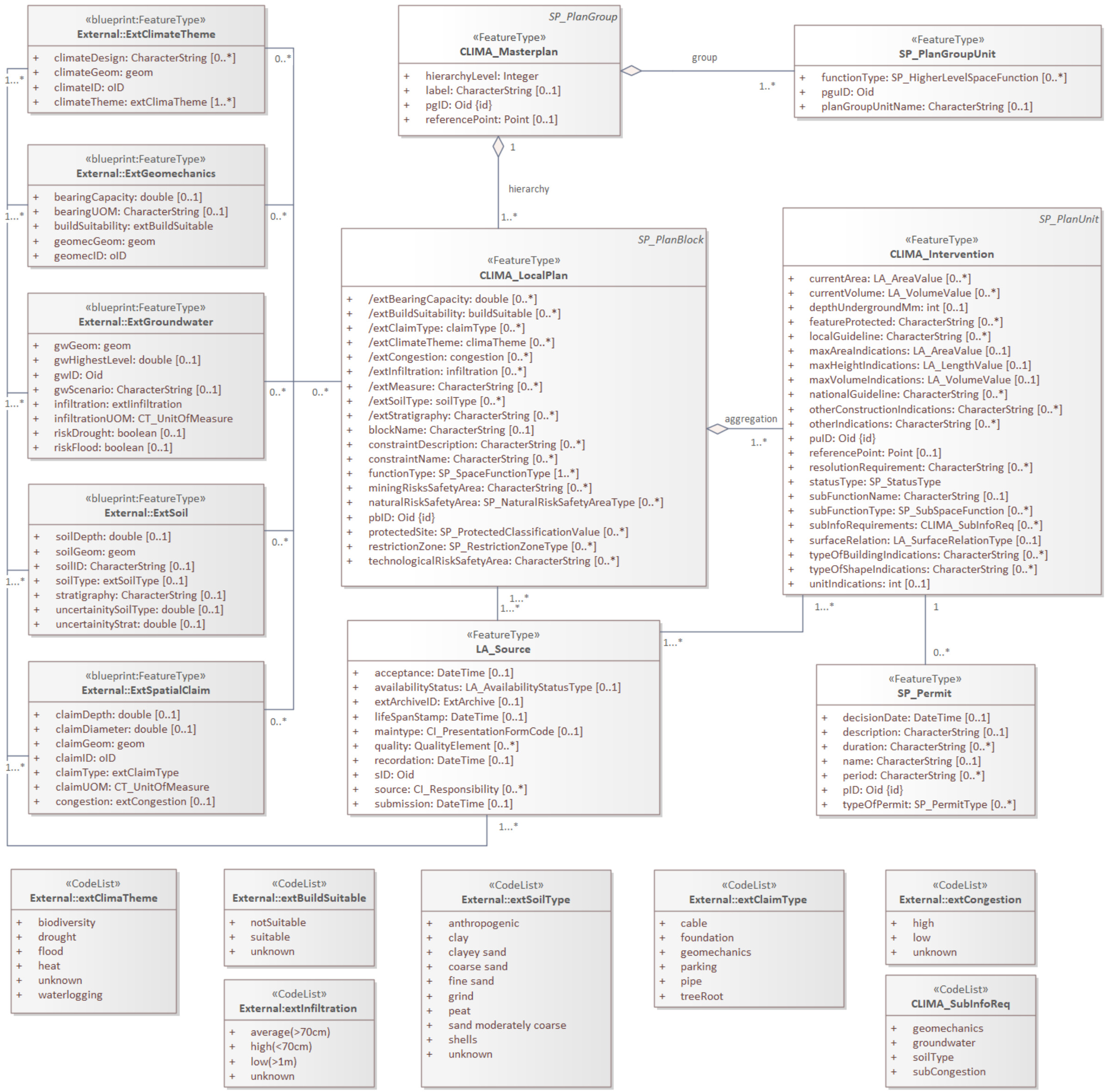


**Figure 2.** Revised LADM Part 5 climate adaptation profile

The profile's classes and subclasses adhere to Part 5 of ISO 19152 LADM and are based on the LADM core, including Party, RRR, BAUnit, SpatialUnit, 2D/3D representations (from ISO 19107), and VersionedObject. The LADM Spatial Plan package comprises fundamental classes such as plan groups, plan blocks, plan units, and permits.

