Common Ground:

Bridging 3D Subsurface Information Models and Climate Adaptation Design

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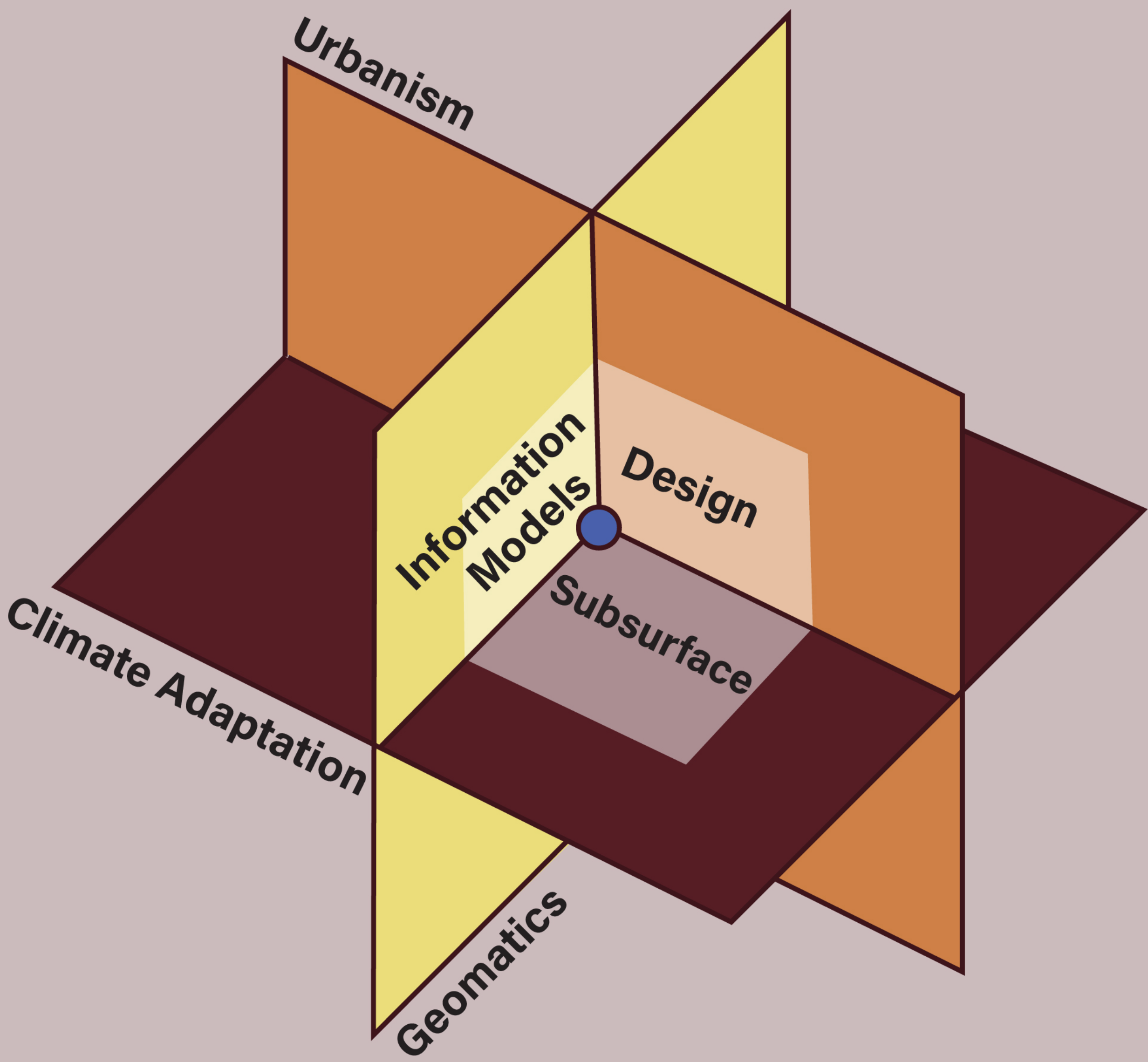

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1 Introduction

The Delta Program states that the Netherlands must be climate-resilient and water-robust by 2050, posing a great challenge to many different fields, including that of spatial planning. [1] This imminent task requires a collaborative, interdisciplinary approach. Relying solely on mono-disciplinary reductionist methods, as argued by Bhaskar, often proves insufficient when confronting complex phenomena because climate adaptation is a multifaceted issue that encompasses ecological, social, economic, and technological dimensions. [2]

One of the many aspects that climate adaptation is directly related to is subsurface information. In 2022, the cabinet selected 'water and soil guiding' as a fundamental principle for spatial planning in the Netherlands. And, while the principle may appear clear-cut initially, translating it into practical solutions proves to be a complex task. [3] To mention a few examples, some design requirements for subsidence do not apply to higher sandy soils and water infiltration rate and capacity are directly related to the soil permeability, indicated by soil types and groundwater level, of the different surface layers. [4]. In addition, the lack of knowledge on subsurface information can lead to undesired consequences, such as groundwater being contaminated by sewage due to lack of knowledge on groundwater levels, parks with high maintenance costs due to the planting of species that are not suitable for a certain soil type, or a building that sinks irregularly because part of it is in a different, more soft, soil type.

There are also financial reasons to justify using subsurface information when designing. For example, Dirksland, located in the South Holland municipality of Goeree-Overflakkee, was a residential area under construction with a total of twenty-seven houses that were demolished in 2014. The reason for this was the use of too short foundation piles, causing the houses to sink and creating cracks in the walls. The contractor attempted to repair the foundation to prevent demolition but without success. This resulted in significantly high costs. [5] By better assessing the soil conditions in advance, the demolition could have been avoided, and additional costs could have been saved.

In this context, data models can support well-informed design decisions, since many interventions related to flood and drought, such as water storage, soil infiltration and underground spatial management, require a deeper knowledge of soil characteristics and configurations. These characteristics have been traditionally represented in 2D. However being 3D objects in real life, 3D representations are arguably beneficial, not only to illustrate the final design, but during the integral design process. [6]

Currently, the Netherlands benefits from 3D data models with subsoil information of the whole country. However, interviews with professionals in relevant fields show that there are still barriers to the integration of existing data models into climate adaptation design. Literature reviews that these barriers are often related to the differences between the way designers and geodata engineers carry out their activities and approach problems in combination with a historical introduction of Geographic information systems (GIS) into urban design. Other barriers are more technological and data-related, such as the fact that cities went from data-poor to data-rich and advances in GIS technologies that were developed separately from planning and are still underused in climate adaptation design due to the lack of knowledge of designers of what is available and how to use it.

In addition, there are barriers related to standardization, both in the geoinformatics and the urban design realms. Through data standardization these models could be integrated in design, planning, and overall land administration to solve multiple urban challenges, including climate adaptation. In a similar way, through design standardization, climate adaption becomes concrete through well-defined interventions, leading to realistic road maps for cities goals related to climate, such as the one defined by the Delta Programme.

As highlighted by the Delta Program, to achieve concrete results it is important to reach an agreement on what climate adaptation means in practical terms, through standardization. [7] For this reason, this research opted to focus on concrete examples of standards for climate adaptation in urban design, coming from the Leidraad 2.0 and the Klimaateffectatlas, and the relationship of these with existing Dutch 3D subsurface data models, namely the 3D Key Registry for the Subsurface.

For the same reason the thesis opted to focus on information models instead of data models in specific. While data models are used in actual implementations, information models are more abstract and focus on the meaning (semantics), attributes and relationships between managed objects.

Thus this thesis explores how standardized information models can aid the cause of climate design adaptation in the Netherlands. For this purpose, the models should relate subsurface properties, existing 3D data models, and design interventions, to indicate where the relationships and dependencies between information and practice is stronger, and thus where climate adaptation is most likely to benefit from existing data models.

Design proposals were made for four different 500 by 500 meter areas in Utrecht, namely Voordorp, Lunetten, Zuilen, and Leidsche Rijn. Each area will cover one of the four landscapes and soil types of Utrecht and in specific storm water events. To focus purely on the relationship between subsurface and climate adaptation, the four chosen areas have similar density, urban morphology and social aspects. For each area, a more specific area of intervention was identified, such as one public space. Once the smaller area is defined, an intervention described the Leidraad 2.0 is tested, remaining sensitive to the subsurface with the help of existing data models. The design proposals showcase how this integrated approach could be and explore the added value for climate adaptation when using information models.

2
Related Work

Currently, the author and mentors are not aware of a study that relates existing standardized climate adaptation interventions to existing subsurface information models in the Netherlands.

However, many studies were published on the relevance of subsurface information to climate adaptation design. This consists of extensive literature and, for this graduation program, it is sufficient to refer to the importance of subsurface in the Dutch design context, exemplified by the cabinet defining 'water and soil guiding' as the fundamental principle for spatial planning in the country.

The most relevant work on the barriers to a geomatics integration in design is mentioned below, along with relevant work on the standardization of both climate adaptation interventions and land administration.

2.1. Related work on barriers for information models in design

Heinemman once stated that "we are born into this world as quasi-interdisciplinary creatures, and the older we get, and the more we identify knowledge packages resulting from knowledge acquisition and personal reflection, the more we tend to become disciplinary creatures." [8] However, the literature argues that to deal with emerging complex problems, such as climate adaptation and mitigation, the integration of multiple expertise in related disciplines is needed. [2] [9]

The integration of information models in climate adaptation design is thus part of the so-needed interdisciplinary approach when dealing with climate change. There are two ways to achieve this goal: through the addition of T-shaped expertise or through interactional expertise. Both solutions face institutional barriers related to the way the disciplines of Geoinformatics and Urban Design are taught in educational environments and to how GIS was introduced in urban design and planning environments.

From the literature related to T-shaped expertise: "The horizontal aspect of the 'T' represents a breadth of expertise, an ability to engage with other experts across a variety of systems and intellectual and disciplinary cultures; the vertical part of the 'T' represents a depth of expertise in a specific knowledge domain.” [9] In the context of this thesis, a T-shape expertise would be a professional with a deep vertical understanding of one of the two related fields, namely Geomatics and Urban Design, but able to expand this knowledge horizontally. From the experience of the author, and literature, students are still not trained to be T-expertise in these and many other fields of study. The thesis argues that this calls for changes in established curriculum that are divided by disciplinary expertise. [9]

As a more broad term, ”interactional expertise” refers to learning the ”language” of another expertise without having to master all the aspects of a certain discipline. [10], or the ability to interact about topics related to a certain discipline without being a practitioner. [11] In the context of this research, it would mean for example for a designer to be able to understand what he or she requests from a data model without fully understanding the informatics aspect of how the data model works. Or to be able to relate subsurface properties to different desing interventions without having full knowledge of Unified Modeling Language.

However, this common ground for knowledge trade faces a barrier that is not only related to how the two disciplines are taught in universities but also to how GIS was integrated in urban design and planning departments once it became commercially available.

As an historical overview, GIS origins can be traced back to the 1960s when computers and early quantitative and computational geography concepts began to take shape. During this period, the academic community played a pivotal role in conducting significant research in the field of GIS. Under the leadership of Michael Goodchild, the National Center for Geographic Information and Analysis played a crucial role in formalizing research related to essential topics in geographic information science, such as spatial analysis and visualization. [12] In the following years, advancements in computation capacity allowed continuous improvement of GIS software tools. However, it was only twenty years later, in the early 1980s, that GIS tools became commercially available. In 1986, the Mapping Display and Analysis System (MIDAS), the first GIS desktop product, became available for the DOS operating system. Later, in 1990, it was rebranded as MapInfo for Windows when it was adapted for the Microsoft Windows platform. This transition marked the commencement of the shift of GIS from the research sector into the realm of business applications. [13]

This early version of commercial GIS, when introduced into planning departments in the 1980s and early 1990s, was received with fear, hesitation and even opposition towards its use. [14]. These negative reactions were not surprising as the GIS software available at the time was not intuitive and often required command-line operations. Furthermore, GIS specialists frequently found themselves in the role of technical support staff, even those with planning backgrounds, something that is still often observed in urban design offices today. The available data layers were often incomplete, and the considerable time spent on data creation and maintenance limited the capacity of GIS specialists to apply GIS for decision support in planning or design. [14]

Thus, how GIS technology was introduced into design did not promote an integrated interdisciplinary approach, and only aggraveted the segregation between the fields of Geoinformatics and Urban Design, and for a data model approach while designing. Even on the occasions in which there was T-shape expertise with knowledge of GIS and a background in planning, this professional assumed a monodisciplinary role. Additionally, designers and planners were not educated on data creation and maintenance, making the task of integrating these new technologies into spatial decisions very time-consuming. Currently, students and professionals face similar barriers even decades after the first introduction of GIS into design and planning, not being educated or able to assume a T-shaped expertise or interactional expertise role. In addition, with GIS technologies rapidly evolving and cities producing more and more diversified data, this institutional barrier is aggravated by technological and semantic barriers.

In this context, data-related issues increasingly become an issue as cities move from data-poor to data-rich environments. Emerging from technological, institutional, social, and business innovations, there is a proliferation of new data sources regarding cities, significantly expanding the opportunities available to urban research. Thus there are challenges regarding innovative approaches to accessing existing data sources and new methods for linking data from various domains and owners are giving rise to interconnected data systems in addition to the traditional barriers to integrating GIS to urban planning and design found by previous research. [15]

While adaptation is required, research shows that through the integration of extensive data, planners can attain a comprehensive understanding of the urban environment. A data-rich environment enables, for example, the identification of critical vulnerability zones that necessitate strategic intervention. [16]. However, to fully benefit from the opportunities of a data-rich environment, this data needs to be processed and made readable to planners.

In this context, urban informatics emerges as an interdisciplinary approach to understanding, managing and designing urban systems through information and communication technology, grounded in contemporary developments of computers. [17] It remains a relatively new concept, being the term used for the first time in an article published in 2003 by Rheingold [18], and was disciplinarily grouped as a single research lab for the first time in 2011. [19] At the time of the publication, part of this research lab focus was on real-time information to inform new design approaches and information interfaces that contributed to a low-carbon future. [19]

This is just an example of a combination of geoinformatics and design to tackle a complex urban challenge by data modelling, where choices were made regarding the presentation and standardization of the collected data. The use of existing data models in combination with new forms of data, or through data-driven urban data modeling, allows urban processes and behaviours to be in a new, and arguably more time-efficient, manner. [20] In addition, the knowledge discovery aspects of data-driven models can attract the attention of citizens and decision-makers on urban problems and stimulate new hypotheses about urban phenomena, which could potentially be rigorously tested using inferential new data models. [20]

The EU adaptation strategy clearly states that digital transformation is critical to achieving the Green Deal adaptation objectives. New instruments such as Destination Earth and Digital Twins hold great promise to boost our understanding of present and future climate impacts at a planetary and local scale. Ocean measurements and observation will also be further strengthened [21]

For example, a case study in New York concluded that combining different data sources regarding energy in one model was crucial for CO_2 reduction city planning. [22] In particular, the paper analyzed the status quo and tested different scenarios for a district in Brooklyn, using Web 3D data models to handle the spatial and temporal data diversity, making it possible to quantify the energy and CO_2 contributions of different urban sectors by combining data regarding electricity consumption, food related consumption and organic waste. The information provided by the data model allowed planners to identify that a cooling set point increases and lowering infiltration losses could reduce the annual cooling demand by 63%, reducing heating demand by 12%. [22] This exemplifies how data models can contribute to quantifying aspects of sustainability in urban design and lead to more well-informed solutions and realistic road maps for cities' climate mitigation.

