Survey Review

ISSN: 0039-6265 (Print) 1752-2706 (Online) Journal homepage: www.tandfonline.com/journals/ysre20

Integrating subsurface data into urban planning for climate adaptation using land administration domain model part 5

Maria Luisa Tarozzo Kawasaki, Laura Thomas, Ulf Hackauf, Rob van der Krogt, Wilfred Visser & Peter van Oosterom

To cite this article: Maria Luisa Tarozzo Kawasaki, Laura Thomas, Ulf Hackauf, Rob van der Krogt, Wilfred Visser & Peter van Oosterom (03 Aug 2025): Integrating subsurface data into urban planning for climate adaptation using land administration domain model part 5, Survey Review, DOI: 10.1080/00396265.2025.2539606

To link to this article: https://doi.org/10.1080/00396265.2025.2539606

Published online: 03 Aug 2025.

Integrating subsurface data into urban planning for climate adaptation using land administration domain model part 5

Maria Luisa Tarozzo Kawasaki[a]*, Laura Thomas[b], Ulf Hackauf[b], Rob van der Krogt[a], Wilfred Visser[a] and Peter van Oosterom[b]

In 2022, the Netherlands introduced ‘water and soil’ as a guiding principle for spatial planning, aiding the country’s goal for climate resilience by 2050. Applying it requires integrating subsurface data, spatial planning, and climate adaptation. Despite existing subsurface models, no cohesive approach links them to spatial planning. This paper assesses current models and identifies data requirements. Key barriers include data accessibility and standardization. To address this, plan information was standardized using a proposed Land Administration Domain Model (LADM) Part 5 climate adaptation profile. Additionally, a digital tool, CLIMACAT, was developed to make relevant subsurface data accessible for climate adaptation design.

KEYWORDS: Land Administration, Subsurface Data, Climate Adaptation, Spatial Planning, Urban Design, Spatial Information Model, Geodata

1. Introduction

The introduction in 2022 of water and soil as guiding principles in Dutch urban planning (Harbers and Heijnen, 2022) highlights the need for subsurface information. Understanding soil composition, groundwater dynamics, and land stability is essential for making informed design decisions, influencing the feasibility of construction, and long-term land use (Volchko *et al.*, 2020). Knowledge of soil and groundwater also facilitates a natural approach when adapting to climate-related urban challenges, such as heat, drought, and heavy rain (Hooimeijer and Maring, 2018). Therefore, integrating subsurface data into planning processes is crucial, particularly as the Netherlands works towards climate resilience and water robustness by 2050 (Government of the Netherlands, 2023). However, although the Netherlands has multiple subsurface data models, integrating these into urban planning remains a challenge. Interviews revealed that the main barriers to effectively incorporating subsurface data into spatial planning were the lack of a unified approach, data accessibility, and insufficient knowledge among designers on how to efficiently use this data in spatial planning (Norkunaite and Chevtchenko, 2025; van Spaandonk, 2025). Thus, this paper explores how structured data frameworks can enhance climate-adaptive spatial planning by bridging the gap between subsurface data and urban design, ensuring that subsurface constraints and opportunities are effectively incorporated into decision-making.

The paper introduces CLIMACAT, a developed online portal that consolidates subsurface and climate adaptation design information. Moreover, the paper exemplifies the storage and exchange of climate adaptation plan information using the ISO 19152 Land Administration Domain Model (LADM) Part 5. Within this standard, the paper proposes attributes and external classes tailored for climate adaptation interventions and the use of subsurface data sources in spatial planning. The goal is to develop a framework for integrating standardized subsurface information into climate adaptation efforts, addressing a global challenge in urban planning and land administration. The proposed LADM Part 5 Spatial Plan Information CLIMA specialization has been designed with a generic structure and is expected to be applicable in various countries, as climate resilience is a global challenge. The proposed LADM climate specialization profile will be incorporated into Annex C of the latest version of ISO 19152 Part 5. As with other components of LADM, Part 5 requires individual countries to develop their own national profiles by adapting and incorporating country-specific information. For countries intending to integrate climate adaptation into their spatial planning frameworks, it is recommended to start with the paper’s proposed LADM Part 5 climate adaptation generic profile and subsequently tailor it to their specific

[a]GeoData & Information Management Department, TNO, Princetonlaan 6, Utrecht, The Netherlands
[b]Faculty of Architecture and the Built Environment, TU Delft, Delft, The Netherlands

*Corresponding author. Email: maria_luisa.tarozzokawasaki@tno.nl

Received 29 March 2025; accepted 21 July 2025
DOI 10.1080/00396265.2025.2539606

national contexts. To illustrate the application of this profile in a country-specific context, the paper includes an example diagram showcasing real plan information from the Dutch city of Almere, standardized using the proposed LADM climate specialization profile. This work contributes to various Sustainable Development Goals (SDG's), especially relevant are the SDG's 11 (Sustainable cities and communities) and 13 (Climate action) (United Nations, 2023).

Section 2 outlines the paper's methodology. Section 3 examines the role of subsurface data in spatial planning for climate adaptation, using literature and interviews. Section 4 reviews existing subsurface models based on data needs, while Section 5 discusses data integration challenges. Section 6 introduces CLIMACAT, an online portal integrating data sources. Section 7 presents the LADM climate adaptation profile and a Dutch example. Section 8 evaluates the approach based on planners' feedback, and Section 9 concludes, with Section 10 suggesting future research directions.

2. Methodology

This research used a multi-stage methodology to bridge the gap between subsurface data availability and its practical application in climate-adaptive spatial planning, executed through the following steps:

(1) **Problem Definition and Requirements Analysis**: This foundational stage established the research context and defined the needs for integrating subsurface data into climate-adaptive urban planning, achieved through:

- A literature review on the role of subsurface data in climate-adaptive spatial planning, focusing on Dutch policies and design guidelines (Section 3).
- Qualitative data collection through interviews with urban planners from two design offices to gather practical insights on subsurface data in spatial planning (Section 3).
- An analysis of relevant subsurface models based on the identified subsurface data needs in Dutch spatial planning (Section 4).
- An examination of prevailing data integration challenges identified during the interviews. (Section 5).

(2) **Framework Development**: Addressing the identified requirements, a core component of this research was the proposal of a structured framework for incorporating subsurface data into climate-adaptive spatial planning. This involved:

1 Developing a profile for the ISO 19152-5 LADM to integrate subsurface and climate adaptation information into standardized spatial plan information. This included defining attributes and potential external class linkages to external information sources (Section 7).
2 Developing an online portal consolidating climate adaptation design and subsurface information by hyperlinking different data sources and describing their use in spatial planning (Section 6).

(3) **Implementation Example**: To demonstrate the practical utility and application of the proposed framework, the methodology included:

- The application of the proposed LADM climate adaptation profile using a case study approach. Plan information from the Dutch city of Almere was standardized according to the developed profile, illustrating its feasibility and function in a specific national context (Section 7).

(4) **Qualitative Assessment**: The final methodological step involved evaluating the proposed framework and its potential impact. This was conducted through:

- Gathering qualitative feedback from interviewed urban planners regarding the developed LADM climate adaptation profile and design portal and analyzing it to assess the proposed combined framework (Section 8).

This integrated sequence, progressing from problem analysis to the development of the LADM profile and design portal, and then to practical demonstration and expert assessment, provides the methodological structure underpinning the contributions presented in this paper.

3. The role of subsurface data in urban planning

Traditionally, spatial planning has focused on surface-level considerations, often neglecting the critical impact of subsurface conditions on sustainable urban development. However, as cities face growing challenges related to infrastructure expansion, water management, and ecological balance, planners are beginning to incorporate subsurface data into their strategies. This data is related to both subsurface properties and functions. Subsurface property refers to a certain quality of the subsurface like soil structure. This can involve for example the presence of certain soil types, such as sand and clay. Different soil and water properties are suited to different functions, potentially guiding a planner's design. For example, planners must evaluate factors like soil load-bearing capacity, because soft ground cannot support new structures. Groundwater levels also require attention. Excessively low levels can contribute to subsidence (Climate Adaptation Services, 2021), whereas high levels may foster moisture problems and related health risks such as mold (Chen and Hu, 2004). Consequently, a clear understanding of local soil and groundwater conditions facilitates better decision-making.

In 2022, the Netherlands established 'soil and water' as key guiding principles for sustainable spatial planning (Harbers and Heijnen, 2022). And while some argue that this guiding principle requires a broader perspective (de Rooij *et al.*, 2023), certain Dutch municipalities start incorporating subsurface and water considerations into their spatial planning. For example, the Municipality of Utrecht commissioned PosadMaxwan to inventory and visualize current and future spatial claims in the subsurface for their Vision on Subsurface 2040, aiming to integrate subsurface planning into broader strategic decision-making (Norkunaite and Chevtchenko, 2025). This recognition is also increasingly emerging from designers themselves, pushed by agendas that focus on including soil and water considerations in spatial planning and design. One example is PosadMaxwan's recent project for a vision for Almere center. In the coming years, fifteen thousand new housing units need to be added. In this project, subsurface information was used to guide decisions on where and how to develop it. As a design choice, densification in this project was not the goal in itself but something that must aligned 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 (Norkunaite and Chevtchenko, 2025). This project is shown in Figure 1.

