BrabantStad

Breda University of Applied Sciences

Digital Urban Brabant

Making (common) sense of urban digital twins

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Summary

Planning has become increasingly complex. More and more functions need to be accommodated in the same number of square meters. This problem lies at the root of the housing, nitrogen, and climate crises. There is no longer a person who oversees the entire system, raising the question: could digital twins contribute to the solution? This has been investigated for BrabantStad by Breda University of Applied Sciences (BUas) through three steps and six sub-questions.

Complex world and concepts – what are digital twins?

1. *What does the urban digital twin pipeline look like?*
   The urban digital twin pipeline consists of six steps for developing urban digital twins: data collection and data spaces are the basic requirements, while in practice, the other steps are often combined under the heading "urban digital twins.". Four types of digital twins can be defined according to Boyes and Watson (2022) :
   Digital models: Visualizing static information with manual data flows.
   Digital generators: Automatic simulations based on manual data input.
   Digital shadows: Use real-time data with manual interpretation.
   Autonomous digital twins: Fully autonomous simulations.
   This hierarchy means that each step builds on the underlying techniques, from visualizing to simulating, partially automating to fully automating, and adding new functionalities at each step. The choice of the correct level depends on the purpose, use, and complexity of the system to be modelled.

2. *How are urban digital twins concretely applied in the Netherlands, and how do these applications connect to the different steps of the digital twin pipeline?*
   To answer this question, we looked at 22 examples of urban digital twins in the Netherlands. What is striking is that 13 twins are actually digital models, 2 are digital generators, and 7 use real-time data and, therefore, fall into the digital shadow category. No urban digital twins that operate completely autonomously have been found. When looking at the needs of end users, it appears that the current offering cannot yet meet the information needs.

3. *What kind of complexity can the current generation of urban digital twins handle*?
   The modified Cynefin Framework (Stacey, 2002) was used to answer this question. This framework distinguishes four domains. In "Simple", with the clear agreement of values and goals and reasonable certainty of data, we mainly work on digital models to visualise static objects. " Complex " is about the future through digital generators for iterative simulations for policy choices, for example. For this, you need consensus on the values and goals. Future data is, by definition, uncertain because it concerns the future, but fortunately, validated historical data can provide insight. In " Complicated ", digital shadows use real-time data and simulations to identify hidden cause-and-effect relationships, from moving objects like people and traffic to changing contexts like the weather. Autonomous digital twins are only suitable for domains with high agreement, data certainty, and limited risk. Issues with low agreement on values and goals and low agreement on data and rules are difficult to simulate with an urban digital twin. Policy issues such as the housing crisis benefit from consensus to be able to simulate meaningfully in an urban digital twin. A digital generator that provides insight into integral complex problems best meets these needs.

Making (common) sense of urban digital twins

4. *What perceptions do policymakers, academics, and companies have about the impact and value of urban digital twins – What are the similarities and differences in perceptions?*
   This was investigated using a Q study. For this purpose, 29 participants from governments, companies, and knowledge institutions were interviewed. This has resulted in three dominant views on urban digital twins:
   Techno-utopianism: This group sees urban digital twins as powerful tools for better decision-making and emphasizes collaboration between the public and private sectors. They believe that urban digital twins can have a positive impact but may have little insight into the limitations.
   Critical perspective: Critics are concerned that urban digital twins are not neutral and doubt the quality of data, which, in their view, makes urban digital twins of limited use for decision-making. They emphasize the need for ethical research and user education.
   Integrators: This group sees urban digital twins as digital copies of real objects and emphasizes 3D visualization and data harmonization. They are less concerned about data quality.
   All views are right in certain areas. The utopians are often the drivers of development; the critical perspective is aware of the risks, but construction also needs to happen. These are usually the integrators. These three visions can help to illuminate the further development of urban digital twins from different perspectives.