In addition, models in three dimensions provide the advantage of offering a more user-friendly visualization, given that 3D objects closely mimic human interactions with city objects. For example, it is arguably more intuitive for a person to think of a simple building as a 3D solid instead of a rectangle. Because humans move and interact with objects in three dimensions, and because these objects are also 3D, we perceive cities as three-dimensional. [23] An extensive literature exists on the use of 3D data models for participatory design [24] [25] and to solve societal and environmental urban challenges. [26] [27] [28] however the literature often covers only above surface urban data models.

A digital twin is often used for urban design integrating 3D data models, that is a virtual replica of a physical object, such as a building, or an entire system, such as a city. Digital twins make the physical aspects of the urban environment more apparent. This is particularly interesting for the underground, a space in the urban environment which is often not visible. This made risks and potentials in the subsurface finally emerge, adding a new dimension to the urban design task at hand.

This is particularly interesting for aspects of climate mitigation and adaptation that are directly related to the underground, such as many aspects of urban climate adaptation or mitigation and energy transition. For example, a subsurface 3D data model could indicate which surface is more adequate for water infiltration due to their soil type or indicate where to place a new sustainable energy network on a congested urban underground.

Furthermore, research suggests that a 3D spatial data model that can integrate above surface and subsurface elements will have a significant impact on engineering, spatial and urban planning, and the built environment. [29] This type of data model combines the well-studied benefits in urban planning and design of above-surface 3D elements with the often hidden information about the underground.

In the Netherlands, urban design and planning have proven benefits from 3D subsurface data models when tackling the following urban challenges: energy transition, housing crisis, and climate adaptation. [30] This is mainly because these challenges are highly related to the social and morphological characteristics of the country. The Netherlands is a densely populated country, where space is scarce, both below and above the surface. In addition, it is largely below sea level, making challenges related to climate change and sea-level rise particularly important.

To simplify the data used to solve some of these challenges, a system of basic registers has been developed in the Netherlands. This information is publicly available through the web service of the 3D Key Registry for the Subsurface. This service is however is still underused for concrete climate adaptation actions and one of the reasons for this is related to climate adaptation definitions, where often a lack of standardization poses a barrier in relating a design intervention with the best data model to be integrated to it.

2.2. Related work on standards

Standards are often the hidden backbone of many aspects of daily life, ensuring consistency and quality across everything from products to global systems. The International Standard Organization refers to standards as the answer to a simple question: "What's the best way of doing this?" [31] In the context of climate change, they provide a structured approach to both adaptation and mitigation strategies. Specifically in climate adaptation, standards regulate design methods and standardize the crucial data needed for testing these strategies. However, despite progress in standardizing design and data models separately in the Netherlands, there's a missing piece: a unified framework that brings these standards together. This gap hampers our ability to effectively tackle climate change comprehensively.

From the design side of standardization in climate adaptation, there is an ongoing effort of a national standardizing design guidelines for adaptation design as a response to climate change. These guidelines emerge a structure to give substance to this term. Examples of such guidelines are the Leidraad 2.0 [32] and the Klimaateffectatlas. [33]. The first presents specific guidelines from different regions of the country, when existing, about specifications and requirements for design interventions. It also present, for each requirement, interventions that are related to that requirement. The requirements are organized based on different climate challenges, namely flooding, drought, heat stress, subsidence, biodiversity, floods and drinking water management.

The second one present the same climate challenges however it goes more in detail on how these challenges related to their surrounding, emphasizing how different adaptation design interventions depend on their location, being directly related to above and/or bellow the surface. These design interventions are often more generic than in the Leidaard, for example, the Klimaateffectatlas refer to water bodies as a design intervention while the Leidaard present different examples of water bodies such as urban waterways, urban wetlands, water squares, among others. An integration of the two documents would be therefore interesting for designers, combining the local requirements with the (sub)surface characteristics that are related to different groups of design interventions. But where to find information regarding these characteristics? Are they also standardized?

The answer is yes and no. The information is standardized in the "data" meaning of the word but it is however not yet standardized to be used for design purposes. Present information regarding the subsurface in the Netherlands is derived from borehole logs, cone penetration tests, and groundwater measuring points. The predominant source of existing data on the Dutch subsurface involves boreholes that are commonly drilled beyond 100 meters, employing lightweight drilling equipment, and occasionally, deeper boreholes using heavy drilling machinery. [34]

The Basisregistratie Ondergrond (BRO), also known as the Key Registry for the Subsurface, is designed to offer transparent and easily accessible information about the subsurface. It operates in accordance with the government's open data policy. [34]. The Key Registry for the Subsurface (BRO) is integrated into the network of key registers, which consolidates fundamental data about the Netherlands, encompassing topography, addresses, buildings, individuals, and vehicle registrations. The BRO contributes to this array of information by including data and details about the subsurface. [35] TNO is responsible for developing and managing the subsurface aspect of the Key Register.

While these models are organized and can be combined between them, there is still not an integrated system combining or relating the existing models, which contain crucial information for climate adaptation design, to the national design guidelines. This thesis aim to fill this gap and relate the different design interventions and requirements to the data models where the needed information about the subsurface can be found. The goal is to create an ”information roadmap” for designer to understand where to find the needed information and for geoinformaticians to understand what are the use cases in urban design for their models.

In addition, standardization plays a role on how the models are presented and how can users interact with them, by, for example, adding representation of their desired design intervention as a 3D layer to the model. Standards that support web services facilitate this interaction. Previously, individuals utilizing subsurface data and BRO models had to download and modify them independently to integrate them into geographic software. In collaboration with the Ministry of the Interior and Kingdom Relations, the Geological Survey of the Netherlands (TNO), ESRI, and the Land Registry developed BRO 3D web services to simplify this process. By presenting data and models as accessible 3D web services through an API interface, they can be directly utilized in various standard 3D viewers (such as ArcGIS and CesiumJS version 1.99) and game engines (like Unity and Unreal via SDKs). Open OGC standards are employed for this purpose, [36] providing a user-friendly web interface which does not require any previous knowledge of GIS software. Through the website, users can add and remove different layers from ESRI Living Atlas in addition to 3D BRO data layers. It is clear of the potential of a web service for the integration of these models in design activities.

There is also related work on the standardization of land adminstration plans, including urban design plans. The Land Administration Domain Model (LADM) establishes a unified vocabulary for Land Administration (LA), offering a shared ontology. Edition I encompasses support for spatial units in 3D, along with a smooth fusion of 2D and 3D spatial representations. [37]

The design and development of LADM Edition II is based on the inclusion of rights, restrictions and responsibilities (RRRs) concerning, among others, spatial plan information and 3D representations. In particular, Part 5 of LADM Edition II deals with spatial planning information and includes urban planning zoning, resulting in RRRs, while Part 6 is planned to be about implementation of the LADM developed in collaboration with the Open Geospatial Consortium (OGC). [38]

The LADM standard defines the “process of determining, recording and disseminating information 69 about the relation between people and land” where land is defined, im the LADM Edition II, as the 70 “spatial extent to be covered by rights, restrictions and responsibilities and encompass the wet 71 and dry parts of the Earth surface, including all space above and below”. [38]

Several workshops were organized for the revision LADM Edition. From these, the main outcome was the interest of the LADM community in the integration of spatial plan information within the LADM and the provision of LA in 3D (below, on and above the surface) on land as well as at sea. This interest is clearly linked to the topics discussed on this thesis, as it defends that the standardization of 3D subsurface data models are crucial for interdisciplinary climate adaptation design.

From the identified requirements, the Requirement 5-2 ‘Plan Information Dissemination’ is defined as ”Spatial plan information systems using this part of LADM shall allow open dissemination and clear visualization (2D/3D) plan information.”

In addition, in the first edition of the LADM, the term ‘land administration’ refers to geographical areas encompassing water, land, and elements both above and below the earth’s surface. In response to the Standards Council of Canada’s input, a broader term, ‘georegulation,’ is introduced. Georegulation is defined as the “activity involving the delimitation and enforcement of control over geographical spaces through regulatory measures.” [38]

Extensive utilization of land vertically has led to intricate legal connections among diverse spatial units like land, marine, air, underground parcels, and infrastructure objects. Consequently, employing 3D models becomes essential not just to vividly depict real estate and its related rights but also to illustrate 3D representations of limitations and obligations. These stem from both private and public law, emphasizing the necessity for clear representation. [38]

The Spatial plan information package [39] utilizes fundamental LADM classes from the party package and administrative package to depict the involved parties in spatial planning procedures. This package models these parties, engaged in incorporating legal aspects (RRRs) in spatial planning, utilizing Party package classes from Part 2.

3

Research Question

The topics introduced thus far lead to the following research question:

How could 3D data subsurface information models support standardized local climate adaptation design?

The goal is to create a common ground for subsurface 3D information and climate adaptation design interaction. Climate adaptation is highly dependent on 3D subsurface characteristics and while this information is available at a national level in the Netherlands, it is still underused. This thesis aims to highlight the relationship between different design interventions and subsurface properties that can be found on existing 3D data models while exploring what are the data requirements for different design interventions. It aims to explore what are climate adaptation design requirements and how precise do information in the data models must be. By exploring these topics, the research is able to fulfill its main ambition: understand how to make structured subsurface information beneficial for concrete climate adaptation design. To answer this main research question, the thesis explores different subquestions such as:

- In which ways is climate adaptation depends or relates to subsurface characteristics?
- What are the existing barriers or challenges for effective utilization of 3D subsurface information models in Dutch climate adaptation strategies?
- What specific design interventions are commonly employed in Dutch climate adaptation? How do they relate to the subsurface?
- What is the data resolution or scale needed for different climate adaptation interventions? How precise do models have to be to suffice design needs?
- How comprehensive and accurate are the current national-level 3D subsurface data models in the Netherlands, particularly concerning their relevance to climate adaptation needs? Can we improve existing models?
- What is this added value of integrating information models to climate adaptation design? Can this added value be quantified?
- What methodologies can be established for the integration of subsurface information models into urban design?

4

Methodology

This thesis explores the relationships between subsurface characteristics that can be found in existing data models on a national level and the requirements of standardized local climate adaptation design. The main focus of this study is to understand what is needed in terms of scale and data resolution for standardized local climate adaptation design to benefit from subsurface information models. Is the information models that currently exist in the Netherlands enough? If not, what is needed in terms of data resolutions and scale to support local climate adaptation interventions? The answers to theses questions can be found when studying the explicit and implicit requirements stated in standardization design documents for climate adaptation such as the Leidraad 2.0, or product manuals for smaller scale interventions. How are certain interventions represented and how to they relate to the subsurface indicate which resolution is needed.

The Urbanism research setup thus includes understanding what are the requirements for standardized climate adaptation design, through the study of existing standardization guidelines, relevant literature, and product manuals. It also tests the requirements for different interventions in practice, by proposing spatial interventions in four different neighborhoods in Utrecht, which also showcase a design methodology supported by information models.

The Geomatics setup includes understanding what is needed, in technical terms, to meet the requirements identified by the Urbanism side of this thesis. If for design it is a matter of which information is needed and in what scale, for Geomatics these are related to data resolution and information models, often represented in Unified Modeling Language (UML) diagrams. The Geomatics aspect of this research relates the requirements of standardized local interventions with existing data models, and compares which information are fulfilled and which ones are not, highlighting what are the weakness and strengths of existing models.

4.1. Methodology Urbanism

In short, *the Urbanism aspect of this thesis is in determining what is the necessary information, including scale, for standardized local climate adaptation design.* As a methodology, that means firstly gathering the requirements from guidelines and manuals, such as the Leidraad 2.0, Klimaateffectatlas, but also from interdisciplinary literature, such as geosciences or civil engineering, and product specifications. The methodology aims to give a well informed answer to questions such as: How precise do we have to be? Which information is needed for local climate adaptation design? And in what resolution?

When it comes to requirements, it is important to understand how the defined requirements relate to the different layers of subsurface. Some interventions are mainly related to the immediate subsurface layer while others may be related to deeper layers. In this sense, data resolution in 3D becomes interesting, it is not a matter of producing different 2D maps of different specific depths in the subsurface, but an integrated 3D model. One of the answer the research aims to answer is in which resolution should be this model made to support local climate adaptation design. The method will test if the model of the subsurface is more beneficial for climate adaptation when it is made of standardized little cubes, assessing what should be the minimum size for each cube, or different shapes that are not uniformed.

The setup thus includes studying what are the requirements but also by testing them through design interventions, where different interventions will have different requirements.

The interventions will be all chosen from well documented measures found in the Bouw Adaptief website, which uses the Leidraad 2.0 and to the Groen Blauwe Netwerken as its basis. Thus, the interventions will not be freely designed but will be chosen from existing guidelines. The choice between the different interventions will be made based on standards and themes relevant to the area, for example if an area is more or less prone to draught, heat stress, drought or other climate themes, and to the subsurface condition, for example soil type and ground water level.

In this context, there are three identified ways in which local climate adaptation design relates to subsurface property, namely:

- *The subsurface dictates what a designer can and cannot do.* For example some soil types, such as peat or clay, cannot support much weight and thus heavily built interventions cannot be done in areas where this soil type is present at certain layers.
- *Ground water level dictates to which extend can you infiltrate.* Even if soil conditions are favorable for water absorption, the ground water level can interfere in the amount of water that can be stored.
- *Interventions are more or less suitable for different soil types.* In this case, soil types do not dictate what can be done but are, to some degree, more or less suitable to different interventions. For example, sandy soils are known to absorb more water and faster than other soil types. Thus open soil interventions related to rainwater retention do not depend on, but would benefit, from such soil type.

To which extend and in which resolution this information regarding the subsurface should be delivered to suffice local climate adaptation design is what this thesis explores, though literature review and spatial interventions.