These examples are not how traditionally the Netherlands was designed. Historically, Dutch spatial planning approach to urban development overlooked subsurface conditions, developing urban expansions by placing a thick layer of sand on top of the polder without considering long-term water management. These areas today face water management and subsidence issues, and the sand layer can be considered as a biodiversity desert. Urban planners are now exploring ways to solve soil and water issues and introduce biodiversity by, for instance, leveraging natural water fluctuations. This requires a detailed understanding of soil types, water systems, and vegetation compatibility. The use of subsurface information as a basis for urban planning is referred to as designing 'from the ground up'. This concept emphasizes incorporating subsurface information as an integral part of spatial planning rather than as an afterthought. For the purpose of gathering more information on the use of subsurface information in spatial planning by designing 'from the ground up', interviews were conducted in two different moments with urban design offices, namely PosadMaxwan and Bright. Interviewed designers stated that, while this approach does not fundamentally alter the design process, it expands the scope of analysis (Norkunaite and Chevtchenko, 2025). Understanding subsurface conditions allows for more informed and cost-effective decisions, such as planning buildings and their foundations. Since altering subsurface conditions is costly, integrating these factors early ensures urban projects align with natural and infrastructure constraints (Norkunaite and Chevtchenko, 2025).

Designing 'from the ground up' involves several key steps, described by the interviewed designers (van Spaandonk, 2025; Norkunaite and Chevtchenko, 2025). First, planners must gather and analyze data related to soil composition, groundwater levels, and climate projections. Next, subarea profiles are developed to categorize land based on soil and water dynamics, facilitating the identification of suitable interventions. Other topics of spatial planning are then integrated, such as mobility and public space allocation, ensuring a holistic approach to development. Then, project evaluation frameworks are established to measure whether planning objectives, such as sustainability targets, are met. Finally, the spatial plans are adopted by authorities.

Therefore incorporating subsurface data into spatial planning requires an iterative process where design and analysis can happen simultaneously (van Spaandonk, 2025), an approach known as 'research by design'. An example of this is the masterplan for Almere Pampus where subsurface data played a crucial role in shaping the project (Gemeente Almere and Rijksvastgoedbedrijf, 2024). The masterplan includes twenty-five to thirty-five thousand homes, at least sixteen thousand jobs, and all associated public and commercial facilities for healthcare, education, recreation, and daily shopping, meanwhile addressing energy, ecological and subsurface concerns. Soil and water data guided decisions on the city's layout, including water infiltration, open spaces, and energy stations (Gemeente Almere and Rijksvastgoedbedrijf, 2024; van Spaandonk, 2025). This is because some climate related vulnerabilities can be explained by soil characteristics. For example, clay-rich areas are more sensitive to waterlogging after heavy rainfall than sandy areas. And sandy areas are much more sensitive to drought than loamy areas (Climate Adaptation Services, 2021). The design, based on subsurface conditions, ensured minimal soil disturbance while leveraging soil properties to address urban challenges. The project emphasized collaboration among experts (van Spaandonk, 2025), using subsurface data to refine decisions. The final masterplan reflects the 'from the ground-up' approach. Due to the use of subsurface information during the entire spatial planning process, the paper standardizes information from this masterplan, using the proposed LADM climate adaptation profile, in Section 7.

3.1. Subsurface data and climate adaptation design

Effective climate adaptation involves nature-based solutions that rely heavily on subsurface and water information, such as soil types and groundwater levels (Timmermans, 2020; Hempelmann, 2022). For example, soil types significantly impact the feasibility of rainwater infiltration to address flooding or waterlogging. High-infiltration soils, like sandy types, are ideal for this

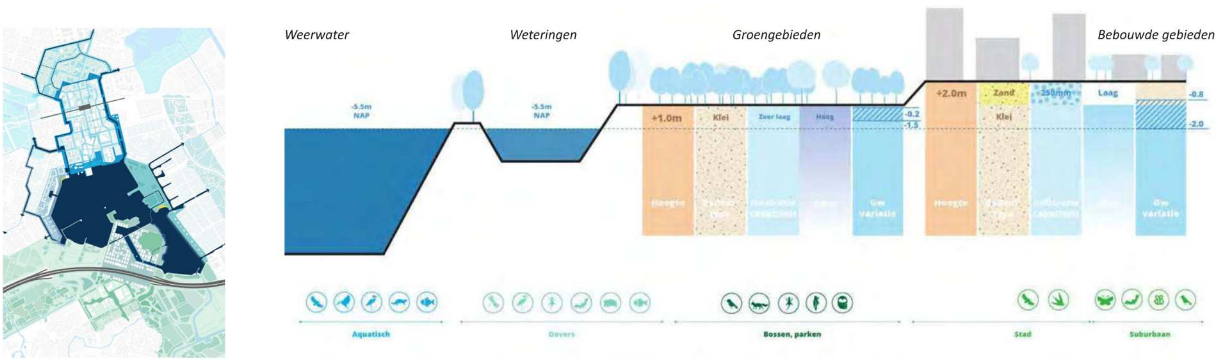


Figure 1. Plan and Section for Almere Vision. Water and soil guided design choices. (Source: PosadMaxwan).

purpose, while low-infiltration soils, such as clay or peat, are less suitable (Deltares, 2020). In urban areas, subsurface infrastructures for water, heat, electricity, and data can limit spatial adaptation interventions. Localized subsurface data, including soil maps, drilling profiles, and infrastructure details, are crucial for identifying viable climate adaptation strategies. Furthermore, assessing available subsurface space is vital, as obstructions like pipes are often only mapped locally. Climate adaptation design must incorporate these subsurface characteristics to effectively address challenges like flooding and heat stress. In 2020, the Dutch Ministry of the Interior and Kingdom Relations compiled a summary of twenty-five prevalent climate adaptation interventions, including associated costs and maintenance requirements (Rijksoverheid, 2020). However, this summary lacks information on subsurface properties. To bridge this gap, this paper examines these interventions to determine subsurface data requirements in spatial planning and assess existing data. The study used as a source the guidelines of the Leidraad Klimaatadaptief Bouwen 2.0 (Climate-Adaptive Building Guide 2.0 in English) (Bouwadaptief, 2022), which is publicly accessible through Bouwadaptief (Building Adaptive in English), an interactive website providing information for climate-adaptive construction, including regarding the twenty-five interventions. Compared to the Dutch government's 2020 document, this source offers more detailed insights into subsurface requirements. The findings of this study also informed the development of the proposed portal presented in Section 6, and LADM profile presented in Section 7. A comprehensive overview of these interventions and their relationship on different subsurface information can be found in Table 1. Six of the studied interventions, such as bat boxes, did not involve subsurface information and were therefore excluded from the overview. Based on these interventions, subsurface data needs are categorized into four main groups (see Figure 2):

- **Groundwater Level**: Infiltration capacity is higher when highest groundwater level is less than 70 cm below surface level (Deltares, 2020).
- **Spatial Claim**: The presence and density of subsurface natural or built elements, such as cables or tree roots, determine how much space is available for other interventions.
- **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).
- **Geomechanics**: This refers to the load-bearing capacity of the ground, which influences construction material and method choices.

Adaptation measures should be tailored to these subsurface properties. For example, sandy soils with low groundwater levels can better support rainwater infiltration through permeable pavements, while clay soils with high groundwater levels might be better suited for artificial water storage solutions, such as roof rain catchment systems combined with ground catchment tanks. Ultimately, incorporating subsurface knowledge into spatial planning is about making better-informed design decisions. This requires relevant and reliable subsurface data. The next section examines existing subsurface models, assessing their suitability in spatial planning.

4. Subsurface models assessment for urban planning

Four categories of subsurface information were identified as important for spatial planning, particularly in the context of climate adaptation design: soil type, spatial claim, geomechanics, and groundwater level (see Figure 2). These categories are derived from the subsurface data requirements identified in the analysis of twenty-five climate adaptation interventions recommended by the Dutch government (Rijksoverheid, 2020) (see Table 1). This section reviews existing subsurface models related to these four categories, assessing their relevance to spatial planning. While most models are available at the national level, the assessment also includes data at the

Table 1. Subsurface data needs for prevalent climate-adaptive interventions, derived from Leidraad Klimaatadaptief Bouwen 2.0, and grouped by groundwater level, soil type, geomechanics, and spatial claim.

Intervention	Groundwater Level	Soil Type	Geomechanics	Spatial Claim
Water Square	▮	–	–	▮
Permeable Pavement	▮	–	–	▮
Ground Level Elevation	–	▯	▮	–
(Natural) Wadis	▮	▮	–	▮
Façade Garden	–	–	–	▮
Soil Structure Improve	–	▮	–	–
Water Storage (Pavement)	–	–	–	▮
Shadow Routes	–	–	–	▮
Water Storage (Building)	–	–	–	▮
Cool Places	–	–	–	▮
Rural Waterways	▮	–	–	–
Natural Playground	–	▮	–	▯
Tree Planting	–	▮	▯	▮
Infiltration Crates/Wells	▮	▯	–	▮
Disconnected Downspout	–	▮	–	▯
Green Façade	–	–	▯	▮
Green Garden	–	–	–	▮
Green Fence	–	–	▯	▮
Surface Water	▮	–	–	▮

Note: Symbols: ▮ = high need, ▯ = low need, and – = no need.

