# Bringing Subsurface Information Models and Climate Adaptation Design into LADM Part 5 Spatial Plan Information

**Maria Luisa TAROZZO KAWASAKI, Rob VAN DER KROGT, Wilfred VISSER, Ulf HACKAUF, Alexander WANDL, Peter VAN OOSTEROM, The Netherlands**

**Key words**: climate adaptation, urban design, subsurface, information model, LADM part 5

## SUMMARY

The Netherlands aims to achieve climate resilience and water robustness by 2050, necessitating an interdisciplinary approach to spatial planning due to the complex nature of climate adaptation. A critical need exists for subsurface data, especially for interventions related to underground elements like water storage, soil infiltration, and subsurface management. This need became particularly relevant when the Dutch government adopted 'water and soil guiding' as a core principle for spatial planning in 2022 (Ministerie van Infrastructuur en Waterstaat, 2022). Translating this principle into practical solutions is complex, requiring detailed knowledge of subsurface characteristics. The absence of such information can lead to issues like groundwater contamination and high-maintenance parks.

Despite the necessity for interdisciplinary and subsurface data, organizational, technological, and institutional barriers hinder the use of information models and standards in climate adaptation design. Currently, even though there are many subsurface models and standards available, the Netherlands lacks an integrated approach linking subsurface information models with local climate adaptation design. It also lacks an example of the use of standards to exchange planning information containing climate adaptation design interventions.

This research explores how subsurface data models can enhance urban climate adaptation design. By assessing existing models, it identifies data requirements for effective interventions based on Dutch policy documents. The paper introduces CLIMACAT, an online tool integrating subsurface information models and other crucial data in one online catalogue following FAIR (findable, accessible, interoperable, and reusable) data principles, tested in four Utrecht neighborhoods.

The findings emphasize the importance of integrating subsurface information models into urban planning to achieve more effective and context-sensitive climate adaptation interventions. Significant barriers include data accessibility and standardization. New spatial plans were standardized using Land Administration Domain Model (LADM) Part 5 (ISO 19152-5), tailoring some attributes for climate adaptation design, facilitating cross-border information exchange. This approach addresses specific challenges in the Netherlands and provides a framework for international adoption, contributing to global urban climate adaptation efforts. The research highlights the need for accessible subsurface data and interdisciplinary collaboration, supported by continuous technological and policy advancements.

# Bringing Subsurface Information Models and Climate Adaptation Design into LADM Part 5 Spatial Plan Information

**Maria Luisa TAROZZO KAWASAKI, Rob VAN DER KROGT, Wilfred VISSER, Ulf HACKAUF, Alexander WANDL, Peter VAN OOSTEROM, The Netherlands**

## 1. INTRODUCTION

The Delta Programme, a national initiative by the Dutch government, aims to protect the Netherlands from flooding and improve water management, requiring the country to achieve climate resilience and water robustness by 2050 (Ministry of Infrastructure and Water Management, 2023). This presents a significant challenge to spatial planning, necessitating an interdisciplinary approach. A key aspect is subsurface information, particularly since 'water and soil guiding' was established as a principle in Dutch spatial planning in 2022. Standardized information models are crucial for making informed design decisions, as many interventions related to flood and drought management, such as water storage, soil infiltration, and underground spatial management, require detailed knowledge of soil characteristics.

While the Netherlands has several subsurface data models at municipal and national levels, integrating these models into climate adaptation design remains challenging. Issues arise from differences in practices between designers and geodata engineers, as well as the historical development of Geographic Information Systems (GIS). Technological barriers, such as the evolution from data-poor to data-rich environments and the separate development of GIS technologies, also contribute to this challenge. Moreover, standardization issues in both geoinformatics and urban design further complicate integration. This paper examines how incorporating subsurface and design information into standardized models, such as Land Administration Domain Model (LADM) Part 5, or utilizing tools like online geoportals, can enhance climate adaptation efforts.

As highlighted by the Delta Programme, practical definitions of climate adaptation through standardization are essential (Ministerie van Infrastructuur en Waterstaat, 2022). This research focuses on climate adaptation guidelines and resources such as the *Leidraad Klimaatadaptief bouwen 2.0* (Bouw Adaptief), *Maatlat voor een klimaatadaptieve groene Gebouwde Omgeving* (Rijksoverheid), and *Klimaateffectatlas* (Klimaateffectatlas), and their integration with Dutch subsurface data models, including the Key Registry for the Subsurface (BRO) (Basisregistratie Ondergrond) and municipal models from Utrecht. Design proposals for four 500x500 meter areas in Utrecht, namely Kop Voordorp, Lunetten Zuid, Kanaleneiland Noord, and Voordorp, were developed to address local climate challenges, using existing subsurface models and a new online tool.

The paper introduces CLIMACAT, a tool that consolidates climate adaptation design information into a single online catalogue. Moreover, the paper exemplifies the storage and exchange of climate adaptation planning information using LADM Part 5. From this standard, it uses existing classes with new attributes tailored for climate adaptation. The goal is to develop a framework for integrating standardized subsurface information into climate adaptation efforts, addressing a global urban planning and land administration challenge. The presented LADM Part 5 Spatial Plan Information CLIMACAT specialization is rather generic and it is expected that it can also be used in other countries as climate adaption is a global challenge. Similar to other LADM parts, also for part 5 Spatial Plan Information, countries need to develop their own country profiles (customizing/ adding country specific information). If a country plans to address the climate adaption in its spatial plans, then it is recommended to start with the CLIMACAT profile of LADM part 5, and then add country specifics.

In short, this paper explores the integration of CLIMACAT and LADM Part 5, providing a comprehensive framework for addressing the challenges of incorporating subsurface information into climate adaptation design. It aims to demonstrate how these tools can overcome the institutional, technological, and semantic barriers that have historically hindered the effective use of subsurface data in urban planning. By examining the functionality and synergies between CLIMACAT, an online catalogue that consolidates vital information for climate adaptation, and LADM Part 5, which standardizes the documentation and sharing of urban plans, this research highlights a pathway towards more informed and effective climate adaptation strategies. This work contributes to realizing various Sustainable Development Goals (SDG's), especially relevant are the SDG's 11 (Sustainable cities and communities) and 13 (Climate action).

The paper is structured to first introduce the significance of integrating subsurface data into climate adaptation design. Section 2 delves into the relationship between subsurface information and climate adaptation design, emphasizing the importance of incorporating natural characteristics into adaptation strategies. This section also presents an overview of the existing subsurface models on a municipal and national level. Following this, Section 3 addresses the challenges in integrating subsurface information, highlighting the necessity of interdisciplinary approaches and standardization. Section 4 introduces CLIMACAT, detailing its role in facilitating the integration of climate adaptation data and design information. Section 5 explores the application of LADM Part 5 for storing and exchanging climate adaptation planning information. The subsequent Section 6 presents the results of design explorations in Utrecht, showcasing the use of subsurface models and CLIMACAT in selecting and implementing climate adaptation interventions. Section 7 evaluates the proposed designs through a survey, assessing the effectiveness and potential biases of the chosen interventions. Finally, Section 8 concludes this paper, emphasizing how the combined use of CLIMACAT and LADM Part 5 ensures that climate adaptation designs are well-informed, accessible, and standardized. This dual approach effectively addresses the challenges of integrating geoinformatics with urban design, ultimately enhancing climate resilience through improved integration of subsurface information into urban planning processes.

## 2. SUBSURFACE INFORMATION AND CLIMATE ADAPTATION

This section explores the role of subsurface information in the context of climate adaptation design, illustrating how the understanding of natural characteristics can enhance the effectiveness of adaptation strategies. In subsection 2.1, the necessity of integrating subsurface data, such as soil types, groundwater levels, and urban infrastructure, is discussed.