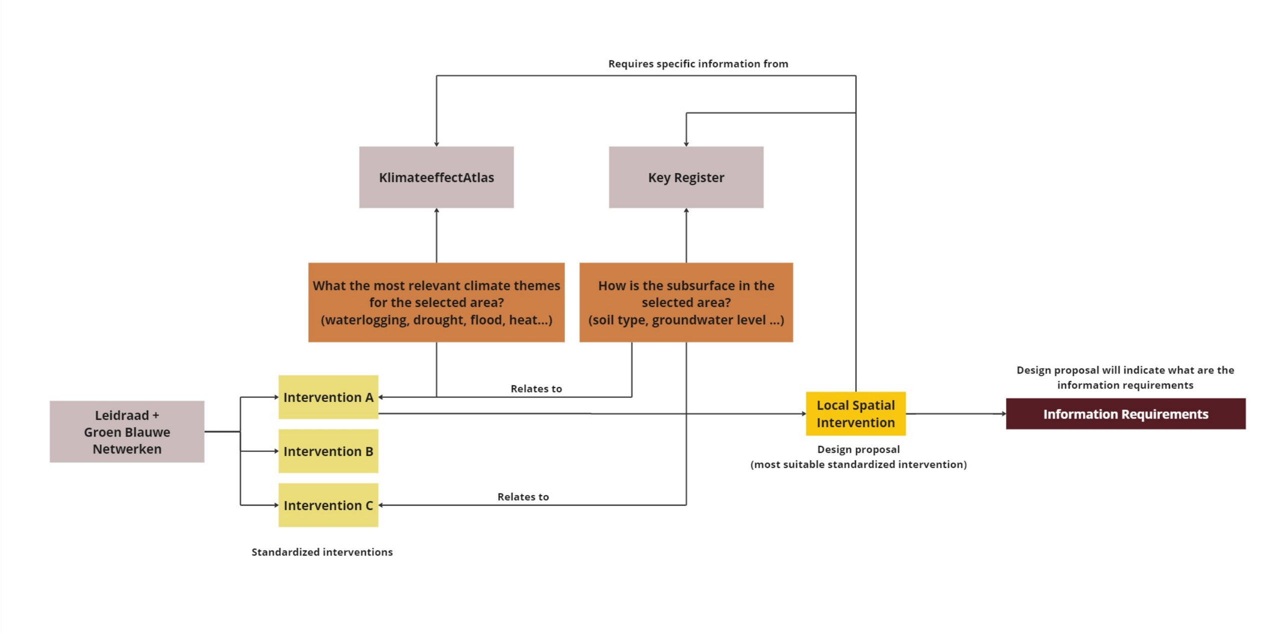


Figure 4.1: Methodology Urbanism

4.1.1. Spatial Interventions: Locations

Once a review of existing standardized climate adaptation interventions is made and their requirements are well studied, spatial interventions are proposed in the city of Utrecht, a city with four different well-divided subsurface and landscape types. To showcase how information models can support climate adaptation design and explore how, in practice, different interventions have different requirements, four areas of 500 by 500 metres in Utrecht were defined with the help of designer from the city's municipality. These areas are in the neighborhoods of Voordorp, Lunetten, Zuilen, and Leidsche Rijn.

Each area represents one of the four subsurface types in Utrecht and have similar urban functions (mainly residential), allowing the focus to be mainly in the subsurface characteristics while exploring interventions in four very different subsurface conditions. For each squared area, a smaller area of interest was identified. For example, a public space or a paved area that would benefit from open soil.

The goals for the spatial interventions is to adapt a selected area inside of a 500 by 500 squared zone in one of the four selected neighborhoods in Utrecht. To test climate adaptability, storm event scenarios were used. Moreover, by doing that, an approach for local climate adaptation design including information models is showcased and the data requirements for different interventions are tested in practical design exercises.

The knowledge of the author in urban design allows the choice of interventions to be sensitive to a broader context of urban qualitative aspects. Attention is paid when choosing an intervention on how it related to its context such as which urban activities already exist on public spaces in the area, and what are demographic and social aspects of the population. In addition, if more than one intervention is selected, attention was paid on how they relate to each other, and choices were made between a chain design effect or punctual interventions.

Even though the main focus of the spatial intervention is to better understand the information

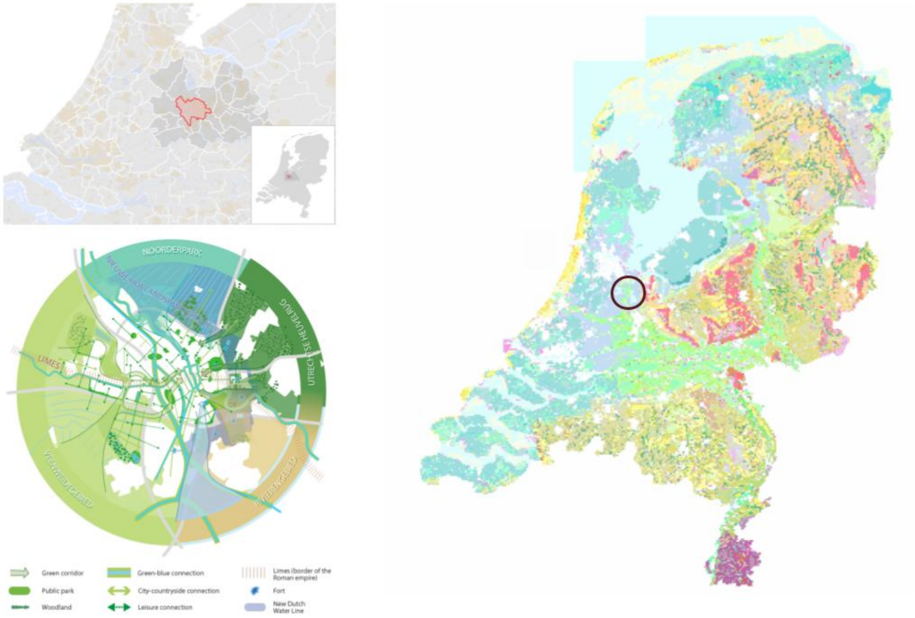
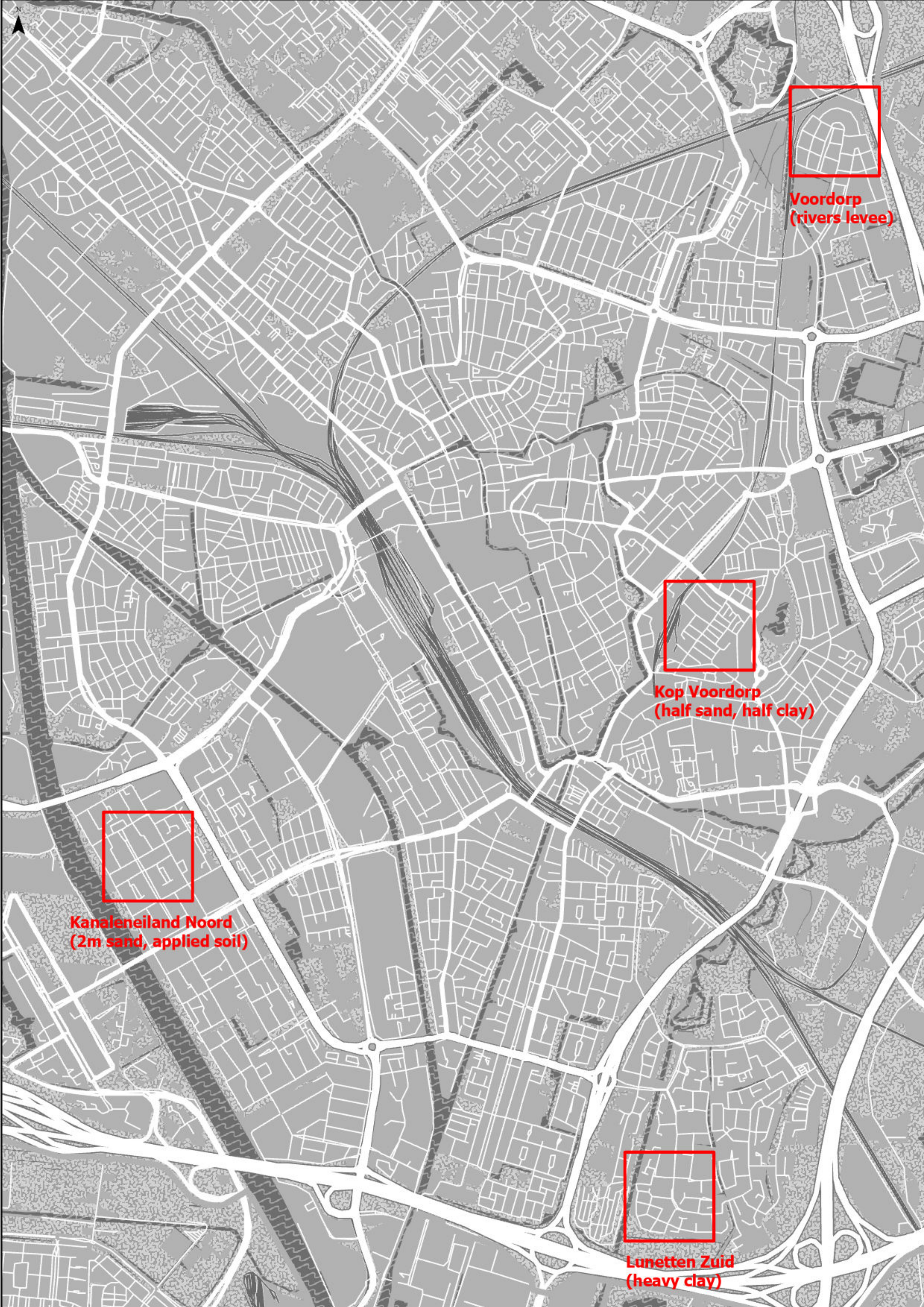


Figure 4.2: The four soiltypes in Utrecht

and scale requirements for local climate adaptation, other challenges could potentially also be answered by the design, and the interventions remained sensitive to urban transformations, such as densification, that happened or are planned to happen in the neighborhood. In these cases, climate adaptation remains the focus, but it is included or related to other transformations.


N
Voordorp
(rivers levee)
Kop Voordorp
(half sand, half clay)
Kanaleneiland Noord
(2m sand, applied soil)
Lunetten Zuid
(heavy clay)

Location 1: Kop Voordorp (half sand, half clay)

The area is located between two main parks, the Wilhemina Park and the Sonnenborgh Park. The East part of the 500 by 500 metres squared area selected by the municipality of Utrecht, a part of the Het Spoorweg Museum is included. This is a museum on railways and is located inside of a railway station from the 19th century.

The area thus contains many interesting cultural and ecological elements, however the public spaces inside of the residential area that is studied do not seem to indicate the presence of these activities. For example, the main public areas right in front of the museum are used as a parking lot and an open space, with permeable pavement but no other seemingly activity. In addition, the greenery inside of squared area comes mainly from to private gardens, with few exceptions. This can also be seen in the map created using the BARCODE division of urban functions created by the municipality of Utrecht. The red in the map indicates unpaved ground, making it more clear how the greenery is concentrated on private properties.

Therefore the aim of the design for this area is to better connect the two main parks and the museum. This can be done through solutions such as a green corrdior or other design interventions that indicate a path connecting the two. The main areas of intervention thus are inside of this created connecting path.

The path aims to connect also the few scattered public spaces, mainly smaller squares and playgrounds, and make them climate adaptable to the climate scenarios chosen for the purpose of the spatial interventions. One example of such a location is the small square located in Nicolaasweg 46.

Location 2: Lunetten Zuid (heavy clay)

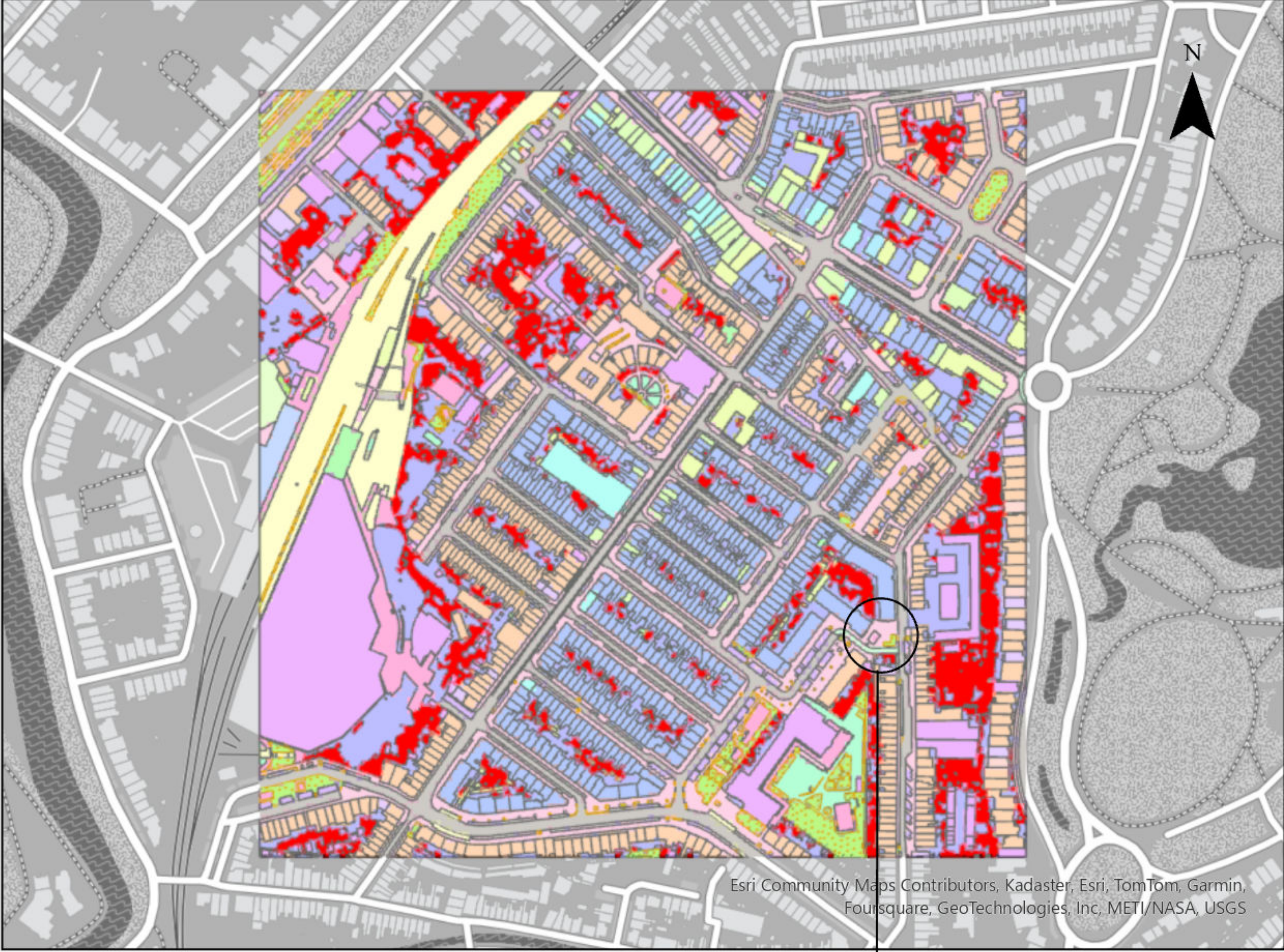
The squared area in the neighborhood of Lunetten Zuid is protected from the highway through a green buffer. The buffer is a substantial green area and includes several parks connected by a corridor around the neighborhood. However, differently from Kop Voordorp (area 1), the main parks can be connected by a green corridor that horizontally connects the two extremes of the green buffer.

This connection is sparse bigger areas of greenery that intersects Simplonbaan street. However, these areas could be qualitatively improved, highlighting the connective effect of this corridor. The spatial intervention will thus focus on this strip, and, in particular, on the intersection point between the corridor and Simplobaan street.

The design will also take into consideration the fact that the subsurface is mainly made of heavy clay. Thus, interventions will be thought to be aligned with this type of soil, a soil with poor drainage, which can leas to waterlogging and flooding during heavy rainfalls, such as the storm event simulated for this desing exploration. Heavy clay is also known for its tendence to retain heat, thus natural or artificial shades, and avoiding reflective materials, are key in this design. Since there is already a great concentration of public greenery, the native vegetation will be kept whenever possible.

