# EXPLORING THE POTENTIAL OF URBAN DIGITAL TWINS IN CLIMATE ADAPTIVE DEVELOPMENT

## A CASE STUDY RESEARCH ON THE GNEPHOEKPOLDER, THE NETHERLANDS

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# Abstract

Cities are becoming increasingly vulnerable to the negative impacts of climate change and, consequently, the urgent need for incorporating climate adaptation strategies into urban planning is frequently highlighted. In this context, Urban Digital Twins (UDTs) have emerged as a promising technology that can potentially aid urban planning processes and facilitate the implementation of climate adaptive initiatives. Despite the rapid development of this technology, UDT research is still in its infancy and more research is required to justify its potential in this context. Therefore, this research investigates the practical application of UDT technology in the context of urban development, with a specific focus climate adaptation. This study is performed through a real-world case study approach on the Gnephoekpolder, an area with significant urban development plans in the Netherlands. This study demonstrates the wide range of possibilities offered by the UDT, which can aid better-informed decision-making regarding climate adaptive efforts. Furthermore, this study identifies the benefits, risks and limitations of UDT technology through a comprehensive user evaluation, based on the UTAUT framework. These insights can serve as a guide for future development of the UDTs. Moreover, the strength and significance of the most important drivers for the adoption of UDT technology are determined. In this study, the importance of social influence is highlighted. With this information, practitioners can design strategies to promote successful adoption the technology in the context of climate adaptation in urban development. Finally, the findings are synthesised, limitations are acknowledged, and future research directions are determined regarding UDT technology in the context of climate adaptation in urban development.

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# List of Abbreviations

| | | |
|---|---|---|
| AHN | = | Algemeen Hoogtemodel Nederland |
| AVE | = | Average Variance Extracted |
| BI | = | Behavioural Intention |
| CA | = | Cronbach’s Alpha |
| CAD | = | Computer-Aided Design |
| CAUD | = | Climate Adaptive Urban Development |
| CDT | = | City Digital Twin |
| CR | = | Composite Reliability |
| DPRA | = | Deltaplan Ruimtelijke Adaptatie |
| DTC | = | Digital Twin City |
| DV | = | Discriminant Validity |
| DXF | = | Drawing Exchange Format |
| EE | = | Effort Expectancy |
| FC | = | Facilitating Conditions |
| FL | = | Factor Loadings |
| FME | = | Feature Manipulation Engine |
| HTMT | = | HeteroTrait-MonoTrait |
| ICT | = | Information and Communication Technology |
| LKB | = | Leidraad Klimaatadaptief Bouwen |
| ND | = | No Development |
| PE | = | Performance Expectancy |
| PET | = | Physiological Equivalent Temperature |
| SI | = | Social Influence |
| SUD | = | Standard Urban Development |
| UDT | = | Urban Digital Twin |
| UTAUT | = | Unified Theory of Acceptance and Use of Technology |
| VIF | = | Variance Inflation Factor |

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# Chapter 1: Introduction

In this chapter, the background of the research is outlined, and research gap is identified in Section 1.1. Section 1.2 presents the research questions. Furthermore, in Section 1.3 the research objectives are explained. Finally, in Section 1.4 an outline of the remaining chapters of the thesis is included.

## 1.1 BACKGROUND

We are currently living in an unprecedented era of urbanisation, with around 3.5 billion people living in urban areas and it is expected that more than two-thirds of the population will live in cities by 2050 (United Nations, 2017). At the same time, global temperatures are steadily increasing over time, primarily caused by anthropogenic activities, known as climate change. Climate change has significant impacts on the earth's climate and weather conditions, including increased likelihood of excessive rainfall, prolonged periods of heat waves and droughts and increased risks of flooding (IPCC, 2021). Cities are particularly vulnerable to climate change, due to the concentration of people, infrastructures and economic services in combination with the large and growing urban population (Geneletti & Zardo, 2016). Exposure to climate-driven impacts, such as extreme precipitation and prolonged heat waves, has an increased impact on people and assets in cities. This impact is expected to worsen in the mid-and long-term future with further projected global warming (IPCC, 2022). Because of the inevitable challenges that climate change will bring, governments of all levels are encouraged to generate activities, innovations, and transformative changes to help cities address the impacts of climate change (Lin et al., 2021; Araos et al., 2016). This is referred to as climate adaptation, meaning to implement measures that reduce the risk and impacts of climate change on urban infrastructure, services and the population (Chu et al., 2019). Climate adaptation efforts can enhance the city's ability to cope with climate-related events.

A promising concept that can potentially aid urban planning processes towards climate adaptive city development, is the emergence of the 'digital twins' technology (Shahat, Hyun & Yeom, 2021). Most commonly, a digital twin in simple terms is described as a digital replica, representation or mirror of a physical asset (Ketzler et al., 2020). Urban digital twins (UDTs) are a type of digital twin that represents a real-world city in a virtual environment. By combining data from various sources, such as sensors, satellites and other forms of urban data, a comprehensive and interactive virtual replica of a city including its properties, conditions and behaviour can be created (Haag & Anderl, 2018). UDTs provide an extensive and dynamic representation of a city's assets, infrastructure, and environment, including its buildings, roads, green spaces, water and transportation systems. According to Ferré-Bigorra et al. (2022), the integration of various urban facets in a UDT has the potential to consolidate city planning and management into a single tool, eliminating the necessity for multiple management tools. One of the main advantages of UDTs is providing useful insights about future development plans and city operations scenarios, by simulating planning and policy scenarios in a virtual environment before actual implementation in the real world, offering significant benefits in decision-making processes (Shahat, Hyun & Yeom, 2021; Balogun et al., 2020). According to Capari et al (2022), the concept of digital twins applied to cities, sustainable urban development, and urban governance is currently one of the most discussed and cutting-edge topics in the scientific and cultural discourse of urbanism.

The advancement of UDTs have already made a notable impact on improving the management, functions, and operations of cities. Generally, UDTs have led to improvements in the digital visualisation of urban areas, increased awareness of various spatiotemporal situations, accurate predictions of future scenarios, and better integration of city domains and stakeholders (Shahat, Hyun & Yeom, 2021; Ketzler et al., 2020). More specifically, in the German city Herrenberg an UDT has shown the potential to enable decision-makers to gain a better understanding of urban systems, and the city is applying UDTs as a solution-oriented holistic approach (Dembski et al., 2020). Similarly, in the city of Zurich, climate issues are integrated into the planning and decision-making process through reliable data from an UDT (Schrotter & Hürzeler, 2020). Furthermore, some cities in the Netherlands are in the early stage of applying UDTs for improved city planning, and the city of The Hague utilises UDTs to monitor mobility patterns (de Matos et al., 2022).

Although Urban Digital Twin (UDT) research shows a rapid pace of development towards fully utilising digital twin technology in the advancement of cities, it is still a relatively young field of research (Shahat et al., 2021). Most of the academic literature in this field has been published very recently (after 2016), with a focus on the modelling aspects of UDTs rather than their applicability on the actual urban context (Shahat et al., 2021) Particularly, the number of publications focusing on novel technologies in the context of climate-resilient cities is expected to grow significantly in the near future, partially caused by the increased interest in UDT technology from the European Union and other public bodies (Riaz et al., 2023). Given that UDTs are still in their early stages of adoption in smart city environments, there are only a limited number of real-world digital twin implementations available (Hämäläinen, 2021). Albeit Capari et al. (2022) highlighted that we must wait for more UDT research to justify if such technological advancement can facilitate urban policy choices and aid sustainable and climate adaptive planning. To further advance UDT research, it is recommended to conduct more case study research to explore the practical application of digital twin technology in a real-world setting (Riaz, McAfee & Gharbia, 2023). Therefore, this research delves deeper into the real-word application of UDTs, specifically within the urban climate adaptation context.

## 1.2 RESEARCH QUESTIONS

To further explore the potential of UDT technology in the context of urban climate adaptation, case study research is performed on the Gnephoekpolder. The Gnephoekpolder is a region in Alphen aan den Rijn, a city located in the western part of the Netherland and is identified as one of the designated areas for significant residential development (Rijksoverheid, 2021). In response to the need for urban housing development in the area, the municipality of Alphen aan den Rijn has been planning for many years to construct thousands of houses in the Gnephoekpolder (Wolzak & van Rein, 2022). Despite the housing development plans originating from the municipality, the province of South-Holland has raised serious concerns regarding the unsuitability of the Gnephoekpolder for housing development due to water- and soil-related risks and issues (Moeys, 2023), leading to extensive delays in the design process and preventing the development process so far. Nevertheless, in October 2022 the Dutch Minister of Housing pushed for the construction of 5,500 homes in the Gnephoekpolder (Trouw, 2022). The recommendation to proceed with the construction in Gnephoekpolder was provided by the former Deltacommissioner, who contended that building in the area is feasible, provided that strict climate-adaptive measures are implemented with regards to environmental, soil and water management (Kuijken, 2022).

The high demand for climate adaptation efforts in the Gnephoekpolder, coupled with the persisting debate between the governmental authorities, makes the area an excellent case study for researching the potential of UDT technology in the context of climate adaptation efforts in urban development. Therefore, the first research question of this study is:

1. *How can Urban Digital Twins (UDTs) be employed in urban development projects to aid better-informed decision-making in the context of climate adaptation efforts in urban development strategies?*

To address the first research question, a UDT representing the latest urban development plans in the Gnephoekpolder is created. Two different scenarios are created: one without climate adaptive measures and one scenario incorporating climate adaptive measures. Subsequently, the UDT is utilised to simulate and visualise various climate change-related risks on both urban development scenarios. The output scenarios are assessed and evaluated, to determine the usability of the technology in facilitating better-informed decision-making. This section demonstrates the potential application of UDTs in a real-world environment in the context of climate adaptation in urban development.

Secondly, a comprehensive user evaluation is carried out on the results of the climate-change scenarios on the urban development plans, generated by the UDT in the first part. The user evaluation is done in cooperation with various stakeholders who are involved in the building development process of the Gnephoekpolder. The goal of the user evaluation is to determine the strengths and weaknesses of UDT technology in the context of climate adaptation. Moreover, the potential adoption of UDT technology is assessed in this study, including its most important drivers. By doing so, this research aims to justify if UDTs can facilitate urban policy choices, through answering two additional research questions stated below:

2. *Which benefits, risks and limitations of Urban Digital Twin (UDT) technology are identified by stakeholders and how can their needs direct the future developments of UDTs in the context of climate adaptation efforts in urban development?*
3. *Which factors have the greatest influence on the technology adoption of Urban Digital Twin (UDT) in the context of climate adaptation efforts in urban development?*

In order to address and answer these research questions, the Unified Theory of Use and Acceptance of Technology (UTAUT) framework is utilised (Venkatesh et al., 2003). This framework serves as a comprehensive guide for investigating the most important factors that influence an individual's behavioural intention and use behaviour to adopt new technology. The UTAUT framework allows researchers to get an understanding of the acceptance and use of novel technologies and gain insights into strengths and weaknesses. With this information, researchers can design strategies to promote the successful adoption and sustained use of certain technologies. The UTAUT framework is explained and elaborated upon in section 5.1.

## 1.3 RESEARCH OBJECTIVE

As cities worldwide are becoming increasingly vulnerable to the effects of climate change, the pressing need for climate-adaptive urban planning and development is highlighted. The increasing development of UDTs is a promising innovation that opens new approaches for urban strategies, with arguably great potential in supporting city planners and decision-makers to foster climate-adaptive urban development. This study consists of two main parts. First, this study tries to investigate the potential applicability of UDTs technology in the context of climate adaptation efforts in urban development. This is performed by exploiting the practical use and possibilities of UDTs by conducting a real-world case study in the Gnephoekpolder. Secondly, this study tries to identify the benefits, risks and limitations related to the implementation of UDTs technology, which can be used to guide the future development of the technology. Additionally, this study tries to create novel insights into the expected use and acceptance of UDTs technology, through a user evaluation based on the UTAUT framework. The insights extracted from this process can serve to determine the expected adoption of UDTs technology in the context of climate adaptation in urban development. Ultimately, this study aims to facilitate climate adaptation efforts in urban development by exploring the potential application of UDT technology and address its challenges and opportunities.

## 1.4 RESEARCH OUTLINE

This research is structured into seven main chapters, each contributing to the overall understanding of UDT technology in the field of urban climate adaptation.

Chapter 1 provided an introduction on the context of UDTs and climate adaptation and presents the research gap. Furthermore, the research questions and research objectives are defined.

Chapter 2 provides a theoretical background on the key definitions of this research: UDT technology and climate adaptation. First, the definition of UDTs is elaborated upon, highlighting its current application in the context of climate adaptation. Secondly, the concept of climate adaptation is defined, including its application into urban planning and development.

Chapter 3 delves into the research design and methods deployed to determine the potential application of UDT technology in the context of urban climate adaptation. This includes an exploration on the UDT software used. Moreover, the process of simulating urban development of the Gnephoekpolder in a UDT is described and the process of conducting climate adaptation analysis is being explained.

Chapter 4 presents the result of the simulated urban development scenarios and showcases the outputs of the climate adaption analyses, which are all performed in the UDT.

Chapter 5 conceptualizes the second part of this research, regarding the user evaluation. It starts with an introduction into UTAUT. Afterwards, the methods are described to perform the user evaluation, including data gathering and its subsequent analysis. Lastly, the findings from the user evaluation are presented.

Chapter 6, the research findings are synthesized. This chapter critically evaluates the results, describes the potential implications of the study, addresses the limitation and recommends future research directions.

Chapter 7 concludes the research. This chapter encompasses a brief summary and reflective analysis of the research, effectively answering the research questions posed in this study.

# Chapter 2: Theoretical Background

This chapter provides a theoretical background on the following topics: Urban Digital Twins (Section 2.1), including its definition and the application into urban planning and development, and Climate Adaption (Section 2.2), also including its definition and application into urban planning and development. This chapter sets the foundation of this study and contextualizes the research objective.

## 2.1 URBAN DIGITAL TWINS

A digital twin is generally described as '*an integrated multi-physical, multiscale probabilistic simulation of a complex object that uses physical, mathematical, simulative and other models to obtain the most accurate representation of the corresponding real object based on analysis of data from sensor networks and other sources*' (Ivanov, 2020, p179). Digital twins have primarily been developed and utilised in fields such as the manufacturing industries and aerospace engineering (White et al., 2021; Hämäläinen, 2021; & Jiang et al., 2022). However, they are increasingly finding new applications in other fields, such as the urban context. The term "Urban Digital Twin" (UDT) is used to describe the application of digital twin technology to cities, which is also referred to as "Digital Twin City" or "City Digital Twin" in (academic) literature. While the concept of digital twins has been present in literature for about two decades, there is no standard definition as it varies depending on the disciplinary context and purpose for which it was developed (Carpari et al., 2022). Therefore, an overview of some of the most common definitions of digital twins applied to cities is provided in Table 1.

Table 1: Definition of Digital Twins applied to Cities

| Author & Year | Definition of Digital Twin |
|---|---|
| Deng et al. (2021) | 'This paper outlines the blueprint of a digital twin city (DTC): all entities in DTCs will exist simultaneously in parallel with historical records that can be traced, a present state that can be checked, and a future state that can be predicted. In this blueprint, the digital twin becomes the most important power engine of urban wisdom.' (p. 126) |
| Dembski et al. (2020) | 'An Urban Digital Twin (UDT) is not the exact copy of reality, but a sophisticated abstraction of ibidem. It can be best characterised as a container for models, data, and simulations.' (p. 2) |
| Yang & Kim (2021) | 'In an Urban Digital Twin (UDT) the actual urban space is reproduced in the same digital space; all the domains and systems of the city are reflected in this digital platform. In this virtual city, real-time interaction between physical reality and the virtual model takes place, including real-time monitoring of the city and prediction of the future through simulation, and visualisation of various characteristics.' (p. 365) |
| Ferré-Bigorra et al. (2022) | 'City digital twins (CDT) not only can model, mirror and interact with the physical aspect of the city but can also be centred on the social and economic aspects. In fact, the continuous and bidirectional data exchange allows the model inside the digital twin to be the most accurate representation possible of the real city and its systems.' (p. 2) |
| Michalik et al. (2022) | A Digital Twin City (DTC) is the further development of 3D city models which are enriched by interconnections to the city's information and data sources. Its realisation is enabled by using key technologies such as 'surveying and mapping technology, building information modelling (BIM) technology, IoT, 5G, collaborative computing, blockchain and simulation' (p. 293) |

Although the concept of digital twins applied to cities started to thrive since the early 2000s, no consensus has been reached regarding the correct definition of the term (Saeed et al., 2022). According to the definitions from Table 1, an important aspect of UDTs is the connectivity between the virtual and physical counterparts, as emphasised by Capari et al. (2022). In the case of a digital twin applied to cities, the actual urban space is replicated in a digital platform, where all the domains and systems of the city should be reflected. This interaction includes real-time monitoring, analysis of various phenomena, prediction of the future through simulation, and visualisation of various characteristics (Yang & Kim, 2021). Therefore, as highlighted by e.g., Botin-Sanabria et al. (2022), in a fully integrated digital twin information should flow automatically to and from both the physical and virtual world. This should enable data, information and simulations from the virtual world to be useful for examining changes in the physical world. Additionally, data from the physical twin should automatically influence the virtual twin in a way that ensures the virtual twin accurately represents the current state and evolution of its physical counterpart.

To date, numerous instances of UDTs have been created, however, every implementation has exhibited different characteristics and therefore there is no clear understanding of what an UDT exactly entails in each specific context and what the system models. For example, existing UDTs have been utilised for an array of different applications, varying from water infrastructure management (Pedersen et al., 2021), urban transportation (Nochta et al. 2021), citizen participation (Dembski et al. 2020) and urban planning (Schrotter & Hurzeler, 2020). In the Netherlands, more than 1/3 of the Dutch municipalities with over 100.000 inhabitants are already working on UDT projects, aiming to improve the communication between residents and project initiators, and to create more insights into the design phase with data-based scenario creations (de Matos et al., 2022).

This research places its emphasis on the utilization of an UDTs within the context of urban planning and development. One of the ultimate goals of such an UDT is to create a digital representation of the city in which complex challenges, such as urban planning and climate change, can be simulated in a virtual environment before implementation in the real world. For this purpose, it would be beneficial if components of the digital twin are updated with different intervals and, where appropriate, enriched with real-time data (Schrotter et al. 2020). For example, according to Henriksen et al. (2022), implementing weather forecasts into a UDT can support adaptive planning and the use of climate adaptation measures. However, Lehtola et al. (2022) identified an interesting gap in between what can theoretically be done with UDTs and what is done in practice. Although solid data infrastructure forms the foundation of successful UDT implementation, the integration of real-time data into urban modelling is currently still in its development stages. Indeed, much existing literature acknowledge that the potential of UDT could be amplified by the continuous advancement of ICT applications and the integration of other forms of real-time monitoring systems (Saeed et al. 2022). However, due to the complex nature of cities, managing and processing data of a large-sized city model including its domains and systems imposes significant challenges (Shahat et al., 2021). Additionally, according to Batty (2018), a complete digital replica of a city with real-time monitoring and interaction could never be achieved due to giant challenges in capturing social and economic factors in a digital twin.

In the case of UDT application for urban planning, the most established approach to realize an UDT appears to be the use of a 3D city information model as their starting point (Lehtola et al. 2022). For example, previously conducted case study research on utilising UDTs for urban planning in Vienna (Lehnr & Dorffner, 2020), Zurich (Schrotter & Hürzeler, 2020) and Helsinki (Hämäläinen, 2021) used this methodology. Although examples exist where 2D models are used in UDTs, 3D models have numerous competitive advantages compared to 2D, and therefore 3D city models are defined as the minimal foundation of digital twins applied to cities (Ferré-Bigorra, 2022). At the same time, there appears to be a commonly shared recognition that the digital twin extends beyond a mere 3D city model, containing additional properties and characteristics. For example, an UDT can expand the scope of a 3D city model through stakeholders' relation modelling, and the simulation of processes and future scenarios (Nguyen and Kolbe, 2021). Apart from the real-time aspect, Henriksen et al. (2022) identified the predictive and prescriptive capabilities also as critical markers of digital twins applied to cities, after conducting a systematic literature review.

Indeed, one of the main advantages of UDTs identified is the ability to provide useful insights about future development plans and city operations scenarios, by simulating planning and policy scenarios in a virtual environment before actual implementation in the real world (Shahat, Hyun & Yeom, 2021; Balogun et al., 2020). This particular research focusses specifically on the application of UDT in the context of urban planning and development, potentially facilitating climate adaptive efforts. Hence, within the context of this research, a UDT is defined as an extended 3D city model with, at least, simulation capabilities to enable the assessment of various scenarios. Nonetheless, it is important to bear in mind that digital twins exist in diverse forms and have varying definitions, yet they remain united under the digital twin umbrella.

## 2.2 CLIMATE ADAPTATION

Regardless of numerous global, national, and local efforts aimed at mitigating climate change, it remains inevitable that a certain level of climate change will occur (IPCC, 2021). The concentration of population, infrastructure, and economic activities in urban areas intensifies the vulnerability of cities to the consequences of climate change (Dawson et al., 2017; Geneletti & Zardo, 2016). In cities worldwide, local governments are compelled to explore strategies for adapting public and private spaces to reduce the impact of anticipated climate change events, a process known as climate adaptation (Wamsler et al., 2013; Bulkeley & Castán Broto, 2013). Climate change adaptation has gained prominence in scientific and policy discussions as a complementary approach to mitigation efforts (de Bruin et al., 2009). It is considered essential to minimise climate-related risks such as increased heat stress, flooding, and drought, as these hazards can lead to social disruption, property damage, and significant loss of life (Uittenbroek et al., 2013; Stern, 2006). Adaptation planning encompasses multiple aspects and involves a wide range of stakeholders. In such complex, multi-stakeholder settings, facilitating decision-making and planning processes while addressing long-term impacts and navigating high levels of uncertainty poses significant challenges (Goossen et al., 2014).

The potential impacts of climate change on the Netherlands have been extensively documented in various reports, including the Environmental Balance, the Climate Policy report commissioned by the Parliament and the Climate reports published by the Royal Netherlands Meteorological Institute (de Bruin et al., 2009). The Netherlands has developed a national climate adaptation program aimed at making the country 'climate proof' in the face of increasing temperatures, more extreme weather events, and prolonged drought periods (de Bruin et al., 2009). Given the high population density in the Netherlands, intensive economic activities, and the spatial component of adaptation measures, climate change adaptation is closely intertwined with spatial planning in the country (Goossen et al., 2014). While urban planners are generally considered responsible and capable of adapting to disasters and climate risks, their specific roles, actions, and the responsibilities of city authorities often lack clarity (Wamsler et al., 2013). It is crucial for policymakers and urban planners to establish clear goals and targets based on policy objectives for adaptation and mitigation efforts (Grafakos et al., 2019). Mainstreaming climate adaptation into existing policy domains necessitates that stakeholders consider the impacts of climate change within their respective policy areas and make informed decisions regarding vulnerability reduction measures (Uittenbroek et al., 2013). The Netherlands is renowned for its planning system as well as its experience with the integration of environmental policy and urban planning (Runhaar et al. 2009). By integrating adaptation measures into interconnected policy documents and processes, society has a better chance of becoming resilient to climate change impacts, ultimately achieving the goal of being 'climate proof' (Uittenbroek et al., 2013).

### 2.2.1 Guideline on Climate Adaptive Urban Development

To mainstream climate adaptation policies in urban development, the ‘Leidraad Klimaatadaptief Bouwen 2.0’ (LKB) (Guideline on Climate-Adaptive Urban Development) has been published recently (van den Dool et al., 2022). The LKB serves as a comprehensive resource for all stakeholders involved in climate-adaptive urban development, design, and construction. It has been collaboratively developed by public and private entities within the Dutch provinces of Zuid-Holland, Utrecht, Gelderland and the Metropolitan Region Amsterdam. These entities have established agreements, defined goals, and formulated performance requirements to promote the construction and design of climate-adaptive structures and urban development projects. Building upon previous related documents as the Reiswijzer Gebiedsontwikkeling and the Roadmap Klimaatrobuuste Gebiedsontwikkeling (van den Dool et al., 2022), the updated LKB offers a practical tool for authorities and project developers to swiftly identify suitable approaches for climate-adaptive urban development. By emphasising the practical possibilities available to stakeholders in the development process, the LKB aims to facilitate effective climate adaptation in urban development. Furthermore, it consolidates the goals and requirements specific to each region into a practical overview for easy reference and implementation. The LKB serves as a comprehensive resource throughout this research.

### 2.2.2 Climate Adaptation Themes

The LKB delves into the six identified climate adaptation themes, offering a comprehensive overview of the most important areas regarding climate adaptation in the urban context. These themes are extreme rainfall, drought, heat stress, soil subsidence, biodiversity, and flooding. By examining these themes, policymakers, businesses, and individuals can gain insights into the challenges and opportunities associated with climate change-related risks and make informed decisions when developing and designing a new urban area. Below, each of the themes is briefly discussed and elaborated upon.

Extreme Rainfall

Extreme rainfall refers to the risk of intense precipitation from cloudbursts that can result in flooding of the urban area. In the last five decades, there has been an increase in the intensity and frequency of heavy rain events in the Netherlands (Ritzema & Van Loon-Steensma, 2018). Consequently, this can lead to water accumulation in streets, cause nuisance and damage to buildings and other structures, and pose potential risks to human life. Currently, Dutch cities are already grappling with the impacts of these extreme rain events, and as the climate continues to change, the occurrence of such extreme weather events may become more frequent, disrupting urban life (Albers et al., 2015). The risk of urban flooding due to extreme rainfall can be reduced by increasing water storage and improving infiltration capacity (Uittenbroek et al., 2019). Additionally, employing measures such as different building methods, creating higher doorsteps, or floating houses can raise the threshold for buildings to be impacted (Albers et al., 2015).

Drought

Severe drought conditions increase water demand and exacerbate water shortages, leading to various challenges in urban areas. These challenges include foundation damage, depletion of greenery, and deterioration of water quality (Voskamp & Van de Ven, 2015). Despite the Netherlands having a maritime climate, projections indicate an anticipated increase in both the frequency and severity of droughts (van Duinen et al., 2015). Consequently, urbanised low-lying regions in the Netherlands will face heightened vulnerability to droughts due to factors such as urbanisation, land subsidence, and sea level rise (de Graaf et al., 2007). To effectively cope with these evolving risks from droughts, cities must adapt their water management strategies to mitigate the adverse effects of droughts (de Graaf, 2009). By implementing adaptive measures, urban areas can enhance their resilience and minimise the impacts of drought events.

Heat Stress

Heat stress refers to the adverse consequences arising from more intense, more frequent and prolonged heat waves in urban areas (Wouters et al., 2017). Cities typically experience significantly higher temperatures for most of the day compared to their surrounding rural areas, a phenomenon which is also known as the Urban Heat Island (UHI) effect (Koopmans et al., 2018). Important factors that cause these increased temperatures in cities include the use of anthropogenic heat sources, and increased absorption and re-radiation of heat by urban materials and structures such as buildings, bitumen, concrete and asphalt. The scarcity of green and blue infrastructure further exacerbates this effect (Koch et al., 2020, Koopmans et al., 2018). Elevated temperatures in the city can have multiple negative impacts, such as increased mortality rates, economic losses, infrastructure damage and reduced labour productivity (Wouters et al. 2017; Hatvani-Kovacks et al., 2016). For instance, a study in the Netherlands revealed a 12% rise in mortality per heatwave day, resulting in approximately 40 additional daily deaths (Klok & Kluck, 2018). As the climate continues to warm, the severity, frequency, and duration of extreme heat events are anticipated to increase. Without the implementation of adaptation and mitigation measures, the negative impacts of heat stress are expected to worsen (Oleson et al., 2015; Zhao, 2018). Climate-adaptive measures that exist to reduce heat stress include increasing the albedo of building materials and surfaces, expanding water bodies, minimising human-induced heat generation and increasing urban greening (Wong et al., 2021).

Soil Subsidence

Soil subsidence is generally defined as continuous land subsidence caused by the oxidation of peat, clink and geological processes in the deeper subsoil. Additionally, subsidence can be caused by settlement, where the soil is compressed under the influence of a load influenced by changing water levels. Therefore, soil subsidence has a strong relationship with intended urban development plans. Climate change can increase soil subsidence, as higher temperatures in combination with lower groundwater levels during dry periods can cause faster degradation of peat (van Gils et al., 2021). Soil subsidence in urban areas leads to detrimental effects, such as damage to the foundation of buildings and infrastructure. In the Netherlands, the increasing number of people and economic assets that are exposed to soil subsidence and damage costs are accumulating to over 5 billion euros for infrastructure alone till 2050 (Stouthamer et al., 2020). In order to prevent additional soil subsidence in the Netherlands, urban planning strategies must incorporate climate-adaptive initiatives, which have not been done enough thus far (de Groot-Reichwein, 2014). According to Kwakernaak (2015), effectively managing climate impacts within the peatland region requires an integrated and site-specific approach, and support for adaptation measures predominantly emerges when economic and ecological concerns are also satisfied.