It emphasizes how these elements influence the selection and implementation of climate adaptation interventions and highlights the significance of localized data in addressing specific climate challenges. Subsection 2.2 reviews existing information models that capture various subsurface characteristics, namely soil type, subsurface congestion, geomechanics, and groundwater level, relevant to climate adaptation efforts. Collectively, this section underscores the importance of subsurface data to inform design choices that are both sustainable and context-specific, thereby facilitating effective climate adaptation in urban environments.

### 2.1 Subsurface and Climate Adaptation Design

Literature shows the necessity of integrating natural characteristics into climate adaptation strategies to ensure their sustainability (Deltares, 2020). Effective adaptation often involves nature-based solutions, which rely heavily on subsurface and water information, such as soil types and groundwater levels (Straatbeeld, 2020). For instance, soil types significantly impact the feasibility of rainwater infiltration to address flooding or waterlogging. High infiltration soils, like sandy types, are ideal for this purpose, while low infiltration soils, such as clay or peat, are less suitable (Deltares, 2020). Urban areas further complicate adaptation efforts due to man-made infrastructure that affects design decisions. Localized subsurface data, including soil maps, drilling profiles, and infrastructure details, are crucial for identifying viable climate adaptation interventions. Moreover, it's essential to assess the subsurface space available for adaptation, as obstructions like pipes are typically mapped only locally. Local climate adaptation design involves implementing interventions to address climate challenges, such as flooding or heat stress, and must account for the area's specific subsurface properties. These interventions, based on subsurface characteristics, can be categorized into four main groups (see Figure 1):

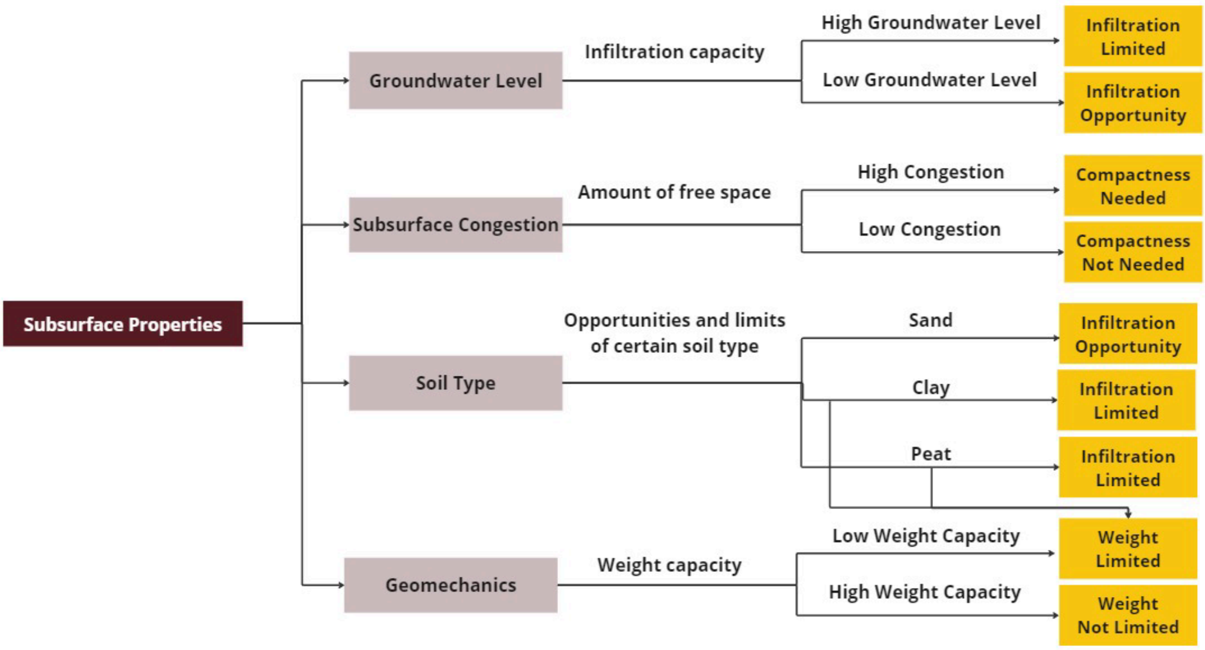


**Figure 1.** Decision tree for design interventions based on subsurface properties

– **Groundwater Level:** The highest groundwater level determines an area's infiltration capacity. Optimal infiltration occurs in the first 0.7 meters of the subsurface (Deltares, 2020).
– **Subsurface Congestion:** The presence or lack of subsurface congestion, e.g. the presence of cables/pipes, indicates the compactness level required for an intervention.
– **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.
– **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 support rainwater infiltration through permeable pavements, while clay soils with high groundwater levels might be better suited for artificial water storage solutions.

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. This summary, applicable to both new and existing buildings, identifies which soil types are suited for each intervention (Rijksoverheid, 2020). However, it lacks detailed information on subsurface properties. To address this gap, this paper incorporates the twenty-five interventions with additional subsurface information requirements using guidelines from the *Leidraad Klimaatadaptief bouwen 2.0* (Bouw Adaptief). These guidelines, available through the interactive Bouwadaptief website, offer more detailed insights into subsurface requirements than the 2020 government document.

### 2.2 Subsurface Information Models

Several models are available for above-ground elements in the Netherlands, such as trees and buildings, but fewer exist for subsurface information. This section reviews standardized models relevant to subsurface properties for climate adaptation in Utrecht for the four categories identified as relevant to local climate adaptation design, namely soil type, subsurface congestion, geomechanics, and groundwater level (see Figure 1).

Regarding the first identified subsurface property, soil type, GeoTOP is a 3D model depicting subsurface layers up to 50 meters deep, represented in 100 x 100 x 0.5 meter voxel blocks. It provides insights into soil types and is useful for large-scale applications like infrastructure planning and groundwater research (Basisregistratie Ondergrond, 2023). Despite its utility, GeoTOP's resolution may be inadequate for specific local interventions, necessitating additional local data for precise applications.

It is important to notice 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. This is indicated for example as 85% probability of sand. For accurate design or planning, local soil confirmation is often needed. The model is accessible via the 3D BRO webservices (Basisregistratie Ondergrond, 2023). This platform 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.

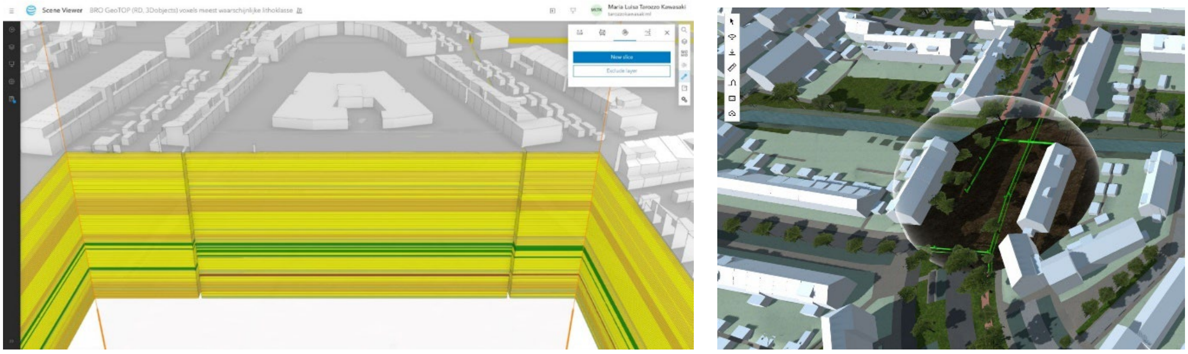

**Figure 2.** GeoTOP used to visualize soil types (left) and Utrecht3D used to visualize subsurface congestion (right)

Subsurface congestion is the second identified property, related to the available space underground for climate adaptation interventions. For this purpose, Utrecht's 3D digital twin can be used. This model includes subsurface elements such as cables and pipes, viewable through the municipality's web viewer (Gemeente Utrecht). This model supports local design needs by visualizing subsurface congestion.