5. *What urban digital twin development needs are there in North Brabant?*
   The 29 participants were asked about which issues they think urban digital twins can contribute to in their work. Six overarching categories have been defined from this: 26% need an integrated approach to issues and coordination with stakeholders, 21% citizen participation and transparency, 17% best practices and awareness, 15% joint data space and data-driven working, 13% cycling, mobility and transport, and 9% need more insight into water storage, heat stress, and energy (9%).

How do we move forward*?*

6. *Which cases are interesting for the future?*
   Based on the conceptual frameworks, the frames, and the needs, 5 cases have been defined for further research:
   Tiny City Twins: a way to generate data cheaply through portable hardware that can map a different part of the city each time.
   BUrDS View: a digital model focused on residential construction.
   URBAN-PASS: a digital model with an interface similar to the one in the popular The Sims™ 4 game, aimed at citizen participation.
   DIGI-URBAN: a digital generator aimed at developing different scenarios for housing construction.
   DIALOGUE: a prompt-based Artificial Intelligence urban digital twin interface, trained on the data in the digital twin.

These cases can be used separately or together, for example, in the Digital Europe call: Data Spaces and smart communities. This call has not yet been published, so it is not yet certain whether these cases meet the call.

This study investigated whether digital twins can contribute to addressing the space problem outlined. The answer is yes, but there is still work to be done. Urban digital twins are complex and expensive, and no one has found the golden egg. However, given the costs and complexity, it is certain that collaboration is necessary to move forward. This study and the cases provide a starting point for this.

We look forward to further shaping this together in the future.

Preface

We can rightly say that Brabant is innovating and digitizing. While the influence of data platforms on the Brabant government, entrepreneurship, and society has previously been explored, the urgency to think collectively about the (im)possibilities of digital twins has also been recognised. North Brabant does not start from zero. Urban digital twin projects are already being implemented in all major cities in Brabant.

While the triple helix collaboration between government, businesses, and knowledge institutions in Brabant is becoming increasingly common, there is still room for improvement. For example, organizations are not always aware of what is happening next door, and confusion quickly arises regarding urban digital twins. Sometimes, the twin itself seems like a must-have for municipalities without a clear plan for application or purpose in practice.

To create a shared starting point, we have taken a step back to basics so that we can then accelerate together as Brabant. This study reflected on what is actually meant by a digital twin and looked beyond the province's borders to what kind of complexity urban digital twins can now handle. This has provided frameworks that can help create a common language to understand urban digital twins- and each other. Because one twin is not the same as the other. We also looked ahead and defined cases with a vision for the future. We have aimed for this report to be a building block for joining forces, initiating new (European) projects, and thus driving data-driven policy innovation.

Writing a study like this is always a challenge. You also want people to read it. This means that a trade-off must be made every time: when do you add enough nuance, and when does it become too long or unreadable? How do you make complex matters accessible to a mixed audience without being too simplistic? This was probably not always successful for everyone. We have done our best to keep the report readable. For example, it was decided not to write it in a too scientific or too official manner in an attempt to make it accessible to a wider audience. For the sake of brevity, potentially relevant information has sometimes been deleted. For example, we have developed not five but three frames, and chapters have been added and then deleted. There is more, much more information, but we hope that this is the version that can help Brabant move forward.

We want to thank everyone who made time for us to share their vision of urban digital twins.