A plan group in the LADM represents an administrative hierarchy that organizes spatial plans. Higher-level plans, such as a national, provincial or regional spatial plans, guide and encompass more detailed lower-level plans, like a masterplan, a model of local urban plan in the Netherlands, in which the form and function of buildings and the design of public space are combined in one integrated proposal. For climate adaptation design, this hierarchy is crucial for aligning various planning levels. The attributes of the SP_PlanGroup class include: the plan group identifier (pgID), hierarchy level (hierarchyLevel), hierarchy name (label), and a reference point (referencePoint). The CLIMA_PlanGroup subclass inherits these attributes.

The subclass also associates information to LA_Party and LA_Source to indicate the responsible party and the source of the plan as approved by the relevant authority.
A plan block consists of a set of plan units decided or approved by authorities. The SP_PlanBlock class includes attributes such as an identifier (pbID), block name (blockName), planned function type (functionType), protected zone type (protectedSite), and natural risk areas (naturalRiskSafetyArea). For climate adaptation design, additional attributes are introduced to store climate themes and subsurface characteristics, which are derived from external classes. In this case, external classes are used to represent subsurface and climate adaptation data sources, encompassing attributes such as soil type, groundwater levels, and other subsurface and climate related aspects. These datasets, which are typically maintained by specialized institutions, provide essential information for climate resilient land administration. Subsection 4.2 provides a detailed overview of the profile's external classes.
A plan unit represents the smallest planning unit. The SP_PlanUnit class includes attributes like an identifier (puID), plan unit description (subFunctionType, subFunctionName), volume, area, height, status (statusType), and surface relationship (surfaceRelation). For climate adaptation, new attributes were added to capture subsurface requirements (subInfoRequirements), required depth (depthUndergroundMm), resolution needs, and relevant guidelines. The subInfoRequirements attribute includes a CodeList for key subsurface properties such as soil type, groundwater level, subsurface congestion, and geomechanics. These can be used as a guideline to identify which external sources are needed. Moreover, LADM Part 5 supports permit registration linked to plan units. The SP_Permit class handles permit-related information for zero or more plan units. Its inclusion facilitates integrating permit information into climate adaptation designs.

### 4.2 External classes and data integration

Climate adaptation in spatial planning benefits from the integration of information from external sources, such as geological models, and climate projections. In LA, this would mean having attributes such as soil type, groundwater levels, and other subsurface and climate-related conditions. These datasets, which are typically maintained by external specialized agencies or institutions, provide essential information for climate resilient land administration. In the LADM climate adaptation profile, these attributes are derived from external classes. In the context of LADM, external classes refer to information models that exist outside the core LADM framework but are linked, within the Spatial Information Infrastructure (SII), to ensure interoperability with external datasets and domain-specific information. There are five external classes in the profile, one for climate projections and four for each of the subsurface characteristics described in section 2.

- **External::ExtClimateTheme**: Includes attributes such as climateTheme (categorizes climate risks like flooding, heat stress, drought; CodeList extClimaTheme) and climateDesign (adaptation design measures). Essential for evaluating climate impacts and informing adaptation strategies.
- **External::ExtGeomechanics**: Captures geotechnical data for building suitability. Key attributes: bearingCapacity (soil's bearing capacity) and Suitability (construction suitability; CodeList extBuildSuitable).