Biodiversity Decrease

Due to the intensification of land use in combination with climate change patterns, the biodiversity level in the Netherlands is steadily decreasing (van den Dool, 2022). There is increasing evidence of the advantages that biodiversity provides to residents of urban areas, which are referred to as ecosystem services, including enhanced air quality, better human health, temperature regulation, food generation, and the mitigation of water runoff (Boehnke et al., 2022). Although urbanisation may exacerbate the threat to biodiversity, studies indicate that urban development driven by adaptation efforts does not necessarily mean bad news for the already vulnerable species and ecosystems (Butt et al., 2018). Cities can play a significant role in biodiversity conservation by offering habitats to numerous threatened species, and therefore the adaptation response of urban areas is important. To date, the majority of efforts within biodiversity and ecosystem conservation have centred on strategies to maintain existing conditions. However, considering the significance of ecosystem services, climate adaptation strategies must adopt a more forward-looking and proactive approach (Stein et al., 2013). By engaging conservation planners in urban climate adaptation strategies, the potential biodiversity gains can be optimised where possible and the impacts on existing biodiversity can be minimised (Butt et al., 2018).

Flooding

Flooding refers to the mitigation of risks in urban areas associated with sea level rise-induced flooding. Due to climate change, the sea level is continuously increasing, and it is expected to worsen in the near future (IPCC, 2019). The Netherlands is a low-lying country, with 60% of the country being situated below sea level, making it susceptible to flooding. Without its dikes and other protective measures, two-thirds of the country would have been flooded already (Stead, 2014). Flood risk management in the Netherlands has been largely dominated by technical flood prevention measures such as dikes and levees. However, apart from flood prevention, there has been an increasing interest in reducing potential flood damage with smart spatial planning, including building level measures and retrofitting existing buildings in flood-prone areas (de Moel et al., 2014). As sea level rise accelerates, there is a growing need for more frequent implementation of climate adaptive measures. Therefore, when decisions have to be made regarding urban development strategies, adaptive measures to increase flood resilience should be promoted, to avoid potential damage and high costs (van Alphen et al., 2022).

In this study, three of these climate adaptation themes, mentioned above, are assessed in the UDT in a later stage of this research. These include heat stress, extreme rainfall and flooding. This choice is elaborated upon further in the methodology section, Chapter 3.

### 2.2.3 Climate Adaptation in the Building Process

To get a clear understanding on how climate adaptation is incorporated in the building process in the Netherlands, a clear overview is provided in the LKB. In Figure 3 below, the main process of building and urban area development is described, including how climate adaptation is included in the process and which instruments are relevant. The building process consists of four distinct phases, which are shortly described below.

Initiative Phase: This phase involves assessing the feasibility of a development and concludes with a tender or intent agreement that establishes the climate targets.

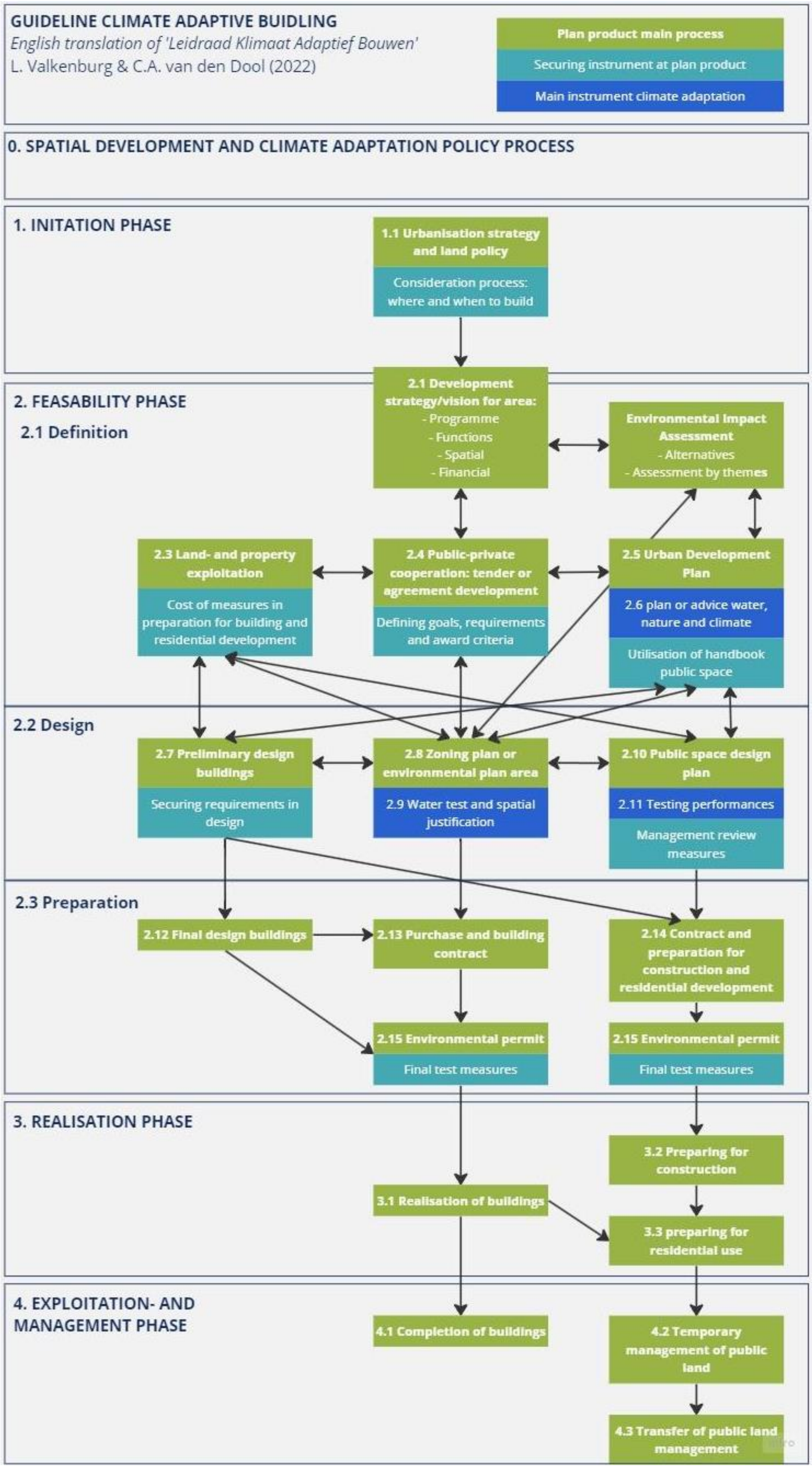
Feasibility Phase: This phase is further divided into three sub-phases. The definition sub-phase focuses on spatially enabling the development, the design sub-phase transforms it into a concrete plan, and the preparation sub-phase concentrates on detailing and contracting for the following realisation phase. During the definition sub-phase, requirements are selected based on the established goals. Throughout the design and preparation processes, the extent to which the design meets the set requirements and achieves the aforementioned goals is evaluated.

Realisation Phase: This is the stage where the urban development plan is physically constructed.

Operation/Management/Sales Phase: In this phase, the completed development is utilised and maintained, including its ongoing management and potential sales activities.

During the creative process of the design phase (Figure 3, 2.2), significant impacts can be made related to sustainable requirements and climate-adaptive urban planning and design (van den Dool et al., 2022). By carefully incorporating climate, soil, and water considerations into spatial planning choices, this process aims to guide urban development in a sustainable and climate adaptive manner. In step 2.11 of the design phase, the performances of the public space design plan are to be tested against predetermined requirements. Related to climate adaptation, this is where an UDT can come into place, by testing the performance of an urban development plan against climate-adaptive rules and requirements. In this study, the application of UDT technology in the context of climate adaption in urban development focuses specifically on step 2.11 of the building process, as set out in the LKB.

Figure 1: The process of climate adaptation in urban development (van den Dool et al., 2022)



### 2.2.4 Important Stakeholders in the Building Process

Developing and constructing climate-adaptive and nature-inclusive urban development projects involves a difficult and creative process. To achieve this, several stakeholders from different disciplines have to work closely together to come up with the right urban development plan. The key stakeholders that participate in this process according to the LKB are listed below in Table 2. During the user evaluation, which is the second phase of this research, an effort is made to gather insights and perspectives from all stakeholders involved in the building process in accordance with this list. By having a complete representation of stakeholders, a comprehensive understanding of the benefits, risks and limitations of UDT technology for climate adaptive efforts can be obtained from various roles. Furthermore, when assessing the adoption of UDT technology, a broad range of stakeholders needs to be involved as the UDT technology relies on collaborative and cooperative usage in order to be beneficial for climate adaptation efforts.

Table 2: Stakeholders involved in the building process and their respective role (van den Dool et al., 2022)

| Stakeholder | Role in Building Process |
|---|---|
| Municipalities | Responsible for the direct spatial development and housing construction within their own boundaries, including the design and management of public spaces. |
| Developers | The driving force behind the development of buildings and areas for the market. |
| Housing Corporations | Provide development and new construction of social rental housing in cooperation with municipalities. |
| Financiers | Invest in real estate and/or in a development and set requirements for (climate) risks from their role. |
| Water Boards | Safeguard the water and climate interest via the water test in a zoning or environmental plan and the issuing of permits in spatial development. |
| Provinces | Responsible for directing site selection, setting frameworks for the housing process at the provincial level, and protecting and strengthening nature and groundwater. |
| Consultancy & Design Firms | Provide advice and design areas and buildings for public and private parties, including knowledge institutions with an advisory role in a development. |

# Chapter 3: Methodology

This chapter the tools and the designs methods adopted by this research, to achieve the aims and objectives of this study are described. Section **Fout! Verwijzingsbron niet gevonden.** introduces the UDT software employed for the simulation of urban development and climate adaptation analyses. Section **Fout! Verwijzingsbron niet gevonden.** describes the process of constructing the urban development scenarios in the UDT and introduces two different scenarios, one with and one without climate adaptive measures. Section 3.3 outlines the procedure of the climate adaptation analyses that are performed in Tygron, including important decisions being made and a justification of parameters chosen. Lastly, Section 3.4 briefly explains the software used to quantify the results of the climate adaptation analyses.

## 3.1 TYGRON

To recreate the urban development plan of the Gnephoekpolder virtually and perform climate change-related scenarios, an UDT is employed. In this research, the Tygron Geodesign Platform, further referred to as Tygron, is utilised for this purpose. Tygron is one of the UDT software tools currently used in the Dutch landscape of digital twins (de Matos et al., 2022). Tygron is commercial software, which provides a user-friendly graphical interface of a 3D city model, which does not require specific programming skills (Pueyo-Ros et al., 2023). Tygron empowers engineers, planners, and governments by enabling them to process geospatial data and conduct advanced analytics and simulations for urban planning, climate adaptation, and environmental analysis (Tygron, 2023). Tygron allows the creation of a realistic, dynamic and interactive 3D model of the city, which can be shared with colleagues, stakeholders, customers and other users. With Tygron, users can automatically import diverse openly available datasets, including elevation maps, buildings and roads, land types and more. In addition, the Tygron Platform is designed to be open and interoperable. This means that users can seamlessly import, and export data using open standards and seamlessly integrate the platform with other applications.

Tygron is originally developed as a serious game, but currently branded as a digital twin (Mayer, 2018). The platform offers a wide range of tools to simulate different scenarios and evaluate the potential impact of climate change-related events, including, for example, heat stress (Brink, 2018). It can be used for, among others, 3D modelling of spatial development projects before implementation in the real world (Hardeveld et al., 2020). Therefore, it fits our definition of an UDT in the context of urban planning and development. The capabilities of Tygron can potentially facilitate informed decision-making on complex issues such as flooding, heat stress, mobility, and nature conservation. However, as aforementioned, more UDT research is needed to justify if such technological advancement can facilitate sustainable urban planning and development choices (Riaz et al., 2023).

## 3.2 SIMULATING URBAN DEVELOPMENT

### 3.2.1 Study Area

In this research, the Gnephoekpolder has been selected as the case study area for to assess the benefits, risks and limitations of a UDT technology for climate adaptation efforts in a real-life context. In the Netherlands, the shortage of housing and its affordability has emerged as a primary concern on the social and political agenda over recent years. Over the past 15 years, housing affordability for individuals with average incomes has declined by half, and the demand for housing has consistently outpaced its supply for several decades (Verheul & Hobma, 2022). The Netherlands faces significant challenges in spatial planning due to high housing demand, and therefore, the government's 2021 coalition agreement commits to accelerating housing construction to approximately 100,000 homes per year (Rijksoverheid, 2021). One of the designated areas for housing development is the Gnephoekpolder (Figure 2). The Gnephoekpolder is an old polder located in the north-western part of the city Alphen aan den Rijn, a medium-sized municipality with around 115.000 inhabitants (CBS, 2023) in the province of South-Holland. The Gnephoekpolder is located at the edge of the built-up area of Alphen aan den Rijn, in the north-western direction from the city centre. Initially functioning as a water board, it was partially managed together with the Vrouwgeestpolder, located directly above the Gnephoekpolder, which was involved in peat extraction and reclamation from 1757 to 1813 (Kuijken, 2022). The Gnephoekpolder serves as a typical representation of a peat meadow area within the Groene Hart of the Netherlands. Spanning a total area of 220 hectares, it encompasses a marshy polder with straight watercourses throughout the entire area (Figure 3). The Gnephoekpolder is situated approximately two meters below sea level, making it vulnerable to flooding if the dykes would break through.

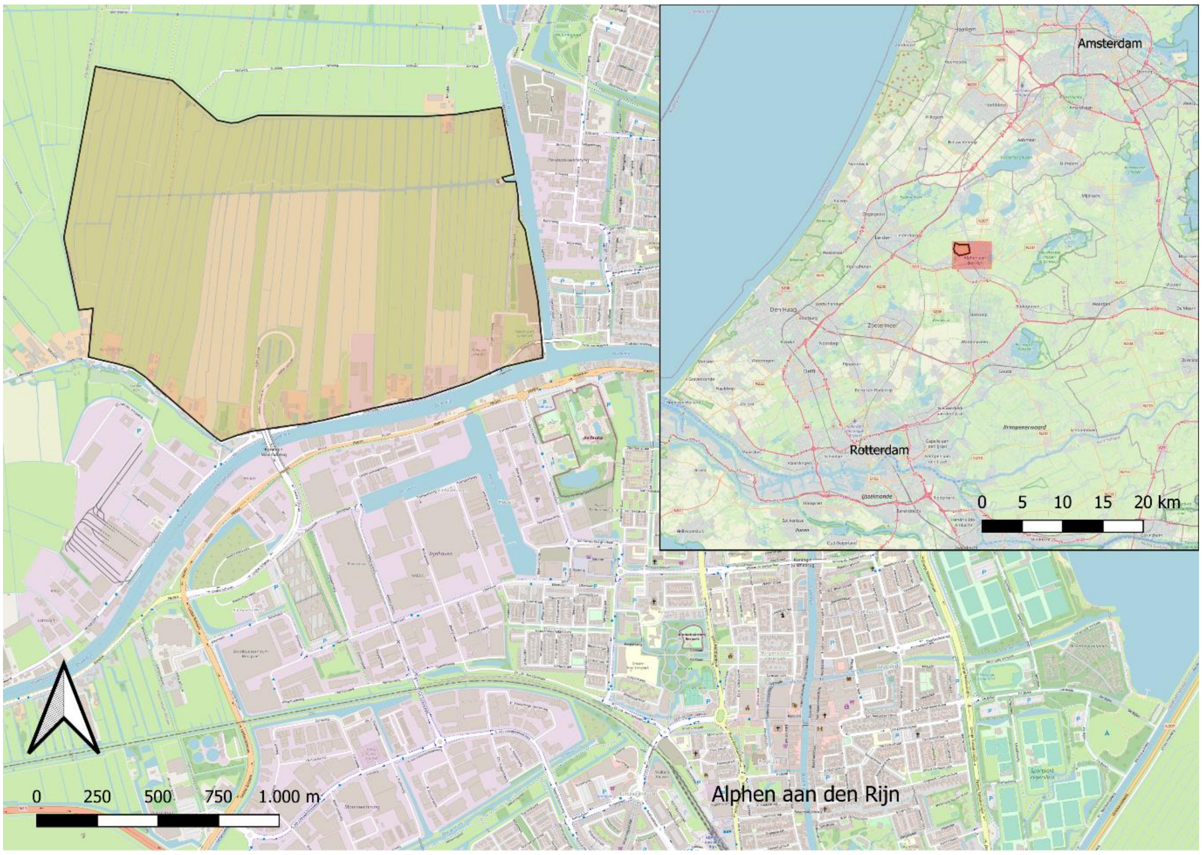



Figure 2: Map of study area – The Gnephoekpolder

Figure 3: Aerial view on North-Eastern part of the Gnephoekpolder (Studio Alphen, 2022)

In response to the need for urban housing development in the area, the municipality of Alphen aan den Rijn has been planning to construct thousands of houses in the Gnephoekpolder for many years (Wolzak & van Rein, 2022). The city of Alphen aan den Rijn lies in the so-called 'Groene Hart', an area with a unique peat meadow landscape in between the agglomeration of Amsterdam, Rotterdam, Utrecht and Den Haag. The Groene Hart is widely regarded as a pleasant place to live and enjoy recreational activities by both residents and visitors and the area's location within the urban sphere makes it particularly attractive for housing development (Pieterse et al., 2015). Despite the municipalities' housing development plans, the province of South-Holland has raised serious concerns regarding the unsuitability of the Gnephoekpolder for housing development due to water- and soil-related risks and issues (Moeys, 2023), leading to extensive delays in the design process and preventing the development process so far. Nevertheless, in October 2022 the Dutch Minister of Housing pushed for the construction of 5,500 homes in the Gnephoekpolder (Trouw, 2022). The recommendation to proceed with the construction in Gnephoekpolder was provided by the former Delta commissioner, Wim Kuijken, who contended that building in the area is feasible, provided that strict climate-adaptive measures are implemented with regard to environmental, soil and water management (Kuijken, 2022).

To build an UDT model of the urban development plans in the Gnephoekpolder, in-depth information about the urban development plan had to be gathered, which was a crucial step in this study. To do so, an in-depth literature review was conducted to obtain a comprehensive understanding of the current state of the Gnephoekpolder, including reviewing relevant literature, news articles and other supporting documents. Additionally, active participation in the 'Ruimtelijke Kwaliteit' (Spatial Quality) working group was pursued, consisting of representatives from the municipality, urban developers, urban designers and consultancies who are actively engaged in the planning and design stages of the Gnephoekpolder. This involvement enabled close observation and up-to-date tracking of the latest urban development plans and stages. Accordingly, the urban development plan of the Gnephoekpolder is currently positioned between the *2.1 Design* and *2.2 Development* phases in the building process, as previously illustrated in Figure 1. As aforementioned, this presents a good opportunity to test the performance of urban development plans on climate adaptation, in which an UDT could play a significant role.

Unfortunately, the stakeholders involved in the planning process were still engaged in extensive discussions regarding the layout of the area, including crucial elements such as the positioning of houses, roads, and natural spaces, as well as the desired building densities. As a result, a complete urban development plan for the Gnephoekpolder is not yet finalised and is not going to be completed within the timeframe of this study. Nevertheless, some of the most important characteristics of the urban development proposal became evident. First of all, the proposed plan involves the construction of approximately 5,500 residential units and the allocation of 40 hectares for water bodies. Secondly, the utilisation of roughly half of the total area, spanning a total of 220 hectares, is reserved for built structures. Thirdly, it became evident that the highest building densities were required at the south-eastern side and higher building densities at the southern and eastern part of the area, due to the soil composition.

According to the Hoogheemraadschap van Rijnland, the responsible waterboard for the city of Alphen, the soil conditions in the area can be classified into three distinct categories. Along the Old Rhine, the soil primarily consists of recent river deposits, which is most suitable for development. This portion covers approximately 80 hectares, mainly comprising clay soil located in the south-eastern corner. In the northern Vrouwgeestpolder, the soil has undergone previous peat reclamation, making it unsuitable for conventional housing development. Any housing projects in this area would require further technical analysis, considering water safety aspects and higher management costs. In the middle of the polders, there is a thick layer of peat with a thin layer of clay on top. The bearing capacity of this soil is poor, making it the moderately suitable for housing purposes. The prevalent soil type in the region is peat, which is prone to subsidence due to drainage. This could lead to substantial and increasing management costs for government authorities, along with additional expenses incurred for housing development on the soft subsoil.

Figure 4 showcases the most recent sketches of the urban development scenarios in the Gnephoekpolder at the time of writing, created by KuiperCompagnons, an architecture and design firm represented in the working group. Due to the lack of more detailed alternatives, this sketch and the information acquired at the working group sessions is used for further analysis to simulate urban development in a UDT.

Figure 4: Sketch of the most recent urban development scenario for the Gnephoekpolder (KuiperCompagnons)

### 3.2.2 Development Approaches

The Tygron Platform offers three distinct approaches for simulating an urban development plan in the UDT software:

The first approach is parametric design, which involves automatically placing elements of a spatial plan, such as buildings, roads, greenspaces, and waterways, in a predefined layout for a given area. Design requirements can be configured using a set of parameters that determine the desired proportions of houses, parks, and waterways within the specified area. The algorithm underlying the parametric design aims to adhere to the specified requirements while generating an urban development design. Although conceptualising the design process in terms of parametric design allows for quick systematic analysis and design in the early urban development stage, it reduces individual freedom of the urban design significantly (Steinø, 2005). Given that the urban development plans and designs of the Gnephoekpolder have advanced beyond the exploratory phase and prioritise a certain degree of design freedom, the parametric design method is not utilised in this study.

The second approach entails importing an urban development plan in a DXF (Drawing Exchange Format) file, commonly used for exchanging CAD (Computer-Aided Design) drawings, directly into the Tygron Platform. By doing so, the Tygron Platform enables the visualisation of the spatial layout, design elements, and attributes of an urban development plan, including features such as buildings, roads, infrastructure, green spaces, water features, and other relevant information. Although this option was initially preferred, it became evident during the study that the urban development plan for the Gnephoekpolder was still in the first step of the feasibility phase (Figure 3) and unlikely to reach its finalisation within the study's timeframe.

The third approach involves the implementation of individual measures, which serve as tools for modifying the virtual environment and simulating urban development scenarios within the Tygron platform. These measures encompass a broad range of actions, including constructing new buildings, implementing green spaces, adjusting the elevation model, and creating water spaces. By applying these individual measures simultaneously within the platform, users can thoroughly analyse and evaluate the potential outcomes and impacts of different interventions on the urban environment.

Given the limitations of the parametric design approach in the Tygron platform and the unavailability of a complete urban development plan in a DXF format, the third approach to create a digital twin of the urban development of the Gnephoekpolder was chosen. The subsequent section provides further elaboration on the process and choices involved in creating and implementing these measures.

***Tiles System***

Based on findings from the data collection and discussions held during the working group sessions, several key aspects of the urban development plan in the Gnephoekpolder became clear. The envisioned plan entailed the construction of approximately 5,500 houses, predominantly on the south-eastern and southern part of the area due to the stronger soil composition. Additionally, about half of the total area (110 ha out of 220 ha) should be used for urban development, including the allocation of approximately 40 hectares of water. To transform these key aspects of the urban development plans in combination with the urban design sketch (Figures 5) into measures on the Tygron Platform, a Geographic Information

System (GIS) was employed as a means to recreate the urban development plans. Specifically, the QGIS software was utilised for its robust suite of tools and functionalities, enabling spatial analysis and visualisation.

To simulate the urban development plan based on these findings, the study area was divided into different tiles measuring exactly 1 hectare, equivalent to 100 meters by 100 meters, as shown in Figure 5. The QGIS "Create Grid" tool was utilised for this purpose, wherein the grid extent was defined by a polygon outlining the Gnephoekpolder, and the horizontal and vertical spacing was set at 100 meters. Subsequently, the total area of each tile was calculated by multiplying the horizontal and vertical lengths in the “Raster Calculator” tool. For the sake of simplification and optimization of the look of the design, tiles with a total area smaller than 0.4 hectares were excluded from further analysis. The remaining tiles were assigned different colours, representing specific building densities, water bodies, infrastructure or areas left undeveloped. To determine if the urban development plan was aligned with the predetermined goals of 5,500 houses, 40 hectares of water, and approximately 110 hectares of built-up area in the Gnephoekpolder, the tiles were added up together. In instances where a partial tile did not represent a complete hectare, the total number of houses was adjusted by multiplying it with the factor corresponding to the total area represented by the tile. Employing Microsoft Excel, Table 3 was constructed, outlining the intended objectives for the urban development and presenting the estimated outcomes derived from the urban development scenario created in QGIS. As the results exhibited a considerable level of similarity, this spatial model was utilised for subsequent analysis of the climate change-related scenarios.

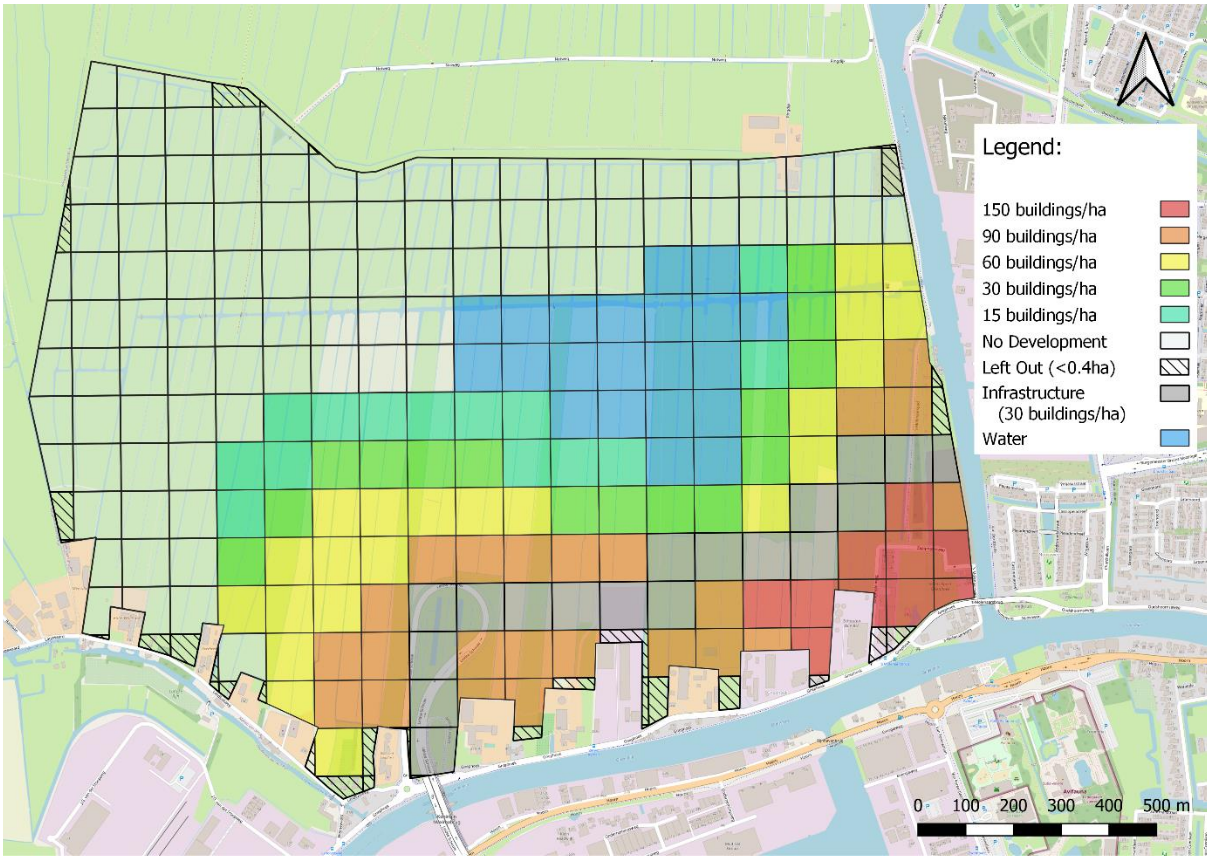



Figure 5: Tiles system in GIS that is used to recreate the urban development plan for the Gnephoekpolder

Table 3: Characteristics of individual tiles from tiles system

| Tile | Characteristics | Total Area (ha) | Total No. of Houses | Total Water Area (ha) |
|---|---|---|---|---|
| 1 | - 150 buildings/ha<br>- 0 ha water | 8.1 | 1217 | 0 |
| 2 | - 90 buildings/ha<br>- 0 ha water | 20.9 | 1884 | 0 |
| 3 | - 60 buildings/ha<br>- 0 ha water | 21.2 | 1274 | 0 |
| 4 | - 30 buildings/ha<br>- 0.2 ha water | 15 | 450 | 6 |
| 5 | - 15 buildings/ha<br>- 0.4 ha water | 14 | 210 | 11.2 |
| 6 | - Main Road<br>- 30 buildings/ha<br>- 0 ha water | 17.4 | 522 | 0 |
| 7 | - 0 buildings/ha<br>- 1 ha water | 21 | 0 | 21 |
| | **TOTAL** | **117.7** | **5557** | **38.2** |

In order to depict the urban densities and water areas of each individual tile in the tiles system method chosen, each tile had to get different characteristics. To create the tiles, various polygons representing unique features such as flats, apartments, houses, parks, trees, roads, and parking spaces were created using QGIS. Each tile was assigned specific characteristics showing both urban density and hectares of water, carefully measured through the utilisation of the "Advanced Digitizing" tool in QGIS. Figure 6 provides an overview of the distinct tiles that are created, along with their corresponding properties. By combining each individual tile together into one model, in accordance with the proposed lay-out (as seen in Figure 5), an urban development scenario can be created that aligns with requirements. This tile system serves as the basis for constructing a hypothetical urban development scenario of the Gnephoekpolder, which will be subjected to climate-change related risk scenarios using the Tygron platform.