10 October 2023.

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Introduction

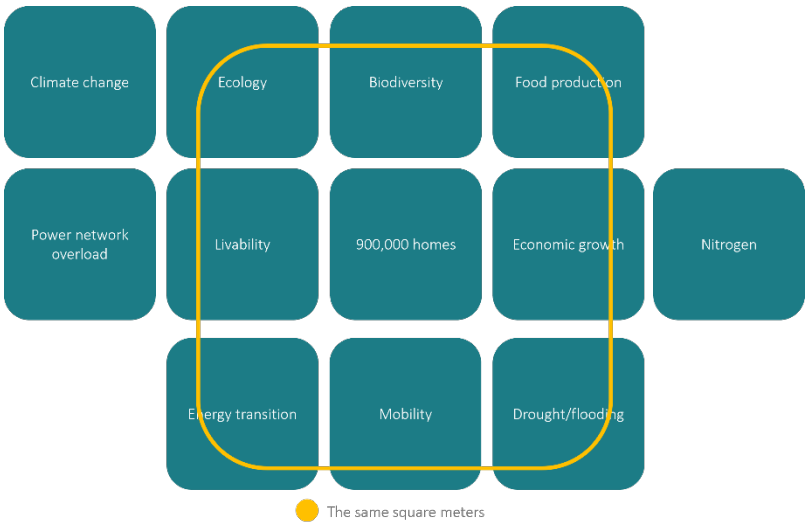
Context

Human ingenuity is the driving force behind innovation. Cities have never been as densely populated and interconnected as they are today. Every day, many commuters travel through Brabant and earn an income that has never been so high. This connection not only ensures that people and goods can move faster and faster, but this connection is also digital. Digital innovation is infiltrating all sectors of society at astonishing speed, and cities are also being digitally transformed, designed, and experienced. Intelligent systems have a profound impact on urban space. City planning is becoming increasingly computer-generated, simulated, and animated in 3D. The ambitions reach the sky, but we also run into system limits.

This is the great tragedy of society. We have created a world so advanced and, therefore, complex that it has created challenges that are beyond our human comprehension. Nine hundred thousand homes must be built on the same square meters in an accessible, liveable environment that also offers space for economic growth. At the same time, this growth puts pressure on the ecology. Regulations are becoming stricter, and we must take biodiversity and extreme weather conditions into account. This also puts pressure on agriculture outside the cities. At the same time, an energy transition must take place quickly, and the power network in many places in Brabant can no longer cope.

What do these assignments have in common? They all occupy the same square meters, which experts look at from their own backgrounds, often with different interests. All these challenges come together in cities. It is complex; there is no longer a human overseeing the entire system, which raises the question: Could digital twins contribute to the solution?

FIGURE 1: COMPLEXITY ON THE SQUARE METER



The issue

This question is among citizens, the Province of North Brabant, Brabant cities, companies, and knowledge institutions. Experiments are taking place throughout Brabant. Together, we are becoming smarter and learning to work better with digital twins, but there are still plenty of challenges. Experiments are often ad hoc, and not enough is learned from each other. Topics are diverse, and supply and demand are not yet matched. There is much conceptual confusion surrounding the term urban digital twins. Everyone talks about it, but everyone means something different. It is like we do not speak the same language. It is reminiscent of the story of the Tower of Babel, where we see an ambitious society that strives for greatness, but we all speak a different language, and therefore we get stuck. This complicates cooperation and makes it difficult for policymakers to get an idea of which applications they should and should not invest in.

Goal

That is why BrabantStad, with funding from the province of North Brabant, has requested Breda University of Applied Sciences (BUas) to investigate how the discussion around urban digital twins can

be made more effective. Thinking frameworks have been drawn up so that the parties involved can speak the same language. A language that does justice to the complexity of the subject. Research has been conducted into the type of complexity urban digital twins can help with, and lessons from cases in the Netherlands have been derived. It has been determined what parties really need and what proposals have been made for cases that contribute to the strategic further development of urban digital twins in Brabant for (European) projects with a focus on collaboration and innovation.

Questions

This study consists of three parts that address six research questions. The first part frames the concept, and the second part discusses the perceptions and needs for the further development of urban digital twins. The third part is about the future- how do we move forward?

Complex world and concepts – what are digital twins?

1. What does the urban digital twin pipeline look like?
2. How are urban digital twins concretely applied in the Netherlands, and how do these applications connect to the different steps of the digital twin pipeline?
3. What kind of complexity can the current generation of urban digital twins handle?

Making (common) sense of urban digital twins

4. What perceptions do policymakers, academics, and companies have about the impact and value of urban digital twins – What are the similarities and differences in perceptions?
5. What urban digital twin development needs are there in North Brabant?

How do we move forward?

6. Which cases are interesting for the future?

Research design and reading guide

Various complementary methodologies were used to answer these questions.

Complex world and concepts – what are digital twins?