– **External::ExtGroundwater**: Offers data on groundwater conditions: gwHighestLevel (highest groundwater level), infiltration (infiltration capacity), riskDrought/riskFlood (Boolean for drought/flood risk), and gwScenario (climate change groundwater scenarios).
– **External::ExtSoil**: Contains attributes such as soilType, stratigraphy, and uncertainty (degree of uncertainty in soil type and stratigraphy classification).
– **External::ExtSpatialClaim**: Data on underground spatial claims (e.g. infrastructure). Include attributes such as claimType and congestion level (e.g. high due to cables).

For information models where the unit of measure (UOM) is significant, the attribute UOM is included. This attribute employs CT_UnitOfMeasure, a data type defined in ISO 19103 by ISO/TC 211, which provides a framework for specifying units of measurement within geographic information systems (ISO 2024b). Additionally, external classes can include geolocated 3D or 2D geoemtry as an attribute. This is particularly important for overlaying external data with existing land administration data, ensuring that the subsurface and climate-related information can be accurately integrated into spatial plans.

### 4.3 LA Source and data traceability

One of the key pieces of feedback from spatial planners was the need for better data traceability. The revised LADM Part 5 climate adaptation profile addresses this by explicitly using the LA_Source class in the profile. LA_Source is an abstract class that represents any documentary or evidentiary origin of data in LADM (ISO 2012). In the context of the LADM Part 5 climate adaptation profile, this covers the sources of both standardized plan information and external datasets regarding subsurface and other related data. According to ISO (2012), a distinction is made between two main categories of sources: LA_AdministrativeSource and LA_SpatialSource, both of which are relevant to the Part 5 climate adaptation specialization.
A spatial source provides the spatial representation of one or more spatial units (ISO 2012). In the specialization profile, spatial sources link spatial representations (e.g. climate projection maps) to the relevant external classes. In LADM Edition II, LA_SpatialSource is further specialized into LA_SurveySource and LA_DesignSource (Kara et al. 2024). This is relevant for the specialization profile because climate-adaptation inputs may originate from surveying techniques (e.g. borehole measurements) but also from design-based interventions (e.g. climate-adaptive design solutions). Moreover, an administrative source provides the administrative description of the parties involved, the rights, restrictions and responsibilities created, and the basic administrative units affected. This is relevant for the overall spatial plan, but also for climate resilience in areas designated for specific adaptation measures.
Additionally, ISO (2012) notes that 'any kind of document may be added as a source according to ISO 19115'. Accordingly, any relevant source, such as a report or scientific article, can be linked to the external class through LA_Source. In LADM Edition II, the VersionedObject–LA_Source association means source instances can be versioned (Kara et al. 2024), allowing planners to track how data sources change over time. This is crucial for climate adaptation workflows as new research emerges.

### 4.4 Flexibility and structure

The revised LADM Part 5 climate adaptation profile is designed to be a structured framework but to remain adaptable to different planning contexts. This flexibility is achieved through the use of external classes and the LA_Source class, which can accommodate various subsurface and climate-related data sources, including from different international contexts. Planners can choose which external classes to include in their spatial plans based on their specific requirements and availablity of data. Additionally, CodeLists are expandable, making the profi'e's classes expandable. Therefore the profile is designed to be rather generic, allowing planners to adapt the classes as needed and to accommodate emerging data sources around the globe while still being within the same framework. This ensures that the profile can evolve over time to meet land administration needs in a rapidly changing environment, supporting climate resilience, a challenge that is global and does not concern the Netherlands exclusively.

## 5 LADM CLIMATE ADAPTATION PROFILE IMPLEMENTATION

The revised LADM Part 5 climate adaptation profile has been implemented in two different contexts to demonstrate its practical applications. The first implementation focuses on subsurface assessment in the masterplan phase, while the second implementation explores the integration of geological information in 3D city models. These implementations showcase the profile's versatility and its ability to address real-world planning scenarios.