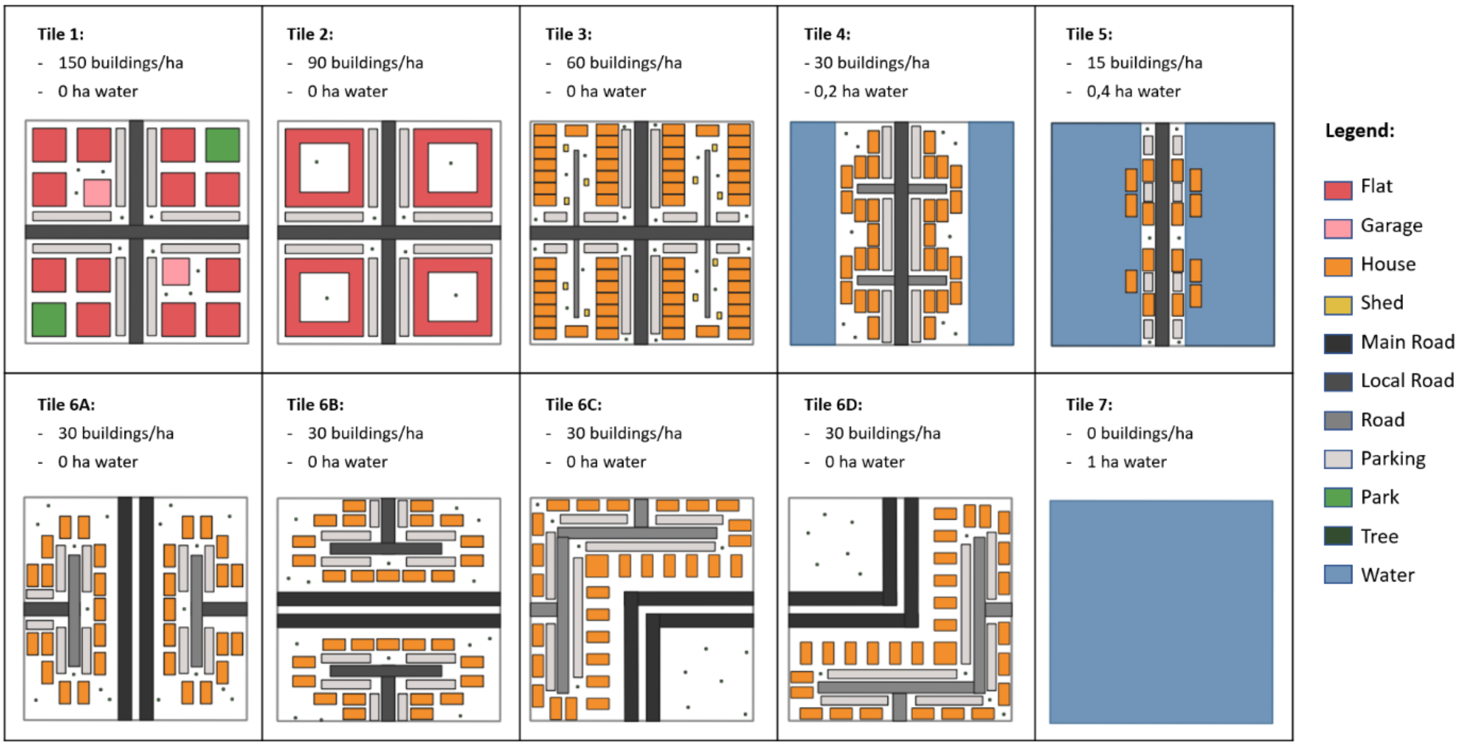



Figure 6: Spatial representation of the characteristics of the individual tiles to fulfill urban development purposes in the Gnephoekpolder

Lastly, in between every three tiles starting from the right, a small waterway with a width of 2 meter was added. This is partly done to retain a bit of the original structure of the area, as suggested by the working group, but also improves the drainage of water in the model. Furthermore, the surface level of the tiles with a housing density of 90/ha or higher are raised with 0.6 meter in height. This represents the extra layer of sand to strengthen the soil conditions for high urban densities, as was discussed in the working group. The other tiles that contain building structures, thus excluding tile 7, are raised with 0.3 meter respectively.

### 3.2.3 Urban Development Scenarios

To assess the impacts of climate-related risks on the hypothetical urban development scenario in the Gnephoekpolder, it is essential to examine the variations resulting from changes in the urban development plans with regard to climate adaptive measures. To facilitate this analysis, two distinct scenarios were created: one scenario without climate adaptive measures, further referred to as the Standard Urban Development (SUD) scenario, and one scenario with climate adaptive measures, further referred to as Climate-Adaptive Urban Development (CAUD) scenario. The current situation, without any urban development, is further referred to as the No Development (ND) scenario.

The first scenario (SUD) is created based exactly on the tile system as aforementioned, without any further alterations. The second scenario (CAUD) incorporates climate adaptation measures in addition to the existing SUD scenario. These measures consist of three things: ecosystem-based adaptation, different water management, and elevating road infrastructure. First of all, ecosystem-based adaptation is defined as the use of biodiversity and ecosystem services to adapt to the adverse effect of climate change (Geneletti & Zardo, 2016). This includes approaches such as more urban parks and tree plantings. The benefits of green infrastructure include better management of storm-water runoff, reduced ambient temperatures and reduced urban heat island effects (Foster et al., 2011). Furthermore, besides the integration of ecosystem-based adaptation, various measures are implemented to transform urban water management into a sponge-like system that captures, stores, and gradually releases water. This approach, in contrast to immediate drainage through the conventional system, effectively reduces stormwater runoff and serves as a fundamental principle in Dutch water management (Dai et al., 2018). Examples of such measures include the installation of green roofs, the implementation of water reservoirs, the use of more permeable soil types and the implementation of structures with additional water storage features. Lastly, to reduce the impact of rising water levels on the infrastructure and maintain access the road infrastructure can be elevated as a climate adaptive measure (Wang et al., 2019), which is done in the case of the Gnephoekpolder for the main road infrastructure.

Below, all the extra climate adaptive measures added in the CAUD scenario are explained, including a brief description of the most important characteristics. It is important to note that the incorporation of these measures primarily serves to facilitate a comparison between climate simulations for various urban development scenarios. This also enables an assessment of how climate adaptive measures influence these outcomes of the climate simulations on the scenarios.

Extra Trees: In the CAUD scenario, around 2.000 extra trees are added in comparison to the SUD scenario. These trees are strategically positioned next to road infrastructure. These trees have a default height set by Tygron of 11.6 meter and a foliage crown of 0.75, similar to all other trees in the SUD scenario.

More Parks: In the CAUD scenario, four extra urban parks are added. Each park has a total size of 200 $m^2$, is publicly accessible and is covered with trees, to maintain a lower average temperature.

WADIs: A WADI stands for 'Water Afvoer Drainage Infiltratie' (Water Discharge Drainage Infiltration) and is also an Arabic word for a (dry) riverbed that only contains water after heavy rainfall. Practically, it acts as a temporary water reservoir in case of extreme rainfall before infiltration in the ground. In the CAUD scenario, 7 WADIs are added in the shape of a hexagon, with a diameter of 30 meter and a gradual decrease in elevation to a maximum depth of 4 meter.

Water Storing Parking Places: In the CAUD scenario, all the imported parking places have an additional water storage capacity. This capacity is set to $0.133m^3/m^2$, based on a state-of-art example of a Dutch water storing parking place (Park Positive, 2023).

Water Storing Parking Garage: In the CAUD scenario, all the imported parking garages have an additional water storage capacity. This capacity is set to $55m3/m^2$, based on an innovative example of an underground water storage garage in Rotterdam, the Netherlands (Tillie, 2017).

Green Roofs: In the CAUD scenario, the roofs of all the imported apartments and flats are changed into a green roof with an additional water storage capacity of $0.083m^3/m^2$, based on a typical green roof in the Netherlands (Busker et al., 2022).

Main Road: In the CAUD scenario, the main road infrastructure is elevated with a relative height difference of 1 meter compared to the SUD scenario.

## 3.3 CLIMATE ADAPATATION ANALYSES

The first research question focuses on how UDTs can be employed to aid decision-making processes in the context of climate adaptation efforts in urban development strategies. In order to address this question, the Tygron platform was employed to conduct various climate-related risk simulations on both the SUD and CAUD scenarios, examining the potential consequences of climate change on the urban development plans. The outcomes of these simulations may provide valuable insights to inform adjustments to the urban development scenario plan, enhancing its climate adaptive capacity. Furthermore, some analyses are performed on the ND scenario, to allow comparison when deemed more suitable. This research places specific emphasis on three climate adaptation themes, namely heat stress, extreme rainfall, and flooding. These themes are specifically chosen for a number of reasons. First of all, these themes are directly related to the climate-change related impacts of changing weather patterns. In the case of biodiversity for example, this is not the case. Secondly, the themes chosen are, together with soils subsidence, deemed most relevant for this study area in consultation with the working group. For soil subsidence however, the model and analysis were excluded because of two reasons. First of all, this theme has more to do with determining the location for urban development based on the best soil conditions prior to urban development, which was already done. Secondly, it was excluded due to the complexity of the model and time limitations. Lastly, drought was excluded as Tygron did not offer a specific analysis for this theme.

The chosen climate adaptation themes, including important characteristics and input parameters, are further elaborated below. The analysis incorporates the goals and requirements outlined in the LKB document, specifically tailored for the province of South-Holland, which includes the region encompassing Alphen aan de Rijn and the Gnephoekpolder. In order to evaluate, assess, and visualize climate change-related risk scenarios within the Tygron platform, several critical decisions were made to facilitate this process. The following section outlines and provides explanations for the key choices made during the study per climate theme. All climate adaptation analyses are performed using a grid cell size of 0.25x0.25m, ensuring precise and accurate outcomes.

### 3.3.1 Heat Stress

As aforementioned, heat stress in urban areas refers to the increased risk and discomfort experienced by individuals due to elevated temperatures, exacerbated by factors such as the urban heat island effect, limited green spaces, high building density, and reduced air circulation. It can lead to heat-related illnesses, reduced productivity, and overall discomfort among the population. The heat stress module and calculations in the Tygron platform are developed based on the guidelines outlined in the 'Deltaplan Ruimtelijke Adaptatie' (DPRA) heat stress report (de Nijs et al, 2019). The DPRA is a collaborative initiative involving multiple levels of the Dutch government aimed at accelerating and guiding efforts to mitigate heat stress. As part of this comprehensive approach, a standardised heat stress testing protocol was established to assess and address heat stress concerns. In this report, the Physiological Equivalent Temperature (PET) was selected as an indicator to assess the onset of issues associated with urban heat. PET is defined as "the *physiological equivalent temperature at any given place and is equivalent to the air temperature at which the heat balance of the human body is maintained with core and skin temperatures equal to those under the conditions being assessed*" (Höppe, 1999, p73). This choice was made because relying solely on temperature does not adequately capture the thermal comfort experienced by individuals in a specific location. Heat stress, as well as cold stress, arises when there is an imbalance between the heat absorbed and released by the human body (DPRA). Physiological heat stress starts to occur when the PET is higher than 23°C. Between 29°C and 35°C the heat stress is considered moderate, between 35°C and 41°C strong, and higher than 41°C extreme (Santos Nouri et al., 2018).

From the LKB document, the following goals and requirements are chosen for further analysis in the Tygron platform:

1. Cool, shaded dwellings with an area greater than 200 square meters and an average PET below 35°C on hot summer days are provided within a walking distance of 300 meters and are publicly accessible.
2. In areas where slow traffic travels, a minimum of 40% shade coverage in the designated plan area during the highest sun position is required.

To address the first requirement, the initial step involves calculating the PET on a hot day. The energy flows that play a crucial role in PET calculations include sensible heat transport, latent heat transport, and radiant load. PET takes into consideration these energy flows and expresses thermal stress resulting from imbalances in these flows on a temperature scale. Several meteorological variables are involved in the calculation, including air temperature, air humidity, wind speed, global radiation, thermal radiation, clothing insulation, and exercise metabolism. In the Tygron platform model, the non-meteorological variables are based on a standardised person (male, 35 years old, 1.75 m, 75 kg, fixed clothing factor and an effort level equal to walking 4 km/h). For the calculation of the PET temperature, the reference date chosen is July 1st, 2015, as specified in the DPRA report (de Nijs et al., 2019). This particular date represents an extremely hot day, occurring approximately once every 5.5 years. The PET temperature for a day is always calculated as the average value between 12:00 and 18:00 local time (de Nijs et al., 2019). The weather data utilised for Alphen aan de Rijn was obtained from the Valkenburg (Zuid-Holland) weather station, specifically for July 1, 2015 (KNMI, 2023) and is presented in Table 4.

Table 4: KNMI weather data for the 1st of July 2015, a typical hot day in the Netherlands (KNMI, 2023)

| **Hour of day** | **Sun Daily Motion** | **Humidity (%)** | **Sun Radiation ($W/m^2$)** | **Temperature (°C)** | **Wind Speed** | **Wind Direction (°)** |
|---|---|---|---|---|---|---|
| 12 | 0.029 | 45 | 1046 | 28 | 4 | 120 |
| 13 | 0.05 | 41 | 1100 | 30 | 5 | 130 |
| 14 | 0.074 | 38 | 1251 | 31 | 5 | 120 |
| 15 | 0.108 | 35 | 1274 | 32 | 5 | 130 |
| 16 | 0.161 | 32 | 1161 | 32 | 5 | 140 |
| 17 | 0.228 | 32 | 986 | 33 | 6 | 130 |
| 18 | 0.312 | 32 | 772 | 33 | 5 | 130 |

In the SUD scenario, four parks with a minimum area of 200 $m^2$ and abundant trees were strategically placed. Similarly, in the CAUD scenario, eight parks were established with a minimum area of 200 $m^2$, all publicly accessible. To assess whether these parks are located within a 300-m walking distance, the 'travel distance' overlay in the Tygron platform is utilised, which is based on the Chebyshev distance measurement. Within this overlay, one can select the mode of transportation for distance calculation, such as biking, driving, or walking. Given that both the SUD and CAUD scenarios focus on simplified road networks with designated car roads, the distance is determined based on a 275-m road distance, along with an additional 25-m proximity from the roads, comprising a total of 300 m. By integrating the travel distance overlay and the calculated PET, we can evaluate both urban development plans against the first specified requirement.

To fulfil the second requirement, the day with the highest sun positions is determined. According to the KNMI (2021), this occurs on June 21st at 13:45 local time in de Bilt, which is chosen as a reference location. In the Tygron analysis, this specific day is selected between the timeframes of 13:00 and 14:00 to calculate the shade coverage, to get a most approximately correct answer. The shade calculation model takes into account the sun's altitude and azimuth angle, which are derived from the provided date and time. Using this information, the shade is calculated based on factors such as building height, terrain, and foliage height of trees. In both urban development scenarios, the tree height remains fixed at a default value of 11.6 meter. Furthermore, the roads are determined based on a specific attribute in the urban development scenarios. By combining these overlays, the analysis reveals which roads are in shadow and which are not. Using FME, the total percentage of shade coverage in the designated urban development scenarios is calculated and compared against the requirement.

### 3.3.2 Extreme Rainfall

As aforementioned, excessive rainfall in urban areas can lead to urban flooding, posing risks to both people and infrastructure. The effects of urban flooding include infrastructure damage, public health risks, service disruptions, economic losses, and psychological impacts. Addressing urban pluvial flooding in cities requires improved urban planning to enhance resilience and protect lives and property.

From the LKB document, the following goal and requirement are chosen for further analysis in the Tygron platform:

1. In the plan area, until 70 mm of rainfall in an hour no damage occurs to buildings, infrastructure and vital facilities and vital facilities continue to function with 90 mm of rainfall in an hour.

A building is classified as damaged when it is surrounded by at least 30cm of rain on the street level within a 1-meter proximity range of the building, as indicated by the Framework of Climate Adaptive Buildings (Kadijk & Prijden, 2022). To test the urban development scenario on this requirement, an extreme rainfall scenario of 70 mm in one hour and 90 mm in one hour is simulated on both the SUD and CAUD scenario. The water module implemented in the Tygron Platform utilises a 2D grid-based shallow water model that is based on the 2D Saint Venant equations. This module is equipped with additional features such as infiltration, evaporation, groundwater flow, and hydraulic structures to enhance its functionality. It simulates the water dynamics within the project area, taking into account factors such as rainfall, breaches, and existing open water bodies. To carry out the calculations, the project area is divided into a grid of cells, each with specific hydrological parameters and water quantities based on the input data. The simulation time is divided into discrete timesteps, and during each timestep, the cells communicate with their adjacent cells to exchange water based on factors such as water levels, surface heights, flow directions, and other relevant considerations. For the analysis, the project area is divided into cells of 0.5 meter and has 24 simulation steps over 2 hours. This ensures great accuracy and reliability, albeit at the expense of increased computational time.

During the process of recreating the water system and performing the analysis, several important decisions are made, which are summarised as follows:

Rain Event: In accordance with the rain stress goals/aims outlined in the LKB, the impact of both a 70-mm and 90-mm rainfall occurrence within one hour is assessed and calculated. The total rainfall event is computed over a period of two hours, with 1 hour of continuous rain followed by 1 hour of dry conditions.

Elevation Model: In the SUD scenario, the Actueel Hoogtebestand Nederland (AHN) dataset is used as the default elevation model, which is automatically imported into the Tygron platform. Furthermore, the tiles from the tiles system are raised with either 0.6 or 0.3 meter, depending on represented the urban density. In the CAUD scenario, the elevation model is modified specifically at the locations of the WADI's. These WADIs are lower the elevation model at their respective locations to accommodate additional water retention and drainage requirements.

Rain Area: To streamline the analysis and optimise computational efficiency while generating regionally relevant outcomes, only the rainfall occurring within the Gnephoekpolder and the northern lying Vrouwgeestpolder areas are considered. This simplification allows for shorter calculation times and focuses on producing results that are specifically pertinent to the local context.

Sewer System: Due to insufficiently detailed data on the sewer system for the newly developed area, the calculations rely on a reference system. This reference system assumes a uniform sewer storage and discharge capacity of up to 20 mm/hour, considering the optimal connection of the paved outdoor space to the sewer system

(Deltares, 2018). Hence, the rain event of 70 mm within a one-hour duration is represented as 50 mm, and 90 mm as 70 mm, for the purpose of analysis.

Culverts: Culverts are used to improve water flow, manage drainage and flooding, and support water resource management. Data on their location, diameter, and length are acquired from Hoogheemraadschap van Rijnland, the responsible waterboard.

Pumps: Within the Gnephoekpolder, there is one existing pump located on the eastern side that connects the Heimanswetering with the waterways present in the polder. The pump has a capacity of 0.315 $m^3/s$, and this value has been determined using data provided by the Hoogheemraadschap Rijnland.

### 3.3.3 Flooding

As previously mentioned, sea-level rise can cause flooding in coastal or low-lying areas, posing significant risks to both individuals and infrastructure. For the purpose of simulating flooding caused by sea-level rise, a dike breach event is used. The consequences of flooding caused by dike breaches encompass infrastructure damage, public health hazards, and service disruptions. Insights into potential flooding events can provide valuable information for smart urban planning, enabling the implementation of appropriate measures to enhance resilience and mitigate the impacts of such events.

From the LKB document, the following goals and requirements are chosen for further analysis in the Tygron platform:

1. Prevent damage (<0.2 meter): in case of flooding, no damage should occur to buildings and electrical installations in public areas and main roads remain passable.
2. Damage limitation (<0.50 meter): measures should be taken to limit damage in the event of a flood, provided they are effective.
3. Protection of vital functions (<2.0 meter): vital functions are protected in the event of flooding and continue to function, provided the measures are effective for this purpose given the regional or national importance.

During the process of recreating the water system and conducting the analysis, similar parameters to those described in the excessive rain paragraph are chosen, except for the fact that there is no rain event. Additionally, specific decisions are made to regarding the levee breach to allow the water system modelling for the flooding scenario. These decisions are outlined below:

Breach Area: The breach area chosen as an example is situated in the southern region of the Gnephoekpolder, adjacent to the Oude Rijn River. The location where the levee breach is happening features minimal built infrastructure or development next to it. The height chosen for the breach is -2 meter, which is similar to the land elevation level behind the dyke. The width parameter is set to 5 meters.

## 3.4 DATA ANALYSIS

In addition to the climate adaptation analyses performed in Tygron, Feature Manipulation Engine (FME), is used to quantify the spatial results of the analysis into numbers. This allows the results to be reflected against the set requirements and the scenarios to be compared to one another. FME is a versatile and robust spatial toolset utilised by numerous professionals worldwide for efficient data translation, transformation, and integration.

# Chapter 4: Results

In this chapter, the results of the the reaccreted urban development scenarios in the Gnephoekpolder are shown in Section 4.1. In Section 4.1, the outputs of climate adaptation simulations performed in Tygron including heat stress, extreme rainfall and floodings are presented. Furthermore, the spatial results are quantified and included in this section.

## 4.1 SIMULATING URBAN DEVELOPMENT

In Figure 7, the ND scenario (top) is shown, and the SUD (middle) and CAUD (bottom) scenarios that are developed in Tygron are illustrated. The SUD and CAUD scenario showcase the construction of approximately 5,500 houses. These scenarios adhere to the tiles system, as outlined in the methodology. In the CAUD scenario, one obvious visible difference is the inclusion of green roofs.

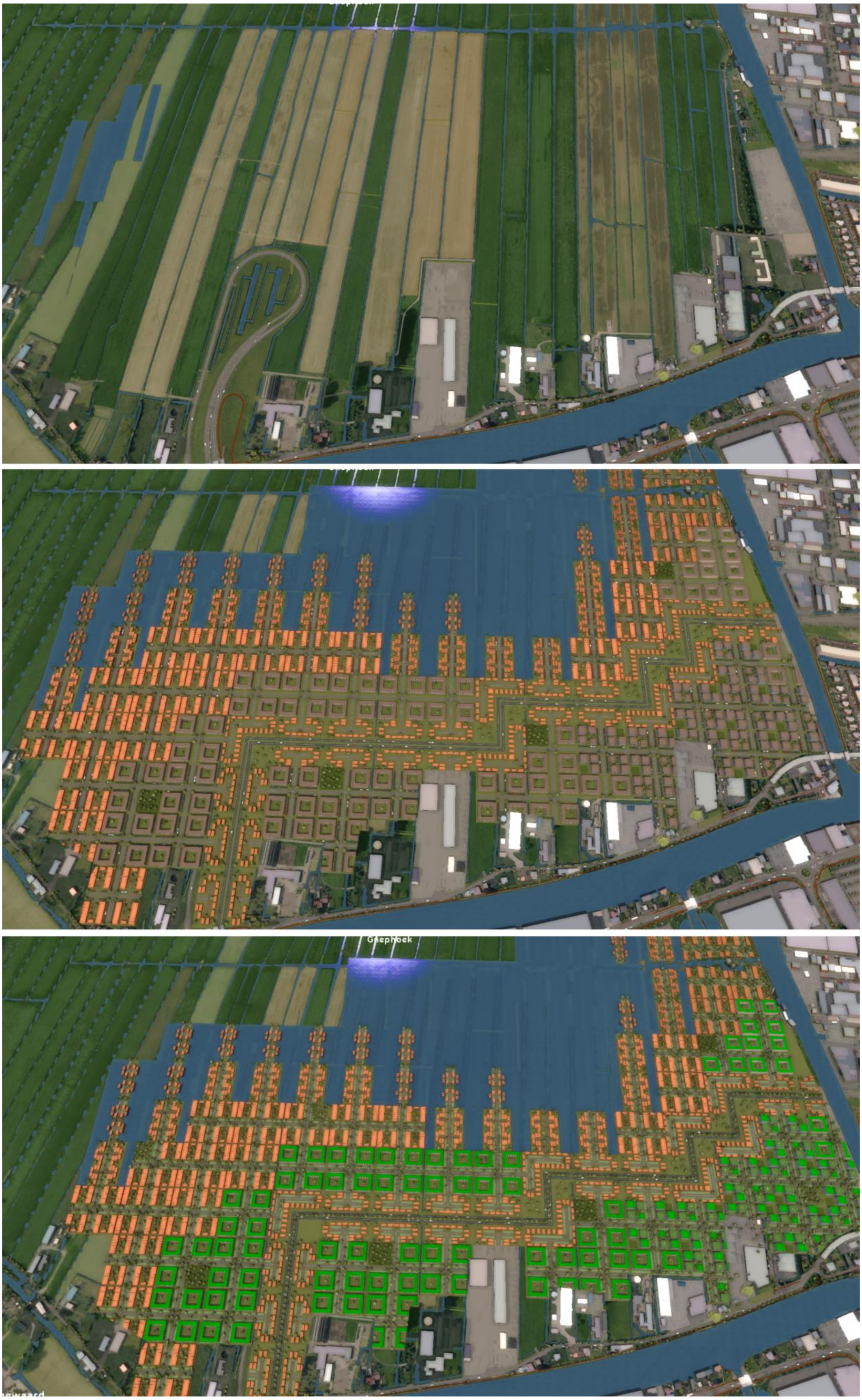



Figure 7: Tygron simulation of the ND (top), SUD (middle) and CAUD (bottom) scenarios in the Gnephoekpolder

## 4.2 CLIMATE ADAPTATION ANALYSIS

### 4.2.1 Heat Stress

First, the PET map was computed for both the SUD and CAUD scenarios. Figure 8 presents an overview of the entire area of both scenarios, as well as a zoomed-in view from the bottom right corner. The data in the Figure corresponds to average PET between 12.00 and 18.00 on 1st of July in 2015. Furthermore, the average and maximum PET over the entire area with new urban development is calculated using FME, which are shown in Table 5. By implementing the SUD and CAUD scenario, the maximum temperature rises by approximately 5°C compared to the ND scenario. The average temperature in the CAUD scenario is about 2.5°C lower than the SUD scenario.

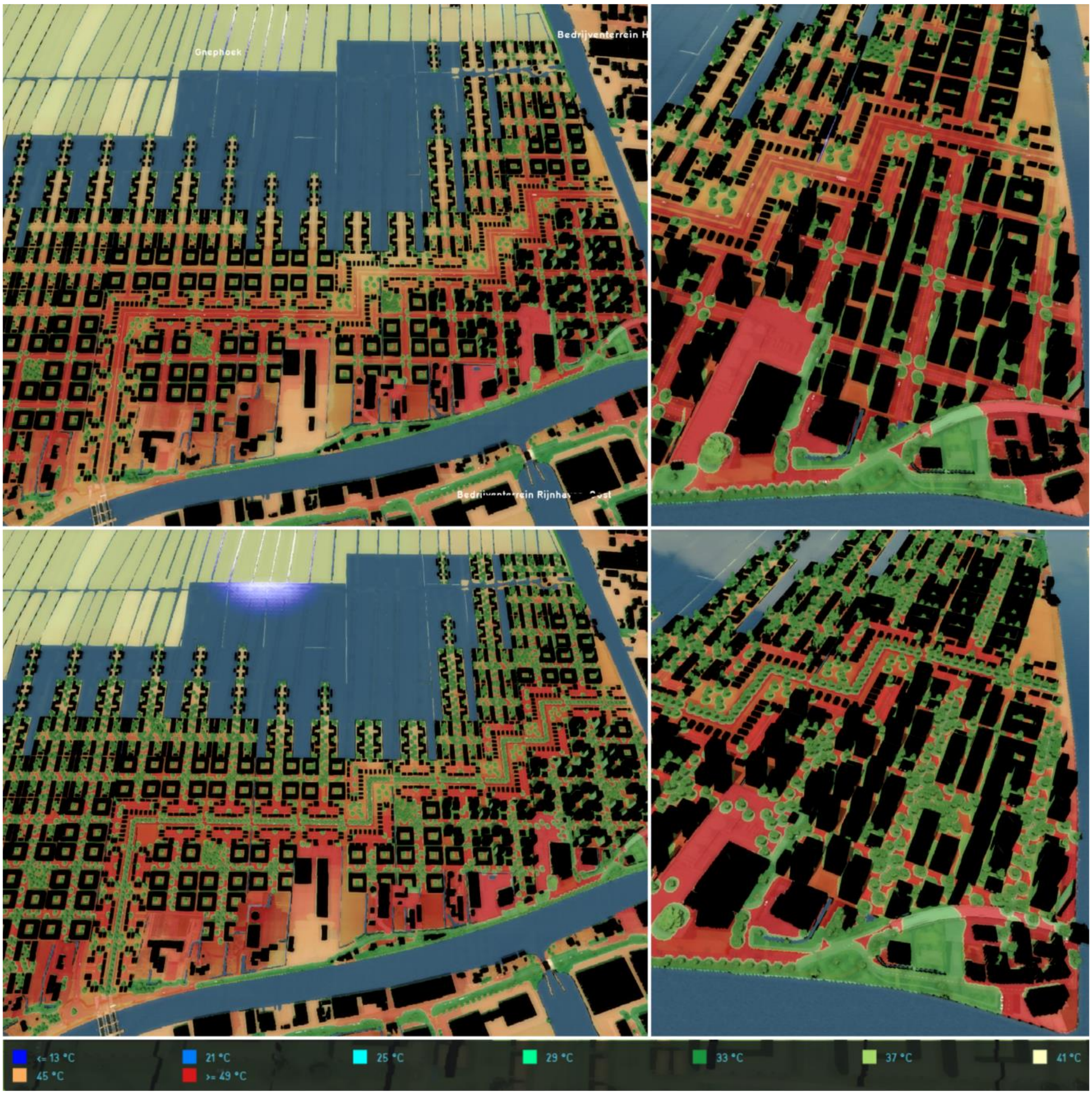



Figure 8: Tygron analysis of PET temperature in SUD (top) and CAUD (bottom) scenarios

Table 5: Maximum and average PET of ND, SUD and CAUD scenario

| Scenario | Maximum PET | Average PET |
|---|---|---|
| ND | 45.6 | 39.2 |
| SUD | 50.5 | 40.0 |
| CAUD | 50.6 | 37.5 |

Secondly, the UHI effect was calculated for both the ND and the SUD scenario. Figure 9 illustrate the results of these calculations. The legend explains the expected temperature difference in °C between rural and urban areas caused by the UHI effect. The results show that extra built environment significantly shifts the UHI effect towards the North-West.