The third property is geomechanics. In the context of urban design, geomechanics models assess subsurface load-bearing capacity. Utrecht provides a 2D map indicating suitability for traditional construction, considering factors like settlement sensitivity (Provincie Utrecht, 2011). While useful for regional design, it requires additional local data from Cone Penetration Tests (CPTs) for precise geotechnical assessments (Basisregistratie Ondergrond). 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 (Basisregistratie Ondergrond). Interpreting these graphs often requires a geotechnical expert, so while the information is publicly accessible, expert assistance is necessary for its application in design.

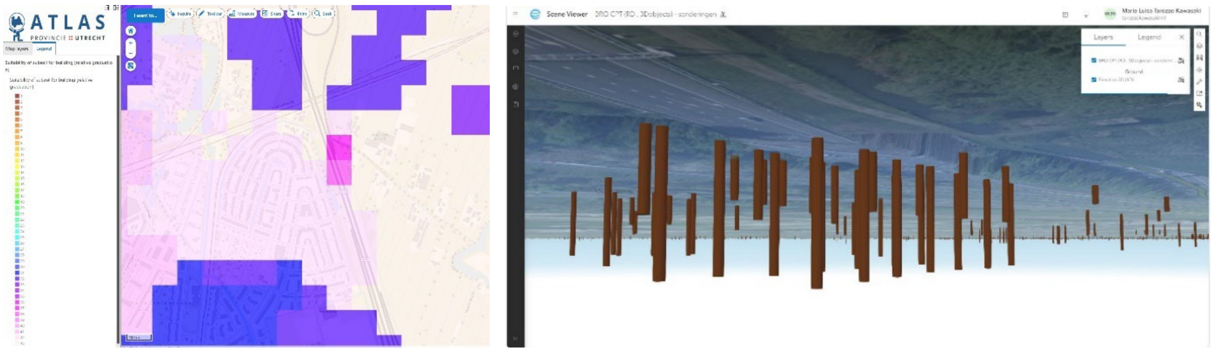


**Figure 3.** ATLAS used to visualize building suitability (left) and BRO 3D used to visualize CPTs (right)

Finally, the highest groundwater level, crucial for assessing subsurface suitability for water infiltration, is represented on a national 2D map of the Netherlands. This map shows the Average Highest Groundwater Level (GHG) under current conditions and is part of the Klimateffectatlas, which integrates national climate data to evaluate flood, waterlogging,

drought, and heat risks based on KNMI'14 climate scenarios. Provided by Esri Netherlands Content, this standardized ESRI map can be viewed via the ArcGIS web viewer or incorporated into ArcGIS software through the LivingAtlas (Kilmateffectatlas, 2022).
Groundwater monitoring wells are used to measure groundwater levels and quality. In the 3D BRO webservice viewer, the layer "Grondwatermonitoringputten" displays these wells as blue tubes, with measured levels in dark blue. Pop-ups provide details about the well, pipes, filters, and a link to BROloket for schematics and groundwater data (Basisregistratie Ondergrond). While this information is publicly available, expert consultation, typically with a hydrologist, is needed to effectively use it in urban planning.

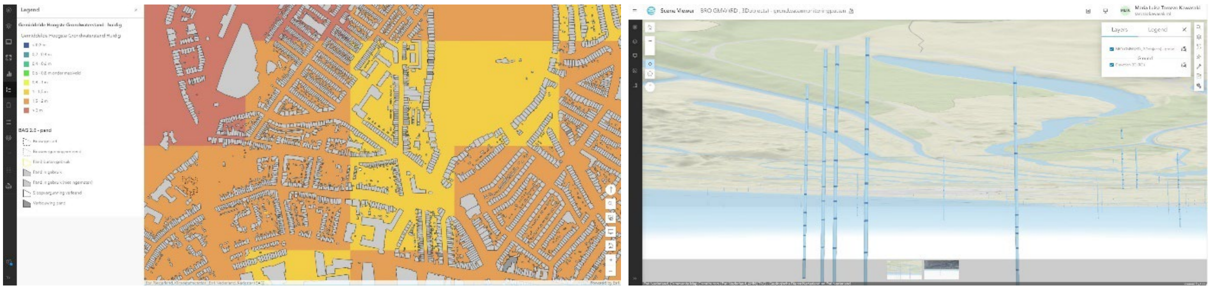

**Figure 4.** Highest groundwater level visualized with Klimateffectatlas (left) Monitoring wells visualized with BRO 3D (right)

## 3. CHALLENGES IN INTEGRATING SUBSURFACE INFORMATION

### 3.1 Barriers to the Interdisciplinary Integration of Information Models

Integrating expertise from various disciplines is essential to address complex issues like climate adaptation (Bhaskar, Frank, Høyer, Næss, & Parker, 2010). This requires T-shaped expertise (deep knowledge in one field and broad engagement across others) or interactional expertise, which involves understanding the language of another field without mastering all its details (Gorman, 2010) (Collins, Evans, & Gorman, 2007). However, it remains challenging to bridge Geoinformatics, Geology, and Urban Planning (Conley, Foley, & Gorman, 2017). This institutional challenge can partly be explained by the historical development of GIS removed from planning practices. GIS began in the 1960s within academia and became commercially available in the 1980s, but its integration into planning departments faced resistance due to its complexity (ESRI) (Zhu, 2016). GIS specialists often became technical support rather than decision-makers, a trend that persists today (Gorman, 2010). This has impeded an interdisciplinary approach, leaving planners and designers poorly trained in data creation and maintenance.
As cities become data-rich, sophisticated data models are increasingly needed. Integrating extensive data helps planners understand urban environments and identify intervention areas (Forgaci, 2020). Urban informatics is a field of research focused in combining geoinformatics and urban design, addressing urban challenges through data modelling (Goodchild, 2021). Digital tools and standards, such as those from the EU adaptation strategy, enhance climate impact understanding and urban planning (Climate-ADAPT). In the Netherlands, 3D subsurface data models have proven beneficial for energy transition, housing crises, and climate adaptation (Basisregistratie Ondergrond, 2022). However, the current models,

standardized and publicly available, are underused due to lack of integration with national design guidelines, appropriate tools, or standards (Zeiss, 2017)

### 3.2 Standardization as an Approach to Interdisciplinarity

Standards are essential for consistency and quality. In climate adaptation, they provide structured design, information and data models. However, an unified framework is missing, hindering effective well-informed climate adaptation design (ISO). Guidelines like the *Leidraad Klimaatadaptief bouwen 2.0* (Bouw Adaptief) and the *Klimaateffectatlas* (Klimaateffectatlas) offer design interventions, but integrating these with subsurface data models remains challenging.
The Basisregistratie Ondergrond (BRO) offers standardized subsurface data but is not fully integrated with design guidelines, limiting its use in climate adaptation (Zeiss, 2017) (Basisregistratie Ondergrond). Developing an integrated system to relate design interventions to subsurface data models would create an "information roadmap" for designers, geologists, and geo-informaticians. Moreover, standardizing 3D data models and web services, through collaborations between companies such as TNO, ESRI, and the Land Registry, can improve user interaction and integration into urban design (Basisregistratie Ondergrond). Standardization is also needed to share the results of designs including climate adaptation interventions. The Land Administration Domain Model (LADM) Part 5 (ISO 19152-5) supports standardized urban plans, crucial for sharing climate adaptation strategies globally (Kara, et al., 2024).
Therefore, the goal of this paper is to combine different crucial information for climate adaptation design in a single place and make use of standards for the exchange of climate adaptation information. For this purpose, an online catalogue, CLIMACAT, is created and described in section 4. This tool takes into consideration the different challenges presented in this paper and aims to be user friendly to designers, data providers and citizens. The tool was tested while designing climate adaptation urban plans for four different areas in Utrecht (see section 6.2). Moreover, in section 5, one of the urban plans and the described subsurface information models, is then stored using LADM Part 5 subclasses, assessing the suitability of this standard to share information regarding climate adaptation design, potentially globally.