### 5.1 Subsurface assessment in masterplan phase using LADM Part 5 CLIMA

The first implementation of the LADM climate adaptation profile using real plan information was done using a masterplan for Almere Pampus, a new urban development project in the Netherlands. The masterplan aims to create a sustainable and climate-resilient urban environment, incorporating subsurface data to guide design decisions. In this example, the profile's external classes correspond to external data sources used by planners, such as a geological model for soil information. An instance level diagram is presented in figure 3, showcasing the use of the profile in a cadastral parcel in Almere. For a full description of the instance diagram, the reader can refer to Kawasaki et al. (2025).

The models and datasets used for the creation of this masterplan, represented as external classes in the diagram, are discussed in a public document with meeting notes (Gemeente Almere and Rijksvastgoedbedrijf 2024). For example, this document states that the climate scenario from the Royal Netherlands Meteorological Institute (KNMI) (Koninklijk Nederlands Meteorologisch Instituut 2023) was used as the basis for assessing climate-related themes (Gemeente Almere and Rijksvastgoedbedrijf 2024). Consequently, climate related attributes are linked to this model through the external class ExtClimateTheme.

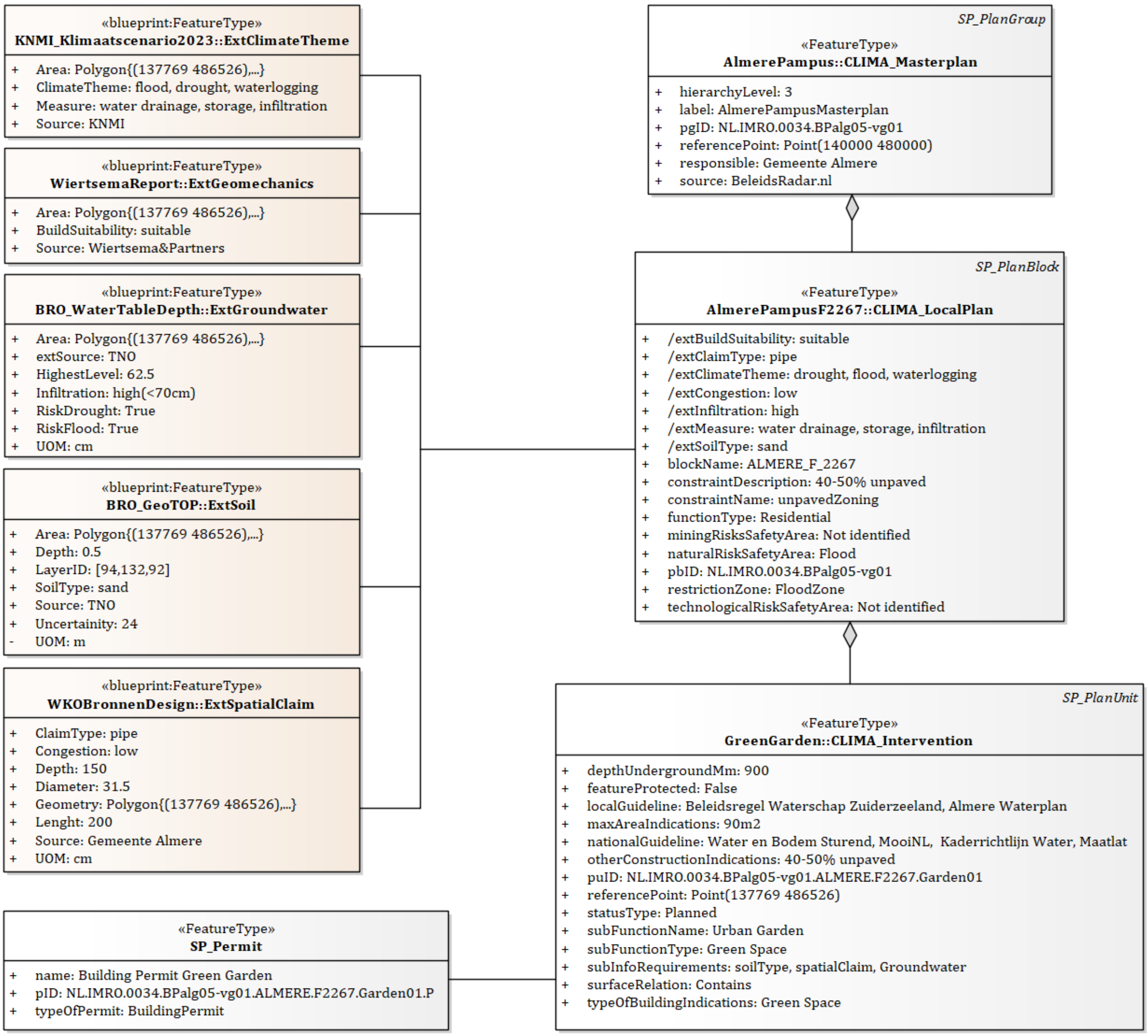


**Figure 3.** Instance diagram of masterplan using LADM Part 5 climate adaptation profile

Regarding the subsurface, the same document states that groundwater attributes were assessed using the BRO Water Table Depth Model 2023-02 (TNO Geologische Dienst Nederland 2023, Gemeente Almere and Rijksvastgoedbedrijf 2024), so the attributes from this model are associated with the external class ExtGroundwater. In a similar manner, soil information used was obtained from GeoTOP (Basisregistratie Ondergrond (BRO) 2023, Gemeente Almere and Rijksvastgoedbedrijf 2024), which is associated with the external class ExtSoil.

### 5.2 Integration of geological information in 3D city models using LADM Part 5 CLIMA

The second implementation of the LADM climate adaptation profile focuses on the integration of geological data in 3D LA systems. The goal is to integrate relevant subsurface data from a geological model, GeoTOP, into an existing 3D city model, 3D BAG, enhancing the plan information with subsurface characteristics, while mantaining the original 3D geometry of the city model. This builds on top of well known 3D capabilities of LADM, supporting projects that both visualize and query 3D properties (Kara et al. 2024).