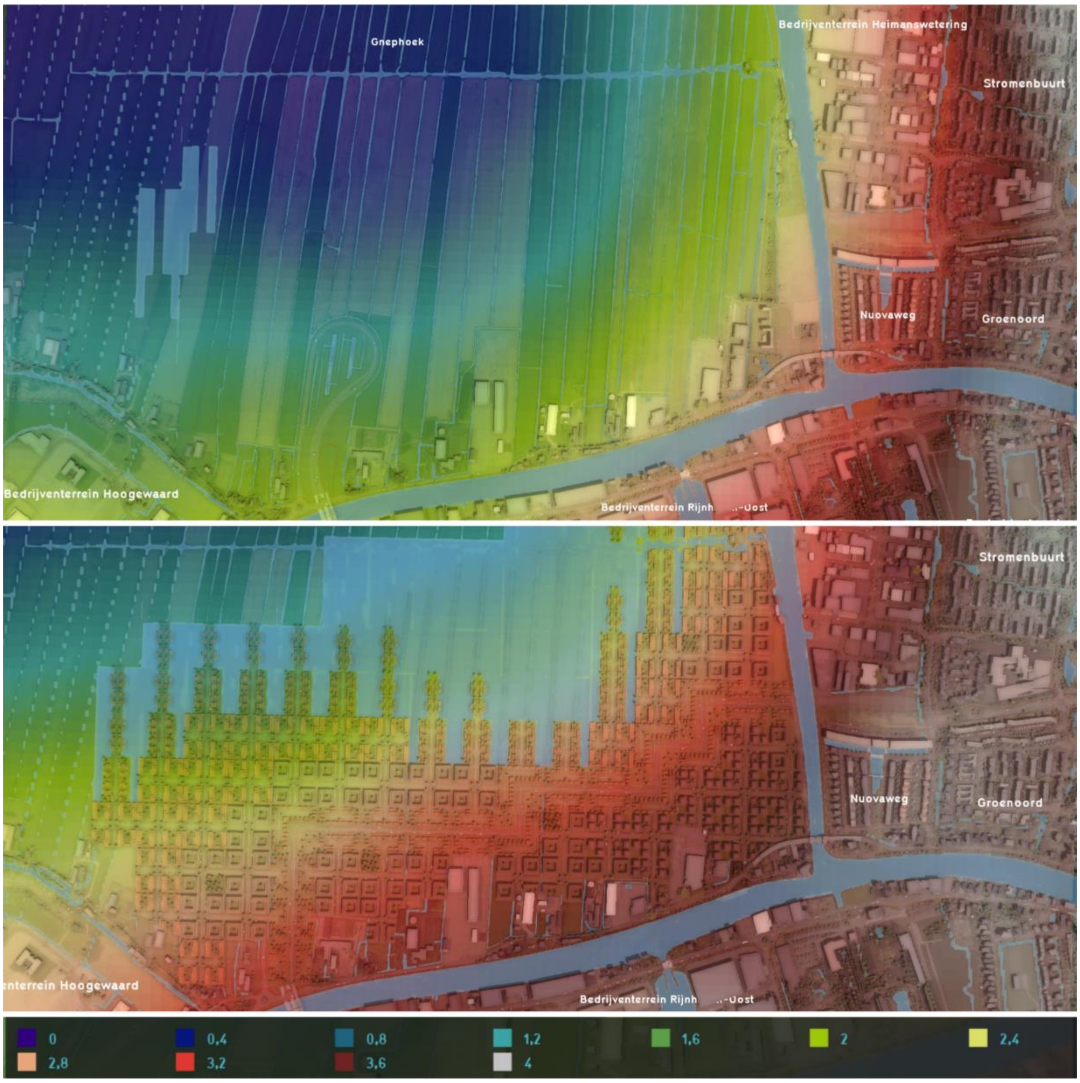



Figure 9: Tygron analysis of UHI for ND (top) and SUD (bottom) scenario (°C)

Thirdly, Figure 10 showcases the results of roads within and without shadow. Utilising FME, it was determined that in the SUD scenario, 11.5% of the roads were located in the shadow, while in the CAUD scenario this percentage increased to 59.7%. Therefore, the CAUD scenario fulfils the second requirement, but the SUD scenario does not.

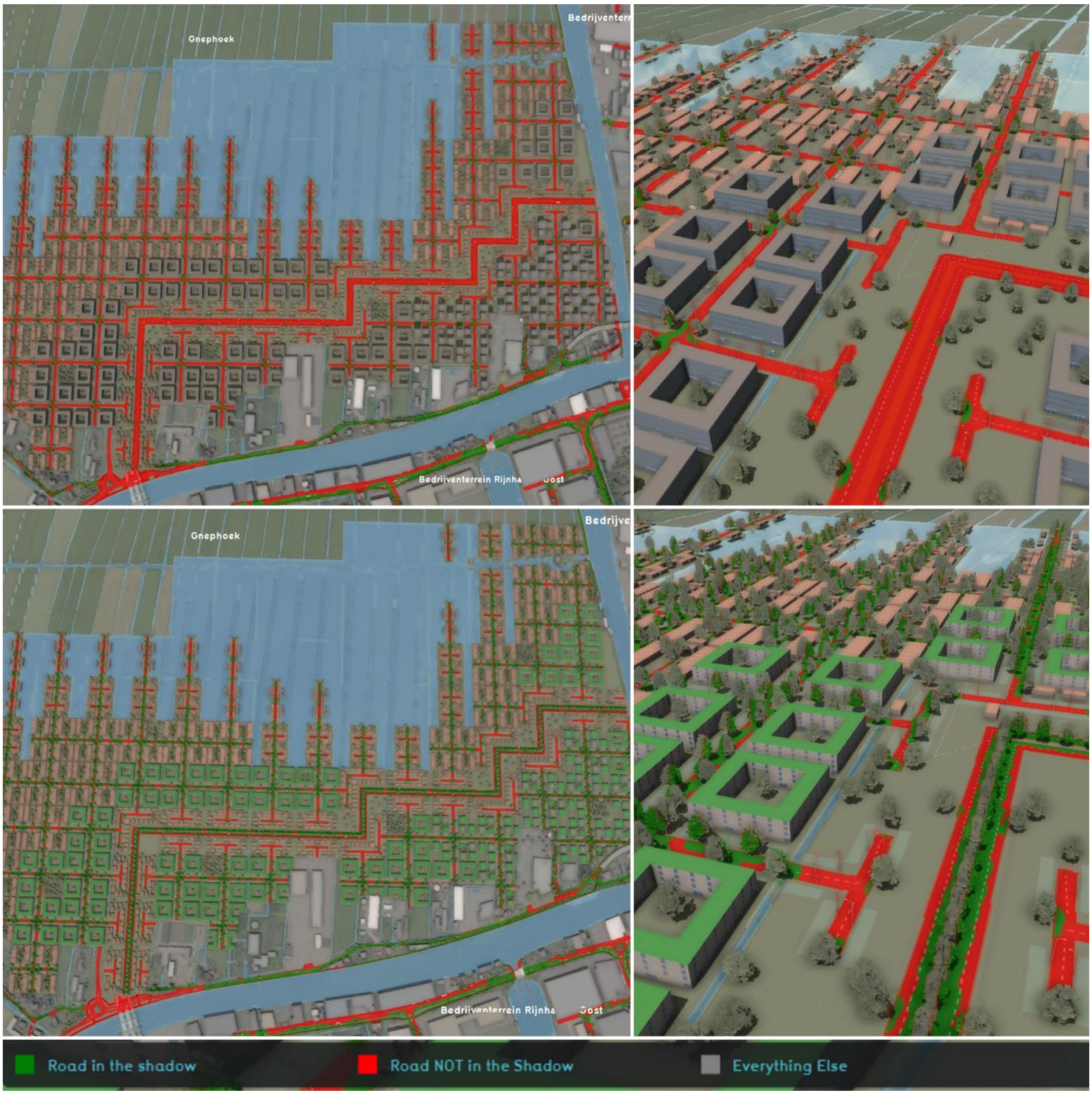



Figure 10: Tygron analysis of roads with and without shadow for the SUD (top) and CAUD (bottom) scenario

Fourthly, both scenarios were evaluated against the requirement of a shaded park within a 300-meter distance from a building, of which the results are presented in Figure 11. The difference in the number of houses within the 300-meter range is clearly evident. Using FME, it was determined that in the SUD scenario, 1416 buildings were located outside the 300-meter reach of parks, whereas in the CAUD scenario, this number decreased significantly to 321 buildings. Although the CAUD scenario does not fully meet the first requirement, as there are still houses not within the 300-meter range, it represents a substantial improvement compared to the SUD scenario. However, because the main road is not connected to the other roads, these results are not perfect.

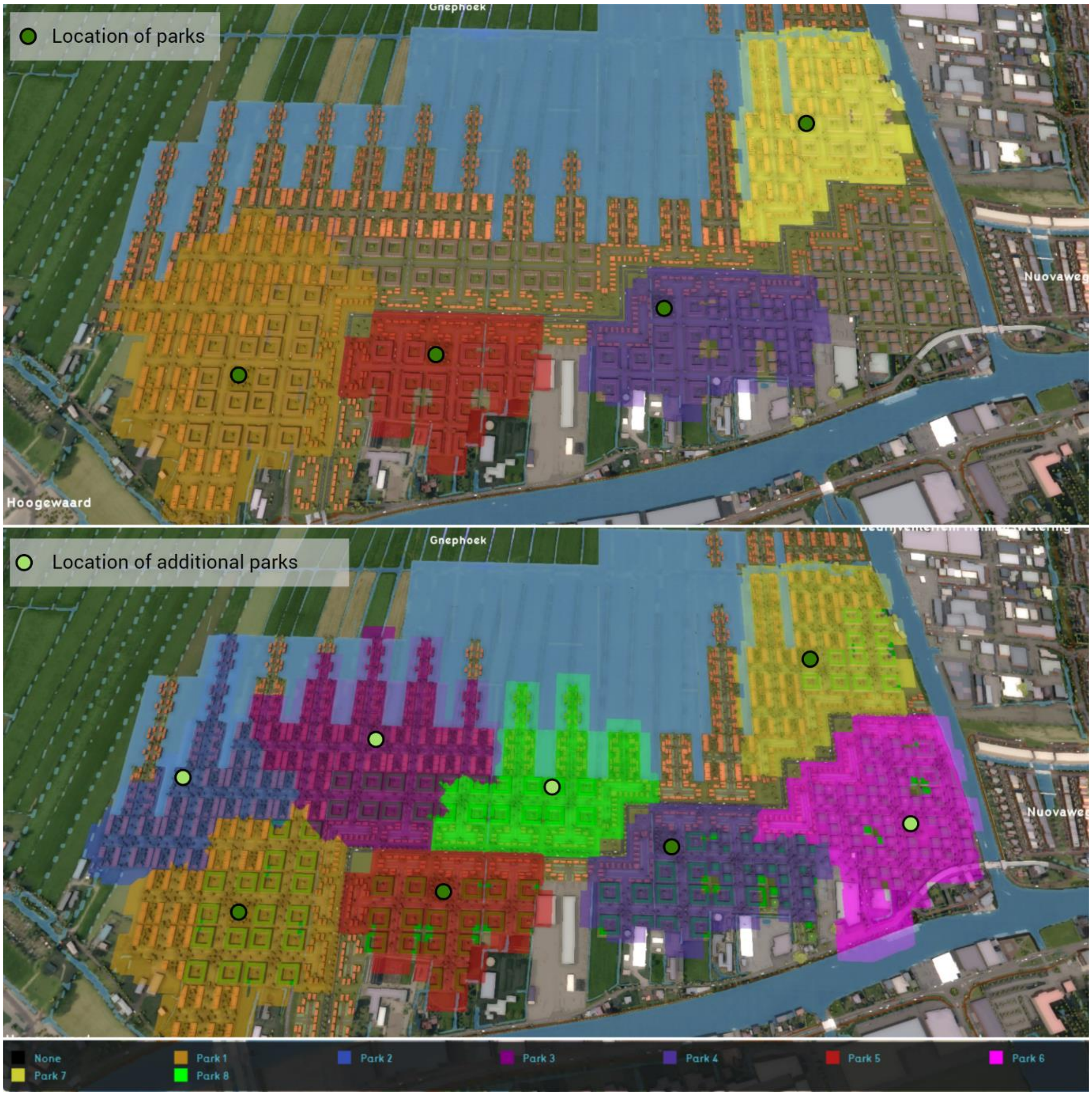



Figure 11: Tygron simulation of 300-meter range overlay of urban parks (>200m) in the SUD (top) and CAUD (bottom) scenario

### 4.2.2 Extreme Rainfall

For the rain scenarios, calculations were performed for both a 70-mm and 90-mm rain event. In Figure 12, the effects of a 70-mm rain event in 1 hour is displayed on both the SUD (left) and CAUD (right) scenario after 30 minutes (top), 1 hour (middle) and 2 hours (bottom). Visually, some clear differences can be observed. For example, in the CAUD scenario, it takes more time before water retains on the surface, due to the storing capacity of climate adaptive measures. Furthermore, in the CAUD scenario the main road remains dry, due to the elevated infrastructure. Lastly, in the CAUD scenario you can see that the WADIs fill up gradually and keep the surrounding area dry. Due to a flat elevation model of the urban development scenarios, the water does not flow towards lower-lying areas, as can be seen in the bottom part of each image where no new urban development took place nor alterations were made.

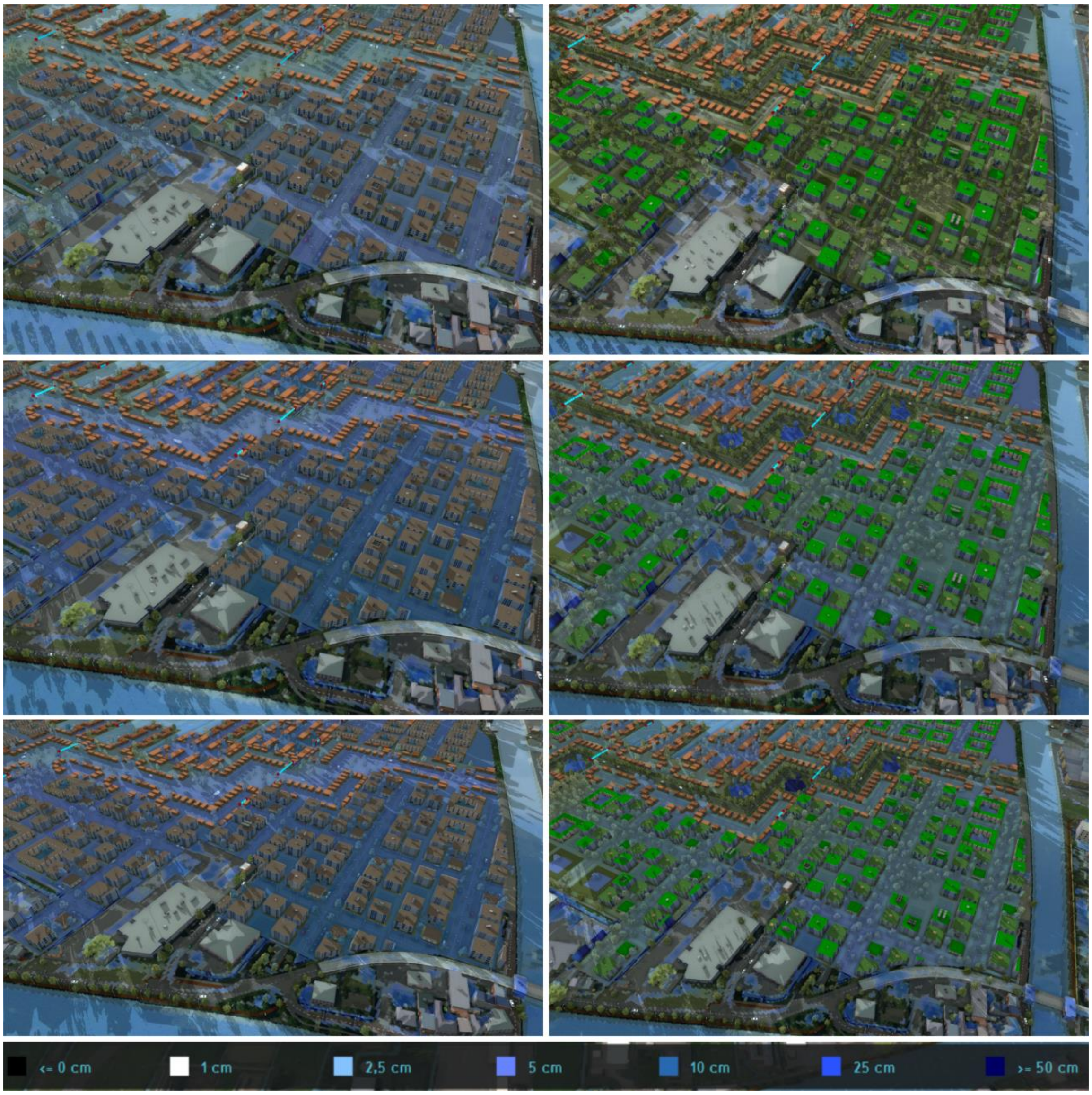



Figure 12: Tygron simulation of 70-mm rain in one hour for the SUD (left) and CAUD (right) scenario after 30 minutes (top), 1 hour (middle) and 2 hours (bottom).

Using FME, the number of damaged buildings were calculated. A building was classified as damaged when 30cm of water retained on the surface within a 1-meter vicinity. In the SUD scenario, 158 houses were classified as damaged, compared to 106 in the CAUD scenario.

### 4.2.3 Flooding

Figure 13 present the flooding simulation for the ND scenario, simulated by a breach in a levee, and illustrated after 4 (top), 12 (middle), and 24 (bottom) hours. This figure highlights the areas that are more susceptible to flooding, particularly the norther lower-lying Vrouwgeestpolder.

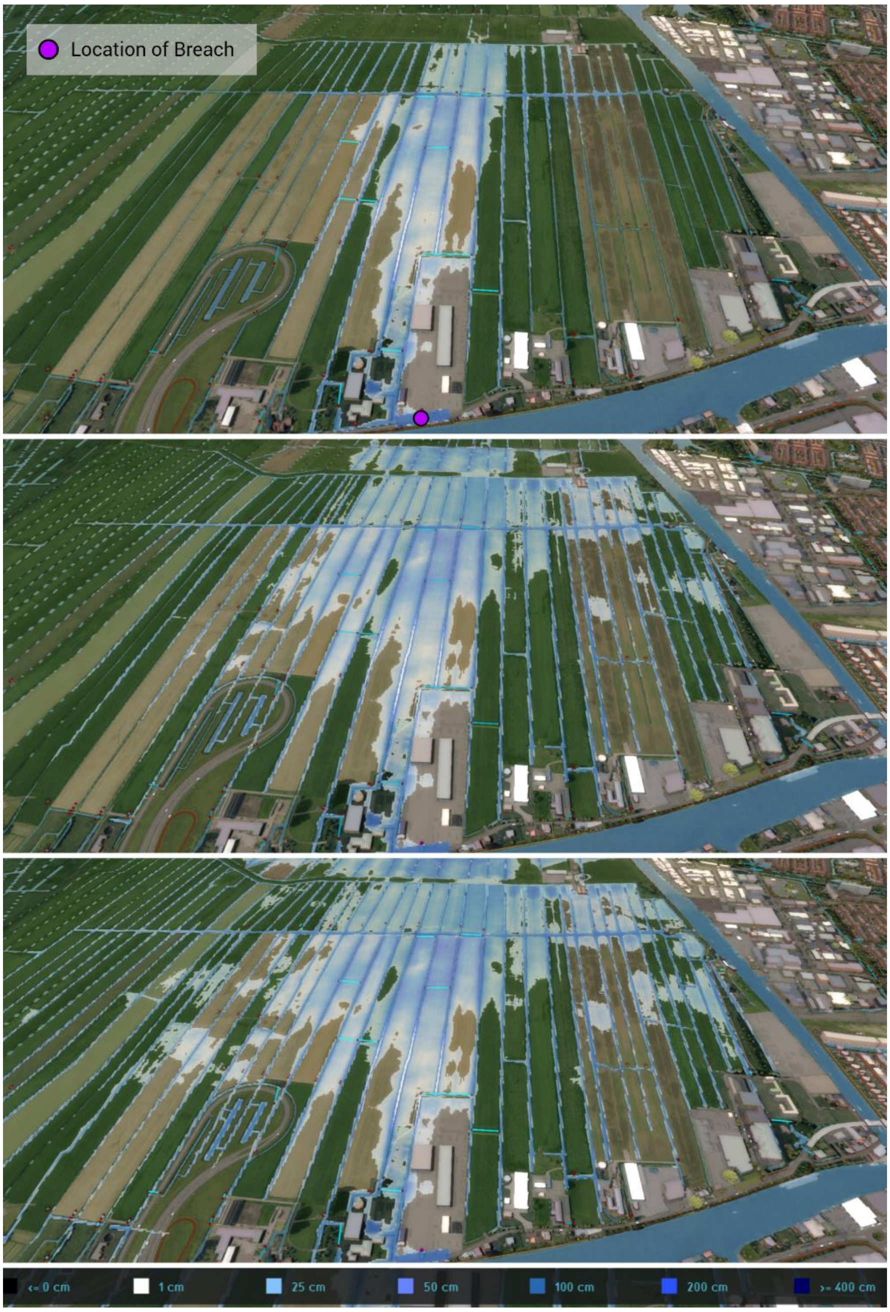



Figure 13: Tygron simulation of flooding in the ND scenario after 4 (top), 12 (middle) and 24 (top) hours

Figure 14 present the flooding simulation for the SUD (left) and CAUD (right) scenario after 1 hour (top), 3 hours (middle), and 12 hours (bottom). The figure presents some striking differences, for example, the elevated road clearly blocks the water from flowing further to the north. Additionally, the water storing climate adaptive measures cause the flooding to generally go slower. Using FME, the number of buildings confronted with a water height of 0.2 and 0.5 meter are identified. According to the requirements, damage should be prevented at a height of 0.2 meter and damage should be limited at 0.5 meter. The results are shown in Table 6.

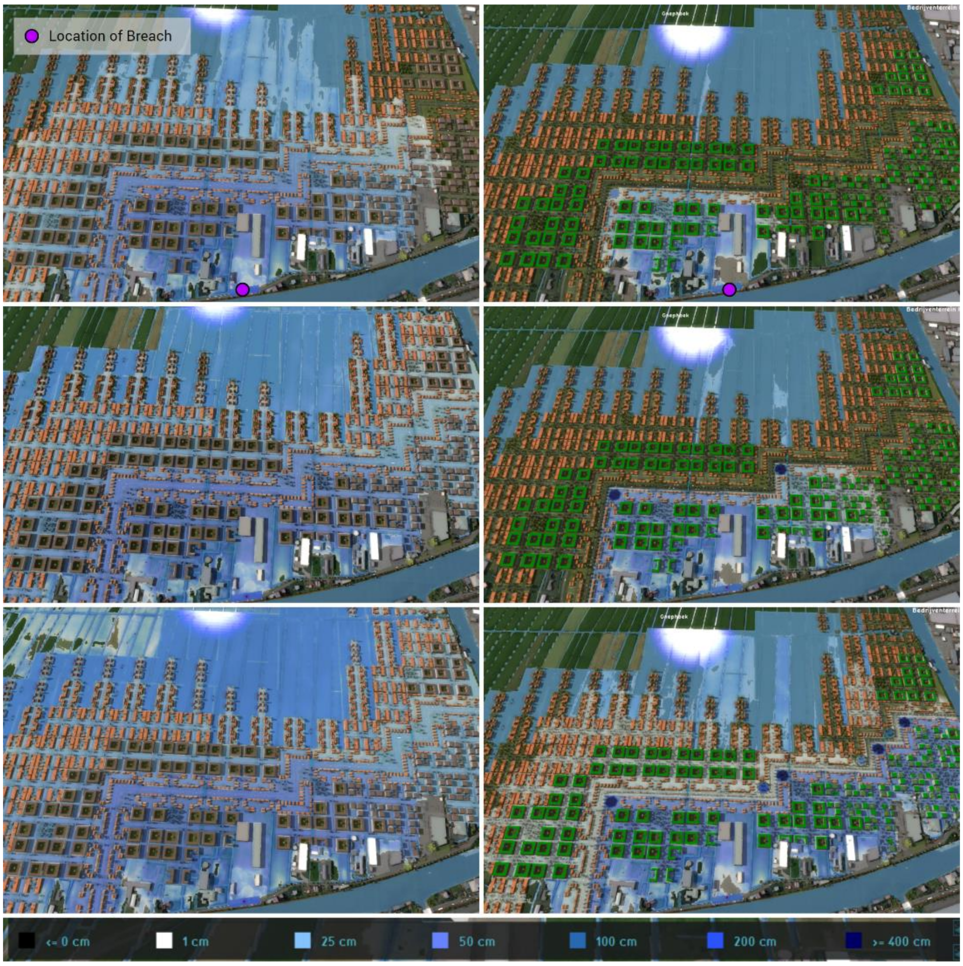



Figure 14: Tygron simulation of flooding in the SUD (right) and CAUD (left) scenario after 1 hour (top), 3 hours (middle) and 12 hours (bottom)

Table 6: FME analysis of buildings at a water depth of 0.2 or 0.5 meter after 6, 12 and 24 hours

| | **Water Depth** | 0.2 meter | | | 0.5 meter | | |
|---|---|---|---|---|---|---|---|
| | **Time Past** | 6 hours | 12 hours | 24 hours | 6 hours | 12 hours | 24 hours |
| **Damaged Buildings** | **SUD** | 2260 | 2311 | 2311 | 741 | 773 | 773 |
| | **CAUD** | 346 | 670 | 595 | 78 | 219 | 185 |

# Chapter 5: User Evaluation

The concept of a digital twin has gained wide acceptance and has demonstrated effectiveness across various industries. However, its application within the smart city context is still in its early stages, even though it is increasingly recognized as a prominent and emerging technology in the urban discourse (Hämäläinen, 2021). Although UDTs have a recognizable potential for improving urban planning, more in-depth research is needed to arrive at more valid conclusions of its usage in real-life settings (Dembski et al., 2020). By gathering insights and feedback from potential users, strengths and weaknesses can be identified, which allows for optimization of the functionality of the technology (Ferre-Bigorra, 2022). Early involvement of potential users during the development process of innovative solutions like UDTs presents a significant opportunity to integrate their needs and requirements in the technology (Arologun, 2020). Therefore, in this step of the research it is tried to identify the benefits, risk and limitation of UDT technology. Furthermore, the possible adoption of UDTs technology is assessed. To do so, a user evaluation is performed with the stakeholders that are involved in the area development of the Gnephoekpolder case study. The results of the previous chapter are used to showcase the possible application of UDTs in the context of climate adaption in urban development. The user evaluation is done according to the Unified Theory of Acceptance and Use of Technology framework (Venkatesh et al., 2012), which is elaborated upon below. Moreover, with the results of the user evaluation, research question 2 and 3 are tried to be answered.

In Section 5.1, an introduction to the UTAUT framework is provided. In Section 5.2 the research methods for the user evaluation are described and justified, including a description of the research model, the process of data collection and the analysis of the data acquired. In Section 5.3, the findings of the user evaluation are presented and explained in two different sections. First, a general exploration of the data is performed to identify the benefits, risks and limitation of UDTs in the context of climate adaption in urban development. This includes an elaborative suggestion based on the open-ended questions from the questionnaire and the interviews. Secondly, the UTAUT model is tested in two steps. First, the measurement model is tested to determine its correctness and robustness. Secondly, the structural model is tested in order to determine the strength and significance of the UTAUT factors influencing the technology adoption of UDTs.

## 5.1 THE UNIFIED THEORY OF ACCEPTANCE AND USE OF TECHNOLOGY

To determine the possible adoption of emerging technologies, several scientific models have been developed to predict and explore their acceptance. Currently, one of the most recent and widely used models in this research field is the Unified Theory of Acceptance and Use of Technology (UTAUT), developed by Venkatesh et al. (2012). The UTAUT Model integrates eight pre-existing models on similar research interest, namely the Theory of Planned Behavior, Technology Acceptance Model, Combined TAM and TPB, Theory of Reasoned Action, Model of PC Utilisation, Social Cognitive Theory, Motivational Model, and Innovation Diffusion Theory (Gunawan, 2018). Because of its endeavour to create a unified model by integrating various existing theories, the UTAUT model is currently regarded as one of the most comprehensive theories in user acceptance of emerging technologies in the smart city domain (Popova & Zagulova, 2022). To explain users' intention to use an emerging technology and their subsequent usage behaviour, the UTAUT framework is a well-established and extensively tested model commonly used in user acceptance of technology research (Zuiderwijk et al., 2015; Puspitasari et a., 2019). The UTAUT model is considered one of the most comprehensive theories in user acceptance of emerging technologies in the smart city domain, as it integrates various existing theories (Popova & Zagulova, 2022). Hence, the UTAUT framework is employed to address the second and third research questions.