## 4. COMBINING INFORMATION: CLIMACAT

The Open Geospatial Consortium (OGC) defines FAIR (findable, accessible, interoperable, and reusable) climate data services as crucial for effective climate information management (Hempelmann, 2022). This paper states that a FAIR climate catalogue, consolidating all relevant local climate adaptation data into a single online resource, is a key solution for integrating and accessing this information.
The digital Dutch climate design portal, named CLIMACAT, includes a climate design catalogue and different information sources necessary for climate adaptation urban design in one single place. Moreover, it introduces the user to climate themes topics and to the relationship between subsurface information, design standards, and climate adaptation design. The potential users for this website are urban designers, data providers, and citizens. Designers benefit from better understanding the information needed for their 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 can use it to better understand climate adaptation needs in the Dutch context.

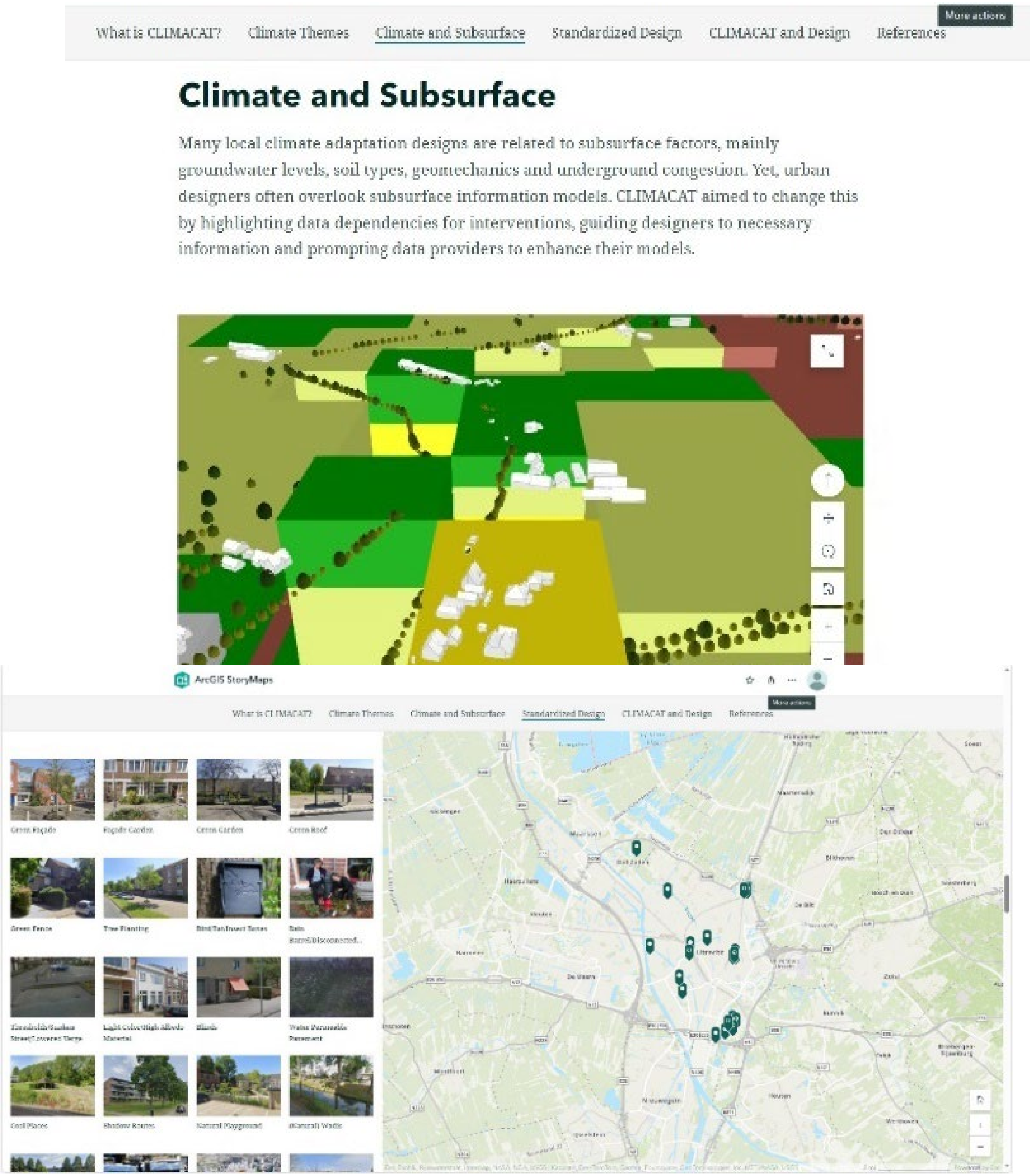


**Figure 5.** CLIMACAT showing subsurface models and the 25 standardized interventions

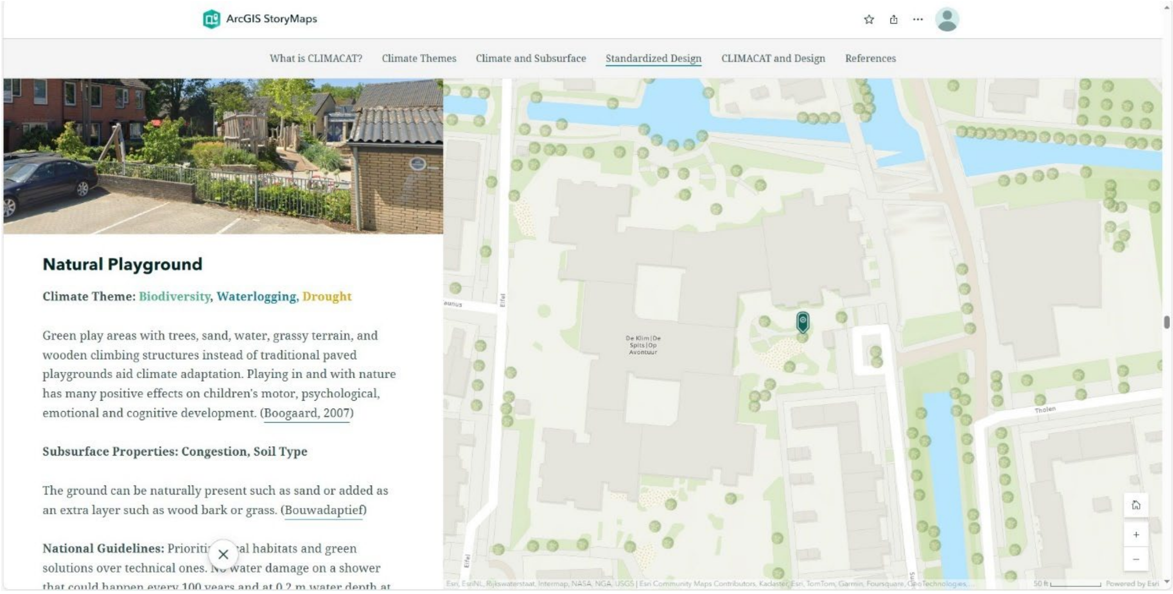


**Figure 6.** CLIMACAT showcasing one intervention along with its needed information and a geolocated example

CLIMACAT has a section on standardized climate adaptation design, where it indicates in a digital catalogue the twenty-five most used climate adaptation interventions in the Netherlands (Rijksoverheid, 2020), with a geolocated example in a map of the city of Utrecht, alongside with relevant information. For each intervention there is an explanation on how the intervention is an adaptation to the related climate theme (Rijksoverheid, 2020) (Bouwadaptief) (Klimaateffectatlas). This explanation often includes a link to technical drawings of the intervention. It then discusses the relevant subsurface properties, based on information from the *Leidraad Klimaatadaptief bouwen 2.0* (Bouwadaptief). The subsurface property name is a link to a web viewer or geoportal where this information can be found. It then indicates relevant national guidelines, taken from the Maatlat (Rijksoverheid) and local standards for the city of Utrecht, taken from the Leidraad (Bouwadaptief).
The online catalogue is concluded with an example use of this tool when designing. In the example, a neighbourhood 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, has all the identified information needs answered in one single place through the catalogue. This proved how a common ground can be found through a FAIR climate adaptation design portal. CLIMACAT is publicly available at https://arcg.is/4jPvG.