Location 1: Kop Voordorp (half sand, half clay)

Location 1: Kop Voordorp (half sand, half clay)



Scale: 1:6000

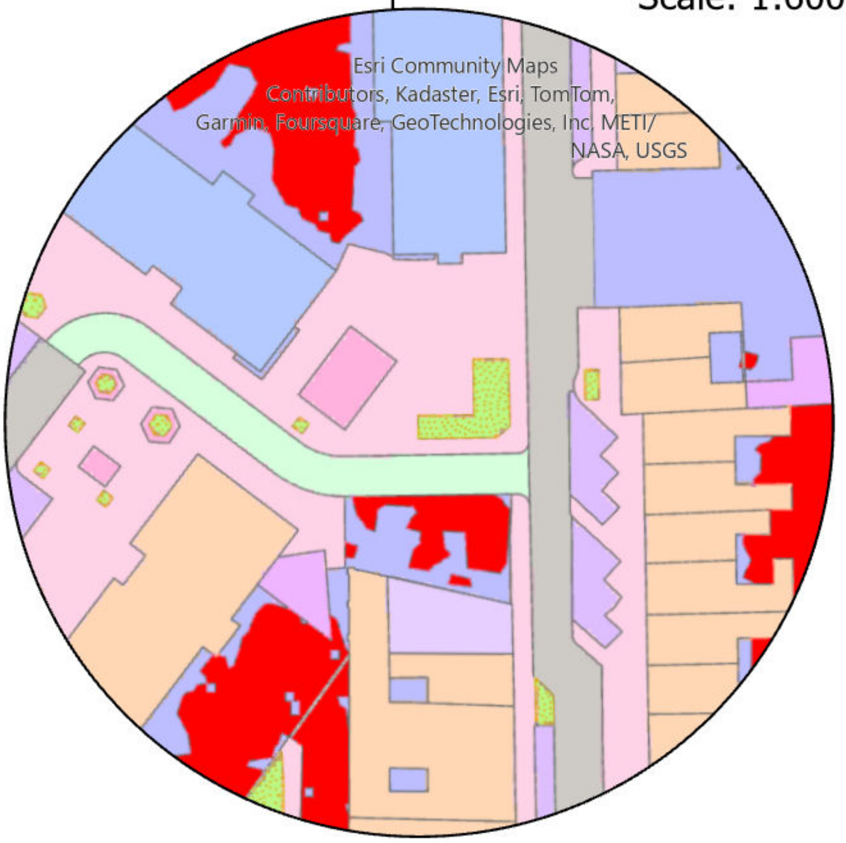
Location 1: Kop Voordorp (half sand, half clay)

Legend

Barcodekaart

Barcode

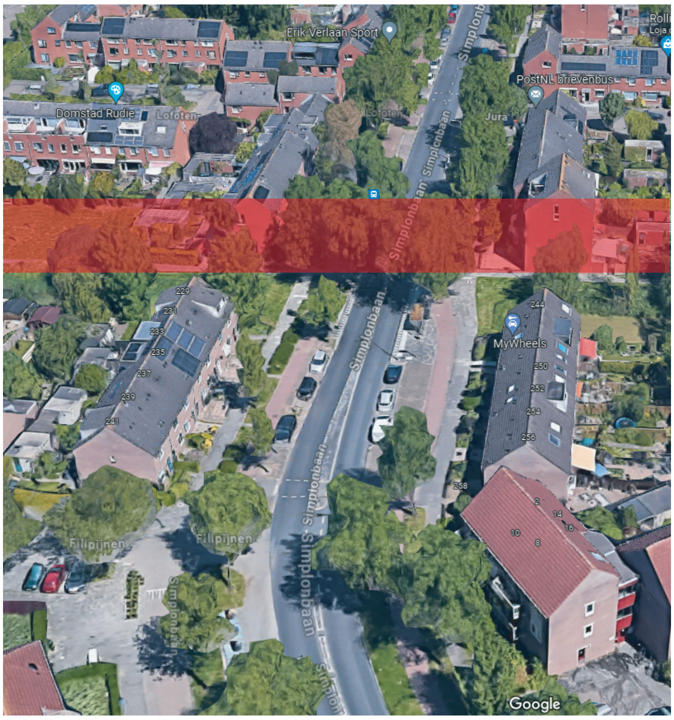
- auto
- bebouwd
- bebouwd - fsi/ functie onbekend
- erf - onverhard
- erf - verhard
- fiets
- groen
- mxi 0 - 0.25 - fsi 0-1
- mxi 0 - 0.25 - fsi 1-2
- mxi 0-0.25 - fsi >3
- mxi 0.25 - 0.5 - fsi 0-1
- mxi 0.25 - 0.5 - fsi 1-2
- mxi 0.5 - 0.75 - fsi 0-1
- mxi 0.5 - 0.75 - fsi 1-2
- mxi 0.75-1.0 - fsi 0-1
- mxi 0.75-1.0 - fsi 1-2
- ov
- overig bebouwd
- overig infrastructuur
- overig onverhard
- overig verhard
- parkeren eigendom openbaar
- parkeren privaat eigendom
- voetganger
- <all other values>



Nicolaasweg square

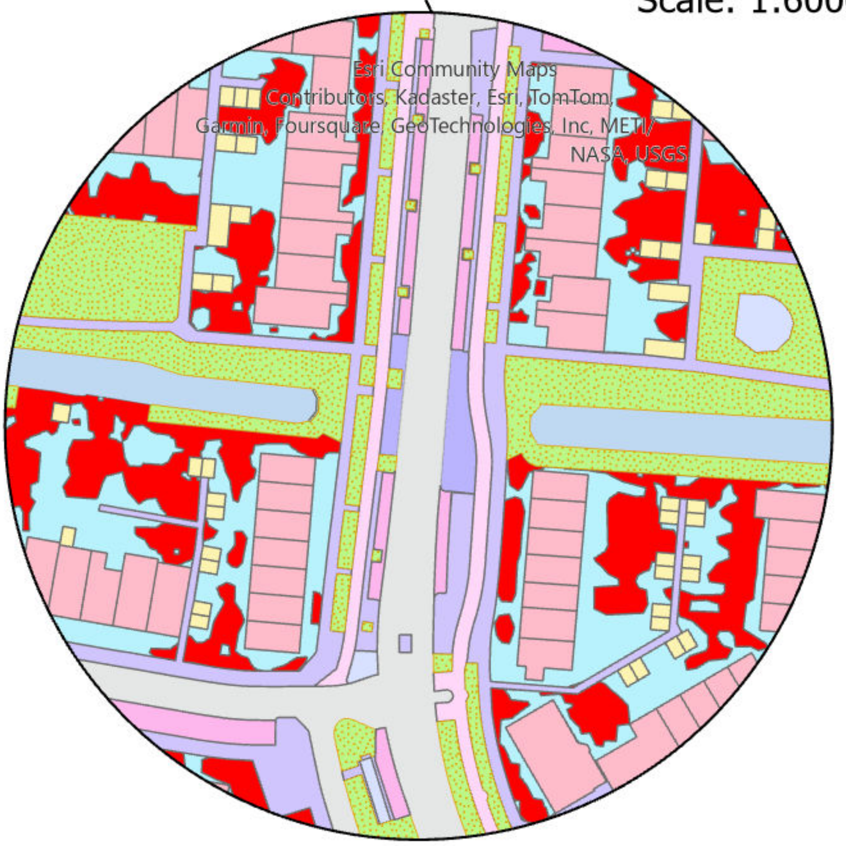
Scale: 1:1000

Location 2: Lunetten Zuid (heavy clay)



Scale: 1:6000

Location 2: Lunetten Zuid (heavy clay)



Intersection Simplonbaan

Scale: 1:2000

Area2

Barcode

- auto
- bebouwd
- erf - onverhard
- erf - verhard
- fiets
- groen
- mxi 0 - 0.25 - fsi 0-1
- mxi 0.5 - 0.75 - fsi 0-1
- mxi 0.75-1.0 - fsi 0-1
- ov
- overig infrastructuur
- overig onverhard
- overig verhard
- parkeren eigendom openbaar
- voetganger
- water
- <all other values>

Barcode

- auto
- bebouwd

Legend

- erf - onverhard
- erf - verhard
- fiets
- groen
- mxi 0 - 0.25 - fsi 0-1
- mxi 0 - 0.25 - fsi 1-2
- mxi 0.5 - 0.75 - fsi 0-1
- mxi 0.5 - 0.75 - fsi 1-2
- mxi 0.75-1.0 - fsi 0-1
- mxi 0.75-1.0 - fsi 1-2
- mxi 0.75-1.0 - fsi >3
- ov
- overig infrastructuur
- overig onverhard
- overig verhard
- parkeren eigendom openbaar
- sportveld
- voetganger
- water
- <all other values>

Barcode

- auto
- bebouwd

- bebouw - fsi/
- erf -
- erf -
- fiets
- groen
- mxi 0 -
- mxi 0 -
- mxi
- mxi
- mxi
- mxi
- mxi
- mxi
- mxi
- ov
- overig
- overig
- overig
- overig
- parkere eigend
- parkere privaat
- voetga

Location 3: Kanaleneiland Noord (2m sand, applied soil)

Kanaleneiland Noord has its main greenery facing the main canal. The green spaces are not only grass but often included urban activities, such as green playgrounds and dog parks.

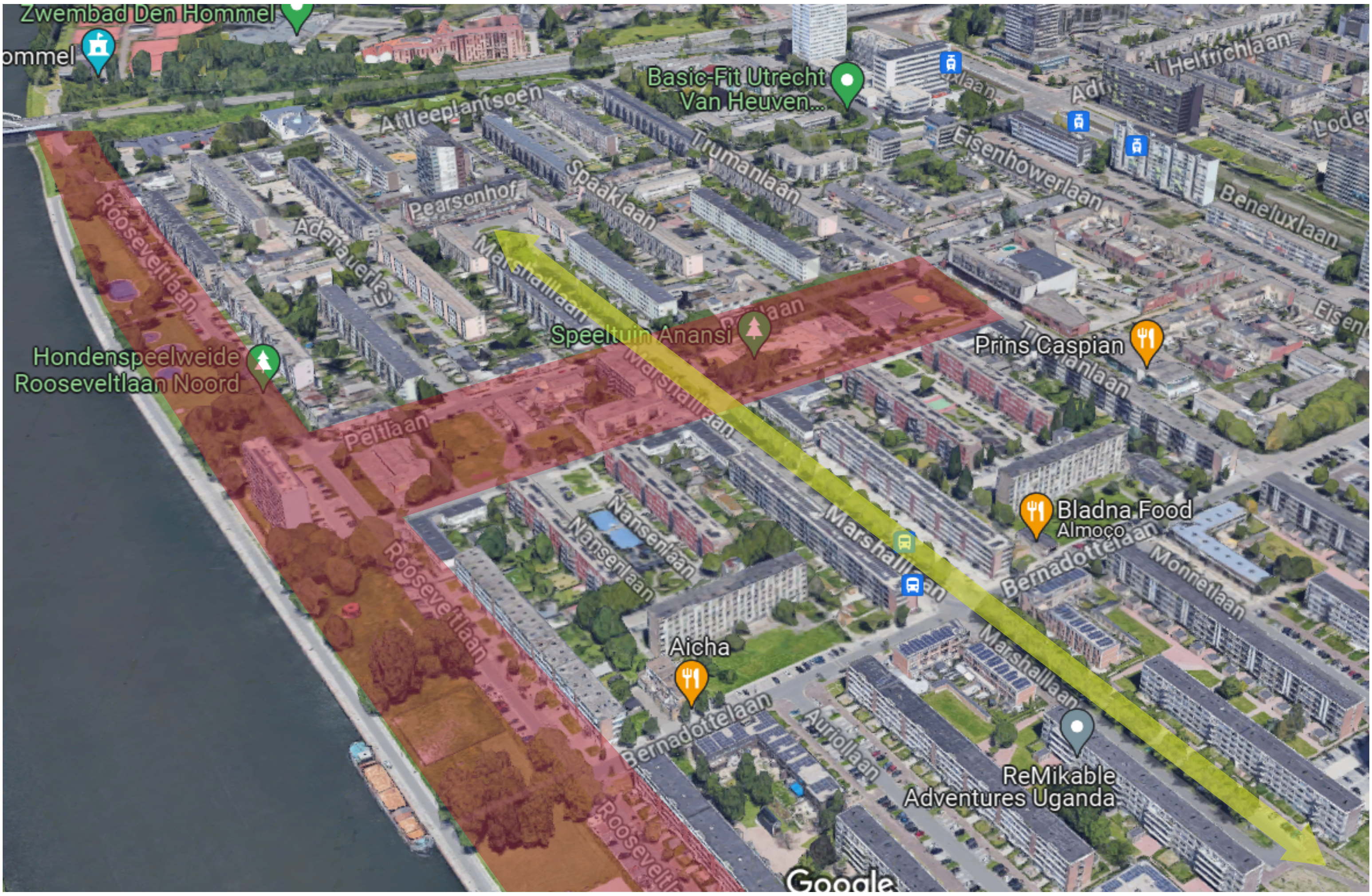
The greenery facing the canal is directly connected to green areas that lead to the Speeltuin Anansi, a relatively big playground that includes greenery, play areas and sport fields. The playground faces a school, connecting the school to the parks facing the canal.

Marshallaan is a street with a high presence of trees that crosses the Speeltuin Anansi, connecting north and south part of Kanaleneiland Noord to these main green spaces. The spatial design will thus focuses on this street, identifying places that would benefit from being unpaved, or adding different qualities to already existing green spaces. For example, there are a few public rain gardens and green squares that currently only have a couple of trees and grass. A potential design intervention would add different qualities to this space, while maintaining or improving its adaptability to climate change. It is interesting how this neighborhood already presents a high concentration of greenery, leaving its sandy soil, which absorbs rainwater faster than other soils, exposed.

Location 4: Voordorp (rivers levee)

Most of the greenery in Voordorp comes from private gardens. In a map indicating the unpaved areas (in red) it is possible to identify that most of them are inside of private properties. With exception of the Chico Mendesstraat, a street with trees and a canal, most of the public spaces lack greenery and unpaved surfaces. Playgrounds and sport fields, for example, are most of the times fully paved. One such example is the playground in front of a school, circled in the map. This area has the potential to be one of the few public spaces, a green square, or an unpaved public area, but currently it is occupied by one playground and one sport field, both fully paved. Unpaving the surface is an intersting climate adaptation intervention in this area, that has on its surface level sandy soil, which can absorb rainwater faster than other soil types. The spatial intervention will thus focus on this area in front of the school.