The UTAUT model is commonly used in research on user acceptance of information technology, and it aims to explain users' intention to use an emerging technology and their subsequent usage behaviour (Puspitasari et al., 2019). According to Venkatesh et al. (2012), UTAUT identifies four primary factors that influence the Behavioural Intention (BI) and the Usage Behaviour (UB) of information technology: Performance Expectancy (PE), Effort Expectancy (EE), Social Influence (SI) and Facilitating Conditions (FC). These determinants of user acceptance and usage behaviour are elaborated upon below:

Performance Expectancy (PE): The degree to which an individual believes that utilising the system or technology will enhance their job performance and yield positive outcomes.

Effort Expectancy (EE): It relates to the perceived ease associated with using the system or technology. It reflects the individual's belief in the simplicity and user-friendliness of the technology.

Social Influence (SI): It encompasses the degree to which an individual perceives that others believe they should adopt and use the new system or technology, based on social norms, opinions and expectations by others.

Facilitating Conditions (FC): The degree to which an individual believes that organisational and technical support is available to facilitate the use of the system or technology. This factor considers the individual's confidence in the presence of resources necessary to use the technology.

The final UTAUT model proposed by Venkatesh et al. (2012) is illustrated in Figure 4. It demonstrates that performance expectancy, effort expectancy, and social influences have a direct association with behavioural intentions, while the facilitating conditions are linked to actual usage. Furthermore, the model suggests that the four determinants of behavioural intentions can be influenced by the factors gender, age, experience, and voluntariness of use.

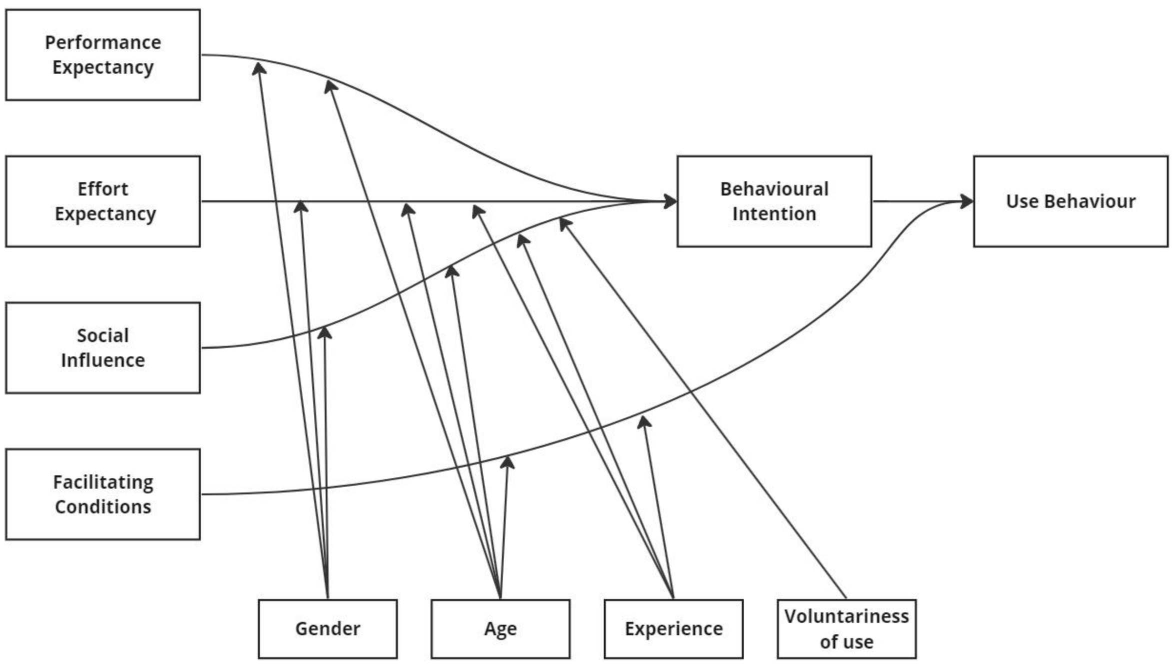



Figure 15: The Unified Theory of Acceptence and Use of Techonlogy (UTAUT)

## 5.2 METHODOLOGY

### 5.2.1 Research Model

Using the UTAUT framework, this study aims to gather comprehensive and detailed insights into the factors influencing the acceptance and use of UDTs technology in the context of climate adaptation in urban development. Additionally, this study aims to determine the strength of the predictors (PE, EE, SI and FC) on stakeholders' intention to accept and use UDTs technology in the context of climate adaptation in urban development. The Use Behaviour as indicated in the original UTAUT model could not be measured within this case study, as the technology is still not in use at the time of writing. Therefore, the model had to be modified. BI has been extensively employed as a reliable predictor of technology adoption in numerous studies within the technology adoption using the UTAUT framework (Dwivedi et al., 2019). Abbad (2021) states that the exploration of BI allows for the discovery of the fundamental factors that contribute to stakeholders' acceptance of technology. As prior research consistently emphasises the positive and direct influence of behavioural intentions on actual usage behaviour (Venkatesh et al., 2003), the stakeholders' acceptance and use of UDT services was accomplished by only assessing the BI in this particular study. In addition, it is worth mentioning that this research focused only on a specific subset of the UTAUT model, similar to many other UTAUT studies (Dwivedi et al., 2019). For example, this study did not consider moderators as age and gender due to the small sample size of the user evaluation, given the fact that it is a location-specific case study research and only stakeholders involved in the urban development process are included. The modified version of the UTAUT model specifically created for this study is depicted in Figure 16.

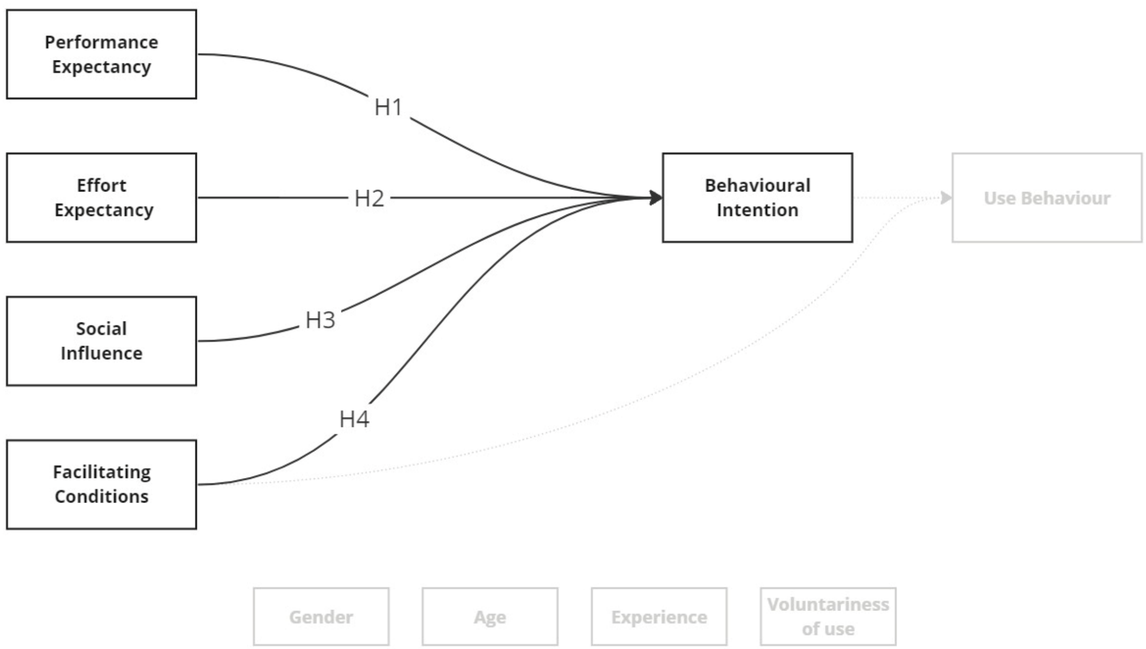



Figure 16: The modified UTAUT specifically for this study

Within this study, the following hypotheses are established to further explore the relationships between the predictors PE, EE, SI and FC on BI. These hypotheses are tested and evaluated upon further on in the findings section.

H1: Performance Expectancy positively influences the behavioural intention to use UDTs in the context of climate adaptation in urban development.

H2: Effort Expectancy positively influences the behavioural intention to use UDTs in the context of climate adaptation in urban development.

H3: Social Influence positively influences the behavioural intention to use UDTs in the context of climate adaptation in urban development.

H4: Facilitating Conditions positively influences the behavioural intention to use UDTs in the context of climate adaptation in urban development.

### 5.2.2 Data Collection

To gather sample data for this study, a mixed-methods approach was chosen. Mixed-method research involves the collection and examination of both qualitative and quantitative data within a single study (Byrne & Humble, 2007). For this particular study, a questionnaire containing both closed and open-ended questions, alongside multiple short interviews, were conducted.

***Questionnaire***

To gather sample data for this study, a structured questionnaire reflecting the UTAUT model was developed, consisting of four distinct sections. The first section provides general information about the questionnaire's purpose, ensuring voluntary participation, anonymous data usage, and its exclusive relevance and usage within this study, based on the ethical considerations for survey research in social science by Oldernick (2012). This involves several key aspects, such as the requirement for respondents to give voluntary and informed consent, ensuring the protection of respondent confidentiality and data, and granting them the freedom to withdraw their participation at any point during the process. The second section comprised demographic questions concerning respondents' gender, age, education and occupation, as well as their knowledge about UDTs and climate adaptation, their previous experience with UDTs and their interest in the research topic.

The third section of the questionnaire consisted of 25 questions related to the UTAUT constructs of the modified model. All the questions are multiple-choice and use a seven-point

Likert scale. Likert scales enable researchers to gather quantitative assessments of subjective traits, generating numerical data that can be summarized and presented visually (South et al., 2022). The Likert scale is straightforward to construct and is likely to yield a highly dependable measurement tool. Moreover, from the participants' viewpoint, it is simple to understand and complete (Taherdoost, 2019). The scale ranged from 1, indicating strongly disagree, to 7, indicating strongly agree. With 2 indicating disagree, 3 somewhat disagree, 4 neutral, 5 somewhat agree, and 6 agree. These questions were organised into various aspects, with 5 questions dedicated to performance expectancy, 5 questions to effort expectancy, 5 questions to social influence, 5 questions to facilitating conditions, 3 questions to behavioural intention. Lastly, 2 extra questions were added based on the researcher's interest, reflecting the benefit of 3D compared to 2D analyses and the sufficient level of detail. Each question presented clearly defined statements regarding specific features of the UDT results in the context of climate adaptation in urban development. Respondents were asked to select a number on the scale to indicate their level of agreement with each statement.

Finally, the fourth and concluding section consisted of five open-ended questions. These questions were designed to gather additional information regarding expected benefits, limitations, opinions, and any other relevant remarks or questions that respondents wanted to share. This section provided an opportunity for participants to provide more detailed and qualitative insights into their perspectives and opinions about the UDT results, which are shown in the previous section. The construction of the questionnaire statements drew upon previous research experiences from various sources related to either a similar research topic or research applying the UTAUT framework (Oirbans et al., n.d.; Michalik et al., 2022; Arulogun et al., 2020; Popova & Zagulova, 2022; Kwok et al., 2021, Venkatesh et al., 2012).

It is considered crucial to address potential issues with questionnaire design, as a poorly constructed questionnaire can result in inaccurate findings and subsequently lead to erroneous conclusions (Hair et al., 2009) Therefore, to ensure the accuracy and effectiveness of the data collection, a trial of the constructed questionnaire was conducted by a colleague. The primary objective of this pilot was to identify and rectify any errors in the questionnaire and to assess whether the questions were understandable and provided participants with sufficient means to express their perspectives accurately. The trial has led to several improvements in the questionnaire. First of all, negatively stated questions were removed to ensure that all questions were framed positively. This adjustment was made to allow for effective comparison of the results. Secondly, some statements were textually improved to clarify from which perspective the participant was expected to answer the questions. Lastly, grammatical and spelling errors present in the content of the questionnaire were rectified. Table 7 presents the definitive version of the third section in the questionnaire, containing the questions related to the UTAUT constructs. First of all, this table translates the questions into English and secondly it serves as a useful reference for the data interpretation during the subsequent analysis below. The complete questionnaire in Dutch that was used in this study is provided in Appendix A.

Table 7: Part of UTAUT Questionnaire Reflecting the Constructs

| Item | Question |
|---|---|
| **Performance Expectancy** | |
| PE1 | The climate-related analyses in Tygron can enhance the overall understanding of climate adaptation in urban development. |
| PE2 | The climate-related analyses in Tygron can support more informed decision-making regarding the implementation of climate adaptation in urban development. |
| PE3 | Using Tygron could improve the efficiency and accuracy of climate adaptation planning and implementation in urban planning strategies. |
| PE4 | Tygron's functionalities and features fit well with the requirements of climate adaptation in urban development. |
| PE5 | Overall, the use of Tygron can have a positive impact on the implementation of climate adaptation in urban development strategies. |
| **Effort Expectancy** | |
| EE1 | The climate-related analyses in Tygron are easy to interpret and understand. |
| EE2 | Integrating climate-related analyses in Tygron into existing work processes for climate adaptation in urban development is feasible and convenient. |
| EE3 | Learning to work with Tygron and the climate-related analyses would be a fun experience. |
| EE4 | Interaction with climate-related analyses in Tygron regarding the effects of climate adaptation in urban development plans are simple and intuitive |
| EE5 | The use of Tygron and climate-related analyses would reduce the time and effort required to bring climate adaptation into the urban development process. |

| | |
|---|---|
| **Social Influence** | |
| SI1 | I think my colleagues would argue that Tygron would be beneficial for climate adaptation in urban development plans. |
| SI2 | I experience a positive attitude in my environment towards using and applying Digital Twins to promote climate adaptation in urban planning. |
| SI3 | Becoming proficient and familiar with using climate-related analysis in Tygron would be useful in my work related to climate adaptation in urban development. |
| SI4 | In my surroundings, Digital Twins developments are seen as an opportunity to improve climate adaptation in urban development. |
| SI5 | In my working environment, the use of Digital Twins as a tool for climate adaptive urban development is increasingly mentioned |
| **Facilitating Conditions** | |
| FC1 | I have sufficient knowledge and understanding to effectively use the climate-related analyses in Tygron to promote climate adaptation in urban development. |
| FC2 | I believe I can trust the output of climate-related analyses in Tygron to use in climate adaptive urban development. |
| FC3 | I believe the reliability and accuracy of the data used in Tygron is sufficient to perform climate-related analyses. |
| FC4 | I have sufficient technical skills and access to technical assistance to use Tygron and climate-related analyses for climate adaptive urban development. |
| FC5 | The organisation where I work would support the implementation and use of Tygron for climate adaptive urban development |
| **Behavioural Intention** | |
| BI1 | I like the idea of using Tygron and climate-related analyses for climate adaptation in urban development. |
| BI2 | I expect to use Tygron and climate-related scenarios in urban development projects in the future. |
| BI3 | I am willing to use Tygron and climate-related scenarios more often in the context of climate adaptation in urban development. |

***Interviews***

Apart from discovering user acceptance through the UTAUT model, early involvement of potential users in the development process of innovative solutions like UDTs presents a valuable opportunity to further identify their needs and requirements (Arologun, 2020; Michalik, 2022), as aforementioned. By actively engaging relevant stakeholders from the beginning, smart city developers can receive context-specific feedback, enabling them to further assess the adoption and acceptance of new digital solutions (Hämäläinen, 2021). Therefore, in addition to the questionnaire, four interviews were conducted with various representatives from stakeholder groups involved in the building process, including a representative from the province, municipality, a consultancy firm and an urban developer. To each stakeholder, four structured questions were asked that dive deeper into the opportunities and barriers of UDTs technology adoption in the context of climate adaptation in urban development. Furthermore, a question regarding the integration of UDTs technology in their current work practices was added. Lastly, their future perspectives on UDT development within their professional domain was asked. These interviews provide further understanding on the given answers to the open-ended questions in the questionnaire. In addition, the answers could potentially elaborate on the needs and requirements indicated by the stakeholders to direct the future developments of UDTs technology. The interviews are added in appendix B.

***Procedure***

To allow for accurate responses to the survey questions, it is considered crucially important to have a clear understanding of the technology's potential assessed within the UTAUT framework, as it significantly influences the decision being made (Michalik, 2022). Because UDT research and development is still in its infancy, a comprehensive understanding of the technology is often lacking. Therefore, prior to distributing the questionnaire, the climate-related analysis as outlined in Section 4.2 were presented and explained to every stakeholder who participated in this research in a consistent manner. To begin the data collection process, the respondents were warmly welcomed either online or in person. Following the introduction, a brief overview of the research topic, including an explanation of the Gnephoekpolder case study area, as well as a general introduction to UDTs, was provided. Subsequently, the climate-related analyses concerning flooding risks, excessive precipitation, and heat stress that were performed in Tygron were presented and explained. After this presentation, the stakeholders were immediately requested to complete the questionnaire before any further discussion. It was considered important to collect their initial perspectives before engaging in further discussion, as their perspectives might be influenced or altered by the information provided by others during the session.

***Participants***

To ensure a comprehensive representation of perspectives, a series of five sessions were organised for data collection purposes. The aim of these sessions was to include all the stakeholders that are involved in the urban development process, as previously outlined in the LKB document and Table 2 in Section 2.2.3. These sessions included one at the municipality of Alphen aan den Rijn, one at the province of South-Holland, one at the consultancy firm Sweco, one at the water board Stichtse Rijnlanden and one at the working group Ruimtelijke Kwaliteit, which consists of individuals representing the municipality, developers, consultancy firms, and design firms. All participants either had direct involvement in the building process of the Gnephoekpolder or possessed a good understanding of urban development happening in the area. By involving diverse stakeholders, the goal was to gather valuable insights from key stakeholders to allow for meaningful data analysis. Table 8 presents the characteristics and background information about the respondents of the questionnaire, including gender, age, where participants are employed and their work experience.

The study population of this research involved a total of 29 expert respondents, who had either direct involvement in the Gnephoekpolder urban development process or possessed at least relevant knowledge about it. The data reveals that approximately 80% of the participants were male, and more than half of the respondents were aged 40 and above. The majority of the participants were employed in consultancy or design firms (37.9%), with significant representation from the province (24.1%). However, fewer responses were collected from urban developers (6.9%). No responses were collected from housing corporations and financiers. Although they are acknowledged as important stakeholders in the urban development process, their involvement typically occurs at a later stage than the current phase of development. More than 80% of the respondents had a minimum of 5 years of work experience in their respective fields, and a substantial 61.1% of this group had over 10 years of work experience, indicating a highly experienced study group.

By describing demographic and socio-economic characteristics of the study population, the reader can better understand the context of the study and in which environment the research was conducted in. Additionally, it allows other researchers to assess the extent to which findings can be generalised to other populations or settings and it becomes easier to compare other and future results across different studies. Lastly, the reproducibility of the research is enhanced by presenting the general descriptives of the study population.

Table 8: Demographic and socio-economic characteristics of the participants who answered the UTAUT questionnaire.

| Variable | No. of Respondents | Percentage (%) |
|---|---|---|
| **Gender** | | |
| Male | 23 | 79.3 |
| Female | 6 | 20.7 |
| **Age** | | |
| 21-30 years | 7 | 24.1 |
| 31-40 years | 5 | 17.2 |
| 41-50 years | 8 | 27.6 |
| 51-60 years | 4 | 13.8 |
| > 60 years | 5 | 17.2 |
| **Work** | | |
| Municipality | 5 | 17.2 |
| Developer | 2 | 6.9 |
| Water Boards | 4 | 13.8 |
| Province | 7 | 24.1 |
| Consultancy & Design | 11 | 37.9 |
| **Work Experience** | | |
| 0-1 years | 3 | 10.3 |
| 1-3 years | 2 | 6.9 |
| 3-5 years | 0 | 0 |
| 5-10 years | 6 | 20.7 |
| > 10 years | 18 | 61.1 |

In Figure 17, the levels of knowledge of the participant about the terms climate adaptation and digital twins are displayed. The figure indicates that the study sample exhibits a relatively high level of knowledge in the field of climate adaptation. In total, 83% indicated a certain degree of agreement and no instances of strong disagreement were recorded to the question *"I have a good understanding of climate adaptation, climate adaptation strategies and their application in addressing climate change impacts in urban domain".* However, their familiarity with the term digital twins appears to be relatively limited. Regarding their knowledge about digital twins, over 40% of the study population responded with varying levels of disagreement to the question *"I have a good understanding of the term 'Digital Twins' and their application in the urban domain".* In the entire study sample, 66% of the participants indicated that they have never worked with Tygron specifically as an UDT software before in their professional career, which was asked in a separate question. This underscored the importance of thoroughly explaining the technology and its potential application prior to proceeding with further data collection, as advocated by (Michalik, 2022).

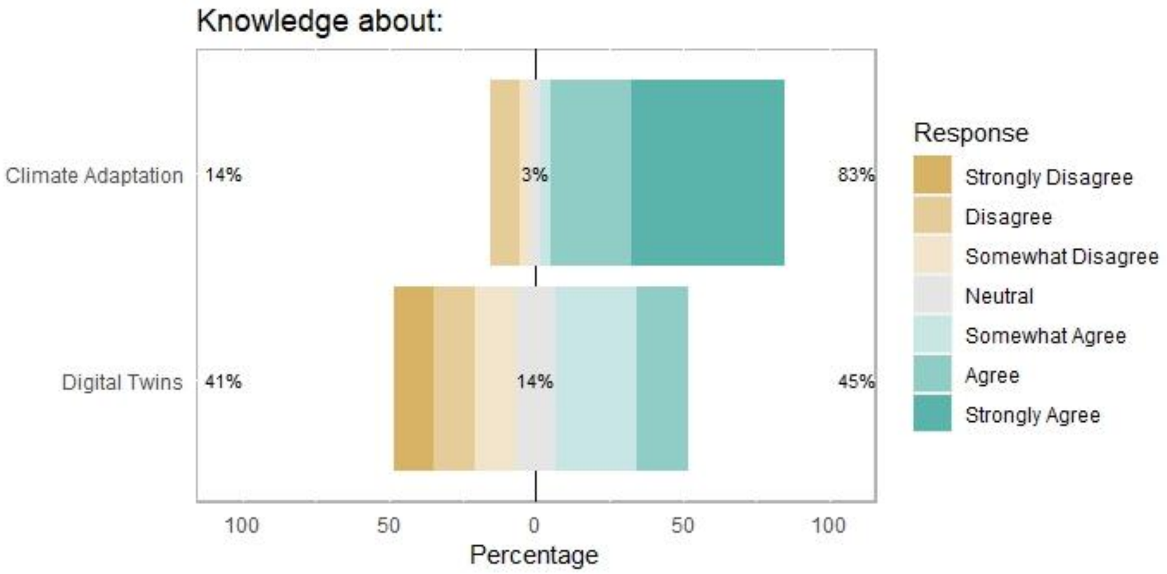



Figure 17: Degree of knowledge of the study population on Digital Twins and Climate Adaptation

### 5.2.3 Data Analysis

After conducting a basic exploratory analysis and finding no specific outliers in the dataset, all the collected data was used for further examination. The data analysis was performed using two popular software packages: R and SmartPLS4. These tools are widely utilised for statistical analysis and provide researchers with a range of tools and packages for data analysis and visualisation. By leveraging the capabilities of R and SmartPLS4, valuable insights regarding relationships and patterns within the collected data were obtained. In addition, Microsoft Excel was employed to import, structure and analyse the data obtained. The data collected for this study from both the questionnaire and the interviews underwent two forms of analysis.

First, a general exploration of the participant's answers in the questionnaire on the determining constructs PE, EE, SI and FC and the BI was conducted. This includes an overview of the range of answers provided by the participants per construct. Within the analysis, an answer ranging from 1 to 3, representing strongly disagree to somewhat disagree, is considered as a negative answer. Similarly, an answer ranging from 5 to 7, representing somewhat agree to strongly agree, is considered a positive answer. Responses of 4, indicating neutrality were also labelled as neutral. In addition to the interpretation of the numerical results, these answers are supported by statements from the open-ended questions in the questionnaire and from the results retrieved from the conducted interviews. With this analysis, an attempt is made to uncover the benefits, risks and limitations of UDTs in the context of climate adaption, answering research question 2.

Secondly, the strength and significance of the determining constructs PE, EE, SI and FC on the BI towards using UDTs technology is assessed. In this way, the most influential factors that influence the adoption of UDT technology in the context of climate adaptation is discovered, thereby addressing research question 3. In this study, partial least squares structural equation modelling (PLS-SEM) is used to identify the strength and significance of the determining constructs for the target construct. PLS-SEM is a widely used method in UTAUT research for estimating path models with latent variables and their relationships (Popova & Zagulova, 2022; Gunawan, 2018). An important advantage of PLS-SEM is the fact that it places minimal demands on sample sizes (Liu & Huang, 2015; Hair et al., 2014; Ifinedo, 2012), making it suiTable for this research with a small group of expert opinions in the specific context of the Gnephoekpolder case study (n = 29). According to Hair et al (2019), PLS-SEM data analysis requires two major steps. These steps include the measurement model assessment and the structural model assessment:

Step 1: The first step involves the examination of the measurement model. The measurement model examines the relationship between the latent variables (PE, EE, SI, FC and BI) and their measures, respectively the questions from the UTAUT questionnaire reflecting the constructs. The assessment includes, among others, composite reliability and discriminant validity. This assessment is referred to as a robustness checks, to support the stability of the results acquired (Hair et al., 2019). The assessment determines if the model meets all the required criteria in order to continue to step two, assessing the structural model.

Step 2: If the measurement model assessment is satisfactory, the next step in evaluating PLS-SEM results is assessing the structural model (Hair et al., 2019). The structural model examines the relationship between the latent variables, which, in the case of this study, refers to the relationship between PE, EE, SI and FC on the BI. The second step includes the evaluation of the coefficient of determination ($R^2$), which is a measure of the model's explanatory power. Furthermore, the statistical significance and relevance of the path coefficients are determined, aimed to establish the strength and significance of the variables PE, EE, SI and FC on BI.

The results of the assessment of the measurement model and the structural model, including the defined criteria, are discussed and elaborated upon within the findings section. Evaluation of the measurement and structural model obtained from the data analysis is done according to PLS-SEM methods suggested by Hair et al. (2019).

## 5.3 FINDINGS

### 5.3.1 Benefits, Risks and Limitations

In the following Figures, the responses of the participants on the questionnaire are provided, organised per UTAUT construct. Additionally, supporting arguments from the open-ended questions and the interviews are used when applicable. This presentation offers a comprehensive overview of the general opinions and sentiments regarding the application of UDTs in the context of climate adaptation in urban development, identifying their benefits, risks and limitations.

***Behavioural Intention***

The questions related to Behavioural Intention (BI) (Figure 18) are generally answered with a high degree of agreement. In total, 80% of the participants answered positively to the questions related to BI construct, while 15% expressed a neutral opinion and 5% answered negatively.

On average, participants rated the BI construct with a 5.3, indicating a *somewhat agree* to *agree* attitude towards an individual's willingness and plans to use UDT technology in the context of climate adaptation in urban development. This aligns with statements from the open interviews, such as "*I think it will be used a lot in the future and has a lot of potential for area development and climate adaptation*" and "*I expect that in 5 or 10 years, we will be working fully integrated with Digital Twins as the basis for the whole process of area development*". Additionally, more than ⅔ of the participants explicitly mentioned words such as '*Promising development'*, '*Useful tooling*' and '*High potential*' in the open questions, related to their general opinion on UDTs technology.

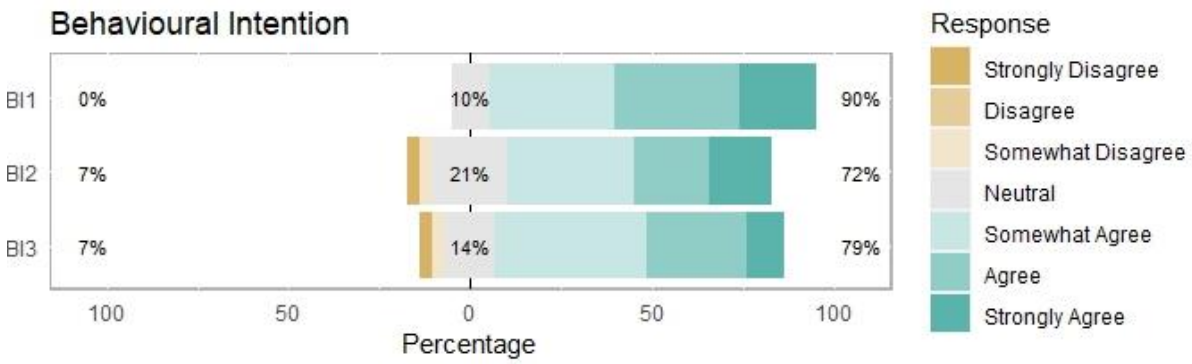



Figure 18: Results of the UTAUT questionnaire on the BI construct

***Performance Expectancy***

The questions related to Performance Expectancy (PE) (Figure 19) show that the participants generally have high expectations regarding the performance of UDTs in the context of climate adaptation in urban development. Only at question PE3, related to the increased efficiency and accuracy of climate adaptation efforts when using UDTs, contains an answer with slight disagreement. The questions PE1, PE4, and PE5 received remarkably high positive responses from almost all participants. In total, 91% of the participants answered positively to the questions related to the PE construct, while 8% expressed a neutral opinion and 1% answered negatively. On average, participants rated the PE construct with a 5.7, indicating an *agree* to *somewhat agree* attitude towards an individual's belief that utilising UDT technology would enhance their job performance and yield positive outcomes in the context of climate adaptation in urban development.