## 5. STANDARDIZING PLANS: LADM PART 5

Standardized urban plans enhance national and international knowledge exchange on diverse urban design and climate adaptation strategies. The LADM provides a unified framework for land administration, supporting spatial representations (Lemmen, Oosterom, Thompson, Hespanha, & Uitermark, 2010). The Spatial Plan Information Package (Indrajit, van Loenen, Ploeger, & van Oosterom, 2020) employs core LADM classes and add new ones to model plan group, block, unit and permit into spatial planning, using Party package classes from Part 2. Adopting a standard designed for sharing urban planning information can enhance the (inter)national exchange of climate adaptation plans and support the development of FAIR climate adaptation information systems. This paper introduces subclasses derived from the existing classes and properties in Land Administration Part 5, adding new attributes specifically for climate adaptation design in the Netherlands. These subclasses inherit the attributes of the original classes while integrating additional features 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 plan permits. The following subsections will detail these classes and outline how the climate adaptation subclasses were developed by extending existing attributes with new, relevant features.

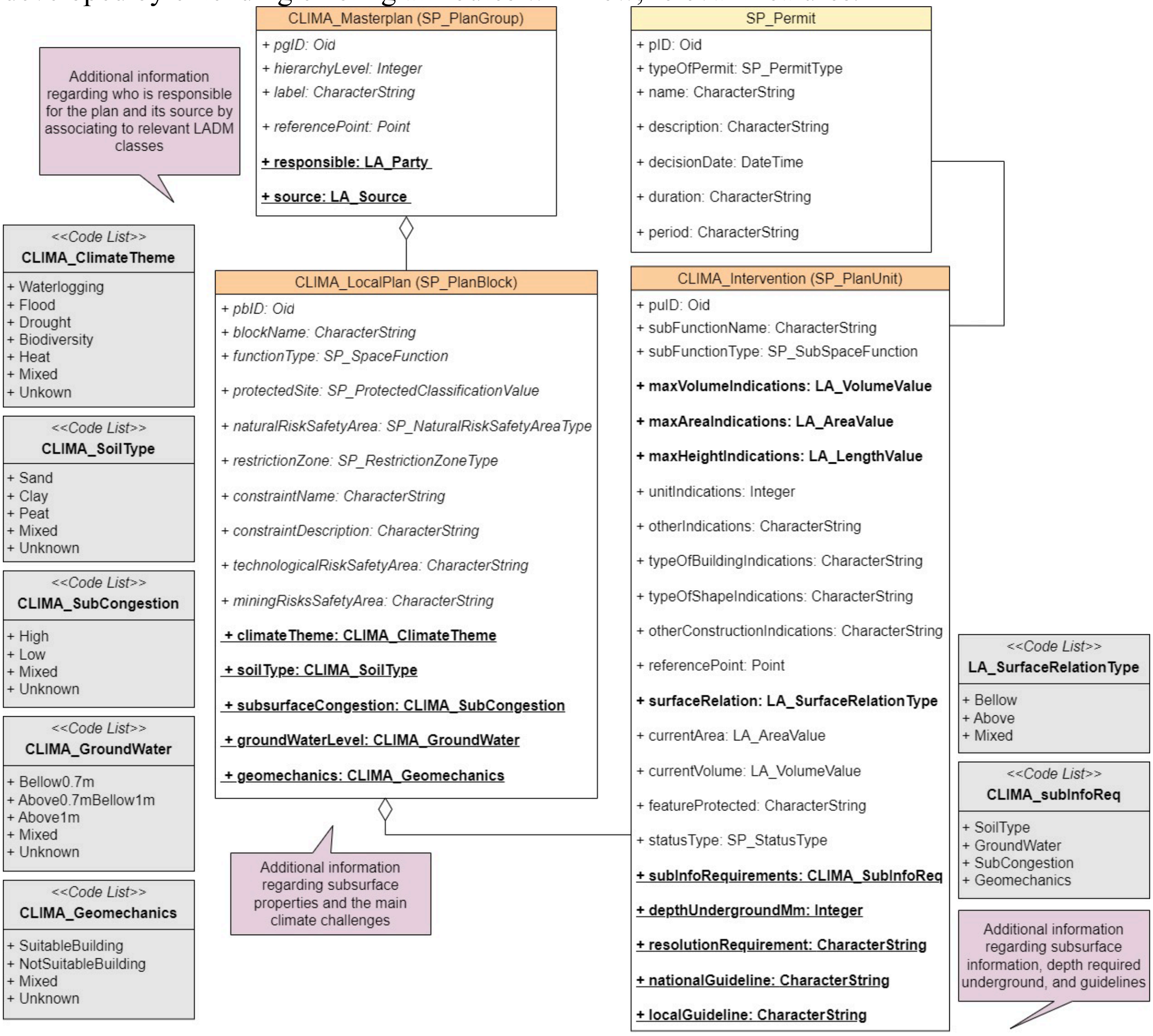


**Figure 7.** LADM Part 5 classes and new attributes (in bold) related to climate adaptation design

## 5.1 LADM Plan Group and CLIMA Plan Group

A Plan Group in the LADM represents an administrative hierarchy that organizes spatial plans. Higher-level plans, such as a national, regional or provincial masterplan, guide and encompass more detailed lower-level plans, like a neighborhood plan. 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.

## 5.2 LADM Plan Block and CLIMA Plan Block

An instance of the SP_PlanGroup class guides a collection of spatial planning blocks, with each block group linked to a single SP_PlanGroup instance. A SP_PlanBlock thus 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). These attributes are vital for climate adaptation, detailing current and future uses and risks. For climate adaptation design, additional attributes are introduced to capture climate themes, soil types, subsurface conditions, groundwater levels, and geomechanics, based on a predefined code list.

## 5.3 LADM Plan Unit and CLIMA Plan Unit

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 code list for key subsurface properties such as soil type, groundwater level, subsurface congestion, and geomechanics.

## 5.4 LADM Permit Registration

LADM Part 5 supports permit registration linked to plan units. The SP_Permit class handles permit-related information for zero or more plan units. Although this class is not central to this study, which focuses on design exploration rather than existing plans with permits, its inclusion is important for scenarios involving real plans where it would facilitate integrating permit information into climate adaptation designs.

# 6. RESULTS

The paper analyses the use of standardized information models, tools and standards in the context of climate adaptation design by proposing design explorations in four different neighbourhoods of Utrecht (see Figure 8). Each area's subsurface properties were carefully studied using relevant information models to address the main identified climate challenges. The interventions selected are based on the opportunities and challenges identified through these subsurface models. CLIMACAT facilitated the selection of interventions based on their subsurface properties, assessing the use of an online catalogue with different information models for design purposes. Finally, the plans were stored using the new and existing class attributes from LADM Part 5, evaluating the suitability of this standard for climate adaptation design.