Location 3: Kanaleneiland-Noord (2m sand, applied soil)



Scale: 1:6000

Location 3: Kanaleneiland Noord (2m sand, applied soil)

Intersection Simplonbaan

Scale: 1:2000

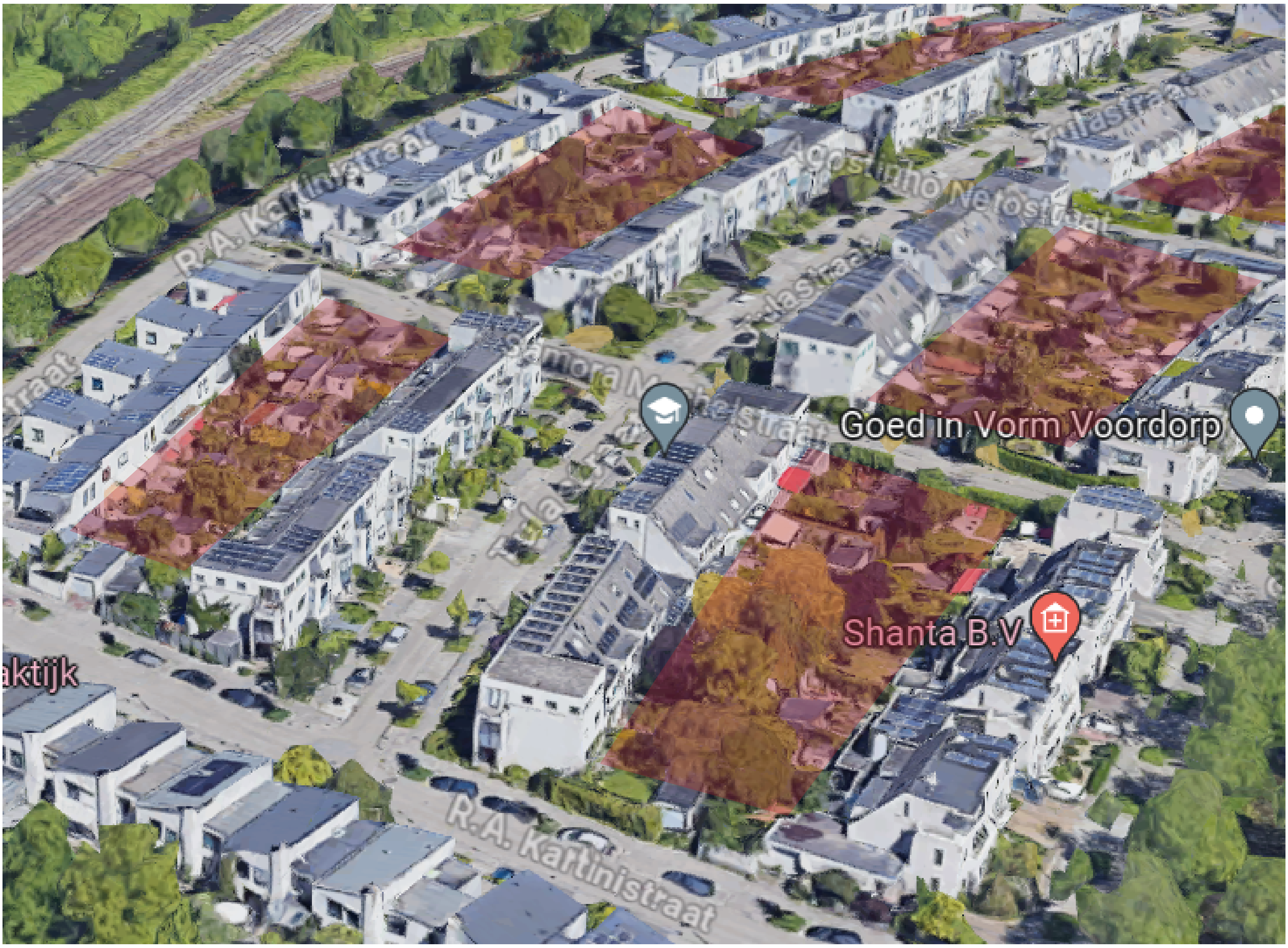
Legend

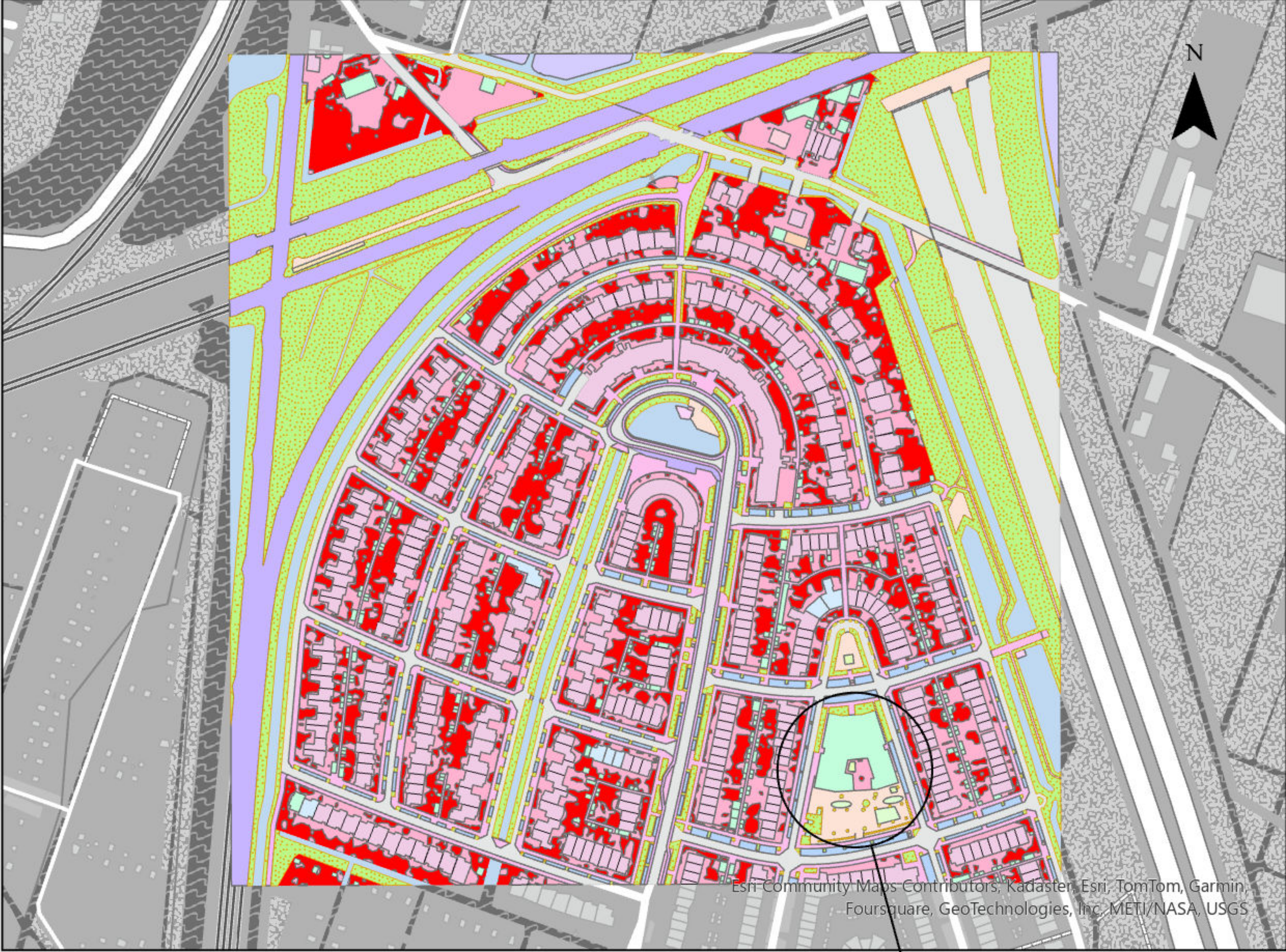
Area 3

Barcode

- auto
- bebouwd
- erf - onverhard
- erf - verhard
- fiets
- groen
- mxi 0 - 0.25 - fsi 0-1
- mxi 0 - 0.25 - fsi 1-2
- mxi 0.5 - 0.75 - fsi 0-1
- mxi 0.5 - 0.75 - fsi 1-2
- mxi 0.75-1.0 - fsi 0-1
- mxi 0.75-1.0 - fsi 1-2
- mxi 0.75-1.0 - fsi >3
- ov
- overig infrastructuur
- overig onverhard
- overig verhard
- parkeren eigendom openbaar
- sportveld
- voetganger
- water
- <all other values>

Location 4: Voordorp (rivers leeves)





Scale: 1:6000

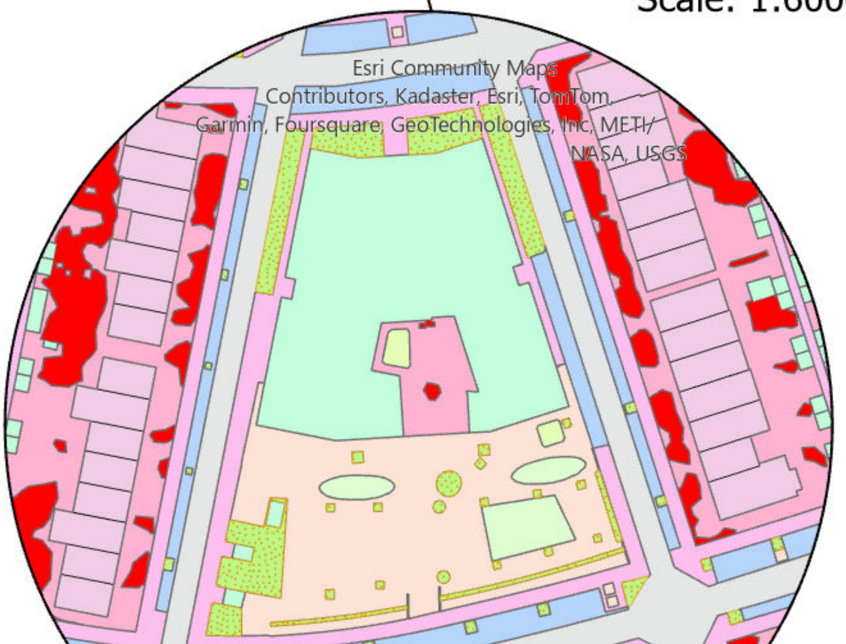
Location 4: Voordorp (rivers levee)

Legend

Barcodekaart

Barcode

- agrarisch
- auto
- bebouwd
- erf - onverhard
- erf - verhard
- fiets
- groen
- mxi 0 - 0.25 - fsi 0-1
- mxi 0.25 - 0.5 - fsi 0-1
- mxi 0.5 - 0.75 - fsi 0-1
- mxi 0.75-1.0 - fsi 0-1
- ov
- overig infrastructuur
- overig onverhard
- overig verhard
- parkeren eigendom openbaar
- parkeren privaat eigendom
- sportveld
- voetganger
- water
- <all other values>



Playground in front of school

Scale: 1:2000

4.1.2. Spatial Interventions: Storm Events

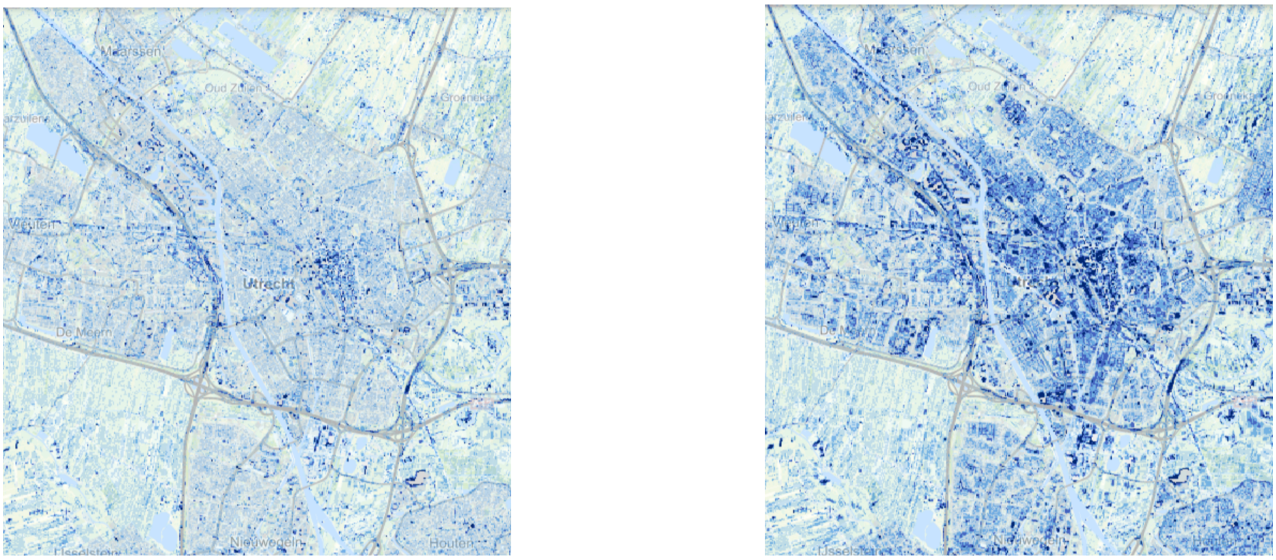
One of the conclusions of literature review is that themes and challenges of climate adaptation relate to the subsurface differently. Some aspects of climate adaptation seem to benefit more from information models support. For example, themes related to water absorption, such as waterlogging and flood, have more interventions with subsurface dependencies than heat, for example. This became even more clear after demonstrating graphically the relationships between standardized climate adaptation interventions and subsurface properties through the creation of an Unified Modeling Language (UML) diagram.

Since water absorption is particularly relevant when assessing the needs for information models that could support local climate adaptation design, it was decided to utilize a storm event scenarios while designing, having the Leidraad and Klimateeffectatlas as references.

The Leidraad shows the expected recurrence times for precipitation events for the current climate and the climate in 2050 with a format for standardization. [40] In addition, Utrecht has three regulations regarding waterlogging that were used to define the storm scenarios. These are:

- *N1: In the planning area, no water damage occurs during a shower that can occur once every 100 years. Vital and vulnerable functions, for example electricity supplies and nursing homes, remain available in the event of a shower that can occur once every 250 years.* In 2018, this was 70 mm for once every 100 years and 90 mm for once every 250 years [40]
- *N2: A large part of the precipitation (50 mm) on private land is infiltrated, retained and/or stored in facilities on private property or in designated additional facilities in the planning area or within the water system boundaries.* Deriving from a shower of 70 mm in an hour for the once every 100 years scenario, that would mean the storage of 50 mm is required. In order to relieve the urban water system, the storage must be gradually drained away in a period from at least 24 hours after the shower (about 2 mm per hour). The storage room must be available again after 60 hours after the shower to absorb a second shower. The emptying times do not apply to controlled water storage systems that use weather forecasts, for example. However, it must be demonstrated that the controlled storage can be used effectively to collect the 50 mm of precipitation
- *N3: The development will be water-neutral and will not lead to additional water supply/drainage. Rainwater is retained and reused as much as possible in the planning area.* Thus, preference should be given to interventions that facilitate the retention and reuse of rainwater

Having the once every 100 years scenario of 70 mm and the laws related to rainwater retention/reuse for the city of Utrecht, two scenarios were defined. For flooding in built-up areas, the short local heavy showers of one hour are often decisive [40], thus in one of the scenarios the 70 mm are reached in one hour, and rain continues with the same intensity for another hour. In a different scenario, a more long term storm scenario was used, and the 70 mm is reached after two hours. Thus the two storm events used for the purpose of the spatial interventions consist of: a shower of 140 mm in two hours (or 70 mm/hour) or a shower of 70 mm in two hours. The consequences in terms of flooding for these two scenarios are available as maps through the Klimateeffectatlas. [41], as is shown in the figures bellow. The source for these maps are Deltares and the Flood Risk Directive (ROR) from 2018.