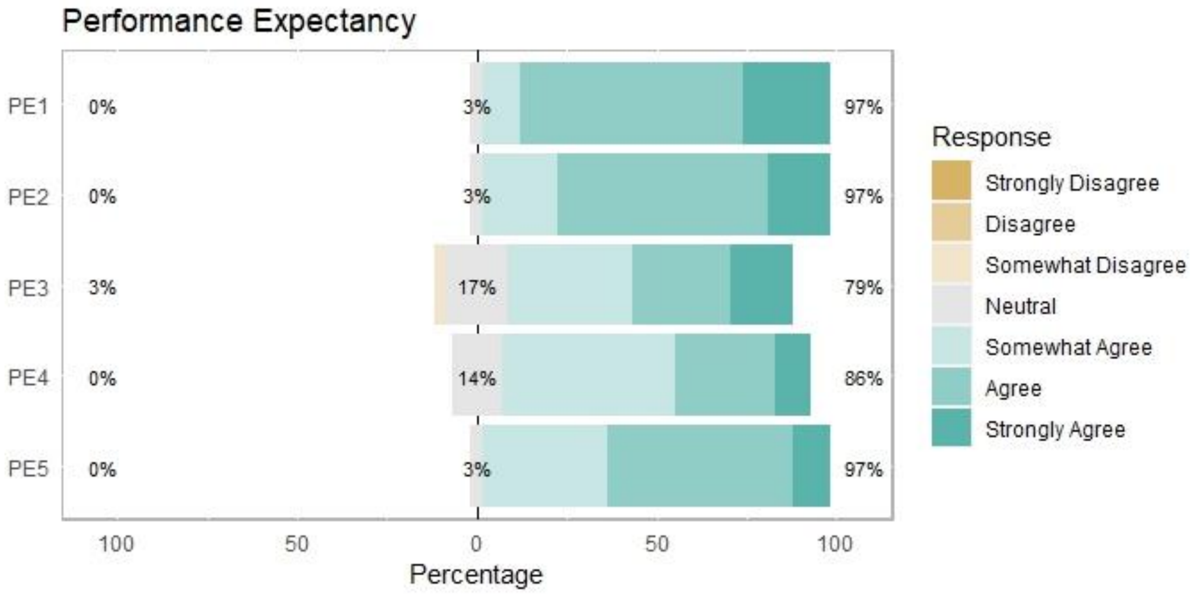



Figure 19: Results of the UTAUT questionnaire on the PE construct

Based on the open interviews and the open questions from the questionnaire, the biggest performance advantages of UDTs in the context of climate adaptation in urban development are generally twofold. Firstly, the respondents frequently highlight the visual benefits and interactive possibilities of UDTs, which make climate adaptation information tangible and accessible. In the questionnaire, 14/29 respondents specifically mentioned the visual capabilities as most important, with answers such as "*Beautiful visualisations that can be understood by non-water and climate experts too*", "*Visually appealing communication tool to include people with less knowledge of climate adaptation*" and "*Relatively simple interaction, gives a good overall picture on different themes, easy to determine the effect of measures*". These statements are supported by data from the interviews, stating "*I think the benefits are mainly on understanding models and results of relationships between different components, such as traffic and air quality, or water and heat. Visualisation is also important, so you can look at the model together with clients or agencies like the municipality, walk through it and generate new design insights and principles for a development*".

Secondly, 10/29 respondents specifically mentioned the application of UDTs to quickly test and assess different urban development scenarios against climate adaptive requirements as the main advantage. Some related answers provided were "*Design support, provides insight into what measures or adaptation are needed*" and "*One advantage is the spatial, area-wide insight at different levels of detail of urban quality/design. Spatial interventions can be introduced relatively easily, and the effects can be visualised*". This advantage is also highlighted during the open interviews, in which it was mentioned that "*Being able to simulate future interventions, making judgements and decisions more informed*" is one of the main advantages. Both the visual capabilities of UDTs and their ability to evaluate different urban design options are again highlighted by another interviewee: "*I think the benefits are twofold. First, of course, it is a tool to get an overall impression of the consequences of measures you design. (...) and I think at least equally important is that it is also good in communicating information to other stakeholders*".

In contrast to the expected benefits, the open questions and interviews also revealed some risks and limitations concerning performance expectancy. One of the key aspects raised is that input data quality is tremendously important to create useful and realistic output data, as mentioned by more than half of the participants of the questionnaire. In other words, poor input data would lead to an inadequate representation of the physical reality, badly influencing the expected performance of UDTs technology. For example, the participants argued that "*Input is output. Data quality is very important, and inputs should be openly transparent. This is a necessary condition for actual use.*" and "*The modelled situation is quickly taken as reality and truth. While it also contains many uncertainties and local details that are unlikely to be included in the model*". A more detailed description of this problem is described by one of the interviewees, stating "*What is your minimum amount of data or maybe in a different way, what is the minimum level of detail you need? (...) Everything that comes out of it is taken for truth, and precisely the sensitivity of those kinds of models is a very important one. It still remains 'shit in, shit out' so to speak. (...) Because one of the most critical points in this whole thing is: Does the input data meet the quality requirements*?"

***Effort Expectancy***

The questions related to Effort Expectancy (EE) (Figure 20) show a moderately positive opinion towards the perceived ease associated with using the technology. In total, 68% of the participants answered positively to the question related to the EE construct, 24% expressed a neutral opinion and 8% answered negatively. On average, participants rated the EE construct with a 4.9, indicating a *somewhat agree* attitude towards the perceived ease and user-friendliness of UDT technology in the context of climate adaptation in urban development. This indicates an overall positive perception, although to a lesser extent than for BI and PE.

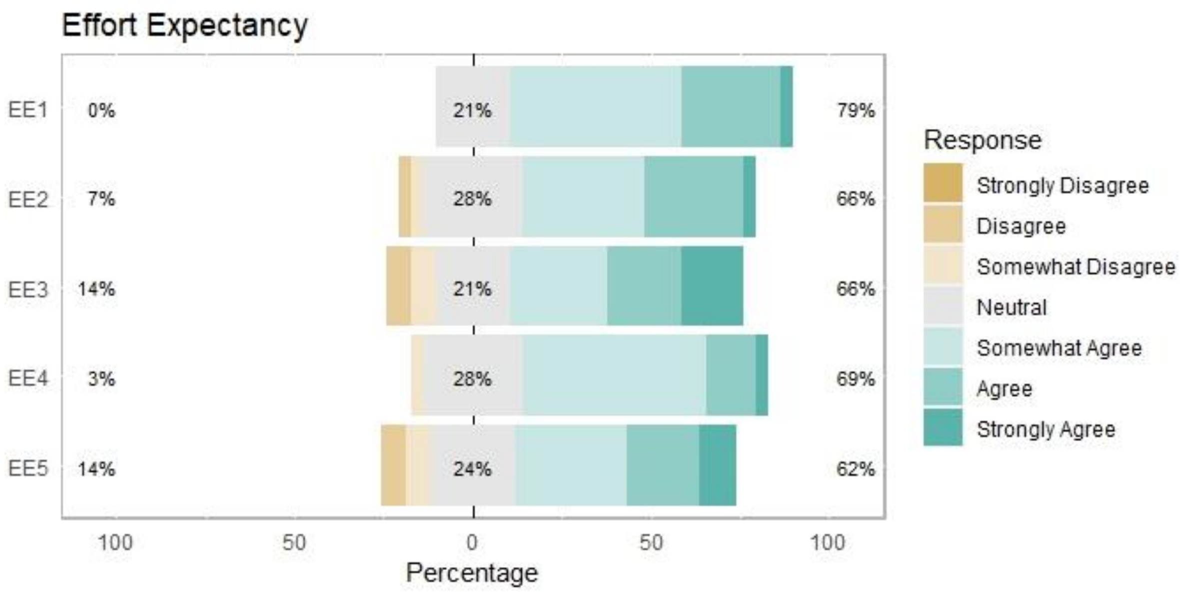



Figure 20: Results of the UTAUT questionnaire on the EE construct

In total, almost a quarter of the participants answered neutrally to the questions related to the EE construct, suggesting a that a relatively large part of the participants had no specific opinion about these topics or were unable to answer the question. The responses to questions EE3 and EE5 entail some negative answers, which respectively question the pleasure of learning to work with UDTs and the potential time- and effort-saving benefits obtained when using UDTs. Based on the open-ended questions in the questionnaire, this might be due to the expected labour-intensive work and high time investments to understand and create a UDT model of urban development. At least 6 participants explicitly mentioned this as the biggest challenge of UDT technology related to the expected effort, stating for example "*Still very labour-intensive to really use it as a convenient and accelerating tool*", "*Difficult and highly technical and time-consuming for most people*" and "*Time investment and learning curve*". These risks and disadvantages related to the expected effort are also highlighted by two of the interviewees, arguing that "*It's quite new, and it's a very technical story. [...] We have certain procedures; things have run as they always have and they are doing just fine. Why should we make it even more difficult? [...] We really need to start informing people, but also in part maybe convincing them or showing them what the power is of this tool because it is unknown. [...] People see it and they think, oh, that's going to take way too much time. [...] And what does it get me in the end?*". Furthermore, another interviewee stated that "*A major concern is that the technology behind Digital Twins is still incomprehensible to many people. [...] People often understand how standard Excel sheets work or how simple calculations are made, but this concept is harder to grasp*."

***Social Influence***

The questions related to Social Influence (SI) (Figure 21) show a moderately positive opinion towards the degree to which an individual perceives that others believe they should adopt and use UDTs based on social norms, opinions and expectations. In total, 67% of the participants answered positively to the questions related to the SI construct, 21% expressed a neutral opinion and 12% answered negatively. On average, participants rated the SI construct with a 5.0, indicating a *somewhat agree* attitude towards an individual's perception that others believe they should adopt and use UDT technology in the context of climate adaptation in urban development.

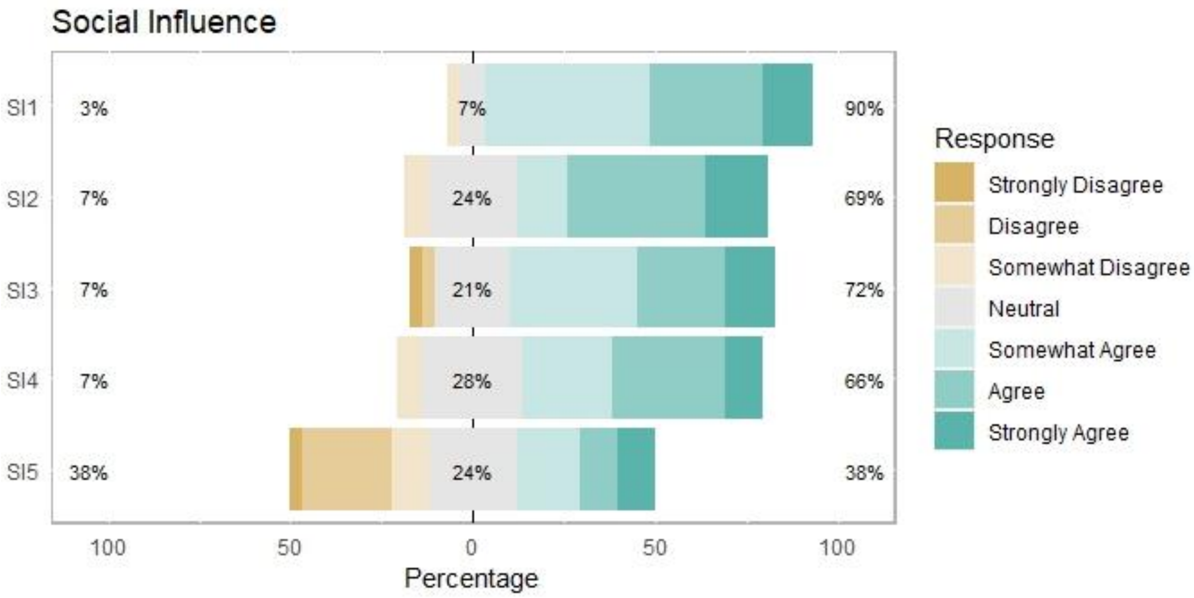



Figure 21: Results of the UTAUT questionnaire on the SI construct

Generally, a considerable number of neutral answers were provided, suggesting a that a relatively large part of the participants had no specific opinion about these topics or were unable to answer the question. Furthermore, wide range of responses were collected, suggesting a greater diversity of opinions and sentiments regarding this particular construct. Question SI5, which inquired about the frequency of the mentioning of UDT technology in their work environment, received a broad range of answers in which over half of the respondents provided negative or neutral responses. The researcher suggests that this depends greatly on the work environment and specific occupation based on the data collection sessions, however this is not proven. Given the fact that more than 40% of the study population indicated a lack of knowledge about UDTs, 66% had never worked with Tygron before and that UDT development is still in its early stages, this might explain the limited mentioning of UDT technology at this moment. Question SI1, referring to the expected positive opinion from colleagues if the individual would use Tygron, received very positive responses, with 90% expressing a certain degree of agreement. This presents an interesting paradox, where a positive attitude toward UDT technology by others is anticipated but the actual mentioning of the technology has not yet been manifested within their work environment. Based on the open-ended questions from the questionnaire and the open interviews, no interesting remarks specifically related to the SI construct are worth mentioning.

***Facilitating Conditions***

The questions related to Facilitating Conditions (FC) (Figure 22) show quite different opinions and sentiments about the individuals' beliefs about the availability of organisational and technical support to facilitate the use of UDT technology in the context of climate adaptation in urban development. Furthermore, the individual's confidence in the presence of resources necessary to use the technology is also considered. In total, 59% of the participants answered positively to the questions related to the FC construct, while 25% expressed a neutral opinion and 16% answered negatively. On average, participants rated the FC construct with a 4.7, indicating a *somewhat agree* to *neutral* attitude towards an individual's belief that organisational and technical support is available to facilitate the use of UDT technology.

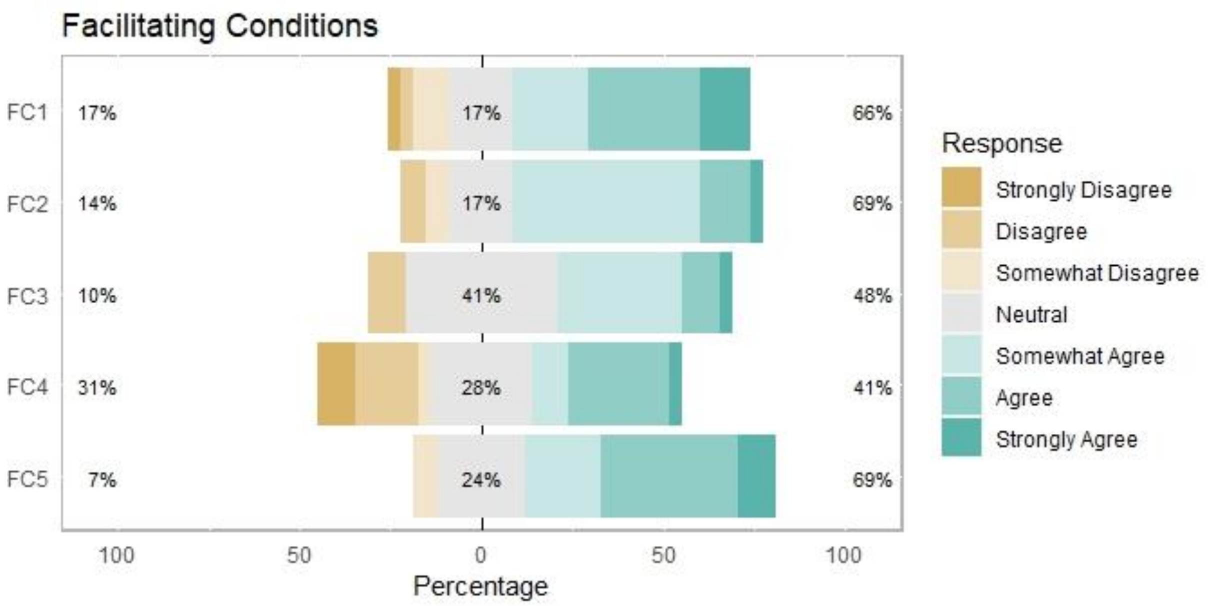



Figure 22: Results of the UTAUT questionnaire on the FC construct

Generally, this construct contained the most diverse set of responses, with an overall tendency toward more negative answers compared to any of the other constructs, and also the widest range of opinions. In particular, question FC3, which reflects the individuals' belief in the accuracy and reliability of the data used, received almost half of the responses in the neutral category, potentially suggesting that the question was ambiguously stated or not known. Although data input quality is considered important by many, as aforementioned, some respondents stated in the open ended questions that they "*Don't have enough knowledge to answer*", "*Insufficiently know what is already included*" and "*I do not know whether the functionalities for modelling the water system is complete*". It is worth mentioning that, in retrospect, this question might not effectively capture organisational and technical support, and therefore, does not adequately represent the FC construct.

Furthermore, it is remarkable to note the relatively high proportion of negative responses for FC4, concerning the possession of adequate skills and knowledge to use UDT technology. This suggests that education and training may be required before effectively using UDT technology, also based on the expected high time investment and learning curve as previously mentioned in the EE construct. Alternatively, one of the interviewees mentioned "*You are at the Table with a number of parties, but then the question is: who takes the lead in working with UDTs? What does that mean for the other parties? It may be that an engineering firm gets to work on that, but then the question is always whether others can also do something with it. I think it is important to have some kind of viewer, where other parties can also work*". This suggests that not necessarily every stakeholder should have the right knowledge and skills to work with UDTs technology, as long as it is possible to cooperate together in some way and the results can be shared and interpreted correctly.

### 5.3.2 Technology Adoption

In the second part of the findings, the most influential factors that influence the adoption of UDT technology in the context of climate adaptation are discovered, thereby addressing research question 3. To do so, PLS-SEM is used, performed in SmartPLS4. As aforementioned, PLS-SEM data analysis requires two major steps: assessment of the measurement model and assessment of the structural model.

***Assessing the Measurement Model***

In the first step, the relationship between the variables PE, EE, SI, FC and BI along with their respective questionnaire items are assessed, checking its quality and robustness. Altogether, the measurement model was assessed using item loadings, convergent validity, reliability analysis of the measure and discriminant validity, which are elaborated upon below (Hair et al., 2019). The results of the assessment are shown, in Table 9.

First, the factor loadings (FL) are determined, which is the correlation between the questionnaire item and its construct. For FL, values above 0.708 are recommended, as this indicates that the construct explains more than 50% of the indicator's variance (Hair et al., 2019). However, multiple studies use a minimum value of 0.60 as the minimum threshold (Afthanorhan et al., 2020; Popova & Zagulova, 2022), which is also used for this research. In addition, Hair et al. (2021) argues that indicators with FL between 0.40 and 0.708 should only be considered for removal if it leads to an increase in the internal consistency reliability or convergent validity. Nevertheless, indicators with loadings below 0.40 should always be eliminated from the measurement model. For this reason, FC2 (0.468) and FC3 (0.323) are eliminated for subsequent analysis. Removing PE1 (0.59) or EE1 (0.59) did not increase the internal consistency reliability or convergent validity. Hence, these items are kept in the model.

Secondly, the reliability of the measures is examined through the use of Cronbach's Alpha (CA) and Composite Reliability (CR). The purpose of assessing CA and CR is to examine the internal consistency and reliability of a construct. In general, the minimum value of CA is 0.7, however, in exploratory research 0.6 is considered fair as well (George & Mallery, 2010). With CR, which is considered slightly better in measuring internal consistency than CA in PLS-SEM (Purwanto, 2012; Hair et al., 2019), values ranging from 0.70 are considered satisfactory and values > 0.8 are very satisfactory (Hair et al., 2019). The only problem found in this model is the CA of FC. However, given that all the CR values are satisfactory, which is considered as a better measurement tool, the model is accepted.

Thirdly, the construct validity is assessed. Construct validity is the degree to which a test accurately measures what it's intended to measure. The first step of assessing construct validity, is through computing the convergent validity (CV), which demonstrate whether two tests that should be highly related to each other are indeed related. In other words, CV takes two measures that are supposed to be measuring the same construct and shows that they are related. The metric used for evaluating a construct's CV is the average variance extracted (AVE) for all items on each construct. An accepTable AVE is 0.5 or higher, indicating that at least 50% of the variance of its items is explained by the construct (Hair et al., 2019). However, an exception can be raised: an AVE of 0.40 can be adequate if the CR is higher than 0.60 (Fornell & Larcker, 1981). Hence, the values of AVE in this study can be accepted, albeit marginally.

Table 9: Measurement model results of Factor Loadings (FL), Composite Reliability (CR), Cronbach's Alpha (CA) and Average Variance Extracted (AVE)

| Construct | Item | FL | CR | CA | AVE |
|---|---|---|---|---|---|
| Behavioural Intention | BI1 | 0.80 | 0.91 | 0.85 | 0.53 |
| | BI2 | 0.91 | | | |
| | BI3 | 0.92 | | | |
| Performance Expectancy | PE1 | 0.59 | 0.79 | 0.68 | 0.43 |
| | PE2 | 0.60 | | | |
| | PE3 | 0.66 | | | |
| | PE4 | 0.65 | | | |
| | PE5 | 0.76 | | | |
| Effort Expectancy | EE1 | 0.59 | 0.80 | 0.70 | 0.45 |
| | EE2 | 0.69 | | | |
| | EE3 | 0.69 | | | |
| | EE4 | 0.59 | | | |
| | EE5 | 0.78 | | | |
| Social Influence | SI1 | 0.61 | 0.83 | 0.74 | 0.50 |
| | SI2 | 0.83 | | | |
| | SI3 | 0.60 | | | |
| | SI4 | 0.80 | | | |
| | SI5 | 0.66 | | | |
| Facilitating Conditions | FC1 | 0.73 | 0.77 | 0.56 | 0.53 |
| | FC4 | 0.72 | | | |
| | FC5 | 0.73 | | | |

Fourth and lastly, the discriminant validity (DV) was determined, which is the second step in assessing construct validity. DV describes the extent to which a construct is distinct from other constructs in the model, or, in other words whether constructs that theoretically should not be related to each other are, in fact, unrelated. The DV is considered satisfactory if the square root of the AVE extracted from each construct does not exceed the correlation between one construct and another in the model (Fornell & Larcker, 1981). In Table 9 the diagonal values in bold represent the square root of AVEs for each construct, while the off-diagonal values represent the correlations between the constructs. From this, it can be concluded that DV does not present an issue in this study. Nevertheless, it is important to mention that recent research indicated that this metric is not the most suitable method for DV assessment (Hair et al., 2019). Instead, Henseler et al. (2015) proposed the heterotrait-monotrait (HTMT) ratio, with a threshold value of 0.9. Using this metric, three minimal issues arise, however, Roemer et al. (2021) argue the HTMT is slightly downward biased for small sample sizes, and therefore it was decided to proceed.

Table 10: Measurement model results of Discriminant Validity (DV) (Fornell & Larcker, 1981)

| | **BI** | **EE** | **FC** | **PE** | **SI** |
|---|---|---|---|---|---|
| **BI** | **0.88** | | | | |
| **EE** | 0.43 | **0.67** | | | |
| **FC** | 0.67 | 0.29 | **0.73** | | |
| **PE** | 0.52 | 0.55 | 0.44 | **0.66** | |
| **SI** | 0.80 | 0.56 | 0.71 | 0.60 | **0.71** |

Lastly, before assessing the structural model to determine the strength and significance of the relationships between the constructs, the collinearity must be examined to rule out potential bias in the regression results (Hair et al., 2019). This is done through assessing the variance inflation factor (VIF) values, which quantifies the extent of correlation between one predictor and the other predictors in a model. VIF values above 5 are indicative of probable collinearity issues among the predictor constructs (Hair et al., 2019). Within this study, no problems are found with the VIF values and therefore the results of the structural model can be interpreted, as further discussed in the subsequent section.

***Assessing the Structural Model***

Because the assessment of the measurement model met all the requirements, the structural models can be assessed by the researcher. First, the evaluation of $R^2$ can be determined, which is a measure of the model's explanatory power. $R^2$ measures the proportion of variance in the dependent variable BI that are explained by the independent variables PE, EE, SI and FC in a regression model. This metric is commonly used in statistics to evaluate the goodness of fit achieved by a model (Hair et al., 2019). $R^2$ values range from 0 to 1, with higher values signifying a stronger fit between the model and the dataset. For reference, $R^2$ values of 0.25, 0.50, and 0.75 are considered weak, substantial and moderate (Alhalafi, 2023). In this study, the $R^2$ value is 0.655. This value implies that the variable PE, EE, SI and FC in the model explained 65.5% of the variance in BI, thus indicating a moderate to substantial explanatory power.

Furthermore, the path coefficients were examined to test the hypotheses of the relationships between PE, EE, SI and FC on BI, as discussed in Section 5.2.1. To check the statistical significance of path coefficient relationships, the t-test was used. The significance of the path coefficient was tested by bootstrapping resampling in SmartPLS4, with the iterations fixed at 1,000 (Jena, 2022; Guanawan, 2018). The significance level is set to 5%, corresponding to a 95% confidence interval. Thus, only if the p-value is $< 0.05$ the hypothesis is accepted. The hypothesis results are illustrated in Table 11. Based on the Table, it can be stated that only H3 can be accepted:

H1 tested the positive influence of PE on BI of UDTs in the context of climate adaptation in urban development. The analysis of the data in this study finds that PE does not significantly affect the BI ($p = 0.712$). Hence, the hypothesis is not supported. This implies that, according to this study, the degree to which an individual believes that using UDT technology will improve their job performance does not affect their intention to use the technology.

H2 tested the positive influence of EE on BI of UDTs in the context of climate adaptation in urban development. The analysis of the data in this study finds that EE does not significantly affect the BI ($p = 0.990$). Hence, the hypothesis is not supported. This implies that the perceived ease associated with using UDT technology does not affect the intention of stakeholders to use the technology.

H3 tested the positive influence of SI on BI of UDTs in the context of climate adaptation in urban development. The analysis of the data in this study finds that SI significantly affects the BI (p = 0.002), with a path coefficient of 0.618. Hence, the hypothesis is supported. This implies that the degree to which an individual perceives that others believe they should adopt and use UDT technology does substantially affect the intention of stakeholders to use the technology.

H4 tested the positive influence of FC on BI of UDTs in the context of climate adaptation in urban development. The analysis of the data in this study finds that FC does not significantly affect the BI (p = 0.265). Hence, the hypothesis is not supported. This implies that the degree to which an individual believes that organisational and technical support is available to facilitate the use of UDT technology does not affect their intention to use the technology.

Table 11: Hypothesis testing statistics: Patch Coefficient (β), T-statistics and p-value (* is significant)

| **Hypothesis** | **Relation** | **Path Coefficient β** | **T-statistics** | **p-value** | **Decision** |
|---|---|---|---|---|---|
| H1 | PE → BI | 0.061 | 0.370 | 0.712 | not supported |
| H2 | EE → BI | -0.003 | 0.013 | 0.990 | not supported |
| H3 | SI → BI | 0.618 | 3.157 | 0.002* | supported |
| H4 | FC → BI | 0.200 | 1.115 | 0.265 | not supported |

# Chapter 6: Discussion

The discussion chapter aims to analyse and interpret the findings and results of this research. Additionally, the differences and similarities of the findings and results are compared against previous studies and literature. It also highlights the relevance of this research and explores the practical implications of the findings. In Section 6.1, this is done for the practical application of UDT technology in the context of climate adaption in urban development. In Section 6.2, this is done for the findings from the user evaluation. Lastly, the limitations and weaknesses of this research are acknowledged in Section 6.3 and the recommended direction of future research is explained in Section 6.4.

## 6.1 PRACTICAL APPLICATION

In the first part of this study, a comprehensive exploration was undertaken to assess the practical application of UDT technology in the context of climate adaptation in urban development. The overarching goal of this section was to explore how UDT technology could be employed in this particular context and if it would allow better-informed decision-making in addressing climate adaptation efforts and challenges in urban development. This is performed by conducting in-depth case study research on the urban development project in Gnephoekpolder, the Netherlands. This study builds upon existing literature by exploring the use of UDT technology in a real-life context, which only has limited examples thus far (Riaz, McAfee & Gharbia, 2023; Capari et al., 2022). Furthermore, it offers novel insights by delving into the single concept of climate adaptation, a subject with limited previous research.

### 6.1.1 Simulating Urban Development

Before conducting climate change scenarios on the urban development scenario of the Gnephoekpolder, it was necessary to recreate the urban development to allow for implementation in Tygron. At the outset of the study, it was anticipated to obtain a comprehensive and detailed 3D urban development plan for the Gnephoekpolder, which could be seamlessly uploaded into Tygron. Unfortunately, the urban development plan was not yet finished within the time frame of this study. Because the parametric design feature had its limitation in terms of creative freedom (Steino, 2005), the decision was made to create an own design approach based on the most recent sketches obtained. The tiles system is a new and unexplored approach to recreate urban development scenarios in a UDT but was based on similar urban development projects seen in the consulting industry. Although this approach consumed considerable time and resulted in a design that lacked a high degree of realism, it carried the advantage of resonating more closely with the stakeholders engaged in the project. Shahat et al. (2021) argue that deficiencies in the urban model from insufficient data or shortcomings in visualization can impede the efficacy of the UDT to be valuable for planning decisions and predictions of future scenarios. Nonetheless, the emphasis of this study was rather demonstrating the potential application of simulating climate change scenarios rather than generating highly realistic outcomes of the urban development plans.