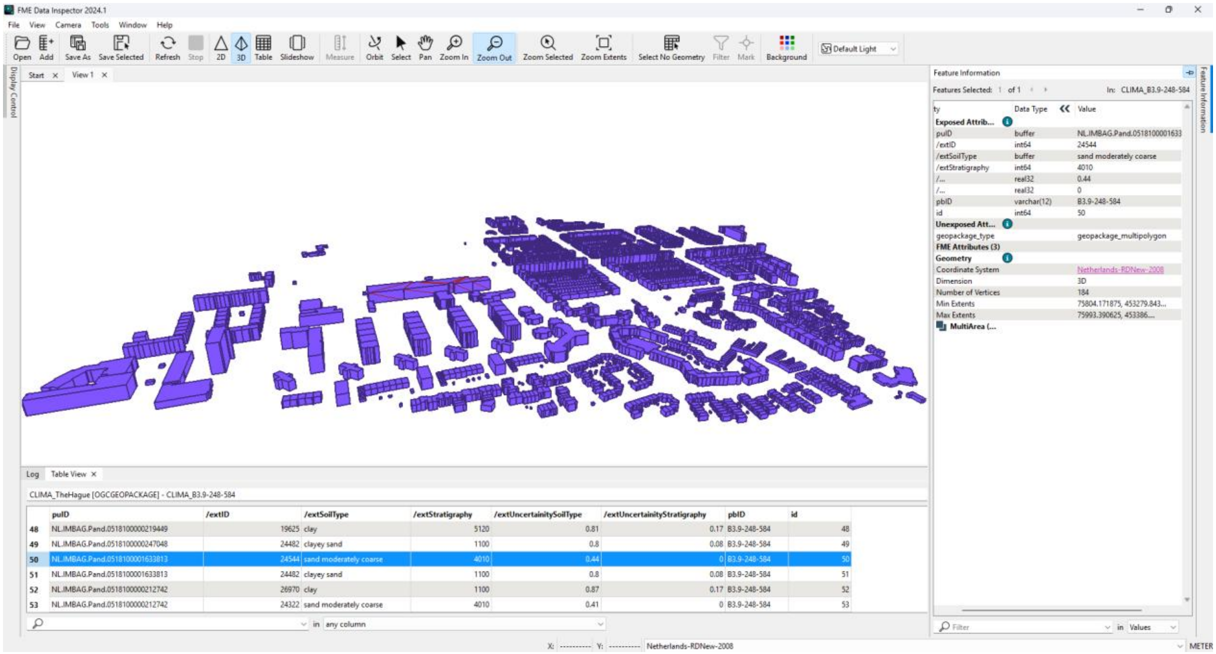


**Figure 4.** City model with subsurface data from external geological model

The integration process was carried out using FME (Feature Manipulation Engine) software, which is widely used for data integration and transformation in the geospatial domain (Safe Software 2025). The geological model used, GeoTOP, is a 3D voxel model of the Netherlands that provides detailed information about subsurface conditions, such as lithographical and litological classes (Basisregistratie Ondergrond (BRO) 2023). The city model used, 3D BAG (Peters et al. 2022), is a regularly updated dataset of 3D buildings for the Netherlands, generated by combining two national open datasets, Basisregistratie Adressen en Gebouwen (BAG) (Kadaster 2025) and Actueel Hoogtebestand Nederland (AHN) (Waterschappen 2025). BAG (Basic Registration of Addresses and Buildings in Dutch) provides the authoritative building footprints and address attributes, while AHN (Current Elevation File Netherlands in Dutch) supplies high-resolution elevation data from LiDAR to shape the 3D geometry. For the implementation, a selected area of these national models was used, in the city of The Hague.

Using FME, GeoTOP and 3D BAG were overlayed and relevant attributes were extracted from both models where an overlap occured. This means that a spatial overlay was performed to associate buildings from 3D BAG (with their relavant plan information attributes) to geological attributes such as soil type (lithological class) and stratigraphy. Subsequently, the combined attributes from both models were mapped to the corresponding classes and attributes in the LADM Part 5 climate adaptation specialization profile. This mapping ensured that the integrated model adhered to the structure and semantics defined in the LADM profile, facilitating interoperability and data exchange within LADM. The final step involved writing this combination to a new dataset, in this case an OGC geopackage (Open Geospatial Consortium 2024). This dataset, as seen in figure 4, contains both building and subsurface attributes, making subsurface information that is relevant for climate adaptation (soil type) integrated into the 3D city model.

## 6 DISCUSSION AND CONCLUSION

The revised LADM Part 5 climate adaptation profile represents a significant advancement in integrating subsurface data into land administration systems for climate-resilient spatial planning. The profile's development was driven by the need to address specific challenges faced by urban planners, including the integration of external data sources, data traceability, and flexibility to accommodate diverse planning contexts.

The revised profile's incorporation of external classes and the LA_Source class enhances its ability to integrate critical subsurface and climate-related information, ensuring that planners can make informed decisions based on comprehensive and reliable data. The profile's flexibility allows it to be adapted to various planning scenarios, making it a valuable tool for planners worldwide. The practical applications of the profile, demonstrated through its implementation in the Almere Pampus masterplan and the integration of geological information in the 3D BAG The Hague city model, showcase its utility in real-world scenarios. These implementations highlight the profile's potential to support climate-resilient urban design practices and facilitate data exchange and integration in land administration systems. Overall, the revised LADM Part 5 climate adaptation profile provides a robust framework for integrating subsurface data into spatial planning, supporting the development and exchange of climate resilient spatial plans.