Sub question 1. **What does the urban digital twin pipeline look like?** A systematic literature search was conducted to describe the digital twin pipeline. Within this, the digital twins are not presented as one definition but as a six-step development process. The pipeline provides insight into the type of urban digital twin that is being discussed and how this can be further developed hierarchically.

Sub question 2. **How are urban digital twins concretely applied in the Netherlands, and how do these applications connect to the different steps of the digital twin pipeline?** Based on Matos et al. (2022), Boyes and Watson (2022), Ortt and Tiihonen (2022), and 29 expert interviews, a list of 22 urban digital twins in the Netherlands was drawn up. This list has been verified and organized at the twin level according to the pipeline to show the current development of urban digital twins.

Sub question 3. **What kind of complexity can the current generation of urban digital twins handle?** The pipeline level you can reach depends on the complexity of the system you want to simulate. For this purpose, Stacey (2002) devised the complexity model based on certainty about data and rules and agreement about values and goals, indicating what kind of complexity can and cannot be simulated.

Making (common) sense of urban digital twins

Sub question 4. **What perceptions do policymakers, academics, and companies have about the impact and value of urban digital twins – What are the similarities and differences in perceptions?** Based on a Q-study and 29 in-depth interviews with policymakers,

academics, and experts from the business community, we explored where the development needs are in Brabant. The Q is a research method that provides both qualitative and quantitative insight into someone's thinking about a subject. Based on the literature review, 41 statements have been compiled that represent the broader discussion around urban digital twins. The 29 experts were then asked to rank those statements based on agreement on a quasi-normal distribution. While completing the Q method, respondents were asked to explain their choices, and all interviews were recorded, transcribed, and coded. Agreement between the participants was then sought by means of an inverse factor analysis. This resulted in five frames that together represent the dominant views on the subject of urban digital twins. The aim is to frame the discussion around urban digital twins, show conflict and consensus, and reflect the development needs of experts in the region.

Sub question 5. **What urban digital twin development needs are there in North Brabant?** After completing the Q methods, the experts were asked where they think urban digital twins can really contribute. Based on the transcripts of the interviews, these needs were collected, categorized, tallied, and described with the aim of providing input for the cases.

How do we move forward?

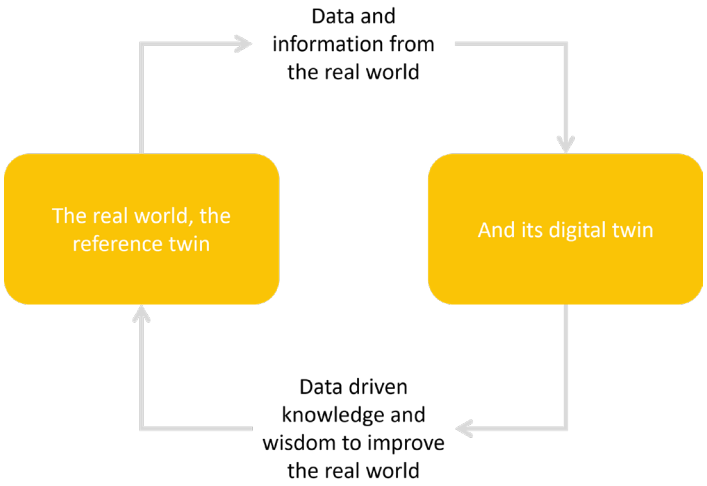
Sub question 6. **Which cases are interesting for the future?** Sub-questions 1-5 make it possible to frame the discussion around urban digital twins through the pipeline and complexity. The case study research shows what urban digital twins in the Netherlands can and cannot do. The Q-study provides insight into which frames are important for experts in Brabant, and the development needs were identified with the help of the follow-up interview. These methods offer a vision for the future with five associated cases that can help Brabant move forward.

We invite you to join us in exploring this fascinating complex topic further.

Complexity in the world and concepts: What are digital twins?