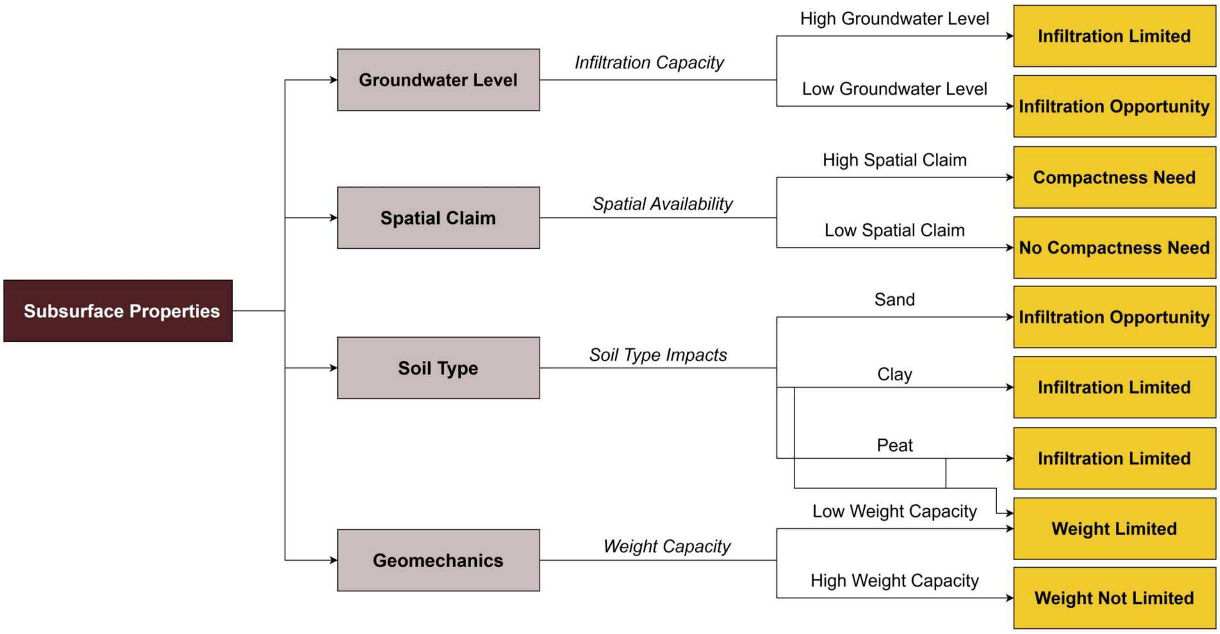


Figure 2. Decision tree for design interventions based on subsurface properties.

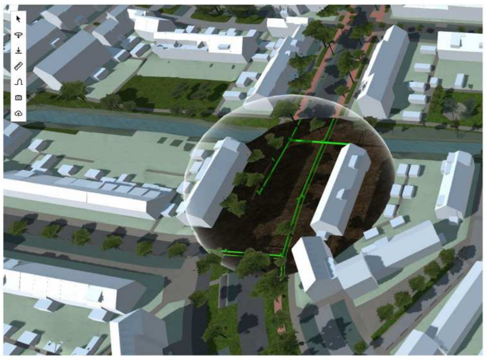
municipal and provincial levels, using the city of Utrecht as a case study.

Regarding soil type, GeoTOP is a national 3D model depicting subsurface layers up to fifty meters deep, represented in 100 × 100 × 0.5 meter voxel blocks containing geological and soil property data. It provides insights into soil types and is valuable for large-scale applications like infrastructure planning and groundwater research (Basisregistratie Ondergrond, 2023b). The existing resolution is sufficient for masterplan-level detail. For Almere Pampus, it provided enough data for an initial design and integration of soil information into spatial planning (van Spaandonk, 2025). Smaller resolutions of GeoTOP are available for some areas but may not be publicly accessible through BROloket or DINOloket. It's important to note that soil type models are probabilistic, based on interpolated data. GeoTOP, for instance, shows the likelihood of a soil type, related to its lithology and lithostratigraphy, for example sand, but in fact this is a probability of 85% sand and 15% clay. While starting with rough soil estimations, like GeoTOP data, is acceptable, the data can be refined as the design progress. For Almere Pampus, soil experts validated assumptions, and later drilling profiles either confirmed or challenged the insights (Gemeente Almere and Rijksvastgoedbedrijf, 2024). Adjustments to the masterplan based on new data were manageable (van Spaandonk, 2025).

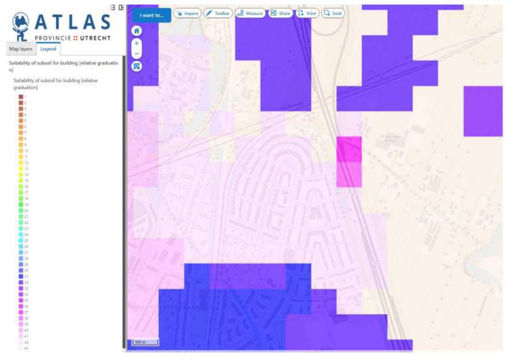
The 3D version of GeoTOP is accessible via the BRO 3D web services (TNO Geologische Dienst Nederland, 2023a), a platform that allows users to visualize and interpret soil voxels from selected locations using a provided legend. Additionally, users can create sections, rotate, and move the model, as can be seen in Figure 3(d). Users can also visualize GeoTOP by downloading SubsurfaceViewer (Niedersachsen Wasser, 2022), a dedicated software tool. Moreover, urban planners commonly work with 2D representations of GeoTOP by generating 2D cross-sections of the model. This approach was also used in the examples presented in this paper, where the interviewed designers analyzed soil layers through 2D sections. These sections were generated using DINOloket (TNO Geologische Dienst Nederland, 2025b), an online portal that provides public access to extensive national subsurface data.

For subsurface spatial claim, related to the available space underground for building new interventions, data is usually available on municipal level. For example, Utrecht's 3D digital twin includes subsurface elements such as cables and pipes, viewable through the municipality's web viewer (Gemeente Utrecht, n.d.). This model can support local design by making subsurface congestion visible. An example of the model being used for this purpose is shown in Figure 3(a). It is important to mention, however, that not every city has a digital twin. Additionally not every city has publicly available datasets of cables and pipes. Whenever these are not publicly available, planners can request the information of an area using the Kadaster KLIC national system, where the data is made available online for visualization and printing (Kadaster, 2024).

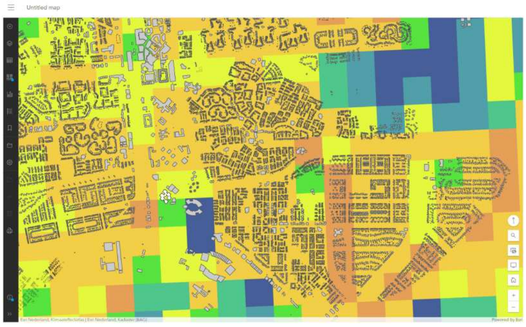
The third identified data need is geomechanics. In the context of urban design, geomechanics models relates to subsurface load-bearing capacity. The province of Utrecht provides a 2D map indicating suitability for traditional construction, considering factors like settlement sensitivity (Provincie Utrecht, 2011). While useful for regional design, it may require additional local data from cone penetration tests (CPTs) for precise geotechnical assessments (Basisregistratie Ondergrond, 2023a). In the BRO 3D webservice, CPTs are displayed in 3D as brown tubes without measurement values, offering immediate insight into their distribution and depth. Users can access detailed measurement data via a link in the pop-up, leading to the BROloket, where relevant graphs are provided (TNO Geologische Dienst Nederland, 2025a). Interpreting these graphs usually requires a geotechnical expert, so while the information is publicly accessible, expert assistance is necessary for its application in design.



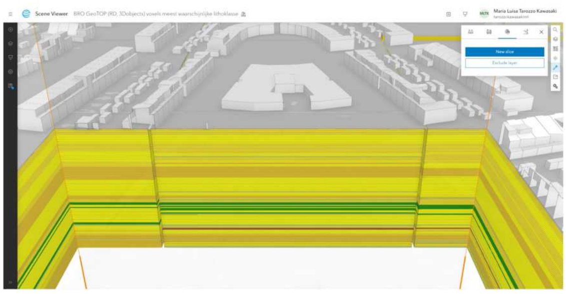
(a) Cables and pipes in Utrecht digital twin.



(b) Building suitability in Utrecht geoportal.



(c) KEA groundwater level model.



(d) Soil layers in GeoTOP.

Figure 3. Examples of existing subsurface models that can be used in spatial planning. (a) Cables and pipes in Utrecht digital twin. (b) Building suitability in Utrecht geoportal. (c) KEA groundwater level model and (d) Soil layers in GeoTOP.

Finally, the highest groundwater level (GHG), crucial for assessing subsurface suitability for water infiltration, is represented on two national level 2D maps, available from both the Klimaateffectatlas (KEA) (Esri Netherlands, 2022), a platform for climate adaptation information, which uses modeled projections based on climate scenarios, and DINOloket (TNO Geologische Dienst Nederland, 2025b). The KEA GHG map, based on the Dutch National Water Model from 2016 (Deltares, 2016), provides information on current groundwater conditions and includes future predictions under various climate scenarios, such as those for 2050. This map, with a resolution of 250 × 250 m, is designed for regional assessments and provides insights into potential future changes. The KEA GHG map is shown in Figure 3(c). In contrast, the DINOloket GHG map is based on the BRO Water Table Depth Model 2023-02 (TNO Geologische Dienst Nederland, 2023b), which uses actual measured data from groundwater monitoring wells to reflect real-world conditions and has a resolution of 100 × 100 m. This makes the DINOloket map more accurate for local applications, particularly in areas with dense groundwater monitoring wells coverage, though there are limitations in urban areas due to fewer monitoring wells. Additionally, Grondwatertools (Groundwater Tools in English), is an open platform that provides data on groundwater heads and analysis of groundwater dynamics (TNO Geologische Dienst Nederland , 2023c), including flow direction, differences between highest and lowest groundwater levels, and groundwater response to precipitation. This data can support planning decisions by helping to assess whether drainage is needed and understanding how quickly groundwater levels react to precipitation and evaporation.