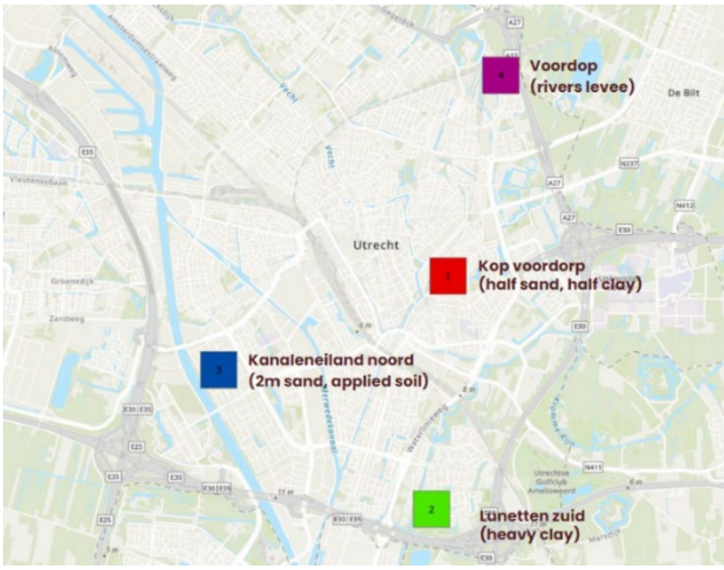


**Figure 8.** Design areas in Utrecht

### 6.1 Assessing Subsurface Information Models

For areas prone to waterlogging and flooding, GeoTOP was used to identify the soil type, assessing its suitability for rainwater infiltration. The first half meter is the most essential to assess direct rainwater infiltration of an area, therefore the resolution of GeoTOP layers (0.5 meter vertically) was adequate. Infiltration potential was further analysed using the Highest Groundwater Level model from Klimateffectatlas, which shows that a mean highest groundwater level above 0.7 meters below the surface reduces infiltration potential. Areas with clay or peat layers and high groundwater levels were considered unsuitable for natural infiltration and alternative interventions like artificial water storage were selected.

Utrecht3D's digital twin assessed subsurface congestion to determine if underground interventions needed size adjustments. This model was crucial for areas with high biodiversity and heat issues, helping to decide whether to use natural solutions like trees or alternatives like green roofs. The Atlas 2D map provided by the Utrecht geoportal was used to evaluate the geomechanical suitability for interventions involving significant weight.

Data resolution requirements varied: GeoTOP's 50 cm vertical resolution was adequate for small-scale interventions, but its 100 m horizontal resolution was less detailed. For larger interventions, this was less of a concern. Groundwater levels were useful, though a 3D model combining soil type and groundwater would provide better insights for natural infiltration. The ATLAS 2D building suitability map had limitations for smaller interventions due to its 100 x 100 meter cell size. The 3D on scale Utrecht3D model was very helpful for designing 3D subsurface elements such as infiltration crates or underground water storage.

### 6.2 Designing Using CLIMACAT

Once the climate challenges and subsurface properties of each area were studied using the existing models, three of the twenty-five standardized interventions were selected for each area. For this purpose, the decision tree presented in section 2.1 of this paper was used. An example of the use of this decision tree is shown in Figure 9.

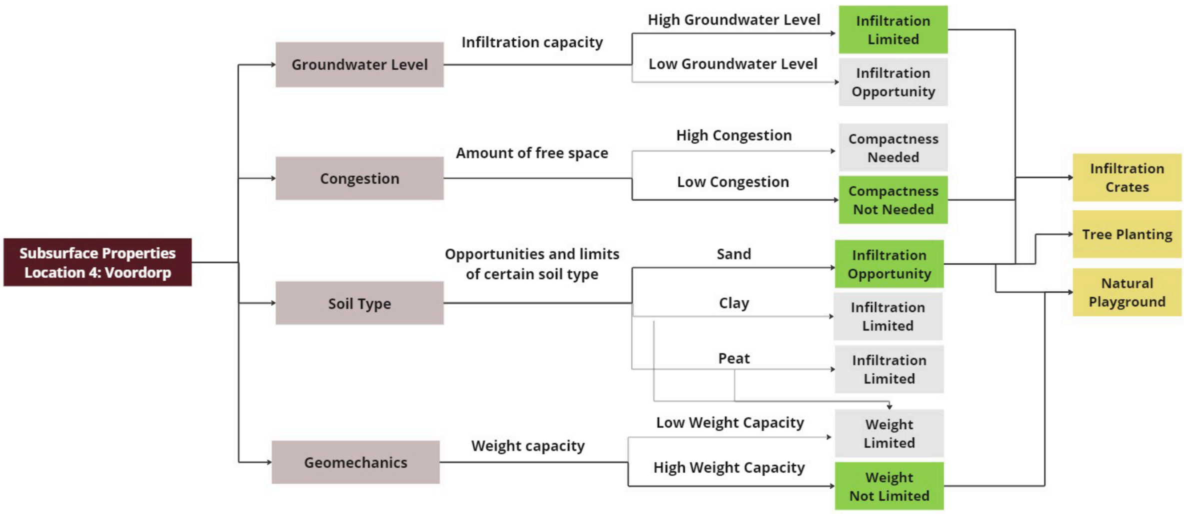


**Figure 9.** Decision tree used for design decisions

Based on subsurface characteristics from existing models, interventions were chosen using CLIMACAT, which efficiently matched interventions with suitable subsurface properties. For instance, in Voordorp, which faces heat stress and waterlogging, sandy soil and low congestion led to selecting infiltration crates and additional trees. The design also incorporated ecological and social factors. In Voordorp, features were added to a playground and public school area, combining underground water storage with infiltrating soil and greenery. The subsurface properties and standardized design interventions selected for each area are shown in Table 1. For detailed design insights, refer to the thesis (Tarozzo Kawasaki, 2024).

**Table 1.** Subsurface characteristics and choice for design interventions

| Neighborhood | Koop Voordop | Lunetten Zuid | Kanaleneiland | Voordorp |
|---|---|---|---|---|
| **Soil type first 0.5 m** | Clay | Clay | Clay | Sand |
| **Groundwater level** | High | High | High | High |
| **Subsurf. congestion** | Low | Low | High AND Low | Low |
| **Weight limitation** | Not limited | Limited AND Not | Not limited | Not limited |
| **Intervention 1** | **Bat/insect box** | **Surface water** | **Water storage paved surface** | **Infiltration crates** |
| **Intervention 2** | **Tree planting** | **Water square** | **Green garden** | **Natural playground** |
| **Intervention 3** | **Green roof** | **Water roof** | **Rain barrel** | **Tree planting** |

## 6.3 Storing Climate Adaptation Planning Information with LADM Part 5 Classes

LADM Part 5 includes classes essential for standardizing urban planning and design information. These basic classes—plan groups, plan blocks, plan units, and plan permits—are detailed in Chapter 5, where new attributes for climate adaptation were added. The Voordorp design proposal illustrates this process. By using adapted subclasses from LADM Part 5, the interventions and plans were stored in a database with both existing and newly defined attributes, demonstrating LADM Part 5's applicability to climate adaptation in urban planning.

```
INSERT INTO clima_planblock (pbid,blockname,functiontype,protectedsite,
    naturalrisksafetyarea,restrictionzone,constraintname,constraintdescription,
    technologicalrisksafetyarea,miningriskssafetyarea,climatetheme,soiltype,
    subsurfacecongestion,groundwaterlevel,geomechanics,plangroup_id) VALUES (
  'UVoord001',
  'VoordorpPlan001',
  'cultivationPublicFacility',
  '',
  'stormRiskZone',
  '',
  '',
  '',
  '',
  '',
  'Waterlogging Heat',
  'Sand',
  'Low',
  'Above1m',
  'SuitableBuilding',
  'MU2040'
);
```

**Figure 10.** Storing information using CLIMA_PlanBlock

A new table was created using the CLIMA_PlanGroup subclass, which builds on the SP_PlanGroup attributes by adding fields for the plan's responsible entity and source. Information about Utrecht's 2040 masterplan was stored here, with the municipality of Utrecht designated as the responsible party. Another table was created using the CLIMA_PlanBlock subclass for local plans, linking them to the masterplan and using the PlanGroup and PlanBlock classes to manage hierarchical relationships. This table incorporated attributes from the Spatial Planning LADM package for local plan functions and natural risks. The CLIMA_PlanBlock subclass added attributes for climate challenges, soil type, subsurface congestion, groundwater level, and geomechanics, storing details for the Voordorp design.