1 What is a digital twin?

FIGURE 2: DIGITAL TWIN CONCEPTUAL MODEL



What is a digital twin? Grieves (2016) was the first to talk about the digital twin concept in 2002. A digital twin consists of three parts. The system in the real world (the reference twin), the system in the virtual world (the digital twin), and the automatic exchange of data, information, knowledge, and wisdom between both systems.

Since then, the term "digital twin" has emerged in multiple sectors, from the human body to aerospace, from manufacturing to the city. However, how does one definition hold up in so many different contexts? The simple answer is that it does not. Despite several attempts in the literature to arrive at a universal definition of digital twins, there appears to be little agreement on what constitutes a digital twin. The lack of agreement, a common language, creates the following problems:

Probleem 1. Some applications meet Grieves (2016) definition of a digital twin, such as the route planner with live feedback from Google Maps. But Google does not call it that. At the same time, many of the practical applications that call themselves a digital twin do not meet Grieves' definition due to the lack of an automated exchange of data, information, knowledge, and wisdom. This makes the term diffuse and creates problem two:

Probleem 2. The lack of consensus causes miscommunication. Both people can talk about a digital twin and mean something different. This happens both between sectors and within sectors. One person can talk about a 3D representation of a city, and the other about a simulation model for integrated urban development. Both can be a digital twin; however, the use and construction are essentially different. This hinders collaboration and innovation.

Probleem 3. Where does the twin begin, and where does it end? Is the dataset used by the digital twin part of the digital twin? Does a 3D map that plots public data on a virtual model a digital twin? Or should the digital twin also be able to simulate processes and calculate plans?

These problems contribute to confusion around digital twins and make collaboration difficult. The question is whether developing another new definition will solve this problem. Boyes and Watson(2022) show that a significant amount of research is being conducted on definitions of digital twins. This is done through a scientific, systematic literature review that attempts to characterize digital twins. The problem with this approach is that it is often a discussion that focuses on semantics and concerns only the scientific community. In practice, the term "digital twin" has become commonplace in many industries, and it is the varying perception of what a digital twin is that defines it in practice.

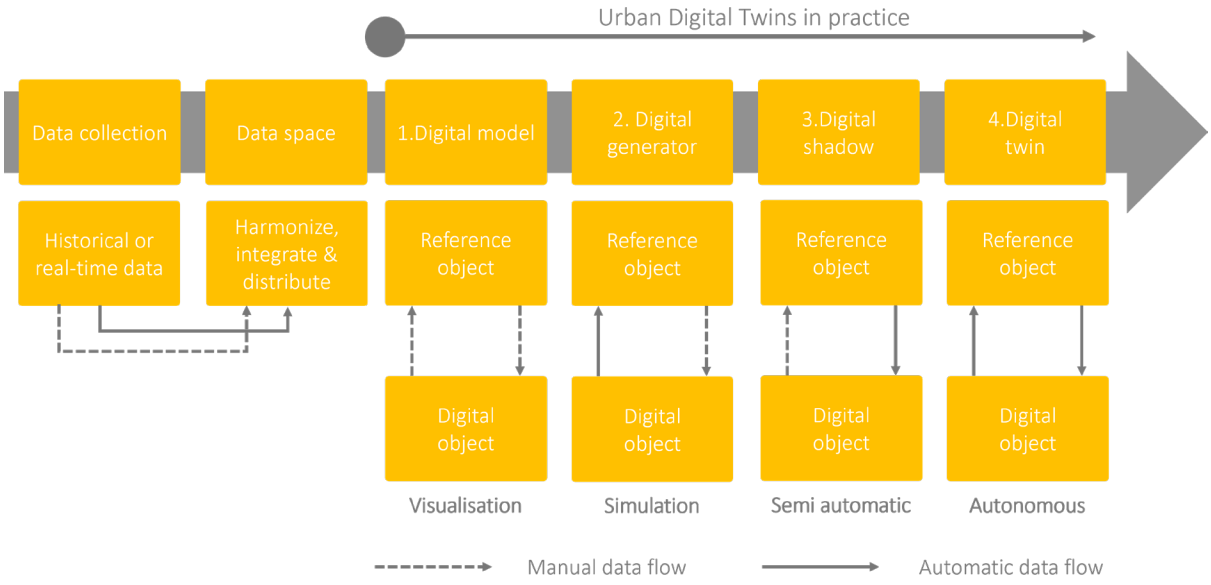
This also has a function. Different definitions and interpretations also encourage creativity and innovation. One definition closes the discussion. Too many definitions make you talk past each other. Rather than aiming for a new universal definition, it may be interesting to look at how urban digital twins