In conclusion, this assessment highlights both the availability and limitations of subsurface models across national, provincial, and municipal scales. An overview of the assessed models is shown in Table 2. The following section discuss the challenges in incorporating these models into spatial planning, based on the presented assessment and interviews with urban planners.

Table 2. Subsurface properties, models, and platforms for the city of Utrecht.

Property	Model	Platform	Resolution (m)	Level
Soil Type	GeoTOP (3D)	BRO3D	100 × 100 × 0.5	National
	GeoTOP (2D Sections)	DINOLoket	100 × 0.5	National
Spatial Claim	Utrecht3D	Utrecht3D	N/A	Municipal
	KLIC (2D)	KLIC	1 (minimum)	National
Geomechanics	Building Suitability (2D)	ATLAS	500 × 500	Provincial
	CPT Distribution (3D)	BRO3D	Var. Depth	National
Groundwater Level	National GHG Map (2D)	KEA	250 × 250	National
	BRO Water Table Depth (2D)	DINOLoket	100 × 100	National

5. Challenges in integrating subsurface data into urban planning

Despite a broad availability of subsurface data in the Netherlands, this information could be more efficiently and more widely used in the planning and design of urban areas. Three barriers were identified that obstruct the use of subsurface data in spatial planning and design practices: the fragmentation of data sources, the quality of available data, and a lack of awareness among designers and stakeholders regarding the relevance of the subsurface for climate adaptation. While existing platforms provide valuable data, designers must still combine multiple sources to obtain comprehensive subsurface information (Norkunaite and Chevtchenko, 2025). Therefore one of the key challenges in integrating subsurface data into spatial planning is data fragmentation. For example at PosadMaxwan, designers utilize an internal geodatabase that consolidates publicly available data and client-provided datasets within a unified working environment, enabling seamless integration with QGIS (Norkunaite and Chevtchenko, 2025). While effective within the office, interviewed designers agree that a centralized portal linking relevant subsurface data sources would further enhance accessibility and usability. Additionally, such a system would improve the visibility of valuable datasets that remain underutilized due to limited awareness.

A second major issue concerns data quality. One aspect of this is data resolution. For city-scale planning, existing datasets, such as those provided by DINOLoket (TNO Geologische Dienst Nederland, 2025b), offer sufficient information, including subsurface sections up to fifty meters deep. This is showcased in Almere Pampus, where the existing resolution of the GeoTOP model combined with other datasets enabled the creation of a well-informed masterplan (van Spaandonk, 2025; Gemeente Almere and Rijksvastgoedbedrijf, 2024). However, for localized neighborhood or street-level planning, the same resolution is often inadequate (Norkunaite and Chevtchenko, 2025). Another quality-related issue is data accuracy, mainly related to the presence of unmapped elements (Norkunaite and Chevtchenko, 2025). Public space projects frequently encounter legacy pipes and cables left in place due to high removal costs. Although databases like KLIC (Kadaster, 2024) track underground utilities, they are not always accurate (Norkunaite and Chevtchenko, 2025). Furthermore, historical city centers pose additional challenges, as the likelihood of subsurface heritage such as Roman artifacts, can significantly constrain development (Norkunaite and Chevtchenko, 2025). Subsurface information can, in some cases, address these accuracy-related challenges. For example, in Almere Pampus, the analysis of historical soil layers and sedimentation patterns informed assessments of potential archaeological findings (van Spaandonk, 2025). Since such discoveries represent constraints that typically cannot be mitigated solely through technical solutions, understanding these geological indicators becomes highly valuable for strategic spatial planning, dictating where development might be feasible or should be avoided entirely.

These examples highlight the critical need for comprehensive subsurface analysis prior to detailed, local-scale planning phases. Such analysis serves multiple purposes: identifying potential constraints like heritage or unmapped infrastructure (addressing accuracy issues), and determining whether higher-resolution data is required (addressing resolution limitations). The Almere Pampus project further illustrates this iterative process: following the initial masterplan, more localized data from CPTs was integrated at a later stage, necessitating adaptations to address discrepancies arising from the initial data resolution (van Spaandonk, 2025; Gemeente Almere and Rijksvastgoedbedrijf, 2024).

Finally, there seems to be a lack of awareness on the importance of subsurface information for spatial planning. The policy letter emphasizing the use of water and soil for Dutch spatial planning is of recent date (Harbers and Heijnen, 2022). Additionally, it is not yet common-practice to apply subsurface knowledge broadly in urban design projects. Even practitioners eager to work with water and soil sometimes lack the necessary knowledge to do so effectively. In the case of Almere Pampus, subsurface data laid the foundation for the masterplan, but it was only through expert consultation that these datasets were transformed into actionable insights (van Spaandonk, 2025). This highlights that, while necessary data is available, collaboration across experts remains necessary to use it.

The interviewed urban designers noted that raw subsurface data alone cannot effectively drive design decisions (Norkunaite and Chevtchenko, 2025; van Spaandonk, 2025). The multiplicity of data sources and resolution of existing models hinder their effective utilization in spatial planning (Norkunaite and Chevtchenko, 2025). At the same time, the complexity of subsurface data interpretation and the lack of knowledge on how to apply this data in design make multidisciplinary expert collaboration necessary (van Spaandonk, 2025). While this collaboration is essential (van Spaandonk, 2025), a unified framework could address some of the identified challenges. In climate adaptation design, standardized intervention guidelines exist (Rijksoverheid, 2020), but information on integrating subsurface data into these interventions is lacking.

Simultaneously, standardized subsurface datasets remain poorly integrated with design guidelines, constraining their application in climate adaptation and broader spatial planning. Developing an integrated system that connects design interventions to subsurface data models would create an 'information roadmap' for incorporating subsurface data into spatial planning. This paper therefore presents a unified framework with two components to address these barriers. First, CLIMACAT, a portal which hyperlinks various data sources to the twenty-five climate adaptation interventions recommended by the Dutch government (Rijksoverheid, 2020), with practical geolocated examples. Second, a LADM Part 5 specialization profile with tailored attributes and external classes aiming to facilitate subsurface and climate information integration into standardized spatial plan data, potentially globally. The following two sections detail these components, while Figure 4 illustrates the proposed approach.

6. Combining information: CLIMACAT

The Open Geospatial Consortium (OGC) defines FAIR (findable, accessible, interoperable, and reusable) climate

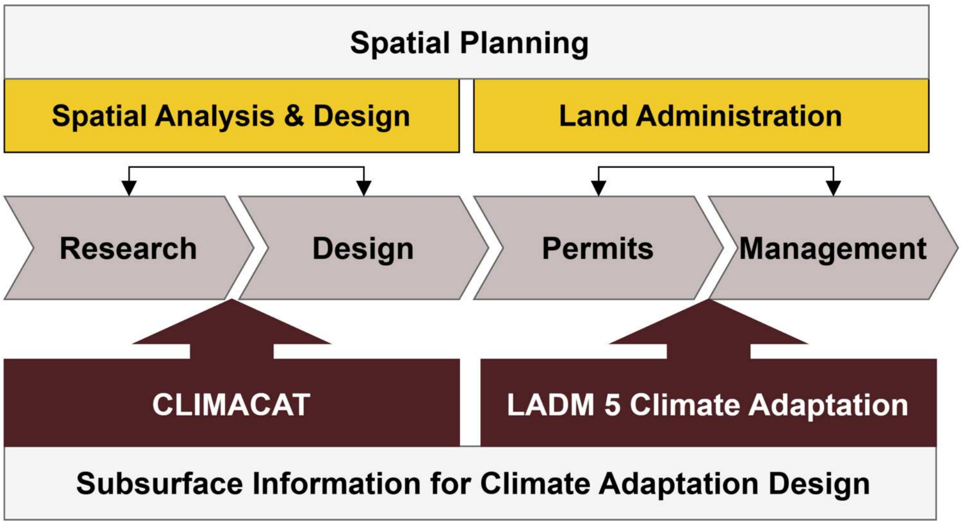


Figure 4. Proposed approach for integrating subsurface data into spatial planning for climate adaptation.

data services as crucial for effective climate information management (Hempelmann, 2022). Our paper states that a FAIR climate adaptation design catalog, consolidating all relevant local climate adaptation data into a single online resource, is a key solution for integrating and accessing this information.

CLIMACAT (climate catalog) is a developed digital Dutch climate design portal featuring the catalog of twenty-five climate adaptation interventions introduced in Section 3 (Rijksoverheid, 2020). Each intervention is hyperlinked to relevant subsurface and climate information sources. The portal aims to consolidate essential information for climate adaptation analysis and design phases of spatial planning (see Figure 4) in one location. In addition to introducing users to climate-related topics, the portal illustrates the relationship between subsurface information and climate adaptation spatial planning. Through the portal, users can use the decision tree presented in Figure 2 as a 'road map' to understand how the four subsurface data categories described in Section 3 may influence design choices. These categories, illustrated using the same decision tree, are described in detail and hyperlinked to the models assessed in Section 4, providing users with easy access to existing subsurface models.