A third table catalogued the specific interventions within the Voordorp local plan, with each row representing one intervention. This table linked to the Voordorp plan and used the PlanUnit subclass to detail attributes like subfunction, area, volume, height, status, and surface relation. The CLIMA_PlanUnit subclass expanded on these with attributes for resolution requirements and guidelines. Though CAD or 3D files could be used with tools like FME, the preliminary nature of the Voordorp designs meant this was not done. Instead, plan information was stored in tables, as shown in this paper.

```sql

INSERT INTO clima_planunit (puid,subfunctionname,subfunctiontype,
    maxvolumeindications,maxareaindications,maxheightindications,unitindications
    ,otherindications,typeofbuildingindications,typeofshapeindications,
    otherconstructionindications,referencepoint,surfacerelation,currentarea,
    currentvolume,featureprotected,statustype,subinforequirements,
    depthundergroundmm,resolutionrequirement,nationalguideline,localguideline,
    planblock_id) VALUES (
  'InfiltrationCrates',
  'underPlayground',
  'education',
  '190',
  '159',
  '1',
  '',
  '',
  '',
  '',
  '',
  '',
  'Bellow',
  '159',
  '0',
  '',
  '',
  'GroundWater␣SoilType␣SubCongestion',
  '1000',
  '0,5x0.5x0.5',
  'Maatlat',
  'N1␣N2␣N3␣D1␣D2',
  '001'
);
```

**Figure 11.** Storing information using CLIMA_PlanUnit

## 7. DESIGN EVALUATION SURVEY

The design choices demonstrate the value of integrating standardized climate adaptation interventions with subsurface information models and tools. However, as the interventions were selected by a single author, a method for evaluating potential biases is proposed. For this, two design areas from this study were compared with proposals from sixteen designers, of which ten were students of architecture, landscape architecture, or urbanism, and six were professional urban designers. An online survey was employed to gather responses on the climate challenges of Lunetten Zuid and Kanaleneiland Noord. Participants were provided

with climate-themed maps and chose from twenty-five standardized interventions, each illustrated with a small image. Following their intervention selections, participants explained their choices and identified potentially useful datasets. While they were aware that the survey was for research purposes, they were not informed about all details.
For Lunetten Zuid, which is prone to heat stress and flooding, designers predominantly selected green gardens, tree planting, natural routes, and natural wadis to increase water infiltration and provide shade. However, due to the area's clay soil and high groundwater levels, the infiltration capacity is limited. With subsurface data, designers might have opted for more suitable interventions such as water squares or green roofs. In Kanaleneiland Noord, which faces biodiversity and waterlogging issues, designers favored green gardens, natural playgrounds, natural wadis, and soil structure improvements to enhance biodiversity and rainwater infiltration. Despite the absence of soil knowledge, many chose soil structure improvements, but given the area's clay soil and high groundwater levels, interventions like artificial water storage and rain barrels would be more appropriate.
When queried about additional helpful information, most designers mentioned demographic data, with only 12.5% highlighting the need for subsurface information, and half of those specifying soil type. This survey underscores how the lack of subsurface information can result in less effective climate adaptation interventions. A comprehensive understanding of soil type, subsurface congestion, groundwater levels, and geomechanical properties is essential for context-sensitive and effective design decisions. Nevertheless, a small proportion of designers recognize the relevance of subsurface data in preliminary climate adaptation design. The approach proposed in this paper, with the use of tools and standards such as CLIMACAT and LADM Part 5, aims to increase this number.

## 8. CONCLUSION

### 8.1 Main Results

The integration of CLIMACAT and LADM Part 5 represents a comprehensive approach to addressing the challenges associated with integrating subsurface information into climate adaptation design using information models and standards. Both tools are essential in overcoming institutional, technological, and semantic barriers that have historically impeded the effective utilization of subsurface data in urban planning.
CLIMACAT, an online catalogue, consolidates various types of information crucial for climate adaptation design. 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 data repository. This approach aligns with the FAIR data principles, ensuring that climate adaptation interventions are well-informed and context specific. On the other hand, LADM Part 5 offers a standardized framework for documenting and sharing urban plans that incorporate climate adaptation strategies. The use of LADM Part 5 facilitates the integration of spatial planning information within a unified model. This standardization is crucial for the international sharing of urban plans, thereby enhancing global knowledge exchange and collaboration on climate adaptation practices. Moreover, the creation of class attributes tailored for climate adaptation design

ensures that specific requirements, such as subsurface properties and intervention suitability, are adequately captured and documented.
The combined use of CLIMACAT and LADM Part 5 ensures that climate adaptation designs are both well-informed and standardized. CLIMACAT enhances the accessibility and usability of critical data, while LADM Part 5 ensures that the resulting plans are documented in a manner that facilitates sharing and interoperability. This dual approach addresses the institutional challenges of integrating geoinformatics with urban design by providing both a practical tool for design and a standardized framework for documentation and dissemination. Thus, the synergy between CLIMACAT and LADM Part 5 represents a comprehensive solution for advancing climate adaptation efforts through improved integration of subsurface information into urban planning processes.

### 8.2 Future work

This paper discusses the combined use of an online portal and standardized information models for the exchange of information related to climate adaptation in the context of the Netherlands, and particularly the city of Utrecht. Future work potentially could include the assessment of this method in different cities and countries. Utrecht benefits from a wide range of information models that make it possible to combine different information into a singular portal. Future work could include the assessment of this approach in smaller municipalities with scarcer data availability. Moreover, this approach is believed to be useful on an international level, but this could be further investigated in new research. Further work could include the use of LADM Part 5 subclasses tailored to climate adaptation in different countries, for example.
In this paper, the LADM Part 5 classes and subclasses were used to store information regarding urban plans created by the authors based on subsurface characteristics. These plans did not contain the detailed planning information that a spatial plan approved by authorities usually does, such as geometry and other detailed attributes. Therefore, future work could include the use of the proposed new attributes for approved urban plans. This would allow, for example, the use of tools such as FME to load planning information, such as (3D) geometry.
Finally, CLIMACAT was created based on the research and experience from the authors. Feedback from users will allow it to improve, leading to further work and a better tool for the purpose of integrating standardized information into climate adaptation design practices.

## REFERENCES


Alphen, J. v. (2016). The Delta Programme and updated flood risk management policies in the Netherlands. *Journal of Flood Risk Management, 9*(4), 310-319. Retrieved 7 16, 2024, from https://onlinelibrary.wiley.com/doi/full/10.1111/jfr3.12183

Basisregistratie Ondergrond. (2022). *De waarde van 3D beleidsvorming voor onze nationale ruimtelijke ordening*. Retrieved from https://www.youtube.com/watch?v=XkCYKMpYn-g

Basisregistratie Ondergrond. (2023). *BRO 3D Webservices*. Retrieved from Basisregistratie Ondergrond: https://3d-bro-webservices-esrinl-content.hub.arcgis.com/

Basisregistratie Ondergrond. (2023). *GeoTOP (GTM)*. Retrieved from Basisregistratie Ondergrond: https://basisregistratieondergrond.nl/inhoud-bro/registratieobjecten/modellen/geotop-gtm/

Basisregistratie Ondergrond. (n.d.). *About the key registry*. Retrieved from Basisregistratie Ondergrond: https://basisregistratieondergrond.nl/english/about-key-registry/

Basisregistratie Ondergrond. (n.d.). *Geotechnisch sondeeronderzoek (CPT).* Retrieved from Basisregistratie Ondergrond: https://basisregistratieondergrond.nl/inhoud-bro/registratieobjecten/bodem-grondonderzoek/geotechnisch-sondeeronderzoek-cpt/

Basisregistratie Ondergrond. (n.d.). *Model Grondwaterspiegeldiepte (WDM).* Retrieved from 3D BRO Webservices: https://3d-bro-webservices-esrinl-content.hub.arcgis.com/pages/f657fe526e7f4a0681eee05b9808582c

Basisregistratie Ondergrond. (n.d.). *Sonderingen.* Retrieved from 3D BRO Webservices: https://3d-bro-webservices-esrinl-content.hub.arcgis.com/pages/41cdb4c913234ad59640b6fa5aeb0891