### 6.1.2 Climate Adaptation Analyses

To assess the potential application of UDTs in enhancing better-informed decision-making for climate adaptation within urban development strategies, various climate change-related simulations are performed in Tygron. The simulations are performed on two different development plans of the Gnephoekpolder, one scenario without climate adaptive measures and one with climate adaptive measures. The results of the analyses were evaluated against various criteria as outlined in the LKB, which is regarded as a leading policy document in the field of climate adaptation within the built environment (van den Dool., 2022). Generally, the results of the simulations in this study reveal that UDT technology can definitely offer valuable insights in the field of climate adaptation. This insight could guide stakeholders in altering urban development plans, thereby improving the climate adaptive capacity.

As an illustration, the heat stress module in Tygron offers a broad range of functions. For example, the PET can be calculated and spatially visualized based on a large quantity of parameters, including sun radiation, temperature, humidity and wind. The results of the PET analysis indicated that for both urban development scenarios the heat stress is considered strong, but that adding climate adaptive measures significantly reduces the average overall temperature. Given the detrimental effects of elevated temperatures, the results of this analysis provide the opportunity to identify areas in the urban development scenario necessitating climate adaptive measures to mitigate adverse effects. In combination with the travel distance overlay in Tygron, urban development scenarios can be tested against predefined requirements, such as the presence of shaded parks within a 300-meter proximity of residential areas, as indicated in the LKB. According to Lindberg et al. (2016), the distance to nearest shaded cool areas can be used to identify areas where vulnerability to heat stress might be high and could therefore be useful for identifying where adaptation measures could be taken to reduce heat stress.  Furthermore, the results showed that shade maps can be calculated based on the sun’s positions and the height and shape of buildings, trees and other structure can be calculated. This facilitates a clear visualization of whether roads are adequately shaded, which is also a requirement proposed in the LKB.

Secondly, by performing extreme rain scenarios in the virtual environment of Tygron, this study showed that the effects of water storing structures and blue-green infrastructure can be visualized for different urban development plans. Using an UDT, it can be demonstrated if certain urban development scenario can or cannot endure extreme precipitation without surpassing critical threshold values of water on the street, if enough climate adaptive measures are implemented. With a better understanding and spatial insights of pluvial flood risks in urban areas, more effective climate adaptation endeavours and approaches can be put into practice (Casiano Flores & Crompvoets, 2020; Szewrański et al., 2018). However, this study encounters a significant limitation in assessing whether buildings, infrastructures and vital facilities remain undamaged during specific periods of intense rainfall, which is a requirement outlined in the LKB. For the urban development scenarios an accurate elevation model was absent, which is considered crucial in modelling pluvial flooding in cities and in incorrect models leads to inaccurate results (Muthusamy et al., 2021). In this study, the built-up area was collectively raised to a predetermined height as it was perceived difficult to change this due to the tiles system applied for the purpose of urban development. Therefore, the water did not flow towards certain accumulation points; instead, the water level tended to gradually increase across the entire area. Correct modelling of pluvial flooding offers substantial benefits, enhancing well-informed decision-making in urban planning. For example, its simulation has been acknowledged as an effective strategy to design urban storm sewers and plan the right drainage system (Laouacheria et al. 2019; Ahamed & Agarwal 2019). Furthermore, it can assist in evaluating the performance of stormwater sewer networks and facilitates evaluation of the effectiveness of climate adaptive solutions (Bulti & Abebe, 2020). Although the outcomes in this study on pluvial flooding due to extreme rain were not optimal, numerous papers are available that have showcased Tygron's capabilities in hydrological modelling with correct elevation models (Renswoude, 2020; Verboom, 2022; Schoonderwoerd, 2022).

Lastly, the flooding module in this study provided insights into areas that are most susceptible to flooding in case of a levee breach. In the LKB, one of the requirements is to protect critical infrastructure from a flooding event given their regional or national importance. Although critical infrastructures are generally designed to withstand climate-related pressures, climate change can increase failures and expose new risks (Vamvakeridou-Lyroudia et al., 2020). With the generated output, the best positioning of critical infrastructure can be ascertained at places that are less likely to inundate, aiming to minimize the risk of negative consequences of a potential flood due to a levee breach. Furthermore, the results demonstrated that by elevating infrastructure damage can be prevented and important roads can remain accessible (Wang et al., 2019). Moreover, an important requirement from the LKB was related to the prevention and limitation of damage to buildings based on certain threshold values for inundation height due to flooding. This study demonstrated that Tygron facilitates the spatial visualization to determine if this requirement is met, and together with FME damaged buildings can also be quantified. However, similarly to the rain module, the absence of an accurate elevation model posed challenges in evaluating this requirement in this study. According to Kumar et al. (2018) the simulation of floods and the visualization of their impacts in 3D instead of 2D can have enormous added value for water experts, policymakers, and decision-makers to assess the seriousness of the situation and make decisions accordingly. Assuming the correct implementation of the elevation model when importing a representative urban development plan into Tygron, the UDT technology possesses the capacity to facilitate decision-making and promote climate adaptive measures tailored to specific development scenarios.

Thus, this research explored the practical application of UDT technology to facilitate climate adaptation efforts in urban development projects. The findings of this study demonstrate that the climate adaptation analyses in Tygron can offer extremely valuable spatial information on the impacts of heat stress, extreme rainfall and flooding, despite some of the aforementioned limitations. The multifaceted possibilities of Tygron align with the requirement from the LKB and can thus enhance climate adaptation strategies. Through the identification of vulnerabilities in the urban development plan and assessing the effectiveness of adaptation strategies, this study showed that UDT technology can aid better-informed decision-making for climate adaptation efforts in urban development. This conclusion is in line with similar research recently performed by Henriksen et al. (2022)

## 6.2 USER EVALUATION

In the second part of this study, a comprehensive user evaluation on UDT technology in the context of climate adaptation in urban development was conducted through a questionnaire and interviews, based on the UTAUT framework developed by Venkatesh et al. (2012). The primary objective of this section was to assess the benefits, risks and limitations associated with UDT technology regarding climate adaptation, as identified by stakeholders engaged in the process of urban development. Moreover, this paper aimed to acquire novel insights into the anticipated acceptance and use of UDT technology in this specific context and tried to identify the factors that have the greatest influence on its adoption.

### 6.2.1 Benefits, Risks and Limitations

The findings of this study revealed that participants recognized the potential and usefulness of UDT technology in advancing climate-adaptive effort in urban development. Despite limited existing knowledge about UDT technology and minimal prior experience with Tygron, two primary performance-related benefits emerged. First of all, the visually appealing features and interactive capabilities of the simulations were frequently highlighted as beneficial by the participants. The participants argued that these capabilities could facilitate a collaborative environment for multiple stakeholders and improved cooperation between stakeholders, a similar result to previous studies (Lv, Shang and Guizami, 2022; Hämäläinen, 2021; Lehtola et al., 2022). The importance and perceived advantage of attractive visualization of the city in an UDT has been previously mentioned in another case study research (Dembski et al., 2020; Schrotter & Hürzeler, 2020). Nevertheless, Shahat et al. (2021) stresses that the visualization of complete physical details is still incomplete due to the tremendous number of details required to comprehensively represent a city in a digital mode. Secondly, participants highlighted the ability to examine and evaluate various urban development scenarios against predefined criteria within a virtual environment as a significant advantage. Similarly, to previous studies, this is regarded as one of the primary benefits of digital twins applied to cities (Shahat et al.  2021; Balogun et al., 2020)

The risks and limitations that emerged from this study concerning the UDT technology's application in the context of climate adaptation are primarily focused around three themes; data quality, time and effort required for use, and the required skills and knowledge. The primary limitation put forward in this study, leading to scepticism towards UDTs, is the risk of inaccurate input data causing incorrect output results and misinterpretations. The strong importance of accurate data quality, good data management and solid data infrastructure to fully leverage the potential of UDT technology is also emphasized by nearly all comparable research (e.g. Ferré-Bigorra et al., 2022; Hämäläinen, 2021; Petrova-Antonova & Ilieva, 2021; Shahet et al., 2021; Lei et al., 2023). This study also emphasised that models similar to those examined are frequently perceived as the truth and an accurate reality, irrespective of the quality of the data. Dembski et al. (2020) also stressed the uncertainty of models functioning effectively in real-life conditions and hence advocated critical evaluation at all times.

Furthermore, the lack of skills and knowledge to use UDTs and the required time and effort to get acquainted with UDTs are put forward as limitations for adoption. Hence, the question is what the willingness of individuals engaged in urban planning field is to change their standard course of action and actively educate themselves, as also stated by Hämäläinen (2021). Surprisingly however, despite the concerns, the behavioural intention to work with UDTs is rated notably high, and numerous positive comments are made regarding the willingness to engage with the technology. One explanation suggested by this study is that the configuration of the model and the development of the simulations are carried out by experienced professionals, such as those working at an engineering firm. Consequently, the stakeholder only has to engage with the output of the UDT simulations, which is perceived as a rather positive and interactive experience. Alternatively, as suggested by similar research, the importance of a user-friendly interface is acknowledged but the perceived benefits of UDTs outweigh the training and skills barrier, making stakeholders confident to master UDT technology (Eri & Elnæs, 2023).

### 6.2.2 Factors Influencing the Technology Adoption of UDTs

In the concluding phase of this research, the objective was to gain further understanding on the acceptance and use of UDT technology in the context of climate adaptation in urban development. This was achieved by assessing the adapted UTAUT framework, tailored specifically for this research. The results from this study suggest that the only construct that significantly affects the behavioural intention to use UDT technology in light of climate adaptation efforts is Social Influence. In other words, the results stress that in order for UDT technology applications to be widely accepted by stakeholders involved in urban planning and development, the organizations in which they work need to address social influence as the priority. Social influence is defined as the degree to which an individual perceives that others believe they should adopt and use a new system or technology, based on social norms, opinions and expectations by others (Venkatesh et al. 2012). Thus, according to the results, a higher degree of social influence would significantly enhance the behavioural intention to adopt UDT technology. Although the impact of social influence on human behaviour in technology adoption has been widely acknowledged (Lorenz & Buhtz, 2017), limited literature was found with regards to UDT technology that yielded similar results, despite numerous efforts. A study by Grandhi & Grandhi (2021) on smart city adoption suggested that the perception of individuals to using a new technology may depend on how strongly other stakeholders feel that it should be used by them. However, in contrast, Gunawan (2018) argued that social influence perception did not affect the habits showing eagerness to use smart city technology. Generally, Lei et al. (2023) argued that social barriers in adopting and managing digital twins applied to cities, such as equal participation, possible collaboration and trustworthiness of the technology, are often overlooked and current research is very much technology focussed.

Nevertheless, this study suggests the following explanation of this finding, in alignment with the obtained results during the user evaluation. Based on the outcomes of this study, the behavioural intention to use UDT technology for promoting climate adaptive effort in urban development receives a remarkably high rating, supported by especially high-performance expectations. However, the results also revealed limited familiarity with UDT technology, a lack of practical use and implementation thus far and minimal mentioning of the technology within their work environment. This is reasonable because, as previously mentioned, UDT technology is still in its early research and development phase and demonstration in real-world projects is limited (Ferré-Bigorra et al., 2022; Shahzad et al., 2022). Surprisingly however, the results from the SI construct expressed that almost all the participants expected a positive sentiment from their colleagues if they would actually use UDT technology to foster climate adaptation. Therefore, these results of this study could indicate that an increased mentioning, utilisation and implementation of UDT technology within the individual’s environment could significantly enhance their perception and understanding of UDT technology, thus promoting the willingness to adopt the technology. This is in line with research conducted by Geertman et al. (2013), which suggest that the introduction of a software and technology into an organization is an ongoing process in which actors seek to persuade others to become enrolled and promote the acceptance of the tools. Thus, to turn UDT technology from pure technical solutions into smart solutions used to change the urban development practices in light of climate adaptive efforts, promoters should be people-centric and facilitate the inclusion of social aspect within their environment.

Although the Facilitating Conditions and Effort Expectancy constructs did not show significant relations towards the behavioural intention to adopt UDT technology in this research, these aspects are often mentioned by other scholars as important. For example, Eri & Elnæs (2023), highlighted the importance of organization adaptation and management support to successfully integrate UDT technology in the urban planning processes. Additionally, Hämäläinen (2020) stressed that cities need to consider changes in organisational culture, processes and structure to guarantee the adoption and diffusion of digital twins in smart-city development. Furthermore, Lei et al. (2023) stated that capacity building is crucial to promote adoption of digital twins, through equipping their employees with adequate skills and knowledge to work with the technology and correctly make use of its advantages. This is supported by Shahzad et al. (2022), expressing the need to upskill the workforce with technical and non-technical competencies to transform the industry with the use of digital twins.

## 6.3 LIMITATIONS AND WEAKNESSES

Although our research yielded valuable insights into the practical application and user acceptance of UDT technology in the context of climate adaptation effort in urban planning and development, it is important to acknowledge limitations and weaknesses that were encountered during this study. These limitations are related to the methodologies employed, data collection methods, sample size, scope and data analysis. Understanding these limitations enhance the understanding of the results and can help future research efforts in a similar direction.

### 6.3.1 Tygron

For this research, specifically the Tygron Geodesign Platform is used as the UDT software. In this study, the results of Tygron are generalized towards the overall concept of UDT technology. However, it is important to note that Tygron is just an example of digital twin software and there are many other similar tools available in the Netherlands and beyond. Therefore, when interpreting the results, it is important to consider that alterative tools and software might produce different results, possess other functionalities or employ alternative methodologies when conduct the climate adaptation assessments.

Secondly, Tygron advocates itself as a digital twin software. However, according to literature, one important aspect that is missing to align with the scientific definition of a digital twin that is currently not (yet) included in Tygron, is the inclusion of real-time data exchange between the virtual and physical counterparts. Nevertheless, Tygron fits the definition of a city 3D model with extended capabilities to perform simulations and assess scenarios, similar to other digital twin definitions in the field of urban planning, and in accordance with the definition used in this research. Current research has defined UDTs in many different ways, and this ambiguity might cause problems when stakeholders start a practical project with this technology without a prior consensus of what a digital twin entails and what is must be capable of.

Lastly, although no specific programming skills are needed to use Tygron due to its friendly user-interface, it is still a software that needs adequate skills and capabilities to fulfil its purpose. Therefore, due to the fact that the researcher had no prior experience with the technology, getting acquainted with the program was a time-intensive process and some limitations were encountered which could not be solved. Nevertheless, it was a rewarding experience, and the acquired skills are expected to be valuable in a further professional career.

### 6.3.2 Limited research foundation

The field of digital twins applied to cities and urban planning is relatively new, and there is little research available to use as a foundation for this study. For example, the majority of academic resources cited in this study were published within the last three years. While this underscores the popularity and significance of this topic, it has constrained the capacity to position the findings of this study within a broader theoretical framework. This might impact the robustness and correctness of the conclusions that are drawn in this study.

### 6.3.3 Data collection

#### *Sample size*

This study relied upon a relatively small sample of participants, due to the case study nature of this study. Although most stakeholders that are involved in urban planning and development processes are represented, having a larger sample would have increased the value of the findings obtained, enhancing the interpretability and allowing for drawing more accurate conclusions.

#### *Geographical context*

This study is limited to the geographical context of the Gnephoekpolder in the Netherlands. As such, the results obtained from this research and its implications are especially relevant to the Dutch context of urban planning and development. For example, the climate adaptation analyses are built around the most recent policy documents that are particularly designed in relation to the Dutch approaches and requirements. The practical application of UDT technology and the expected adoption can vary significantly at other geographical locations due, for example, differences in culture, economy and policies.

#### *Limited experience*

Because UDT technologies are still a relatively new field of research, the stakeholders who participated in this study had limited to no experience or understanding of the technology. As a result, their perceptions and attitudes are, in the case of this study, largely dependent on the explanation of the researcher rather than on personal experiences. This dependency and lack of actual experiences might have influenced participants views and responses on the potential of UDT technology in the context of climate adaptation in urban development.

### 6.3.4 UTAUT

In this study, the UTAUT framework employed is modified to fit the purpose of this research. For example, moderating effects are excluded due to the small sample size, although these might have produced interesting insights. Furthermore, the results obtained are not compared against participants' work or educational background, which might have revealed striking differences. Furthermore, with a larger sample size, interesting differences in answers to the constructs could have emerged, potentially impacting the conclusions drawn from the study.

Secondly, the model depends largely on the questions from the questionnaire that relate to each individual construct. Although the questions are mostly drawn from existing studies in similar topics, it is acknowledged that the creation of some questions are subjective and might not actually represent a certain construct. For example, when looking back, question FC2 and FC3 might not critically reflect the construct of facilitating conditions. Nevertheless, these items were excluded for the model evaluation due to an insignificant factor loading. Furthermore, the question from the questionnaire changes regularly in the perspective of Tygron or, more general, UDT, when addressing certain statements. This was perceived as confusing by the participants.

Thirdly, the results of the results of assessing the structural model in the user evaluation should be interpreted with caution. Although the measurement model successfully passed all the necessary tests, there were instances where it only passed slightly and sometimes exceptions were raised given the exploratory nature of this research. Furthermore, although PLS-SEM is proven to be useful with small sample sizes as well, a larger population sample would have significantly improved the credibility of the results.

## 6.4 FUTURE RESEARCH RECOMMENDATIONS

This research yielded valuable insights into the practical application and user acceptance of UDT technology to facilitate urban climate adaptation efforts. However, it has also uncovered interesting new research directions and suggests potential unanswered questions that could be further explored.

First of all, an interesting direction future research would be to conduct a longitudinal study approach with a similar research interest. Due to the limited time frame of this study, the practical application of UDT technology could only be explored with a simulated urban development scenario based on development sketches. Only at the end of this study, the first version of the 3D model of the urban development scenario was revealed, despite too late for further assessment. If researchers perform a similar study over a longer time frame, it is expected and believed that interesting insights can be revealed. For instance, the practical application of UDT technology cannot only be tested, but it can also be proven if their outputs actually aid better-informed decision-making. In such research, it can be demonstrated if the implementation of climate adaptive efforts is indeed stimulated based on the performed analyses and if urban development plans are indeed altered accordingly. Furthermore, after the urban development in the real world has taken place, the virtual model can be evaluated against the physical reality. This information could further improve the model and justify its potential. If successful implementation of UDT technology throughout the whole cycle of urban development is proven, the willingness to adopt such technology is expected to increase. Through this evaluation, the effect of UDT technology on decision-making regarding climate adaptive efforts and the overall quality of urban development projects can be better understood and evaluated.

Secondly, future research endeavours should aim to research the applicability of UDT technology in the climate adaptation themes that are not discussed in this study, namely drought, biodiversity and soil subsidence. These themes are also considered as important strategies towards a climate-adaptive and resilient city in Dutch policy documents. If the potential application of UDT technology on these approaches could be proven successful, UDT technology can be employed further as an integral and collaborative tool to stimulate climate adaptation efforts in urban development as a whole. From this, UDT technology allows to process and simulate a wide range of different climate adaptive scenarios, allowing urban development and control of climate adaptation efforts in a single tool, thus eliminating the needs for others. However, the practical usability of UDT into these themes has not yet been demonstrated.

Lastly, an important area for future research is to explore and understand the social aspects of technology adoption and identify which social barriers might hamper widespread adoption of UDT technology. This research suggested that social influence has a profound influence on the behavioural intention to use UDT technology. Currently, the social construct and needs identified by stakeholders to allow for the successful adoption of new technologies are often overlooked in existing research. Despite numerous efforts in researching the technical aspects of UDT, the social and non-technical elements should not be neglected. Thus, conducting future research into the social dimension of UDT technology adoption is expected to yield interesting new insights that could be valuable for successful application of UDT technology, especially for climate adaptive efforts in the urban context. Additionally, future research should further address the risks and limitations regarding the performance, especially related to data quality, and the effort, especially related to time investments and skills needed, of UDT technology. With improved insights and information, adequate strategies can be developed to overcome these barriers.

# Chapter 7: Conclusions

To conclude, this research has made a significant contribution to the knowledge and understanding of the practical application and potential adoption of UDT technology in the context of climate adaptation in urban development. Even though UDT research is still in its preliminary stages, this study demonstrated that this promising technology is capable of aiding better-informed decision-making processes for urban development strategies regarding climate adaptation efforts. Through the simulation of climate change-related risk scenarios, including heat stress, extreme rainfall and flooding, in a virtual environment, valuable insights can be obtained. With the results, vulnerable areas in need of climate adaptive measures can be spatially identified. Furthermore, the benefits of climate adaptation efforts can be visually demonstrated and quantified. Future research efforts could concentrate on the assessment of UDT technology during the entire process of urban development, aiming to justify if the practical application of the technology translates into meaningful action and promotion of climate adaptive measures.

Moreover, this study identified and elaborated upon the benefits, risks and limitations of UDT technology, through the execution of a user evaluation comprising both qualitative and quantitative methods. The results identified a strong intention towards adopting UDT technology in the context of this study, driven by the robust visual aspects and interactive features, as well as the simulation capabilities enabling scenario comparison. However, some issues appeared, including the importance of good data quality and the time and effort required to work with the UDT technology, which is not yet resolved. Future research endeavours could investigate how to overcome these limitations that hinder adoption. Lastly, this study demonstrated the importance of social influence in shaping the behavioural intention to engage with UDT technology. Limited existing research on social barriers to the adoption of UDT technology has uncovered a gap that presents an opportunity to explore by other researchers. By taking an in-depth case study approach, with a combined perspective from academia and practice, this work established novel insights on the potential of UDT technology on climate adaptive efforts and can be used as an important reference for subsequent research and development of UDTs.

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# Appendices

## Appendix A: UTAUT Questionnaire

### 1. Introductie

Geachte deelnemer,

Bedankt dat u overweegt deel te nemen aan dit onderzoek. Voordat u verder gaat, wil ik u graag voorzien van belangrijke informatie over uw deelname. Uw vrijwillige deelname aan dit onderzoek wordt zeer op prijs gesteld en zal bijdragen aan waardevolle inzichten en begrip in het potentieel van 'Urban Digital Twins' voor klimaat adaptieve stedelijke ontwikkeling.

Lees de volgende informatie zorgvuldig door voordat u besluit al dan niet deel te nemen. Als u vragen of zorgen heeft, neem dan gerust contact met mij op via de verstrekte contactgegevens.

Doel van de studie:

Het doel van deze enquête is om informatie en perspectieven te verzamelen over Urban Digital Twins en het potentieel voor klimaat adaptieve stedelijke ontwikkeling.

Vrijwillige deelname:

Deelname aan deze enquête is geheel vrijwillig. U hebt het recht om deelname te weigeren of u op elk moment terug te trekken zonder negatieve gevolgen. Uw beslissing om al dan niet deel te nemen heeft geen invloed op uw huidige of toekomstige relatie met de onderzoekers of aanverwante organisaties.

Vertrouwelijkheid, anonimiteit en gegevensbescherming:

Alle in dit onderzoek verzamelde antwoorden worden strikt vertrouwelijk en anoniem behandeld. Uw identiteit wordt op geen enkele manier aan uw antwoorden gekoppeld. De verzamelde gegevens worden veilig opgeslagen en zijn alleen toegankelijk voor het onderzoeksteam. Alleen geaggregeerde resultaten zullen worden gerapporteerd, zodat individuele antwoorden niet kunnen worden geïdentificeerd. Ik zet me in voor de bescherming van uw persoonlijke gegevens. Alle persoonlijke gegevens die tijdens dit onderzoek worden verzameld, zullen worden behandeld in overeenstemming met de toepasselijke wet- en regelgeving inzake gegevensbescherming. Uw persoonlijke gegevens worden alleen gebruikt voor dit onderzoek en worden niet aan derden verstrekt.

Gebruik van gegevens en rapportage:

De verzamelde gegevens zullen uitsluitend worden gebruikt voor onderzoeksdoeleinden en om inzichten in dit onderwerp te genereren. De resultaten kunnen worden gepubliceerd in academische papers, rapporten of presentaties. De gegevens zullen echter worden geanonimiseerd gepresenteerd, zodat geen enkele individuele deelnemer kan worden geïdentificeerd.

Door verder te gaan met dit onderzoek geeft u aan dat u vrijwillig instemt met deelname, dat u de verstrekte informatie hebt gelezen en begrepen en dat u akkoord gaat met de hierboven beschreven voorwaarden. Als u wilt deelnemen, ga dan verder met het onderzoek. Als u niet wenst deel te nemen, kunt u het onderzoek op elk moment verlaten.

Bedankt voor uw tijd en bijdrage aan dit onderzoek.

Met vriendelijke groet,

*Bram* Wolters
MSc Student - Metropolitan Analysis Design & Engineering
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### 1.1 Introductie vragenlijst

LEES ONDERSTAANDE INFORMATIE GOED DOOR:

Alvorens verder te gaan met de enquête, heb ik u verschillende klimaat gerelateerde analyses gepresenteerd die zijn uitgevoerd met behulp van Tygron. Deze analyses richten zich op drie hoofdthema's: Overstromingen, extreme regen en hittestress. De analyses zijn gevisualiseerd op twee stedenbouwkundige scenarios in de Gnephoekpolder, die elk een andere situatie weergeven. Het eerste scenario vertegenwoordigt een normaal ontwikkelingsplan, terwijl het tweede scenario aanvullende klimaat adaptieve maatregelen bevat.

Ik wil u vragen de enquêtevragen te beantwoorden over de klimaat gerelateerde analyses die in Tygron zijn uitgevoerd, op de verschillende scenario's die ik u heb voorgelegd.

Uw feedback en antwoorden zijn uiterst waardevol voor de evaluatie van de effectiviteit van Tygron en zijn vermogen om stedenbouwkundige praktijken te verbeteren, specifiek met betrekking tot klimaatadaptatie.

De vragenlijst duurt ongeveer 10 minuten.

Bij voorbaat dank voor uw deelname.

2. **Algemene informatie**

Wat is uw geslacht?

- Man / Vrouw / Anders

Wat is uw leeftijd?

- 0-20 | 21-30 | 31-40 | 41-50 | 51-60 | >60

Wat is uw opleidingsachtergrond?

- Stedelijke ontwikkeling/planologie
- Architectuur
- Civiele Techniek
- Milieuwetenschappen
- Geografie
- Hydrologie
- Sociale Wetenschappen
- Economie
- Anders:

Ik ben werkzaam bij?

- Gemeente
- Ontwikkelaar
- Woningbouwcorporatie
- Financiers & vastgoedbeleggers
- Waterschappen
- Provincie
- Advies & Ontwerpbureaus
- Anders:

Wat is uw huidige functie?

- …

Hoeveel jaar werkervaring heeft u in uw vakgebied?

- 0-1 | 1-3 | 3-5 | 5-10 | >10

Ik heb eerder gewerkt met Tygron

- Ja | Nee

*Beantwoord de volgende vragen op een schaal van 1 tot 7:*

*1. Sterk mee oneens*
*2. Oneens*
*3. Enigszins oneens*
*4. Neutraal*
*5. Enigszins mee eens*
*6. Mee eens*
*7. Sterk mee eens*

- Ik heb verstand van klimaatadaptatie, de strategieën voor klimaatadaptatie en de toepassing daarvan bij de aanpak van de gevolgen van klimaatverandering in stedelijk domein.
- Ik heb verstand van 'Digital Twins' en hun toepassing in het stedelijke domein.
- Het onderwerp van dit onderzoek over Digital Twins en klimaat adaptieve stedelijke ontwikkeling is iets dat mij interesseert.

## 3. UTAUT vragen

*Beantwoord de volgende vragen op een schaal van 1 tot 7:*

*1. Sterk mee oneens*
*2. Oneens*
*3. Enigszins oneens*
*4. Neutraal*
*5. Enigszins mee eens*
*6. Mee eens*
*7. Sterk mee eens*

Deel 1: Verwachte Prestaties (Performance Expectancy)

- 1. De klimaat gerelateerde analyses in Tygron kunnen het algemene begrip van klimaatadaptatie in stedelijke ontwikkeling vergroten.
- 2. De klimaat gerelateerde analyses in Tygron kunnen een beter geïnformeerde besluitvorming ondersteunen met betrekking tot de implementatie van klimaatadaptatie in stedelijke ontwikkeling.
- 3. Met behulp van Tygron zou de efficiëntie en nauwkeurigheid van de planning en uitvoering van klimaatadaptatie in stedenbouwkundige strategieën kunnen worden verbeterd.
- 4. De functionaliteiten en kenmerken van Tygron sluiten goed aan bij de eisen van klimaatadaptatie in stedelijke ontwikkeling.
- 5. Over het geheel genomen kan het gebruik van Tygron een positief effect hebben op de implementatie van klimaatadaptatie in stedelijke ontwikkelingsstrategieën.

Deel 2: Verwachte Inspanning (Effort Expectancy)

- 1. De klimaat gerelateerde analyses in Tygron zijn gemakkelijk te interpreteren en te begrijpen.
- 2. De integratie van de klimaat gerelateerde analyses in Tygron in bestaande werkprocessen voor klimaatadaptatie in stedelijke ontwikkeling is haalbaar en handig.
- 3. Het leren werken met Tygron en de klimaat gerelateerde analyses zou een leuke ervaring zijn.
- 4. De interactie met de klimaat gerelateerde analyses in Tygron met betrekking tot de effecten van klimaatadaptatie in stedenbouwkundige plannen zijn eenvoudig en intuïtief
- 5. Het gebruik van Tygron en de klimaat gerelateerde analyses zou de tijd en moeite verminderen die nodig zijn om klimaatadaptatie in het proces van stedelijke ontwikkeling te bewerkstelligen.