To demonstrate the application of subsurface data in spatial planning, a 3D map was created using GIS software and linked to the portal. This 3D map integrates open data on buildings (TUDelft3D and 3DGI , 2024) and trees (Esri Netherlands, 2023) with GeoTOP (Basisregistratie Ondergrond, 2023b), a subsurface model representing soil layers. Users can interact with it by moving, rotating, and expanding it to full screen. Figure 5 displays this 3D map exemplifying the relationship between spatial planning and subsurface conditions. The potential users are urban designers, data providers, and citizens. Designers benefit from better understanding the information needed for climate adaptation design, along with where to find relevant information. Data providers benefit from better understanding what are the data requirements for design, using it as basis to improve their own information and data models. Finally, citizens

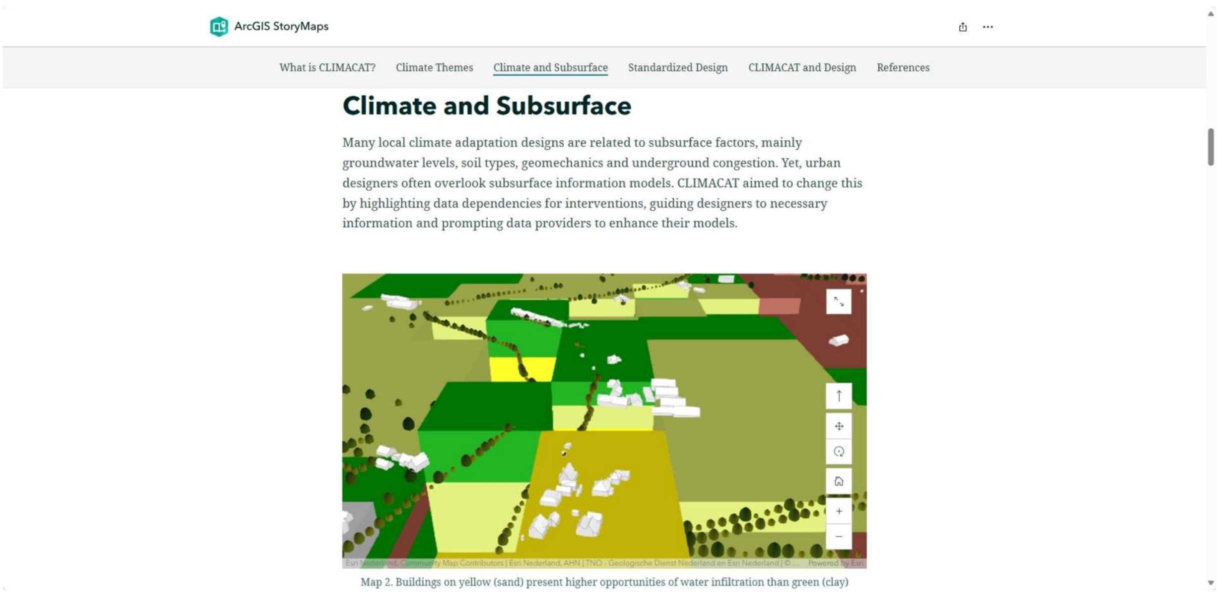


Figure 5. Description of the relationship between design and subsurface along with interactive 3D map.

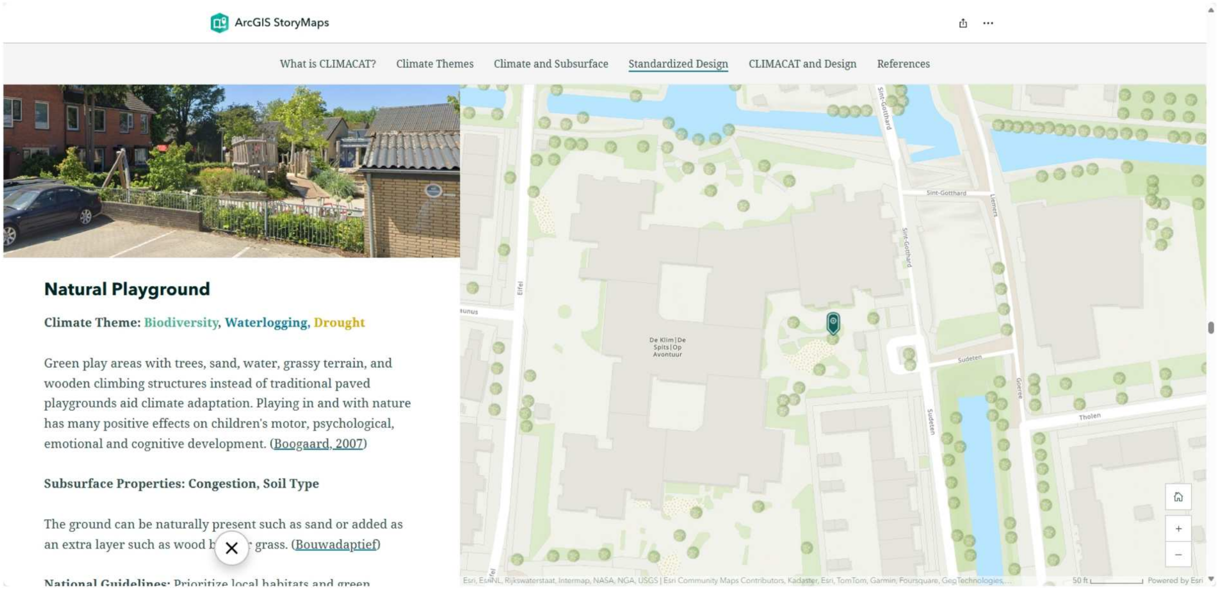


Figure 6. **Example of intervention along with hyperlinked subsurface information and a geolocated example.**

can use it to better understand climate adaptation needs in the country.

Each one of the twenty-five interventions (Rijksoverheid, 2020) in the catalog are exemplified in one geolocated example in the city of Utrecht. Additionally, each one includes a description and an explanation of how the intervention adapts to the related climate theme (Rijksoverheid, 2020; Bouwadaptief, 2022; Esri Netherlands, 2022). This explanation often includes a link to technical drawings of the intervention. It then discusses the relevant subsurface properties for the selected intervention, based on information from the Leidraad Klimaatadaptief Bouwen 2.0 (Bouwadaptief, 2022). It then indicates relevant national guidelines, taken from the Maatlat (Yardstick in English) (Ministerie van Binnenlandse, 2023), a Dutch framework document outlining sustainability and environmental performance criteria for urban development (Rijksoverheid, 2020), and local standards for the city of Utrecht, taken from the Leidraad (Bouwadaptief, 2022). An example of natural playground, one of the twenty-five interventions (Rijksoverheid, 2020), can be seen in Figure 6, along with its geolocated example, description, and hyperlinks to relevant climate theme and subsurface properties.

The online catalog is concluded with an example use of this tool when designing. In the example, a neighborhood in Utrecht, Voordorp, has its information requests and subsurface limitations and opportunities identified. It then exemplifies how a potential intervention, in this case infiltration crates to infiltrate and store water from heavy rain, has all the identified information needs answered in one single place through the online portal. CLIMACAT is publicly available at gdmc.nl/CLIMACAT.

7. LADM PART 5 climate adaptation profile

Standardized urban plan documentation enhance national and international knowledge exchange on diverse planning strategies. The LADM provides a unified framework for land administration, supporting spatial representations (Lemmen *et al.*, 2010). The Spatial Plan Information Package (Part 5) (ISO, 2024a) extends core LADM classes from the Party, Administrative, and Spatial Units packages, incorporating boundary faces, boundary face strings, and spatial units (Indrajit *et al.*, 2020; ISO, 2024a), and introduces new classes, SP_PlanGroup, SP_PlanUnitGroup, SP_PlanBlock, SP_PlanUnit (Indrajit *et al.*, 2020), and SP_Permit (ISO, 2024a), to model zoning, planned land use, and associated Rights, Restrictions, and Responsibilities (RRRs) (Indrajit *et al.*, 2020; ISO, 2024a).

This paper states that an information standard designed for sharing urban plan information, such as LADM, can also enhance the national and international exchange of climate adaptation related plan information. The specialized information model for climate adaptation (CLIMA) adds attributes tailored for climate adaptation design and external classes related to identified subsurface data needs. This generic profile thus aim to add subsurface and climate information into spatial planning. It 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.

The proposed profile inherit the attributes of the original classes while integrating additional attributes and external classes relevant to climate adaptation. All 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 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 and aspects. 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 SP_PlanBlock is the lowest level of plan and consists of a set of neighboring plan units decided or approved by authorities. This 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, soil, subsurface conditions, groundwater levels, and geomechanic properties. 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. 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 conditions. These datasets, which are typically maintained by specialized agencies or institutions, provide essential information that is critical for climate resilient urban planning and land administration.

The External::ExtClimateTheme class includes attributes such as Area, which defines the spatial extent of the climate theme, and ClimateTheme, which categorizes the prevalent climate risks in an area, such as flooding, heat stress, or drought (CodeList extClimaTheme). The Measure attribute describes the adaptation measures proposed to address these climate risks, when existing, and Source references the external datasets or sources from which the climate data originates. This class is essential for evaluating the impacts of climate change and informing adaptation strategies.

The External::ExtGeomechanics class captures geotechnical data relevant to building suitability. Key attributes include BearingCapacity, which measures the soil's bearing capacity, when available, using a certain unity of measure (BearingUOM), and Suitability, which evaluates whether the defined area is suitable for construction, with possible values such as suitable, not suitable, and unknown (CodeList extBuildSuitable).

The External::ExtGroundwater class offers critical data on groundwater conditions. In particular, the attribute HighestLevel, indicates the highest recorded groundwater level in the area, when available. Additionally, the attribute Infiltration categorizes the groundwater infiltration capacity in high, average, low or unknown (CodeList extInfiltration), while extRiskDrought and extRiskFlood (Boolean) flags areas prone to drought and flood conditions. Finally, the Scenario accommodates climate change scenarios.

The External::ExtSoil class contains attributes such as Depth (Double), which indicates the depth of the soil layer, and SoilType, which classifies the soil based on type (clay, sand, peat, or unknow, as defined in CodeList extSoilType), while Uncertainty (Double) captures the degree of uncertainty in the soil data due to interpolation methods, offering a better understanding of soil properties for land development.