(a) Storm event 70 mm in two hours

(b) Storm event 140 mm in two hours

Figure 4.3: Storm Events

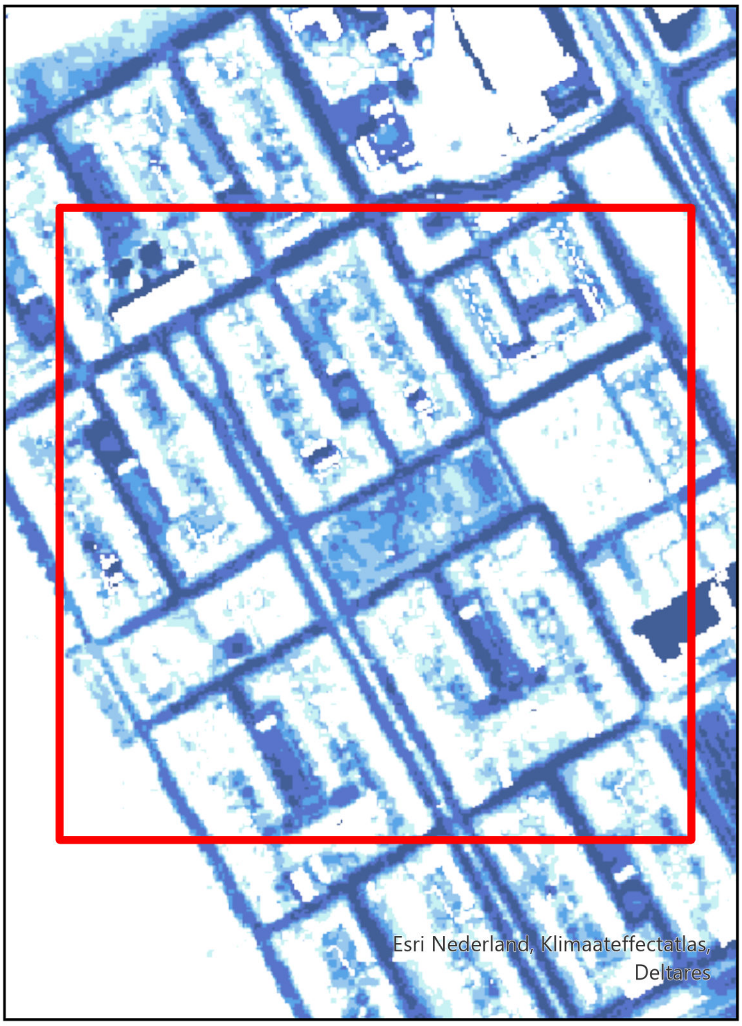
4.1.3. Spatial Interventions: Climate Themes

Even though storm events will be mainly use to simulate climate scenarios to test the adaptability of the chosen interventions, other climate themes will also be included when relevant. Some themes are more relevant than others for different areas. Some areas might be more prone to heat stress or to flooding than the others, for example. Drought scenarios were also simulated, however, in the areas defined by the municipality of Utrecht, drought related to groundwater levels do not seem to be as relevant. This can be seem in a map on the next pages. Similar studies and maps regarding different climate themes will be done for each area, using the maps from the Klimateeffectatlas.

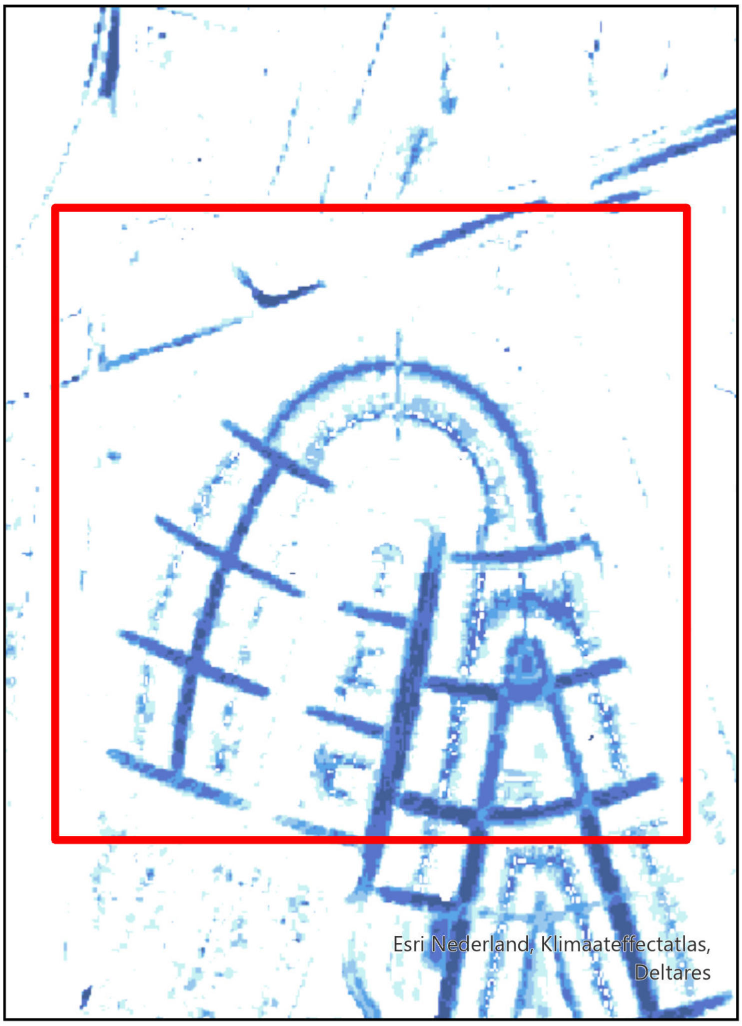
Storm Event 1/1000 years (140 mm/2 hours) - Scale: 1:6.000

Location 1: Kop Voordorp

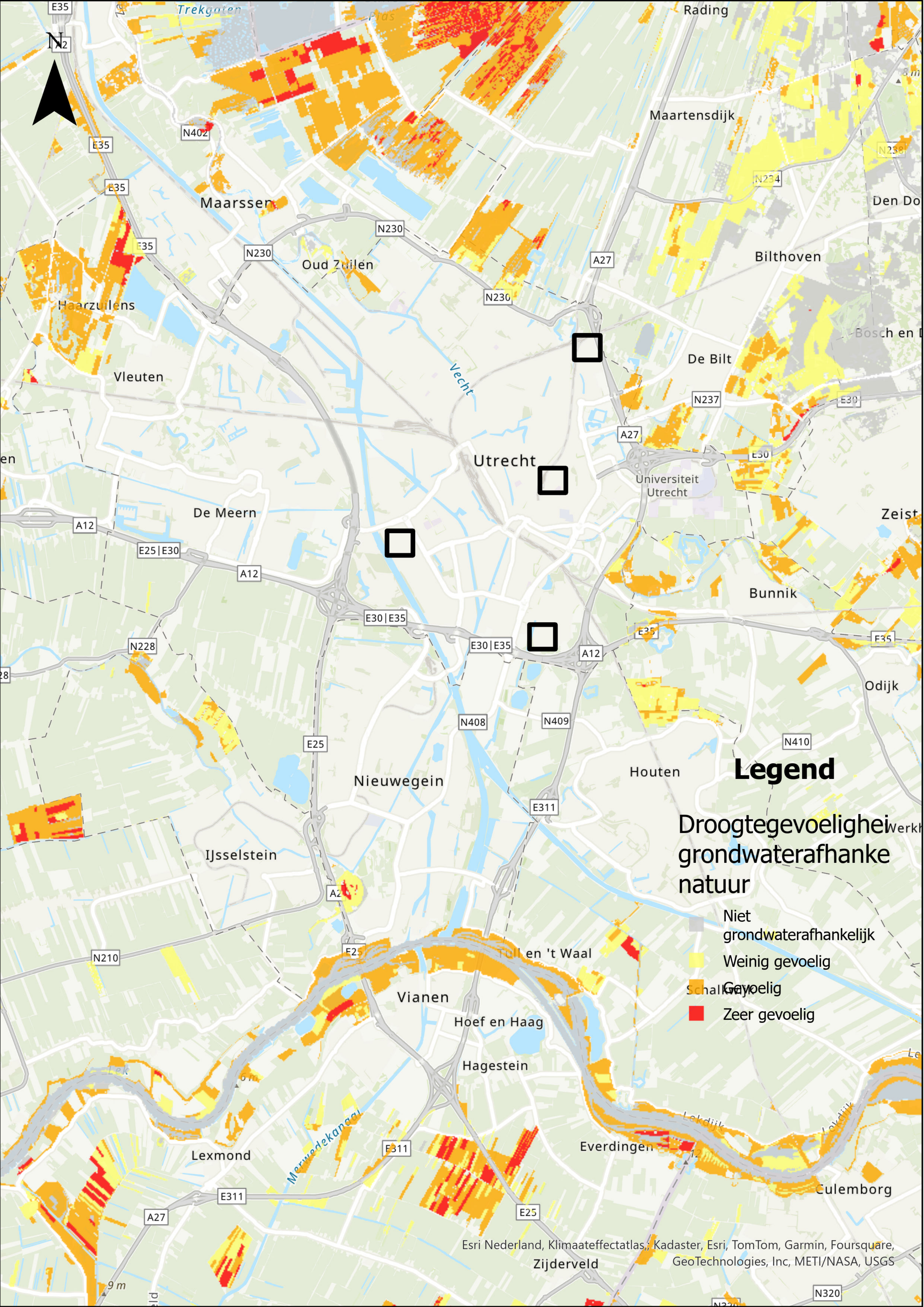
Location 2: Lunetten Zuid



Location 3: Kanaleneiland Noord



Location 4: Voordorp


N
Legend
Droogtegevoeligheid grondwaterafhankelijke natuur
Niet grondwaterafhankelijk
Weinig gevoelig
Gevoelig
Zeer gevoelig
Utrecht
Maarssen
Oud Zuilen
Haarzuilens
Vleuten
De Meern
Maartensdijk
Bilthoven
De Bilt
Universiteit Utrecht
Zeist
Bunnik
Odijk
Houten
Nieuwegein
IJsselstein
Vianen
Hoef en Haag
Hagestein
Lexmond
Everdingen
Culemborg
Zijderveld
Tull en 't Waal
Rading
Vecht
Merwedekanaal
Esri Nederland, Klimaateffectatlas, Kadaster, Esri, TomTom, Garmin, Foursquare, GeoTechnologies, Inc, METI/NASA, USGS

4.2. Methodology Geomatics

In short, *the Geomatics aspect of this thesis is related to the technical aspect of the requirements, in terms of data resolution, to support local climate adaptation interventions.* After assessing what is available in terms of information and data models on a national level regarding the subsurface, the research assesses if the identified requirements are already sufficed by these models. And if they are not, guidelines are drawn on what is needed, from a technical point of view, to reach the desired data resolution. The methodology includes understanding what is necessary, in geodata terms, for an information model to be able to support local climate adaptation, as standardized by the Leidraad 2.0. guideline. The methodology consists of identifying areas of strength and weakness in the existing models for this purpose, serving as a guide for further implementations. For example, if a higher data resolution is needed to represent soil types, methods will be identified to solve this issue. One possible solution is the combination of data from other sources. For example, for top layers, other sources of data could come from the results of a cone penetration test (CPT), a method used to determine the geotechnical engineering properties of soils and delineating soil stratigraphy.

The research setup for the Geomatics side side thus consists of assessing what is available in terms of geodata vs. what is needed, identifying how to improve existing models for the purpose of local climate adaptation design.

Moreover, standards are used as a quantitative measure. In the Netherlands, local climate adaptation interventions are already standardized, and their different data requirements can be drawn from existing literature, guidelines and manuals. This thesis aims to identify areas for improvement in existing information models to support these standards, filling information gaps when identified. The research thus showcase the importance of standards, in both climate adaptation design, and moreover urban design and land administration.

Standards also play an important role when it comes to disseminating knowledge regarding spatial plans.The Land Administration Domain Model (LADM) Part 5 (ISO 19152), which regards the standardization of information regarding spatial plans, defines a general schema for sharing spatial plan information in the context of the land administration.

In addition, the author knowledge in GIS allows the spatial interventions, that showcase the added value of the support of information models in local climate adaptation design, to be represented on a later stage through ArcGIS ESRI products, such as story maps.

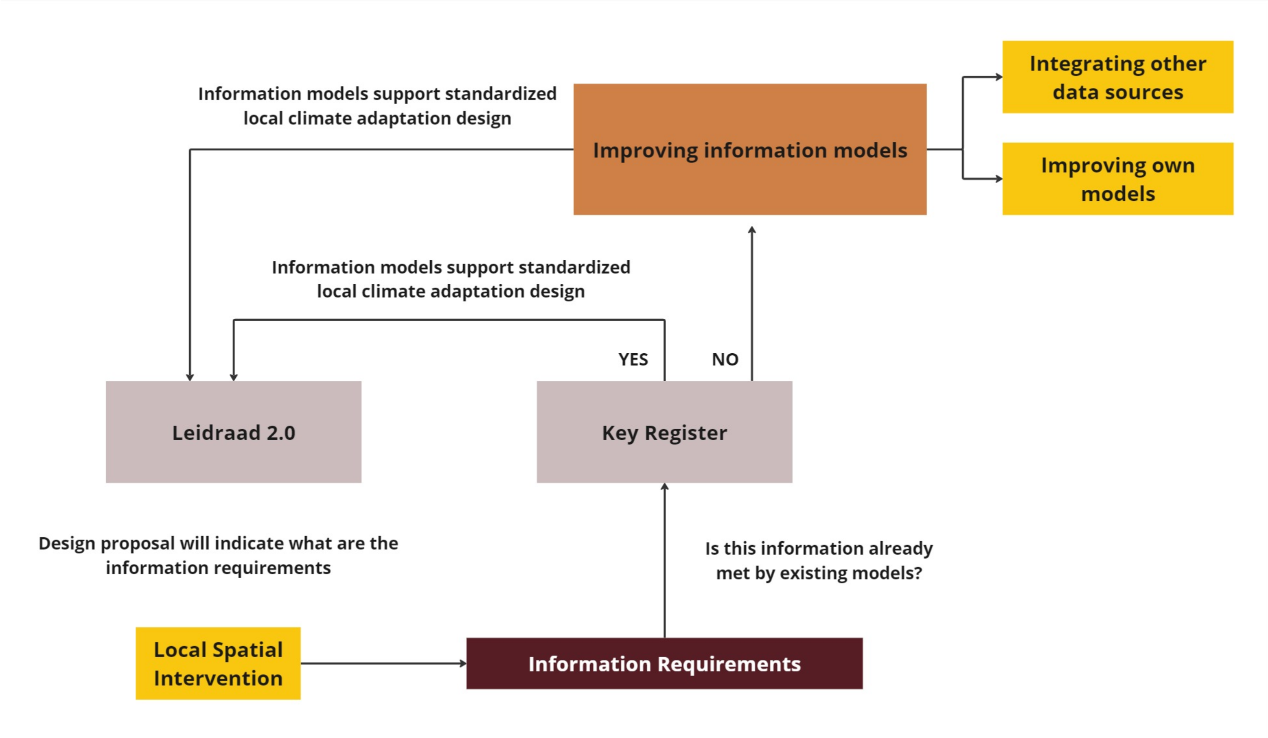


Figure 4.4: Methodology Geomatics

4.3. Thesis Structure

The main question that this research aims to answer is *How could 3D data subsurface information models support standardized local climate adaptation design?*. A general answer for this question would be: *through a common ground where local climate adaptation information requirements meet the data resolution found in information models.*

Thus this thesis is divided into three different parts, aiming to better identified why, what and how to reach this common ground. Part I presents a literature review on **why** a common ground is needed. This first part introduces the reader to the topics of 3D subsurface models and climate adaptation design, advocating that the connection between the two, fuelled by the pressing concern of climate change in the Netherlands, can be a common ground for interdisciplinary collaboration. It includes an overview of what literature defines as the three main challenges regarding an interdisciplinary approach to climate adaptation design and 3D subsurface information model integration. These three barriers are: institutional, technological and semantic. These barriers are then compared to interviews made with urban designers and planners, identifying what are the challenges of a GIS approach to local climate adaptation design. This part also includes an overview on how climate adaptation relates to subsurface information, presenting dependencies found in existing standardized guidelines and examples of situations where the lack of this information had negative consequences.