are interpreted to bridge the gap and find common ground for putting digital twins into practice to provide further insight in this complex world potentially.

1.1 The digital twin pipeline

The digital twin pipeline defines the process more than the concept. It does more justice to the rapid innovations in the field and shows which steps lie behind and ahead of us.
Based on the literature of Tekinerdogan and Verdouw (2020) and Grieves (2016) - inspired by Ortt and Tiihonen (2022)- we have defined six steps that are necessary for the development of digital twins. We added the data collection and data space steps to the pipeline and adapted the terminology of Orrt and Tiihonen (2022) to the terminology used by Boyes and Watson (2022) and Tekinerdogan and Verdouw (2020). The steps are hierarchical, and we assume that the development of urban digital twins progresses in this order. New features are added with each subsequent level. It starts with data and ends at level 4, the autonomous urban digital twin model as defined by Grieves. Each step is described below based on technological principles and functionality.

FIGURE 3: URBAN DIGITAL TWIN PIPELINE



- Data collection: The first question to ask is: what data do we need to gain more insight? In this phase, a wide range of data is collected from new or existing data sources that are relevant to the urban area being modelled. Examples include maps, aerial photographs, and terrain models. In addition, demographic data, traffic data, climate data, construction plans, utilities, historical sensor data, and socio-economic data can also be collected. In addition to historical data, an urban digital twin can also use real-time data collection. Sensors and Internet of Things (IoT) devices can be used to continuously collect data on traffic flows, temperature, and air quality, for example. The data must be FAIR (Findable, Accessible, Interoperable, and Reusable). Garbage in is garbage out. The bigger challenge is bringing it together and ensuring the quality of the data.
- Data space: In this step, the different data sets are integrated and normalized so that they are compatible and can be used for analysis and modelling. This includes resolving inconsistencies and combining data from different sources into a unified representation of the urban area. This sounds clearer than it is. *"However, data spaces are hardly getting off the ground"* (Computable, 2023) based on research by the Centre of Excellence for Data Sharing and Cloud. Due to a lack of knowledge, only 0.3 percent of Dutch organizations (future end users and IT service providers) support the development of a data space. Support is usually limited to the evaluation of designs and does not go beyond remotely monitoring developments within a data space. Subsidized

initiatives such as Talking Traffic (data exchange between road users and intelligent infrastructure) have hardly been taken up by the sector. Getting partners to share data is also still a challenge. Data is often seen as capital, and capital is not something you simply give away. This is still a major challenge in the region, and constructive cooperation sometimes proves to be quite difficult. However, this does not stop us from experimenting with digital twins.

- 1 Digital model (visualization): Anyone who has looked at the picture carefully will see that the numbering only starts with the digital model. This is the moment when we start talking about an urban digital twin in practice. A digital model is a representation of a physical object (street) or system (traffic) in digital form. It is an abstract representation that uses digital data to describe some aspect or behaviour of the object or system, such as a 3D map of a city. The focus is on plotting information on a static map and not on calculating scenarios. Both the data input and output are manual.
- 2 Digital generator (simulate): A digital generator is a software program that automatically generates digital models based on a manual data flow. It is used as a tool to quickly calculate scenarios with variations in design, properties, or conditions. For example, to determine which houses will be flooded during extreme rainfall and to assess the effect of greenery on heat stress. The challenge is to generate reliable models. This becomes more complex as more variables are combined. Data from different sources does not always fit together, and historical data does not guarantee reliable predictions for the future.
- 3 Digital shadow (semi-automatic): A digital shadow is a digital replica of a physical object or system that is updated with data (almost) in real-time. It acts as a virtual reflection of the real object or system. It enables stakeholders to observe, monitor, and analyse crowds around events, for example, in which enforcers can take action. The use of real-time information is especially suitable for moving objects and short-term issues.
- 4 Digital twin (autonomous): This is the step that meets the Grieves definition. A digital twin is a digital model with the function to autonomously monitor and control a physical object or system in real-time. So, it does not just mirror. It can also perform operational actions such as optimizing the flow at a traffic light.