Finally, the External::ExtSpatialClaim class deals with underground spatial claims, particularly in the context of infrastructure such as cables and pipes. This class includes attributes like ClaimType, which classifies the type of spatial claim (e.g. cable, tree root) using the CodeList extClaimType, and Congestion, which indicates the level of congestion in the area due to existing infrastructure (high, low or unknown, according to CodeList extCongestion). The Depth and Diameter specify the depth and diameter of the underground installation, while Length defines its length.

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).

Together, these external classes enhance the LADM by incorporating detailed subsurface and climate adaptation spatial plan data into land administration. They support informed decision-making with the use of associations to external datasets. By using the proposed new attributes linked to external classes, this profile enables urban planners to systematically incorporate subsurface constraints and opportunities into climate-adaptive decision-making processes while maintaining alignment with standardized land administration practices.

The SP_PlanUnit class represents the smallest planning unit, relevant for local climate adaptation interventions. This 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 are used as a guideline for planners to identify which external sources are needed.

Lastly, 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. The LADM climate adaptation profile is illustrated in Figure 7 and will be incorporated into Annex C of the latest version of ISO 19152 Part 5.

To showcase the use of the proposed generic profile in a more country specific way, the Dutch case is used, having the masterplan of Almere Pampus as an example (Gemeente Almere and Rijksvastgoedbedrijf, 2024). The selected area and the masterplan are shown in Figure 8. In the case of the Netherlands, the proposed

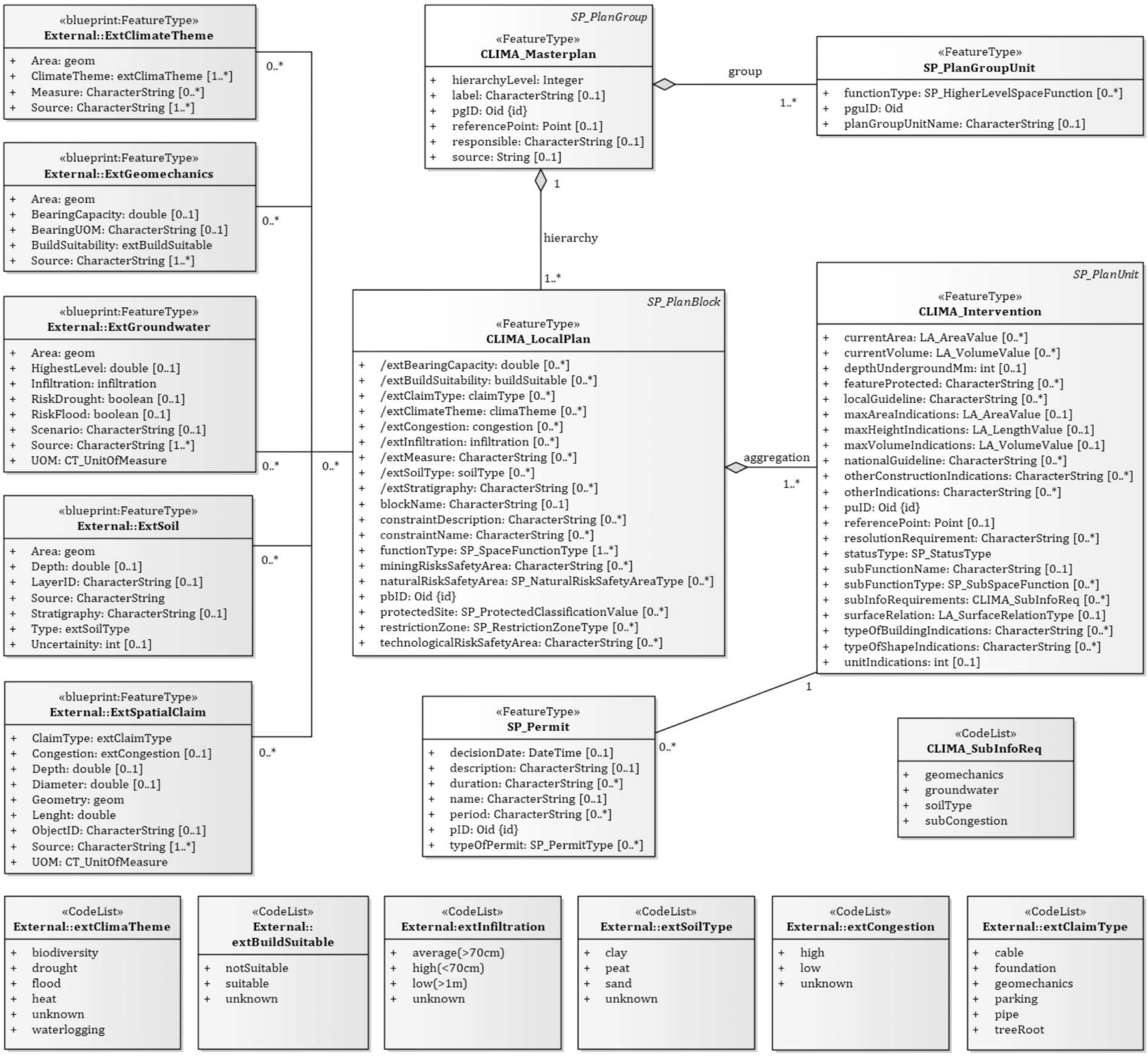


Figure 7. Land administration domain model part 5 climate adaptation profile.

external classes are the external data sources used by urban planners and assessed in Section 4, such as GeoTOP for soil information and DINOLoket for groundwater level. An instance level diagram is presented in Figure 9, showcasing the use of the proposed external classes and tailored attributes in a specific cadastral parcel in Almere. The models and datasets used for the creation of this masterplan, represented as external classes in the instance level diagram, are discussed in a public document with meeting notes (Gemeente Almere and Rijksvastgoedbedrijf, 2024).

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. Information on the bearing capacity of the subsurface and suitability for construction was sourced from a report by Wiertsema & Partners (Gemeente Almere and Rijksvastgoedbedrijf, 2024), and the corresponding suitability assessment property is therefore associated with this report through the external class ExtGeomechanics. Groundwater attributes were assessed using the BRO Water Table Depth Model 2023-02 available via DINOLoket (TNO Geologische Dienst Nederland, 2023b; Gemeente Almere and Rijksvastgoedbedrijf, 2024), so the attributes from this model related to the cadastral parcel in the masterplan are associated with the external class ExtGroundwater.

Soil information used in the masterplan, such as soil type and layer depth, was obtained from GeoTOP (Basisregistratie Ondergrond, 2023b; Gemeente Almere and Rijksvastgoedbedrijf, 2024) and is associated with the external class ExtSoil. The masterplan notes do not describe the use of datasets or models to study underground congestion (Gemeente Almere and Rijksvastgoedbedrijf, 2024). It is possible that congestion is currently low due to the plot's current agricultural use. The masterplan document does, however, discuss future spatial claims related to energy infrastructure (Gemeente Almere and Rijksvastgoedbedrijf, 2024). For example, aquifer thermal energy storage (ATES) infrastructure for geothermal energy must be considered before construction. Even if such infrastructure does not yet exist,

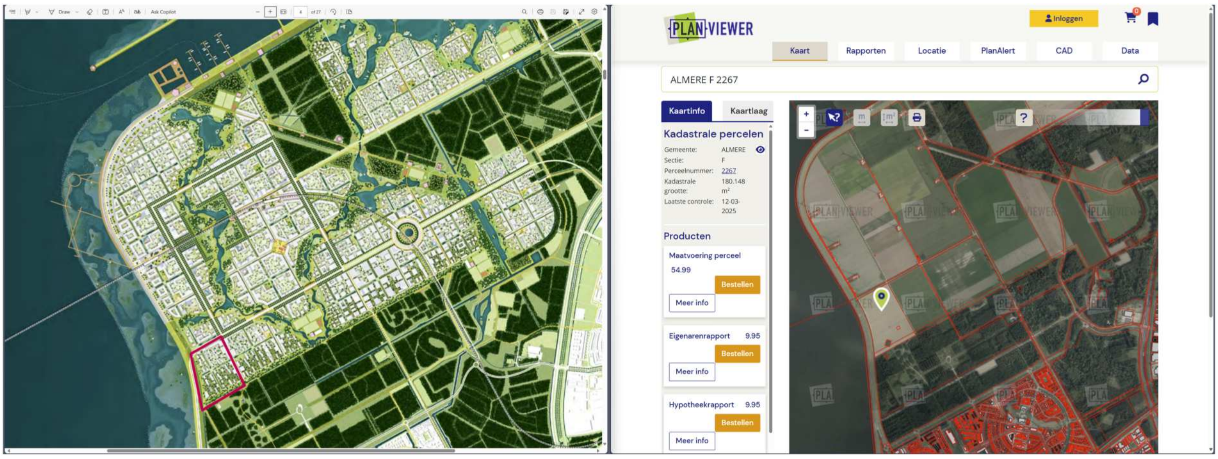


Figure 8. Almere Pampus' masterplan and cadastral parcel.

the required spatial allocation should be accounted for in advance.