In this part, the following subquestions are answered:

- How does climate adaptation relate to subsurface?
- What are the existing challenges for effective utilization of 3D subsurface information models in Dutch climate adaptation strategies?

Part II defines **what** is this common ground.This part presents examples of standardized climate adaptation urban interventions as defined by the Leidraard 2.0, for example, a water square or rainwater pond, and how they relate to 3D subsurface data models in the Netherlands (3D Key Register Subsurface data models). This association is made by studying the requirements for different design interventions, such as the soil type and groundwater level, and identifying where this information can be found. To visually represent these relationships schematically, Unified Modelling Language (UML) diagrams are used.

In this part, the following subquestions are answered:

- What specific design interventions are commonly employed in Dutch climate adaptation? How do they relate to the subsurface?
- How comprehensive and accurate are the current national-level 3D subsurface data models in the Netherlands? Can we improve them?

Finally, Part III discusses **how** to reach this common ground. In this part of the thesis, the identified relationships between specific climate adaptation design interventions and existing information models are tested in practice. A design intervention in four different existing neighbourhoods in Utrecht is made using subsurface information from the Key Register, aiming to make these neighbourhoods adapted to two different storm event scenrios, by applying the interventions standardized by the Leidraad, combined with the subsurface information found in the BRO 3D web services.

By creating spatial interventions, the requirements identified in Part II are tested for different interventions. If Part II tests from a theoretical point of view what is the data resolution needed for local climate adaptation to benefit from information models, Part III showcases how this would work in practice and test if the theoretical benefits exist in a practical exercise.

The design is then evaluated to confirm or refute the hypothesis of information models aiding the cause of climate adaptation in the Netherlands. In this part of the research, the models are tested for urban design and potential improvements may be drawn from this design exploration.

Utrecht is divided into four different main landscapes and soil types, which allows for the integration of data models and climate adaptation design in four different scenarios. The four areas are defined by a 500 by 500 metres square and attention was paid to the similarity of other factors that could influence the design results, such as urban density, morphology and land use. In this way, the focus of the design exploration and the data models assessment is focused exclusively on the subsurface characteristics. The areas are located in Voordorp, Lunetten, Zuilen, and Leidsche Rijn.

In this part, the following subquestions are answered:

- What is the data resolution or scale needed for different climate adaptation interventions? How precise do models have to be to suffice design needs?
- What is this added value of integrating information models to climate adaptation design? Can this added value be quantified?
- What methodologies be established for the integration of subsurface information models into urban design?

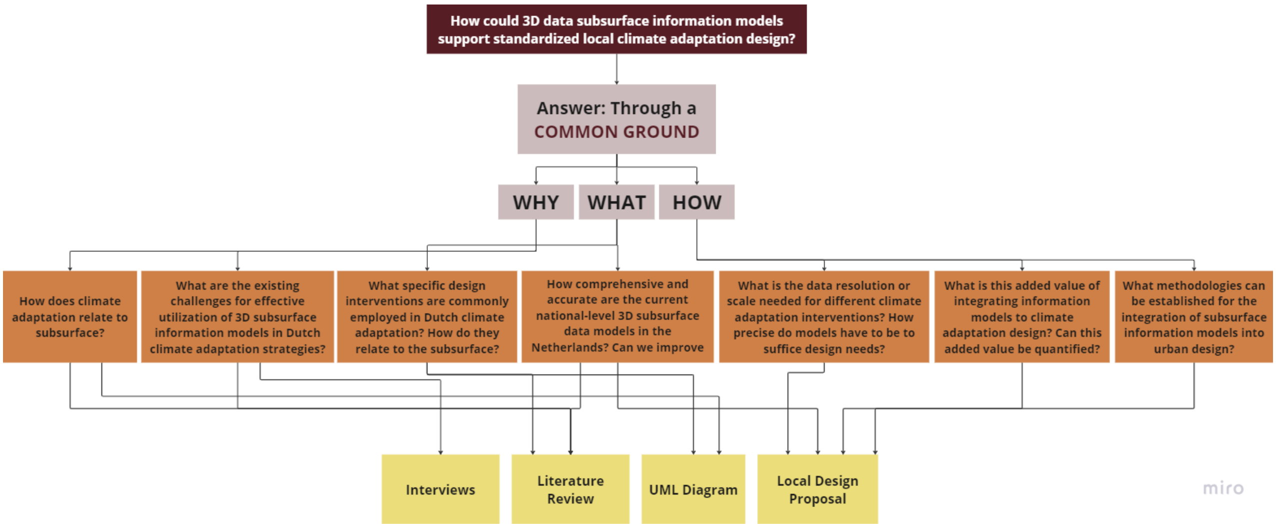


Figure 4.5: Thesis Structure

5

Spatial Interventions

This chapter exemplifies what will be done for each one of the spatial interventions. This is done by explaining how the design proposal can be in done in Voordorp, one of the four areas.

Voordorp is located in an area of Utrecht that has a higher percentage of precipitation than other parts of the city. The neighborhood already has some interventions that are related to avoiding rainwater waterlogging. To mention some of the standardized interventions that are found in the area, there are rain gardens, rainwater buffers, urban waterways, rainwater ponds, permeable pavements, and above all, private gardens.

As mentioned in the subchapter regarding the different locations, the main greenery from Voordorp comes from private gardens. The public spaces in the area, with the exception of the street that contains a canal, are mostly completely paved. The playground in front of the Openbare Basisschool (OBS) Voordorp, a local school, is no exception. The sports fields and playground in this public space are completely paved.

In an area with such a concentration of residential buildings, the playground has the potential to become an attractive public space for the local population. The aim of the design is thus to improve the qualities of the space, promoting a pleasant public space with similar urban functions as it has now, while making it more adaptable to climate change, with a special attention on rainwater waterlogging.

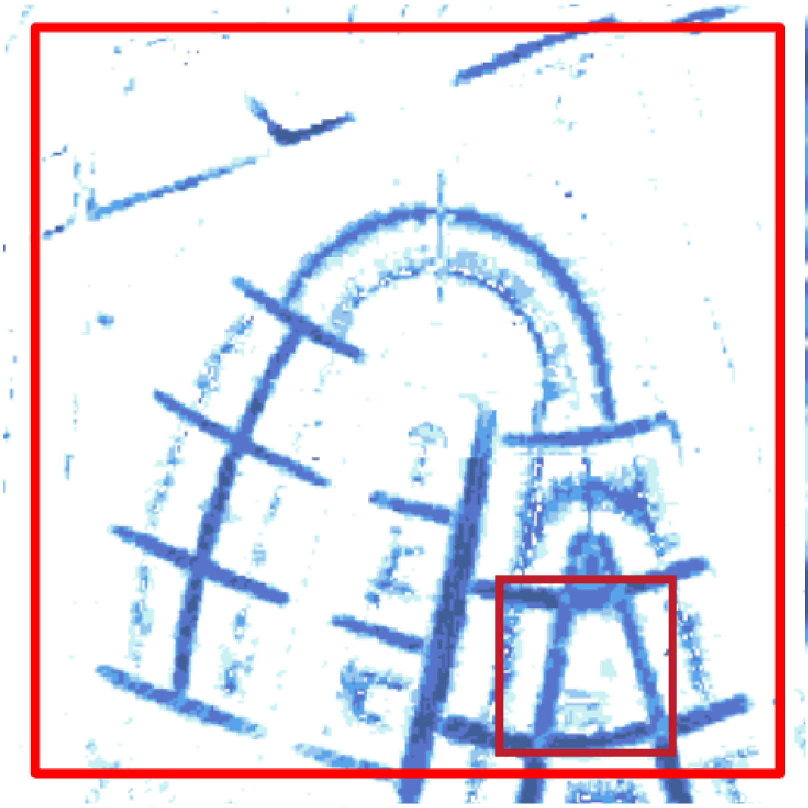
Unpaving this area is particularly interesting in the case of Voordorp because the immediate subsurface layer is this area is sandy, a type of soil that absorbs water faster than other types of soil. From the many interventions standardized by the Bouw Adaptief (which refers to the Leidraad 2.0 and to the Groen Blauwe Netwerken), one that could be tested for the purpose of this design is the storage of rainwater in sportfields. This would keep the main function of the playground, a sportfields. In addition, greenery could be added around the sportfield and playground, in a way that the soil could be kept unpaved, making the most out of the sandy soil, and being more adaptable to storm events.

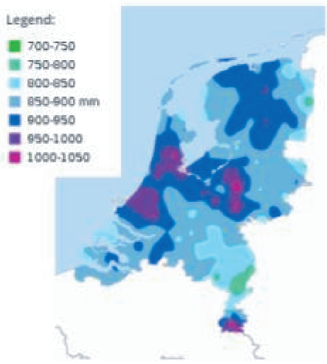
But to make this design more concrete, what information is needed? Each one of the spatial intervention proposals aim to answer this question. For example, for the sportfields, it is important to understand what is the soil type not only in the immediate surface but also underneath, where the crates will go. This already indicates in which resolution the information regarding soil types needs to be for this specific intervention. To answer this question, product manuals can be used.

For example, the ELLIPSE® TANK MODULES produc manual specifies that one module has a lenght of 715mm, height 440mm, and width 400mm. [42] Technical drawings in the same website indicates that around three modules should be used, reaching a height of around 1500mm with extra layers. In the same technical drawing, the soil above the crates is defined as ”permeable soil”, already indicating a preference for soil types that absorbs water more easily, such as sandy soil. Thus for ideal conditions the first 500mm of soil must be permeable, and this should be a resolution that the model that is being used to gather information provides.

Through a more technical approach it is possible to also answer questions regarding the quantitative aspect of climate adaptability. The Dienst Ruimtelijke Ordening (DRO) document, on Waterberging onder sportvelden, by the Gemeente Amsterdam (2010) states that, from the various materials that can be used for this type of intervention, the main ones are Aquaflow or other stone-like materials with large numbers of gaps and synthetic boxes and bulbs. The storage capacity for the first type is approximately 50 oer cent, while the second one offer a higher storage capacity of around 95 per cent. [43] The second material has a higher capacity but is also lighter. Lighter materials are more suitable for certain soil types. An information model should be able to indicate what is the subsurface characteristics where the crates land.

In conclusion, even though only one intervention was analyzed, this example showcases how the design approach will be developed. For each spatial intervention, the climate challenges will be mapped and the most relevant ones will be identified. The focus of the design will be on the identified climate challenges, in this example, waterlogging. Secondly, one or more interventions will be chosen from the standardized interventions provided by the Bouw Adaptief. These interventions will be chosen based on their relevance to the climate themes and to the initial study of the subsurface characteristics, supported by the existing Key Register models. The interventions will then be tested in the area, and by doing so, the information that each intervention requires will become more clear. It is a process of identifying information needs by designing and designing based on the existing information.





Legend:
700-750
750-800
800-850
850-900 mm
900-950
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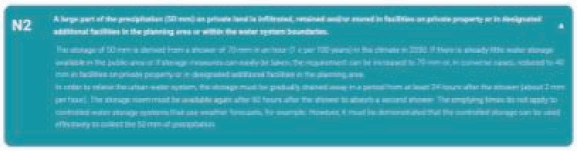
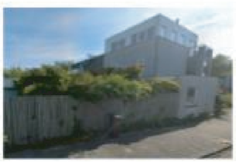
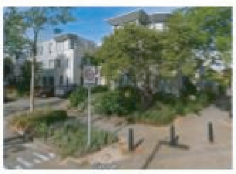
1000-1050

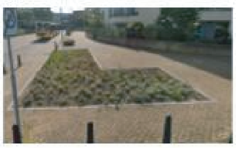
Wijk 34 Noordoost
Buurt 34 Voordorp en Voorveldsepolder



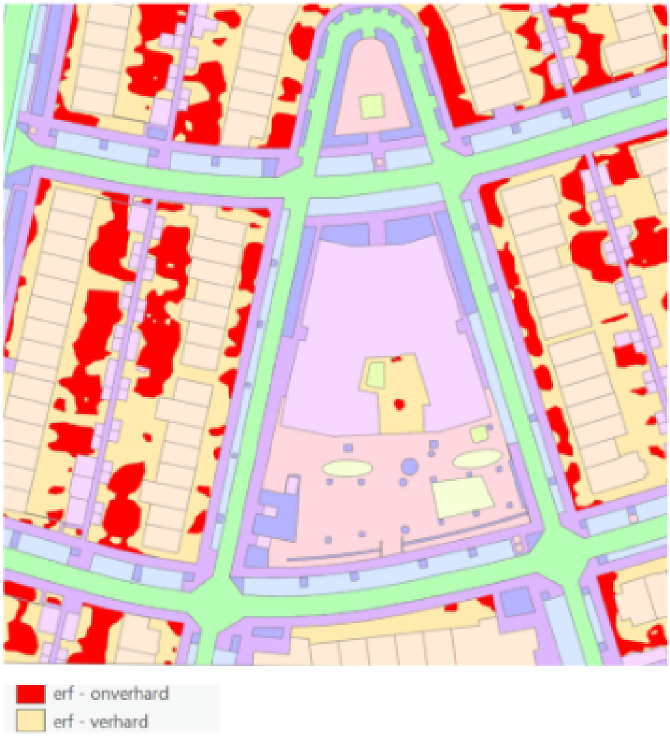
N2
A large part of the precipitation (50 mm) on private land is infiltrated, retained and/or stored in facilities on private property or in designated additional facilities in the planning area or within the water system boundaries.