Basisregistratie Ondergrond. (n.d.). *The BRO 3D services project*. Retrieved from Basisregistratie Ondergrond: https://basisregistratieondergrond.nl/werken-bro/producten-diensten/bro-3d-webservices/project/

Bhaskar, R., Frank, C., Høyer, K. G., Næss, P., & Parker, J. (2010). *Interdisciplinarity and Climate Change*. Retrieved 7 16, 2024, from http://research-information.bristol.ac.uk/en/publications/critical-realist-interdisciplinarity-a-research-agenda-to-support-action-on-global-warming(d1f2ae2b-a3fa-4480-bd36-332fcd973b4e)/export.html

Bouw Adaptief. (n.d.). *Waarom deze leidraad 2.0*. Retrieved from Bouw Adaptief: https://bouwadaptief.nl/leidraad/waarom-deze-leidraad/

Bouwadaptief. (n.d.). *Doelen en eisen klimaatadaptief bouwen*. Retrieved from Bouwadaptief: https://bouwadaptief.nl/leidraad/doelen-en-eisen-klimaatadaptief-bouwen/

Bouwadaptief. (n.d.). *Welkom | Bouw Adaptief*. Retrieved from Bouw Adaptief: https://bouwadaptief.nl/

Climate-ADAPT. (n.d.). *EU Sector Policies: ICT.* Retrieved from Climate-ADAPT: https://climate-adapt.eea.europa.eu/en/eu-adaptation-policy/sector-policies/ict/index_html/

Collins, H. M., Evans, R. J., & Gorman, M. E. (2007). Trading Zones and Interactional Expertise. *Studies in History and Philosophy of Science, 38*(4), 657-666. Retrieved 7 20, 2024, from http://orca.cf.ac.uk/53873

Conley, S., Foley, R., & Gorman, M. (2017). Acquisition of T-shaped expertise: an exploratory study. *Social Epistemology*, 165-183.

Deltacommissaris. (n.d.). *What is the National Delta Programme?* Retrieved from https://english.deltaprogramma.nl/delta-programme/what-is-the-delta-programme#:~:text=Goal%20of%20the%20Delta%20Programme&text=This%20means%20that%20flood%20risk,the%20effects%20of%20climate%20change.

Deltares. (n.d.). *Urban infiltration opportunities*. Retrieved from Klimaateffectatlas: https://www.klimaateffectatlas.nl/en/urban-infiltration-opportunities

Esri. (n.d.). *History of GIS*. Retrieved from Esri: https://www.esri.com/en-us/what-is-gis/history-of-gis

ESRI. (n.d.). *What is GIS?* Retrieved 7 20, 2024, from ESRI: http://www.esri.com/what-is-gis

Forgaci, C. (2020). Smart and resilient cities: How can big data inform spatial design and planning for urban resilience? *Contesti. Città, Territori, Progetti*, 62–71.
Gemeente Utrecht. (n.d.). *Utrecht in 3D*. Retrieved from Gemeente Utrecht: https://www.utrecht.nl/bestuur-en-organisatie/publicaties/utrecht-in-3d/
Goodchild, M. F.-P. (2021). *Urban informatics.* Springer.
Gorman, M. (2010). Trading zones and interactional expertise. *Inside Technology*.
Hempelmann, N. (2022). *OGC Climate Resilience DWG*. Retrieved from https://portal.ogc.org/files/?artifact_id=102202
Indrajit, A., van Loenen, B., Ploeger, H., & van Oosterom, P. (2020). Developing a spatial planning information package in ISO 19152 land administration domain model. *Land Use Policy*, 104-111.
ISO. (n.d.). *Benefits of ISO standards*. Retrieved from ISO: https://www.iso.org/benefits-of-standards.html
Kilmateffectatlas. (2022). *Gemiddelde Hoogste Grondwaterstand - huidig.* Retrieved from Kilmateffectatlas: https://hub.arcgis.com/maps/cdaa261dc20d4b669e8c06525fa2fc96/about?layer=0
Klimaateffectatlas. (n.d.). *Gebruik van de atlas*. Retrieved from Klimaateffectatlas: https://www.klimaateffectatlas.nl/nl/gebruik-van-de-atlas
Klimaateffectatlas. (n.d.). *Viewe*. Retrieved from Klimaateffectatlas: https://www.klimaateffectatlas.nl/en/
Lemmen, C., Oosterom, P., Thompson, R., Hespanha, J., & Uitermark, H. (2010). The modelling of spatial units (parcels) in the land administration domain model (LADM). *XXIV FIG International Congress 2010: Facing the Challenges - Building the Capacity.*
Ministerie van Infrastructuur en Waterstaat. (2022). *VOORTGANGSRAPPORTAGE DELTAPROGRAMMA RUIMTELIJKE ADAPTATIE OVER 2022.* Ministerie van Infrastructuur en Waterstaat.
Ministry of Infrastructure and Water Management. (2023). *Delta Programme 2024.* Ministry of Infrastructure and Water Management.
Provincie Utrecht. (2011). *Soil Suitability Map: Suitability for Building.* Retrieved from Nationaal Georegister: https://www.nationaalgeoregister.nl/geonetwork/srv/api/records/e38c320c-7fe1-4269-b061-4a706b804ba5
Rijksoverheid. (2020). *Klimaatadaptatie Maatregelen.* Retrieved from Infographics RVO: https://infographics.rvo.nl/klimaatadaptatie/maatregelen/#mii-rvokam-bouwen-en-renoveren
Rijksoverheid. (n.d.). *Landelijke maatlat*. Retrieved from Rijksoverheid: https://www.rijksoverheid.nl/documenten/rapporten/2023/03/23/landelijke-maatlat-factsheets-en-overzichtstabel
Tarozzo Kawasaki, M. L. (2024). *Common Ground: Bridging Subsurface Information Models and Climate Adaptation Design.* TU Delft.
Zeiss, G. (2017). Key registry created in the Netherlands to help model the subsurface. *Between the Poles: All About Infrastructure*.
Zhu, X. (2016). *GIS for Environmental Applications: A practical approach.* Routledge.

## BIOGRAPHICAL NOTES

**Maria Luisa Tarozzo Kawasaki** holds two Master of Science degrees in Geomatics and Urban Design from Delft University of Technology. This paper is partly based on her thesis, "Common Ground: Bridging Subsurface Information Models and Climate Adaptation Design." Her research emphasizes interdisciplinary approaches to societal challenges, particularly integrating geoinformatics and design. An example is her article "Digital Surveys to Access Marginalized Views in Favela Communities," published by Urbanet. She currently works as an information analyst at TNO in Utrecht.

**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 meters 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.

**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.

**Alexander Wandl** is an urbanist and associate professor at the chair of Environmental Technology and Design, at the Faculty of Architecture and the Built Environment. His research focuses on developing sustainable urbanisation, using an extended territorial metabolism approach and integrating (GIS-supported) methods and tools from different disciplines. As scientific coordinator of the Horizon 2020 financed research project REPAiR – Resource Management in peri-urban areas– he is at the forefront of developing spatial strategies, which support the transition towards a circular economy. He specifically focuses on the challenges related to the sustainable development of dispersed urban areas and peri-urbanisation processes in Europe.

**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.

## CONTACTS

**Maria Luisa Tarozzo Kawasaki, Rob van der Krogt, Wilfred Visser**
TNO - Geological Survey of the Netherlands
Princetonlaan 6, 3584 CB Utrecht
NETHERLANDS
Phone: + 31 619327169
E-mail: malu.kawasaki@gmail.com, rob.vanderkrogt@tno.nl, wilfred.visser@tno.nl

**Ulf Hackauf, Alexander Wandl, Peter van Oosterom**
TU Delft
Julianalaan 134, 2628 BL Delft
NETHERLANDS
Phone: +31 152787804
Email: UDHackauf@tudelft.nl, A.Wandl@tudelft.nl, P.J.M.vanOosterom@tudelft.nl