## 7 FUTURE WORK

The testing phase of the LADM Part 5 climate adaptation profile is still ongoing. The profile has been implemented in two different contexts, as presented in the previous section, but further testing and validation are needed to ensure its effectiveness and usability in various scenarios. Future work could involve additional implementations of the profile in different urban planning contexts or using different datasets. For example, future research could include the implementation of the specialization profile using different standards for 3D plan information. Previous research have shown the compatibility between LADM and CityGML, particularly in the context of 3D land administration (Sun et al. 2019). The CityGML-LADM combined models could use existing CityGML plan information, as it is already available for many municipalities globally, and add LADM climate adaptation information to it, potentially focusing on integrating subsurface data relevant to climate adaptation to the existing city model. This would involve mapping the LADM Part 5 classes to the corresponding CityGML classes. Classes such as CLIMA_PlanGroup, CLIMA_PlanBlock, and CLIMA_PlanUnit, could be mapped to CityGML classes like CityModel, CityObjectGroup, and Building respectively, similar to the work done by Sun et al. (2019). This would ensure that the spatial relationships and LADM attributes are preserved in the CityGML model.

Moreover, the profile is designed to be adaptable to worldwide contexts, but it has been developed and tested initially in the Netherlands. Future work could involve testing the profile in different countries to assess its applicability and effectiveness in various planning contexts. This could include collaborations with urban planners and land administration experts from different countries to gather feedback and insights on the profile's usability and relevance globally. This will aid spatial plans that are resistent to a global challenge, climate change.

## REFERENCES


Basisregistratie Ondergrond (BRO) (2023). Geotop (gtm) - 3d-model van de ondiepe ondergrond van nederland. https://basisregistratieondergrond.nl/inhoud-bro/registratieobjecten/ modellen/geotop-gtm/. Accessed: 2025-07-16.

Deltares (2020). Urban infiltration opportunities. Klimaateffectatlas.

European Commission (2025). Nature-based solutions. Accessed: 2025-08-15.

Gemeente Almere and Rijksvastgoedbedrijf (2024). Masterplan almere pampus: Ruimtelijke strategische verkenning. Technical report, Gemeente Almere. Bijlage I: Notities Masterplan Almere Pampus.

Harbers, M. and Heijnen, V. (2022). Water en bodem sturend. Kamerbrief, Ministerie van Infrastructuur en Waterstaat.

Indrajit, A., van Loenen, B., Ploeger, H., and van Oosterom, P. (2020). Developing a spatial planning information package in iso 19152 land administration domain model. Land Use Policy, pages 104–111.

ISO (2012). Geographic information — land administration domain model (ladm). Confirmed in 2024. Covers parties, administrative units, rights, responsibilities, restrictions, spatial units, sources, and representations.

ISO (2024a). Geographic information – land administration domain model (ladm) – part 5: Spatial plan information. Final Draft International Standard, Accessed: 2025-05-28.

ISO (2024b). ISO 19103:2024 Geographic information — Conceptual schema language.

Kadaster (2025). Basisregistratie Adressen en Gebouwen (BAG). Dataset landing page on PDOK; service updated daily.

Kalogianni, E., Janecka, K., Kalantari, M., Dimopoulou, E., Bydłosz, J., Radulovi ˇ c, A., Vu ´ ciˇ c, N., Sladi ´ c, D., ´ Govedarica, M., Lemmen, C., and van Oosterom, P. (2021). Methodology for the development of ladm country profiles. Land Use Policy, 105:105380.

Kara, A., Lemmen, C., van Oosterom, P., Kalogianni, E., Alattas, A., and Indrajit, A. (2024). Design of the new structure and capabilities of ladm edition ii including 3d aspects. Land Use Policy, 137:107003.

Kawasaki, M. L. T. (2024). Common ground: Bridging subsurface information models and climate adaptation design. Master’s thesis, Delft University of Technology. Faculty of Architecture and the Built Environment.