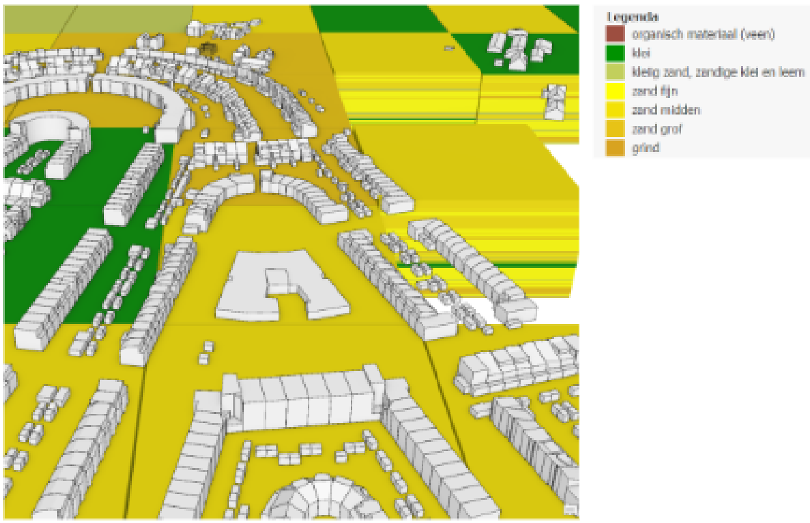






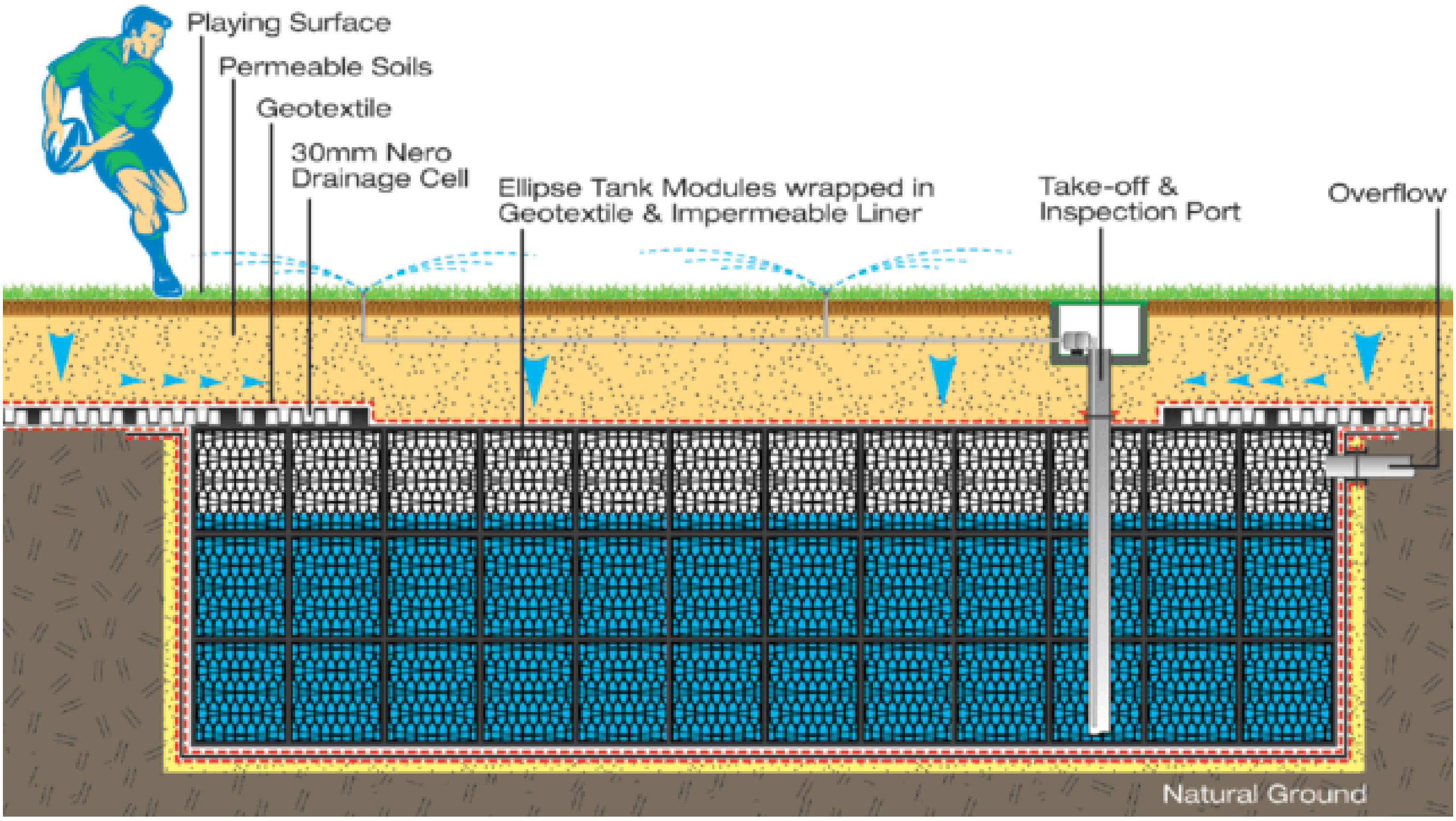
Rain Garden
Raised Sidewalk
Rain Sports Field
Rainwater Buffer
Water Square
Urban Waterway
Rainwater Ponds
Hollow Roads
Roof Garden
Street Gutter
Private Garden
Soil Structure Improvement
Permeable Pavement
Rainwater Underground Storage
Urban Park
Green Square
Water Roof

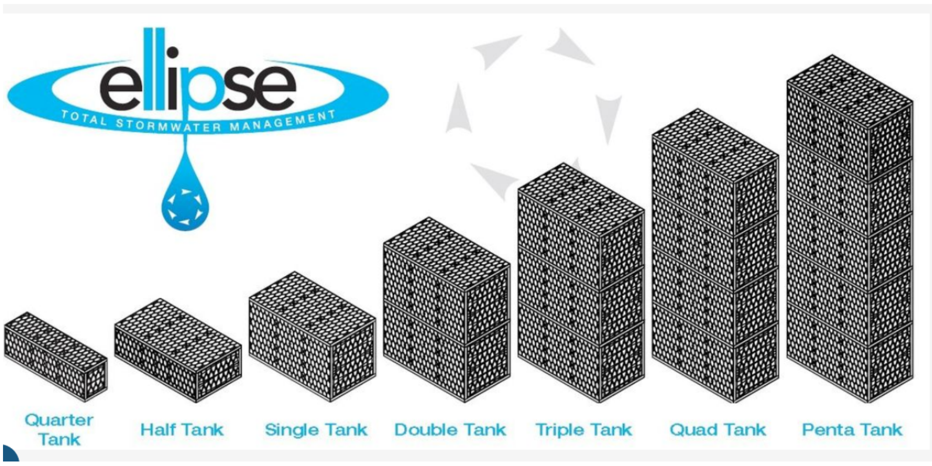




Large amount of private gardens but lack of public unpaved spaces

PART NO: 90001 SINGLE MODULE	METRIC	IMPERIAL
LENGTH	715mm	28.14"
WIDTH	400mm	15.74"
HEIGHT	440mm	17.32"





6

Time Planning

The two initial months of this thesis were dedicated to literature review and the collection of related work, leading to a research question that was presented during the P1 presentation in December.

In the following months, up to February, the relationships between subsurface properties and standardized climate adaptation interventions became more clear through the creation of an Unified Modeling Language (UML) diagram, which related the different standardized interventions to different subsurface requirements, and to the data models in the Key Register where this information could be found. The diagram creation was accompanied to a more careful study of the Leidraad, the Klimateeffectaltas, the Key Register, and other relevant sources. On January and February, there has been also one P2 presentation and two submissions of the graduation plan report.

The research will now focus on the spatial interventions, however, always relating it to the relevant sources, previously mentioned or new ones. The spatial interventions are located in four different areas of Utrecht, described in the previous chapter, and different climate scenarios will be used. The aim of this design exercise is to understand better what are the data resolution requirements when choosing from standardized design interventions for climate adaptation. The UML diagram created already indicated some dependencies and relationships, however, the design of practical spatial interventions will confirm or refute the relationships identified and will moreover showcase an example of urban design methodology that utilizes solenly standardized interventions. This method will also showcase how can subsurface information models support standardized climate adaptation urban design. During the design of the spatial interventions, a P3 could be planned, around April or May.

During the months of July up to September conclusions would be able to be drawn from the spatial interventions. Such conclusions could be related to the experience of designing using standardized interventions, what are the benefits and the drawbacks, and to the information models, what are the weakness and strengths that subsurface information models can bring to urban design. The conclusions will thus showcase examples of both standardized climate adaptation design interventions and their relationships with the subsurface, but also standardized information models for urban design, pointing to potential further research. In October, a potential P4 could be planned, leading to a final P5 in November.

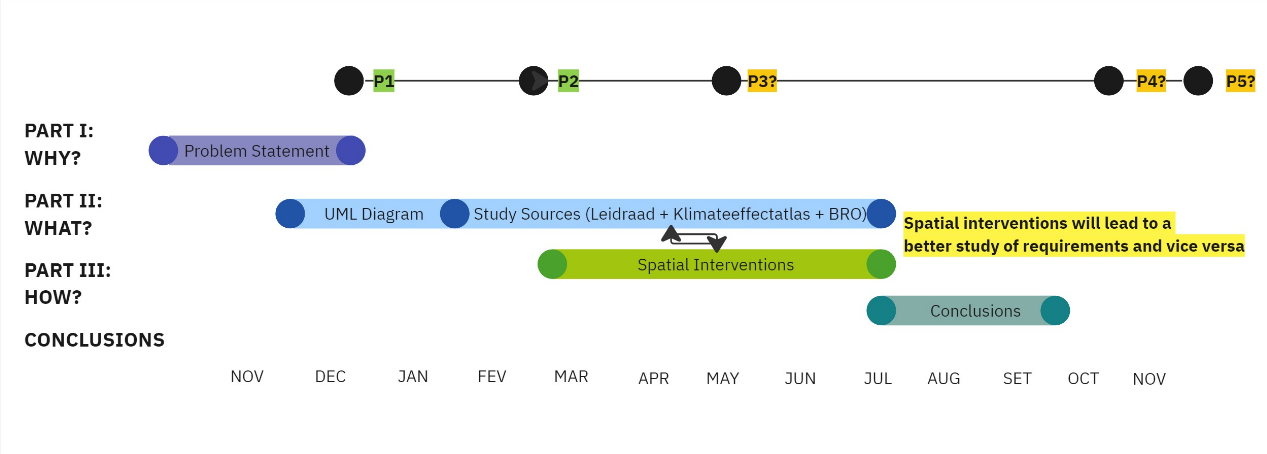


Figure 6.1: Time Planning

During the entire process of this thesis, regular meetings will happen between the students and the different supervisors. There are currently five supervisors in total following this thesis. From TU Delft, there are two from Urbanism, Ulf Hackauf and Alexander Wandl, and one from Geomatics, Peter van Oosterom. The thesis is being conducted in collaboration with an external company, TNO, and there are two mentors from there, Rob van der Krogt and Wilfred Visser.

Individual meetings with the different supervisors will happen biweekly while a general meeting with all the different mentors will happen monthly.

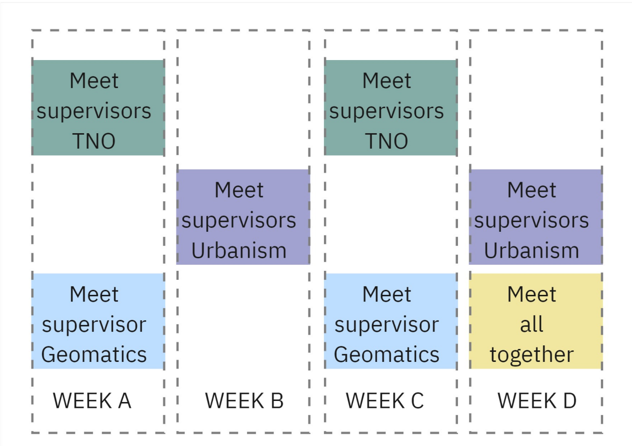


Figure 6.2: Meetings Schedule

7 Tools and Datasets

7.1. The 3D Key Registry for the Subsurface

The thesis uses subsurface information from the Basisregistratie Ondergrond (BRO), also known as the Key Registry for the Subsurface. [34] The Key Registry for the Subsurface (BRO) is integrated into the network of key registers, which consolidates fundamental data about the Netherlands, encompassing topography, addresses, buildings, individuals, and vehicle registrations. The BRO contributes to this array of information by including data and details about the subsurface. [35] TNO is responsible for developing and managing the subsurface aspect of the Key Register.

Previously, individuals utilizing subsurface data and BRO models had to download and modify them independently to integrate them into geographic software. In collaboration with the Ministry of the Interior and Kingdom Relations, TNO, ESRI, and the Land Registry developed BRO 3D web services to simplify this process. By presenting data and models as accessible 3D web services through an API interface, they can be directly utilized in various standard 3D viewers (such as ArcGIS and CesiumJS version 1.99) and game engines (like Unity and Unreal via SDKs). Open OGC standards are employed for this purpose. [36] The web service also provides a user-friendly web interface which does not require any previous knowledge of GIS software. Through the website, users can add and remove different layers from ESRI Living Atlas in addition to 3D BRO data layers.

The four available 3D BRO data models will be used for this research. These consist of data models regarding soil, groundwater, and geotechnical characteristics of the subsurface on a national level. These models will be assessed based on their usability for urban design purposes.

7.2. Leidraad 2.0

The Leidraad 2.0 document, Dutch for Guideline 2.0, aims to provide concrete guidelines to concepts that are often broad in design such as 'subsidence-resistant' and 'nature-inclusive'. The document describes the application of agreements and requirements regarding climate adaptation in building and design solutions as defined in 2022 and is intended to be used by public and private project developers. The core of the Leidraad 2.0 is the process description of climate-adaptive area development. [32] The design solutions proposed by the Leidraad are the ones that were related to the existing subsurface data models and from where the design requirements for climate adaptation were taken from.

7.3. Klimateffectatlas

For an overview of what are climate-related challenges and how they are associated with subsurface information, the Klimaeffectatlas will be used. This uses the same climate themes categories as the Delta Plan. It consists of a four-theme structure: flooding, waterlogging, drought, and heat. In addition to providing a basic impression of how the changing climate may affect the Netherlands, now and in the future, the Atlas also contains context maps, such as storm events maps and maps indicating potential opportunities, which will be taken into consideration.

7.4. Utrecht BARCODE

The Utrecht BARCODE, created by the city planning department, is an integral component of the Ruimtelijke Strategie Utrecht (RSU) 2040. This tool effectively articulates and quantifies the spatial requirements of an expanding city, aligning with the 10-minute city concept to foster sustainable, equitable, and healthy urban development. The BARCODE aims for a precise and quantitative communication, while practitioners appreciate its straightforward visualization of the demands of future urban development.

The BARCODE information regarding the four selected project areas was made available by the Municipality of Utrecht for this thesis. The Municipality also helped to define the most relevant areas, using their experience with the different neighbourhoods and landscapes. This allows an overview of the programs and land use of the 500 by 500 metres area, allowing the focus of the design to be on the relationship between subsurface and climate adaptation.

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