To illustrate this concept using the external class ExtSpatialClaim, the instance diagram assumes that the parcel includes an aquifer thermal energy storage system located less than ten meters from a building. In this scenario, the source installation should precede construction to protect both the building foundation and the energy source (Gemeente Almere and Rijksvastgoedbedrijf, 2024). By utilizing the external class ExtSpatialClaim

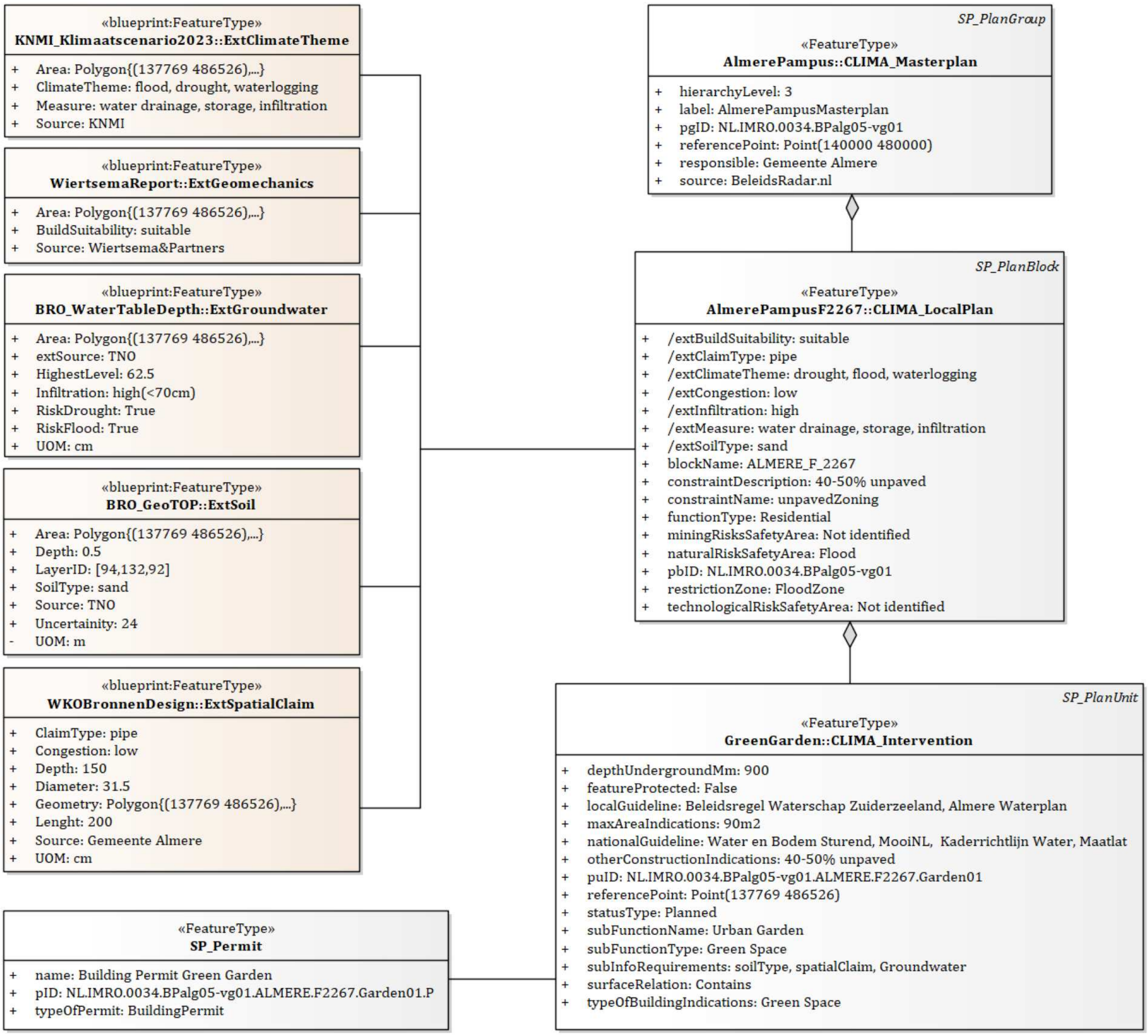


Figure 9. Instance level diagram shows the LADM profile in the Dutch context.

and its attributes, information about this potential energy source was incorporated into the diagram. Additionally, the masterplan includes plans for a metro system (Gemeente Almere and Rijksvastgoedbedrijf, 2024). This, however, does not intersect with the exemplified parcel.

In the example of Almere Pampus, the masterplan document states an aim for 40 to 50% of unpaved surface (Gemeente Almere and Rijksvastgoedbedrijf, 2024). Within residential blocks, such as this parcel, this unpaved surfaces are equivalent to design interventions related to additional greenery, such as food or sports gardens. Therefore, the diagram showcases information regarding a green garden within the SP_PlanBlock, using CLIMA_Intervention (SP_PlanUnit).

8. Evaluation

During the interviews conducted in two different moments with urban planners from two urban design offices, namely PosadMaxwan and Bright, feedback on the proposed approach was given. The key themes from the feedback revolve around improving the usability of developed portal, providing more practical guidance and better data traceability.

In particular, CLIMACAT has been praised for its checklist-based structure, which helps designers navigate complex climate adaptation tasks in a step-by-step manner. The two interviewed designers from PosadMaxwan highlighted how the use of the portal could potentially save time and simplify the decision-making process when including subsurface data (Norkunaite and Chevtchenko, 2025). Quoting one of the designers: 'The website is more or like how the analysis problem goes. You see that you have a climate related problem and then you link it to soil and water.' and 'CLIMACAT is useful because you go through steps. The designer's knowledge is, of course, similar to this process. But the website makes it easier, as a checklist, and saves time to designers' (Norkunaite and Chevtchenko, 2025). Another designer from the same office commented: 'The idea of interlinking things together is very useful' (Norkunaite and Chevtchenko, 2025). The feedback on the developed portal also highlighted the importance of maintaining information integration tools flexible. To quote again one designer from PosadMaxwan: 'Even if you have a toolkit with selected interventions, for example green roof, you still have the freedom regarding how to design that. By creating a checklist you don't limit designers, it is just a tool' (Norkunaite and Chevtchenko, 2025). The same designers did not gave a direct feedback on the LADM climate adaptation profile. However, this feedback was used as its input, aiming to provide a structured yet flexible framework for storing and exchanging urban plan information related to climate adaptation and subsurface data.

Another significant piece of feedback was the desire for more practical examples and tutorials to help users better understand how to apply the tool. One designer from Bright expressed a preference for clearer, step-by-step instructions, suggesting that video tutorials or 'How-To' guides could significantly enhance the user experience (van Spaandonk, 2025). Quoting the interviewed designer: 'Having more data is useful but the more related to practical examples, the better. The guiding tool has to be very practical and precise enough. Just examples are not enough.' and 'In urban planning we often create reports but there are many more ways to transfer information and to put things into action. For example, videos are good way to convey tutorial information' (van Spaandonk, 2025). While a practical example on how to use CLIMACAT for design purposes is included in the portal, step-by-step guides or instructional videos could be added to demonstrate how to use the hyperlinked subsurface data sources or how to link surface data with climate adaptation interventions.

Finally, the importance of data traceability and metadata was a key point raised in the feedback. Designers emphasized that while exact values are important, understanding the source of the data is equally critical for ensuring trust and accuracy in decision-making (van Spaandonk, 2025; Norkunaite and Chevtchenko, 2025). To quote one interviewed designer: 'The (data) traceability is very important. Not the exact value but where this value comes from. In plan information that would mean adding the source of this data inside of a database' (van Spaandonk, 2025). This feedback aligns with the capabilities of the LADM Part 5, specifically through the 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 *et al.*, 2015). To enhance transparency, the LADM profile could incorporate comprehensive metadata, potentially embedding hyperlinks, as supported by LA_Source. This functionality would allow urban planners to trace the origins of the data, verify its accuracy, and assess its relevance, thereby fostering greater confidence in decision-making processes.

In conclusion, the feedback provided valuable input for enhancing the proposed tool, CLIMACAT, and the LADM climate adaptation profile. The insights regarding usability, data integration, practical guidance, and data traceability suggest several key areas for improvement. By incorporating these recommendations, both can be further developed. They should aim to provide a structured yet flexible framework that integrates subsurface and climate data, offers practical guidance, and ensures transparency through detailed metadata. By doing so, they will better equip urban planners to navigate the complexities of climate adaptation and land management in a rapidly changing world.

9. Conclusion

This paper presents a framework for integrating subsurface data into climate adaptation design in the Netherlands. The research addresses key challenges identified through interviews with urban planning professionals, assessment of current design guidelines, and evaluation of relevant information models. To facilitate this integration, the paper proposes a developed website, CLIMACAT, and a LADM climate adaptation profile, with tailored attributes and external classes exemplified in the Dutch context. Through their combined use, the paper presents a solution for overcoming barriers to the effective utilization of subsurface data in Dutch urban planning. Combined, the proposed approaches address two distinct phases of spatial planning: the spatial analysis/design phase and the land administration phase.

CLIMACAT, available at gdmc.nl/CLIMACAT, consolidates various types of information crucial for climate adaptation design, particularly during the spatial analysis and design phase. It provides a user-friendly platform for urban designers, data providers, and citizens, thereby fostering interdisciplinary collaboration. By bringing together information on climate themes, subsurface properties, and national and local guidelines, CLIMACAT addresses the need for a comprehensive and accessible single portal. This approach facilitates well-informed and context specific climate adaptation interventions. This proposed tool address the data gathering and analysis phase in the use of subsurface and climate information in spatial planning. It presents a structured yet flexible platform for users to access and interpret subsurface data in the context of climate-adaptive urban planning.