Deel 3: Sociale Invloed (Social Influence)

- 1. Ik denk dat mijn collega's zouden stellen dat Tygron gunstig zou zijn voor klimaatadaptatie in stadsontwikkelingsplannen.

- 2. Ik ervaar een positieve houding in mijn omgeving ten opzichte van het gebruik en de toepassing Digital Twins om klimaatadaptatie in stedenbouwkundige plannen te bevorderen.
- 3. Het vaardig en vertrouwd raken met het gebruik van klimaat gerelateerde analyses in Tygron zou nuttig zijn in mijn werk met betrekking tot klimaatadaptatie in stedelijke ontwikkeling.
- 4. In mijn omgeving worden de ontwikkelingen van Digital Twins gezien als een kans om klimaatadaptatie in stedelijke ontwikkeling te verbeteren.
- 5. In mijn werkomgeving wordt het gebruik van Digital Twins als tool voor klimaat adaptieve stedelijke ontwikkeling steeds vaker genoemd

<u>Deel 4: Faciliterende Voorwaarden (Facilitating Conditions)</u>

- 1. Ik heb voldoende kennis en begrip om de klimaat gerelateerde analyses in Tygron effectief te gebruiken om klimaatadaptatie in stedelijke ontwikkeling te bevorderen.
- 2. Ik geloof dat ik de output van de klimaat gerelateerde analyses in Tygron kan vertrouwen om te gebruiken bij klimaat adaptieve stadsontwikkeling.
- 3. Ik geloof dat de betrouwbaarheid en nauwkeurigheid van de data die in Tygron worden gebruikt voldoende is om klimaat gerelateerde analyses uit te voeren.
- 4. Ik beschik over voldoende technische vaardigheden en toegang tot technische bijstand om Tygron en de klimaat gerelateerde analyses te gebruiken voor klimaat adaptieve stadsontwikkeling.
- 5. De organisatie waar ik werk zou de implementatie en het gebruik van Tygron voor klimaat adaptieve stedelijke ontwikkeling steunen

<u>Deel 5: Houding (Behavioural Intention)</u>

- 1. Ik vind het een goed idee om Tygron en de klimaat gerelateerde analyses te gebruiken voor klimaatadaptatie in stedelijke ontwikkeling.
- 2. Ik verwacht Tygron en de klimaat gerelateerde scenarios in de toekomst te gebruiken bij stadsontwikkelingsprojecten.
- 3. Ik ben bereid om Tygron en de klimaat gerelateerde scenario's vaker te gebruiken binnen het thema klimaatadaptatie in stedelijke ontwikkeling.

Deel 6: Overig (Extra)

- 4. De 3D klimaat gerelateerde analyses in Tygron bieden meer waardevolle inzichten dan de traditionele 2D analyses met betrekking tot klimaatadaptatie in stedelijke ontwikkeling.
- 5. Het detailniveau van de bebouwde omgeving in Tygron is voldoende om de klimaatadaptatie in stedelijke ontwikkeling te visualiseren.

## 4. Open Vragen

- 1. Wat zijn volgens u de belangrijkste voordelen van het gebruik van Tygron bij klimaat adaptieve stadsontwikkeling?
- 2. Wat zijn volgens u de belangrijkste aandachtspunten of uitdagingen die u voorziet bij de invoering en implementatie van Tygron met betrekking tot klimaatadaptatie in stedelijke ontwikkeling.
- 3. Zijn er specifieke kenmerken of functionaliteiten die volgens u in Tygron zouden moeten worden opgenomen om klimaat adaptieve maatregelen in stedelijke ontwikkeling beter te ondersteunen?
- 4. Wat is in het algemeen uw mening over Digital Twins zoals Tygron met betrekking tot klimaatadaptatie in stedelijke ontwikkeling?
- 5. Heeft u nog laatste op-/aanmerkingen?

# Appendix B: Open Interviews

## Interview 1: Anonymous

*Municipality Alphen aan de Rijn – 14/06/2023*

*Bram*:

Bent u op dit moment specifieke scenario's of situaties tegengekomen waarin u denkt dat Digital Twins nuttig kunnen zijn voor klimaatadaptatie in stedelijke ontwikkeling? Zo ja, kunt u een voorbeeld geven?

*Geïnterviewde*:

Ja, ik denk dat we al een keer samen benoemd hebben. Ik bedoel de Gnephoek zelf daar zie ik best mogelijkheden inderdaad om dat te doen. Maar dat heb je natuurlijk zelf in je presentatie ook al aangegeven wat dat betreft. Dat is natuurlijk de op zich een goed voorbeeld. En ik denk in het algemeen dat bij gebiedsontwikkeling, bij wat grotere ontwikkelingen, het gewoon interessant zou kunnen zijn, dus inderdaad. Waarbij ik wel en met het risico dat ik wel een van je volgende vragen aan het invullen ben, je vraagt natuurlijk wel af van ja, wat is je minimale hoeveelheid data die nodig is aan de voorkant om een goed model op te bouwen? Dat is dan wel even natuurlijk een kritisch punt daarbij.

*Bram*:

Dan inderdaad de tweede vraag, wat zijn volgens u de vermeende voordelen en mogelijkheden van het gebruik van Digital Twins de context van stedelijke ontwikkeling en klimaatadaptatie?

*Geïnterviewde*:

Ik denk dat het tweeledig is, tenminste ik kan twee dingen nu bedenken. Ten eerste is het natuurlijk een tool op een gegeven moment om al globaal een indruk te krijgen wat de consequenties van maatregelen zijn die ontwerpt. En ik denk minstens even belangrijk is dat het ook een heel belangrijk is in de communicatie, dus inderdaad. Je merkt natuurlijk dat als je het hebt over klimaatadaptatie, dat het voor veel partijen nog een beetje abstract blijft, zo maar zeggen, en juist met dit soort modellen zou je inderdaad in de communicatie naar een waterschap toe of naar provincie of naar andere partijen dat toch duidelijker kunnen maken. Ik denk dat dat belangrijk is.

*Bram*:

Dank, mooi antwoord. Dat is meer over de uitdagingen. Wat zijn de zorgen, belemmeringen of bedenkingen die u heeft met betrekking tot de toepassing en implementatie van Digital Twins in de context van stedelijke ontwikkeling en klimaatadaptatie?

*Geïnterviewde*:

Ja, ik wil ik gewoon voorzetje gaf een vraag heen natuurlijk. En dat is met name inderdaad van wat is je minimale hoeveelheid data of misschien op een andere manier moet zeggen, wat is het minimale niveau van uitwerking wat je nodig hebt? Om een goed verhaal neer te zetten en ik denk dat dat wel heel, heel kritisch is wat dat betreft, want als je natuurlijk met een even met een gekampt mankeert model dingen gaat berekenen, ja, ik bedoel, dan heb je het risico. Kijk, en dat is natuurlijk een beetje het risico überhaupt met dit soort modellen waarvan heel veel mensen zoiets denken. God ziet er mooi uit, maar ik begrijp het niet. Alles wat eruit komt wordt voor waarheid aangenomen en juist die gevoeligheid van dat soort modellen om daar een beeld bij te krijgen, dat vind ik wel een hele belangrijke. Er zullen inderdaad van joh, wat ja, het is natuurlijk wel altijd, het blijft nog steeds 'shit in, shit out' om het zo te zeggen. Als je dat testrisico wat je loopt dus. En, dat is denk ik wel een iets wat? Ja want een van de meest kritische punten in dit geheel is van, voldoet de input aan de kwaliteitseisen eigenlijk.

*Bram*:

Ja, ik denk dat dat inderdaad één van de hele belangrijke thema's zal zijn die op dit onderwerp zal spelen. Hoe ziet u de integratie van digitale tweeling of die tot winst dus met bestaande processen en praktijken in stedelijke ontwikkeling en voorziet u mogelijkheden of uitdagingen op het gebied van samenwerking en tijdmanagement.

*Geïnterviewde*:

Dat is heel erg gericht op de integratie van het Van de werkzaamheden nu. Wat ik lastig vind, is dat je al hebt aangegeven dat je met een aantal partijen aan tafel zit, maar dan is het de vraag: wie neemt de leiding daarin? Wat betekent dat voor de andere partijen? Het kan zijn dat een ingenieursbureau daarmee aan de slag gaat, maar dan is het altijd de vraag of anderen daar ook nog iets mee kunnen doen. Ik denk dat het van belang is dat er een soort viewer komt, waarbij andere partijen ook kunnen werken. Want als het een gewoon bureau is dat presenteert, dan ben je de interactiviteit kwijt, en dat is altijd lastig. Kun je de modellen zo maken dat anderen er ook mee kunnen werken? Dat weet ik gewoon niet of dat kan.

*Bram*:

Hoe zie je de rol van de gemeente in de integratie? Welke rol zouden jullie kunnen nemen als je dit zou gebruiken?

*Geïnterviewde*:

De gemeente bestaat natuurlijk uit meerdere rollen, en mijn rol is vergelijkbaar met adviesbureaus, alleen dan meer intern. Mijn rol is om onder de motorkap te kijken en te weten wat de gevoeligheid is. Anderen zullen zich richten op de communicatie en de consequenties daarvan. Bij klimaatatlas draait het ook om meer kosten. Het hoeft niet, maar het kan zo uitkomen. Die meerkosten leveren wel iets op. Voor de politiek is het belangrijk om inspanning en geld te koppelen aan wat je ervoor terugkrijgt.

*Bram*:

Ja, precies. Het draait om kosten en baten en goede afwegingen maken.

*Geïnterviewde*:

Ja, dat is per persoon verschillend. Sommigen willen aan de knoppen draaien, anderen willen vooral de consequenties inzichtelijk maken.

*Bram*:

Hoe zie je in de toekomst de rol en mogelijke evolutie van Digital Twins in klimaat adaptieve stedelijke ontwikkeling in de komende jaren? Welke vooruitgang of veranderingen verwacht je in hun toepassing en impact?

*Geïnterviewde*:

Ik verwacht er veel van. Ik denk dat je dat ook ziet met bijvoorbeeld water en bodem sturend, kijk eens, er is heel veel data. Als je een project aanpakt dan moet je allemaal rapporten door struinen en dergelijk en ik zie een Digital Twin eigenlijk als een goede basis hiervoor. Een Digital Twin kan dienen als opslag van alle kennis en modellering daarvan, inclusief gevoeligheden. Ik denk dat het in de toekomst veel gebruikt zal worden en veel mogelijkheden biedt voor gebiedsontwikkeling en klimaatadaptatie.

Ik denk wel dat de voeding van die modellen een bottleneck kan zijn. Het moet geautomatiseerd zijn en gekoppeld worden aan data. Als dat slim gebeurt, kan het zeker helpen. Het is ook belangrijk om buiten de grenzen te kijken en naar verschillende schaalniveaus te analyseren. Heb je te maken met een bestaand gebied of een gebied waar al gebiedsontwikkeling heeft plaatsgevonden? Op verschillende schaalniveaus analyses doen is zeker nuttig. Er moet gekeken worden naar de beste plek voor de gewenste functie.

*Bram*:

Bedankt …. Ik zal het hierbij afsluiten.

**Interview 2: Anonymous**

*Project Developer – 15/06/2023*

*Bram*:

Wat zijn volgens u de vermeende voordelen en mogelijkheden van het gebruik van Digital Twins in de context van stedelijke ontwikkeling en klimaatadaptatie?

*Geïnterviewde*:

Het kunnen simuleren van toekomstige ingrepen, waardoor oordeelsvorming en beslissingen beter gefundeerd genomen kunnen worden. Ik denk dat het heel erg kan bijdragen aan wat voor beslissingen ergens op worden genomen en je kunt dingen meervoudig bekijken. En ja, dat is de grote asset, denk ik, van dit verhaal.

*Bram*:

En wat zijn volgens u de zorgen, belemmeringen of misschien bedenkingen die u heeft met betrekking tot de toepassing en implementatie van dit soort Digital Twins?

*Geïnterviewde*:

Nou ja, wat ik al eerder heb gezegd, dus het realisme is natuurlijk een ding. Dus ja, het moet heel erg gekoppeld worden aan het ontwerp en aan het ontwerpproces en dan krijg je de beste resultaten. Nou, dat heb je zelf natuurlijk ook gezien en nu zit het hem heel erg in de bovengrondse situatie hè? Terwijl de ondergrondse situatie natuurlijk minstens zo belangrijk is, dus daar zou eigenlijk een soort verdieping op moeten komen.

*Bram*:

Top, duidelijk. En hoe ziet u de integratie van dit soort Digital Twins met bestaande processen en praktijken binnen uw vakgebied? Ziet u daar vooral uitdagingen of mogelijkheden binnen de samenwerking?

*Geïnterviewde*:

Nou, ik denk dat het een soort verzameling van informatie zou kunnen dienen en dat je verschillende gegevens met elkaar eigenlijk bij elkaar brengt in de simulatie en dat je daarmee elke kan variëren, waardoor je betere beslissingen of betere richtingen kunt verkennen en daar kan je eigenlijk veel sneller tot ook tot de kern komen van de juiste oplossing.

*Bram*:

En stel dat je een Digital Twin zou toepassen in bijvoorbeeld een project wat over een maand wordt gestart. Denk je dat dat op dit moment al heel goed geïntegreerd kan worden in jullie werkzaamheden of missen we?

*Geïnterviewde*:

Want je kunt bij wijze van spreken de geografische informatie, alle informatie die er beschikbaar is. Daar zou je al een soort basismodel van kunnen bouwen. Je zou het plangebied kunnen definiëren en dan vervolgens al een grof plan kunnen maken, maar dat zou je wel heel erg moeten koppelen aan het ontwerptraject, aan het schetsontwerptraject. En de juiste uitgangspunten moeten dan ook duidelijk zijn van wat wil je bereiken, wat zijn jouw ambities en waar willen we dan heen? Dus dat is wel belangrijk, denk ik.

*Bram*:

Hoe ziet u vooruitkijkend, dus in de toekomst kijkend, de rol en de mogelijke evolutie van zo'n Digital Twin in de context dus van stedelijke ontwikkelingen en klimaatadaptatie en welke ontwikkeling verwacht je dat er gaan komen?

*Geïnterviewde*:

Nou ja, wij zien sowieso in de wereld van het vastgoed zien we dat simulatie steeds belangrijker wordt. Dat geldt ook voor mobiliteitssimulaties. Dat geldt voor programma. Dus simulaties, wat doe ik als ik daar rijwoningen behoud en daar appartementen, hoe verhoudt dat zich tot de markt? Et cetera? En dat is natuurlijk een stedenbouwkundig component, maar als je dat ook nog kunt verbreden met die klimaatcomponent, ja, dan heb je echt een heel sterk en gefundeerd verhaal. En ik denk dat het steeds meer al die lagen hebt in de gebiedsontwikkeling. Die komen steeds meer samen in een model. Dat is wel de toekomst en ik denk ook meest effectieve manier om steden te plannen. Ik denk dat dit wel de toekomst is.

**Interview 3: Anonymous**

*Province South-Holland – 14/06/2023*

*Bram*:

Bent u op dit moment specifieke scenario's of situaties tegengekomen waarin dit tenminste nuttig kan zijn voor klimaatadaptatie in stedelijke ontwikkeling? En zo ja, kunt u daar een voorbeeld van geven?

*Geïnterviewde*:

Ja, daar ben ik zeker tegengekomen. Het is vrij een hot topic nu, vooral inderdaad, met ontwikkeling van bijvoorbeeld vergroening van bepaalde gemeentes. Dat ze echt een groene gemeente willen zijn, dus zorgen dus specifiek voor meer bomen en ook wat hun toegevoegde waarde is. Ze willen weten van, waar moeten we nou die bomen zetten dat ze echt iets doen voor klimaatadaptatie? Dus niet alleen hitte, maar ook inderdaad voor droogte, water vasthouden, dat soort dingen.

En daarvoor zie ik echt wel dat Digital Twin hier toegevoegde waarde in kan zijn, vooral dus ook omdat je dan berekeningen kan uitvoeren daarmee. Dus dan kan je wat scenario's voor doen van locaties van bomen hier. Wat doet hij hier? Wat bijvoorbeeld inderdaad een park wat mijn andere kant van mijn stad, hoe doet hij het daar? Dus ik zie dat dit echt een beetje de toekomst wordt om onze ideeën en ook om de burgers en ook bijvoorbeeld wethouders mee te nemen en te laten zien van.

Dit moeten wij gewoon oppakken. Dit is het effect daarvan en dan hebben we dus een mooie visuele representatie, ook daarvan in. Niet alleen in kaarten, maar ook echt in 3D-beeld dus echt dat je dan de werkelijkheid als virtueel kan zien en dat stimuleert toch meer dat visueel vermogen van mensen en mijn ervaring is dat dat af en toe veel meer spreekt en het geeft ook meer om over te hebben. Want wat ze zeggen dus toch een foto zegt meer dan een paar woorden dus. Dat zal de Digital Twin zeker een goede bijdrage aan kunnen zijn, ook als doel als visueel component daarvan dus meerdere toepassingen mogelijk.

*Bram*:

Wat zijn volgens u inderdaad misschien nog andere vermeende voordelen en mogelijkheden van het gebruik van een Digital Twin, ook ten opzichte van wat jullie misschien nu gebruiken in de context van stedelijke ontwikkeling en klimaatadaptatie?

*Geïnterviewde*:

Ik heb hiervoor al een paar dingen genoemd natuurlijk. Momenteel gebruiken wij nu niet echt nog een Digital Twins, dus we hebben nu inderdaad wat 2D-plaatjes, kaarten, wordt veel getekend. Ook leuk en handig, maar ja, we zijn ook een data-gedreven organisatie, dus we moeten ook het meeste uit onze data gaan halen. En daar is dan een Digital Twin, die kan die data samen integreren ook. Dus ik zie het niet alleen als een rekentool dat je scenario's kan, berekeningen of ook visualiseren, maar ook om meer integriteit. Zeg maar de integraliteit tussen meerdere onderwerpen kan laten zien, dus dat is nog een component dat ik daarbij wil toevoegen.

*Bram*:

Super dank, dan gaan we door naar de derde vraag, wat zijn de zorgen, belemmeringen of misschien bedenkingen die u heeft met betrekking tot de toepassing en de implementatie van zo'n Digital Twin?

*Geïnterviewde*:

Wat het nu af en toe een beetje lastig maakt en ik verwacht dan misschien in de toekomst zal het een en ander aan weerstand zijn. Het is vrij nieuw, het is een heel technisch verhaal. Niet iedereen is erin thuis. We hebben bepaalde procedures, er zijn dingen gelopen, zoals altijd zijn gelopen en die doen het gewoon goed. Waarom zouden we het nog moeilijker maken? Dus ik voorzie dat dat een belemmering zou kunnen zijn, dus dat we echt mensen moeten gaan informeren, maar ook voor een deel misschien overtuigen of laten zien wat de kracht dan daarvan is, want het is onbekend. Het is technisch, het is specialistisch, zien mensen het en ze denken, oh, dat gaat veel te veel tijd kosten dat daar hebben we nu niet de inspanning voor. En wat levert het me uiteindelijk op? Ja, dat zijn nog een paar drempels waar we overheen moeten.

En je moet ook de juiste mensen daarvoor ook hebben om dat te doen en ook je bestuur bijvoorbeeld, je moet het ook belangrijk vinden. Daar waar er zijn heel veel topics. Maar

misschien is het dan daarin juist, hoe kan je dan zo'n Digital Twin juist daar ook aan op laten aansluiten? Even kijken? Dat zijn volgens mij de belemmeringen die ik voor nu voor ogen zie dus echt het ook het technische, bijvoorbeeld van willen we dat nou intern, willen we dat dan extern, hoe gaan we dat nou doen? Het is echt een beetje de verhouding van ja, wat hebben we nou waar en hoeveel geven we nog weg en hoe wat voor contracten stellen we daarop en?

Ja, hoe gaan we daarmee om? Dus het is, het is een beetje spannend. Nog merk ik voor heel veel mensen. Het is nieuw, hoe gaan we dat doen? Het is nog heel spannend.

*Bram*:

Nou, ik heb natuurlijk een aantal soort van klimaat analyses laten zien zojuist. Hoe ziet u de integratie van dat soort analyses van die zo'n Digital Twin kan produceren met bestaande processen en praktijken in de context bij de provincie, dus voorziet u uitdagingen of vooral mogelijkheden op het gebied van samenwerking of intern het gebruik van zo'n tool?

*Geïnterviewde*:

En intern bedoel je het echt binnen de provincie zelf hè? Dus de integratie van het proces zeg maar van deze analyses intern in jullie werkzaamheden.

*Bram*:

Ja

*Geïnterviewde*:

Nou, ik zie het wel als mogelijkheid, maar ik ben ook optimistisch, heel, heel pro dit maar intern moeten we het meer gaan promoten. Zo ook het hele proces hoe je dit kan gebruiken bij, zeg maar bij het plannen inderdaad, bij plannen van gebieden betekenen heel veel, dus we zijn bewust van de visuele aspecten van wat het kan betekenen en hoe mensen daarmee in gaan en dat ze echt iets kunnen laten zien. Dus dat deel stappen ze alleen dan het overtuigen dat het technische dat niet zo ingewikkeld is. Jongens, we moeten, ja, daar moeten we het gesprek over aangaan en zoals ik zeg, gewoon doen. Soms moet je het een keer doen en een paar mensen meenemen. En dan valt het vaak mee.

*Bram*:

En qua de integratie? Je zei ook al, jullie zijn natuurlijk veel bezig, ook met dit soort plannen en ontwikkelingen sluiten zeg maar de functionaliteiten goed aan bij processen die wij jullie nu doorheen lopen. Of zie je dit ook echt als een losstaande tool, zeg maar.

*Geïnterviewde*:

Nee, voor nu denk ik, is het een beetje een losstaande tool, maar de functionaliteiten, kijk wat je kan laten zien van wat nou bijvoorbeeld een bepaalde plan of een bepaalde locatie van een gebouw of de hoogte daarvan. Wat is de impact voor de klimaatadaptatie en de leefomgeving?

Daar sluit het dan wel mooi bij aan van jongens, hou hier rekening mee. Je moet aan deze randvoorwaarden dan voldoen. Dat betekent dat dit daarvoor goed is en dan kunnen ze ook zien wat de impact is voor de leefomgeving dan op dat moment van oh die hitte, oh nou, dat voelen we dan meteen, dus ik denk dat het op zo'n manier wel kan aansluiten, maar ik zie nu wel dat het even als een losse tool nog zal worden gezien van. Ja, dat komt, dat komt wel, dus ik hoop eigenlijk wel het in het proces mee te gaan nemen. Dat, dat zou heel mooi zijn.

*Bram*:

Top de laatste vraag, hoe ziet u vooruitkijkend in de toekomst, de rol en de mogelijke evolutie van zo'n Digital Twin en welke ontwikkeling verwacht, verwacht u, zeg maar mee te maken in de komende jaren qua toepassing van zo'n Digital Twin?

*Geïnterviewde*:

Nou ik voorzie in de toekomst dat we het een soort van standaard analyse daarvoor op willen gaan bouwen. Want we hebben ook heel veel data en er wordt ook heel veel data openbaar gezet en we hebben al die analyses en van alles nog gehad, dus er is heel veel. En dan zal het mooi zijn als we dat standaard gewoon opzetten en dan toetsen van "Hé dit betekent het, dit zou het kunnen zijn," dus dat zou mooi zijn als we dat kunnen doen.

Daar ga ik ook voor. Daarom beginnen we ook dat project om alvast een pilot ervoor te draaien, dus dat voorzie ik wel dat dat er gaat. Ik, ja, ik weet niet hoe snel, maar wel in de komende jaren had ik het zo zeggen dat het op gegeven moment gestandaardiseerd zeer waarschijnlijk in de toekomst naar verwachting gebruikt gaat worden. Zulke tooling zeg maar, want we willen toch ook heel Nederland in 3D modelleren, dus dan is dit denk ik wel heel mooi daarbij dat je dan je plannen ook daarop kan zetten en ze kan verbinden dat je even wat meer wat breder kijkt dan alleen ons gebiedjes.

*Bram*:

Super, nou dat was hem voor mij denk ik, bedankt.

**Interview 4: Anonymous**

*Province Consultancy Firm – 14/06/2023*

*Bram*:

Laten we beginnen met de eerste vraag: wat zijn volgens u de potentiële voordelen en mogelijkheden van het gebruik van Digital Twins in de context van stedelijke ontwikkeling en klimaatadaptatie?

*Geïnterviewde*:

Ik denk dat de voordelen zich vooral afspelen op het inzichtelijk maken van modellen en resultaten van relaties tussen verschillende onderdelen, zoals verkeer en luchtkwaliteit, of water en hitte. Ook de visualisatie is van belang, zodat je samen met opdrachtgevers of instanties zoals de gemeente naar het model kunt kijken, er doorheen kunt lopen en nieuwe ontwerpinzichten en uitgangspunten kunt genereren voor een ontwikkeling. Bovendien kunnen we met behulp van een Digital Twin het ontwerp simultaan doorrekenen. In de huidige situatie maken we vaak een ontwerp, dat wordt getoetst en daar komen knelpunten uit. Dan moet het ontwerp opnieuw worden aangepast en weer worden getoetst, wat een iteratief proces is. Met een Digital Twin zou dit proces veel sneller kunnen verlopen door eenvoudig een update te sturen, nieuwe resultaten te verkrijgen en daarop aanpassingen te maken.

*Bram*:

Bedankt. Dan nu de tweede vraag. Wat zijn uw zorgen, belemmeringen of bedenkingen met betrekking tot de toepassing van zo'n Digital Twin in deze context?

*Geïnterviewde*:

Een belangrijke zorg is dat de technologie achter Digital Twins voor veel mensen nog onbegrijpelijk is, wat het modelleren ook lastig maakt. Men begrijpt vaak wel hoe standaard Excel-sheets werken of hoe eenvoudige berekeningen worden gemaakt, maar dit concept is moeilijker te doorgronden. Daardoor is het ook lastiger om uit te leggen hoe bepaalde resultaten tot stand komen of hoe de modellering precies werkt. Dit geldt niet alleen voor geavanceerde Digital Twin-modellen, maar ook voor de eenvoudigere berekeningen die bijvoorbeeld een gids kan doen. Als die in het model worden toegepast, kunnen mensen het moeilijk vinden om de uitkomsten te begrijpen. Het is belangrijk dat we als procesmatige gemeenschap deze zorgen adresseren en bespreken hoe we dit proces kunnen stroomlijnen en de gegevens en berekeningen kunnen valideren.

*Bram*:

Duidelijk. Hoe ziet u de integratie van zo'n Digital Twin in uw werk, dus binnen bestaande processen en praktijken van uw huidige functie? Ziet u uitdagingen of vooral mogelijkheden op het gebied van samenwerking?

*Geïnterviewde*:

Ik zie vooral mogelijkheden. In mijn rol binnen gebiedsontwikkeling in woonwijken zie ik vooral kansen in het begin van het proces. Tijdens de verkenningsfase kunnen we bijvoorbeeld een scan uitvoeren en de resultaten met belemmeringen integreren in het Digital Twin-model. Deze gegevens kunnen vervolgens meegenomen worden naar volgende fases. Hierdoor kunnen we al bepaalde belemmeringen zien, zoals een gasleiding die dwars door het plangebied loopt, voordat we zelfs maar een plattegrond hebben ontworpen. Door dit proces kunnen we voorkomen dat we later in het ontwerpproces stapjes moeten terugzetten. Het Digital Twin-model fungeert als een leidraad gedurende het gehele proces en biedt inzichten op alle aspecten.

*Bram*:

Juist. En naast de gasleiding, zijn er nog andere specifieke toepassingen op het gebied van klimaatadaptatie waarvan u denkt dat Digital Twins nuttig zouden kunnen zijn?

*Geïnterviewde*:

Ja, dat denk ik zeker. Eigenlijk geldt dit voor alles. Bijvoorbeeld voor overstromingen, waarbij we kunnen onderzoeken hoe de omgeving met elkaar samenhangt en wat er gebeurt als er een overstroming plaatsvindt. Al deze inzichten kunnen al in een vroeg stadium van het ontwerp worden meegenomen als uitgangspunten, zodat het ontwerp daarop kan worden aangepast.

*Bram*:

Duidelijk, bedankt. Dan de laatste vraag, hoe ziet u de rol en mogelijke evolutie van Digital Twins in de toekomst? Wat zijn uw verwachtingen van de ontwikkeling van dergelijke tools?

*Geïnterviewde*:

Ik verwacht dat Digital Twins de toekomst zullen bepalen, in welke vorm dan ook. Het is onvermijdelijk dat we allemaal met digitale modellen gaan werken en deze zullen gebruiken om snel zaken inzichtelijk te maken en te houden, zelfs tijdens de beheerfase na oplevering. Met real-time data kunnen we bijvoorbeeld controleren of bepaalde zaken werken zoals verwacht en indien nodig aanpassingen doorvoeren. Qua technologische ontwikkelingen kan ik daar niet specifiek op ingaan, omdat ik me vooral op het procesmatige aspect richt. Ik verwacht echter dat we over 5 of 10 jaar volledig geïntegreerd zullen werken met Digital Twins als basis voor het hele proces.

*Bram*:

Heel duidelijk, bedankt … voor dit interview.