Kawasaki, M. L. T., Thomas, L., Hackauf, U., van der Krogt, R., Visser, W., and van Oosterom, P. (2025). Integrating subsurface data into urban planning for climate adaptation using land administration domain model part 5. Survey Review, 0(0):1–16. 15

Koninklijk Nederlands Meteorologisch Instituut (2023). KNMI national climate scenarios 2023 for the netherlands. Climate scenarios, De Bilt, Netherlands.

Lemmen, C. (2015). The land administration domain model. Land Use Policy, 49:535–545.

Open Geospatial Consortium (2024). Ogc® geopackage encoding standard. OGC Standard 12-128r19, Open Geospatial Consortium.

Peters, R., Dukai, B., Vitalis, S., van Liempt, J., and Stoter, J. (2022). Automated 3d reconstruction of lod2 and lod1 models for all 10 million buildings of the netherlands.

PosadMaxwan. (2023). Nature Based City of Almere — Development Plan 2040.

Radulovic, A., Sladi ´ c, D., Govedarica, M., Risti ´ c, A., and Jovanovi ´ c, D. (2019). LADM based utility network cadastre in serbia. ISPRS International Journal of Geo-Information, 8(5).

Rijksoverheid (2020). Klimaatadaptatie maatregelen. Infographics RVO.

Safe Software (2025). Fme by safe software: The all-data platform.

Sun, J., Mi, S., Olsson, P.-O., Paulsson, J., and Harrie, L. (2019). Utilizing BIM and GIS for representation and visualization of 3D cadastre. ISPRS International Journal of Geo-Information, 8:503.

TNO Geologische Dienst Nederland (2023). Bro water table depth model 2023-02.

Volchko, Y., Norrman, J., Ericsson, L., Nilsson, K., Markstedt, A., Öberg, M., Mossmark, F., Bobylev, N., and Tengborg, P. (2020). Subsurface planning: Towards a common understanding of the subsurface as a multifunctional resource. Land Use Policy, 90:104316.

Waterschappen, R. P. (2025). Actueel hoogtebestand nederland (AHN). National elevation dataset (DSM/DTM) distributed via PDOK.

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**Rob van der Krogt** is a Senior Project Manager at TNO Geological Survey of the Netherlands. Throughout his 30 year career, he conducted many interdisciplinary projects involving geoscience data and information, spatial planning, and infrastructure. His main clients are public boards at national, regional, and local levels and European research programs. He has a key role in the national database for the subsurface, which Dutch government bodies are legally obliged to use for certain policies and decisions, and he is project lead for the 3D transformation of this system.

**Wilfred Visser** is a Senior Researcher at TNO Geological Survey of the Netherlands. He has a background in computer science and software development. Working at TNO for over 25 years in the field of acquisition and processing of geoscientific data and information. His knowledge lies in handling large amounts of data, such as seismic sensors but also Distributed Acoustic Sensing (DAS) and InSAR. Also involved in developing subsurface models, such as GeoTOP 3D, a detailed three-dimensional model of the upper 30 to 50 m of the subsurface ofthe Netherlands and REGIS II 3D a hydrogeological subsurface model of the Netherlands. His main clients are other TNO research institutes, universities and the government in advising on the application of Geo Data and information.

**Peter van Oosterom** obtained an MSc in Technical Computer Science in 1985 from Delft University of Technology, the Netherlands. In 1990 he received a PhD from Leiden University. From 1985 until 1995 he worked at the TNO Physics and Electronics laboratory in The Hague. From 1995 until 2000 he was senior information manager at the Dutch Cadastre, where he was involved in the renewal of the Cadastral database. Since 2000, he is Professor at Delft University of Technology, and chair GIS Technology, Digital Technologies Section, Faculty of Architecture and the Built Environment, Delft University of Technology, the Netherlands. He is the current chair of the FIG Working Group on 'LADM and 3D Land Administration' and co-editor of the International Standard for Land Administration Domain, ISO 19152.

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