The proposed LADM Part 5 climate adaptation profile offers a standardized framework for documenting and sharing urban plans during the land administration phase. Through the use of the proposed attributes, along with the existing attributes inherited from the LADM Part 5 classes, the standardized plan information will include data on climate and subsurface themes, which have been proven to be essential for effective climate-adaptive urban planning. Additionally, the proposed external classes enable the integration of external data sources, guiding planners in utilizing subsurface information within documented urban plans. Though adaptable to country-specific contexts, the proposed LADM climate adaptation profile, which will be incorporated into Annex C of the latest ISO 19152 Part 5, enhances global knowledge exchange and facilitates international collaboration on climate adaptation practices.

Therefore the combined use of CLIMACAT and the LADM Part 5 climate adaptation profile, in different phases of spatial planning, facilitates climate-adaptive spatial plans, as showcased in the Dutch context, but has potential for global application, as climate adaptation represents a worldwide challenge. A website such as CLIMACAT enhances the accessibility and usability of critical data, while the LADM Part 5 profile ensures that the resulting plans are documented in a manner that facilitates sharing and interoperability. This dual approach addresses the challenges of integrating subsurface data in urban planning by providing both a practical tool for design and a standardized framework for spatial plan information documentation and exchange. Thus, the synergy between CLIMACAT and LADM Part 5 represents a comprehensive solution for advancing global climate adaptation efforts through improved integration of subsurface information into urban planning processes.

10. Future work

This paper discusses the combined use of an online portal and standardized plan information for the exchange of information related to climate adaptation in the context of the Netherlands. Future work potentially could include the assessment of this method in different countries. The Netherlands benefits from a wide range of subsurface models, making it possible to combine different information into a single portal, or through LADM external classes associations. Future work could include the assessment of this approach in countries with less or different data sources.

On example of further research could include the use of the proposed generic LADM climate adaptation profile in different countries, adapting it to the country's context. This could include, for example, the use of different associations to external classes or new proposed attributes. Similarly, future work could include the development of a similar online portal combining useful subsurface information.

Finally, the online portal and the LADM profile presented in this paper are based on the research and experience from the authors and feedback from a limited amount of local urban planners. Feedback from users and readers will allow them to improve, leading to further work and better approaches for the purpose of integrating subsurface information into climate adaptation design practices.

Acknowledgments

The authors extend their gratitude to the urban designers from PosadMaxwan and Bright who contributed their expertise and insights on the use of subsurface data in urban planning, and provided valuable feedback on the development of the tool and the LADM profile presented in this paper. The authors also express their gratitude to their colleagues at TNO for sharing their expertise and providing valuable guidance through their knowledge of subsurface (models).

Disclosure statement

No potential conflict of interest was reported by the author(s).

Notes on contributors

Maria Luisa Tarozzo Kawasaki is a Junior Geodata Engineer at TNO Geological Survey of the Netherlands. She holds two Master of Science degrees from Delft University of Technology: one in Geomatics and another in Urbanism. Her academic work included a double-degree thesis titled 'Common Ground: Bridging Subsurface Information Models and Climate Adaptation Design', and she continues to contribute to research through ongoing publications. In her role, she focuses on applying geoinformatics, such as GIS and spatial data management, to support spatial planning.

Laura Thomas is a PhD candidate at Delft University of Technology within the European SPADES project: Spatial Planning and Design with Soil. Her research focuses on defining and promoting soil-inclusive spatial planning and design practices. Previously, Laura worked as an urban designer and research coordinator at PosadMaxwan, a spatial strategy and design office in The Hague, where she contributed to research-by-design projects aimed at supporting vital soils in urban environments through spatial interventions. She holds a master's degree in Urbanism from Delft University of Technology.

Ulf Hackauf graduated as Diplom-Ingenieur (MSc) architecture at Technische Universität Braunschweig in 1999. He worked as architect for Erick van Egeraat and for Neutelings Riedijk architecten, both in Rotterdam, on large projects in Germany, Great Britain, Denmark and the Netherlands. From 2007 to 2014, he collaborated with Winy Maas at The Why Factory, TU Delft, using spatial design to imagine consequences of global dynamics and challenges. He co-authored several books of The Why Factory's book series and taught related studios at TU Delft, ETH Zürich and IIT Chicago. Since 2015, Ulf Hackauf is teacher and senior researcher at the section Environmental Technology and Design, department of urbanism. He teaches in Urbanism and Industrial Ecology. His research focusses on multi-scale relations between urban space and sustainable transitions.

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 of the 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.

References

Basisregistratie Ondergrond, 2023a. *Geotechnisch sondeeronderzoek (cpt)*. Data Model.

Basisregistratie Ondergrond, 2023b. *Modellen: GeoTOP (GTM)*. Data Model.

Bouwadaptief, 2022. *Leidraad klimaatadaptief bouwen 2.0*.

Chen, X., and Hu, Q., 2004. Groundwater influences on soil moisture and surface evaporation. *Journal of hydrology*, 297 (1), 285–300.

Climate Adaptation Services, 2021. *Bodembewuste klimaatadaptatie*. [Accessed 6 Mar 2025].

Deltares, 2016. *Dutch national water model*. Available from: https://iplo.nl/thema/water/applicaties-modellen/.

Deltares, 2020. *Urban infiltration opportunities*. Klimaateffectatlas.

de Rooij, B., Woolderink, H., Breman, B., Budding, A., de Graaf, M., and van Rooij, S., 2023. *'water and soil guiding' calls for a broad perspective*. Wageningen University & Research.

Esri Netherlands, 2022. *Gemiddelde hoogste grondwaterstand – huidig*. Online map service. [Accessed 14 Feb 2025].

Esri Netherlands, 2023. *3d bomen rd. Nationwide 3D tree models for the Netherlands (RD coordinates)*. Data actuality: November 2023. Generated based on BGT data with approximate locations and randomized heights (4–14 m). Terms of Use (per linked page): Public Domain.

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

Gemeente Utrecht, n.d. *Utrecht 3D. Web application*. [Accessed 12 Feb 2025].

Government of the Netherlands, 2023. *Delta programme 2024*. Technical Report IEN/BSK-2023/220012, The Hague, Netherlands: Ministry of Infrastructure and Water Management.

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

Hempelmann, N., 2022. *OGC Climate Resilience DWG*. Technical report.

Hooimeijer, F., and Maring, L., 2018. The significance of the subsurface in urban renewal. *Journal of urbanism: international research on placemaking and urban sustainability*, 11 (3), 303–328.

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*, 98, 104111.

ISO, 2024a. *Geographic information – land administration domain model (ladm) – part 5: spatial plan information*. Final Draft International Standard. [Accessed 28 May 2025].

ISO, 2024b. ISO 19103:2024 Geographic information – Conceptual schema language.

Kadaster, 2024. *Klic – kabels en leidingen informatie centrum*. Online dataset.

Koninklijk Nederlands Meteorologisch Instituut, 2023. *Knmi national climate scenarios 2023 for the netherlands*. De Bilt, Netherlands: Climate scenarios.

Lemmen, C., Oosterom, P., Thompson, R., Hespanha, J., and Uitermark, H, 2010. The modelling of spatial units (parcels) in the land administration domain model (LADM). *In*: *XXIV FIG International Congress 2010: Facing the Challenges – Building the Capacity*, Sydney, Australia.

Lemmen, C., van Oosterom, P., and Bennett, R., 2015. The land administration domain model. *Land use policy*, 49, 535–545.

Ministerie van Binnenlandse, 2023. *Maatlat voor klimaatadaptief bouwen*. Technical report, Ministerie van Binnenlandse Zaken en Koninkrijksrelaties. Ontwikkeld in samenwerking met de Vereniging van Nederlandse Gemeenten (VNG), het Interprovinciaal Overleg (IPO) en de Unie van Waterschappen (UvW).

Niedersachsen Wasser, 2022. *Subsurfaceviewer*. Available from: https://www.subsurfaceviewer.de/.

Norkunaite, G., and Chevtchenko, E., 2025. *Interview with designers from posadmaxwan on the use of subsurface data in urban design*. Personal interview. Conducted by Laura Thomas and Maria Luisa Tarozzo Kawasaki, 29 Jan 2025.

Provincie Utrecht, 2011. *Bodemgeschiktheidskaart: geschiktheid voor bouwen*. Dataset.

Rijksoverheid, 2020. *Klimaatadaptatie maatregelen*. Infographics RVO. [Accessed 12 Feb 2025].

Timmermans, W., 2020. *Bodem biedt kansen voor effectieve klimaatadaptatie*. Straatbeeld.

TNO Geologische Dienst Nederland, 2023a. *Bro 3d webservices*. Available from: https://basisregistratieondergrond.nl/werken-bro/producten-diensten/bro-3d-webservices/.

TNO Geologische Dienst Nederland, 2023b. *Bro water table depth model 2023–02*.

TNO Geologische Dienst Nederland, 2023c. *Grondwatertools*. Available from: https://www.grondwatertools.nl/.

TNO Geologische Dienst Nederland, 2025a. *Broloket: Ondergrondgegevens*. Online Database. [Accessed 2 Feb 2025].

TNO Geologische Dienst Nederland, 2025b. *Dinoloket: data en informatie van de nederlandse ondergrond*. Online Database. [Accessed 14 Feb 2025].

TUDelft3D and 3DGI, 2024. *3d bag*. Nationwide 3D building models for the Netherlands (version date: 2024-12-16). Generated from BAG and AHN data. Licensed under CC BY 4.0.

United Nations, 2023. *Sustainable development goals report 2023*. Technical report, United Nations.

van Spaandonk, T., 2025. *Interview with designer from bright on the use of subsurface data in almere pampus masterplan*. Personal interview. Conducted by Laura Thomas and Maria Luisa Tarozzo Kawasaki, 21 Feb 2025.

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.