How does this categorization relate to practice? We identified 22 urban digital twins in the Netherlands based on Matos et al. (2022), Ortt and Tiihonen (2022), and the 29 expert interviews. Only online verified twins are included in the list. Undocumented initiatives may be missing from this study. The urban digital twins are then classified based on the level of the pipeline. The sources mentioned below are hyperlinks with more information about the relevant urban digital twin.

1.2 Urban digital twins in the Netherlands

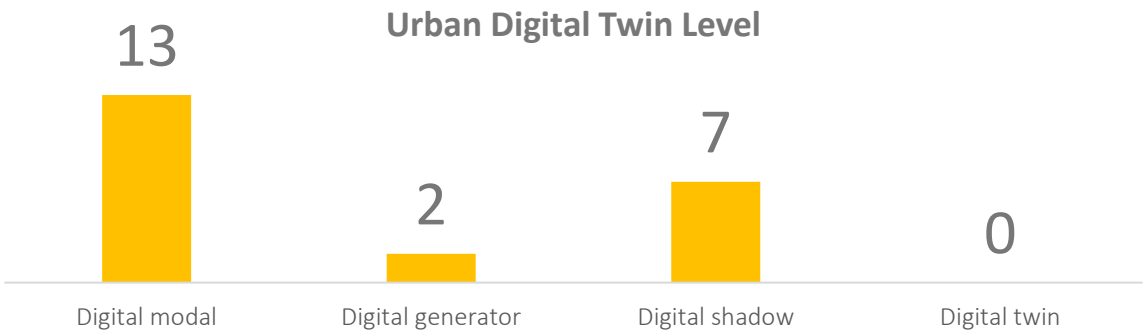
TABLE 1: URBAN DIGITAL TWINS IN THE NETHERLANDS

	Project	Area	Organization(s)	Area	Source	Digital twin level
1	Smart City Alkmaar	Alkmaar	Analysis and Municipality of Alkmaar	Urban planning, housing stock monitoring	(Analyze, 2023)	1 Digital model
2	Almere Digital Twin	Almere	Municipality of Almere	3D model for permits	(MunicipalitiesNL, 2023)	1 Digital model
3	3D Amsterdam	Amsterdam	Municipality of Amsterdam / Unity	City planning: 3D map buildings, roads, vegetation, subsurface	(Municipality of Amsterdam, 2023)	1 Digital model
4	3D Digital City	Groningen	Municipality of Groningen / ArcGis	City planning: 3D map buildings, roads, vegetation, subsurface	(Municipality of Groningen, 2020)	1 Digital model
5	Brainport Smart District Digital Twin	Helmond, Brainport Smart District	Municipality of Helmond / Geodan	Visualizing future homes for residents	(Brainport Smart District, 2023)	1 Digital model
6	Lekdijk Digital Twin	Lekdijk	De Stichtse Rijnlanden Water Board / Geodan	Above and below the Lekdijk	(Geodan, 2023)	1 Digital model
7	Netherlands in 3D	The Netherlands	Future Insight, Sweco, Avineon, Nelen & Schuurmans, Cobra, Kavel10	3D Visualization	(Netherlands in 3D, 2023)	1 Digital model
8	3DNL	The Netherlands	Hexagon and Cyclomedia	Mesh measurements, asset management, shadow analysis, solar capacity calculations and building cross-sections	(Hexagon, 2021)	1 Digital model
9	Atlas liveable city	Province of Brabant	LCB, Argaleo and BUAS	Economic development of industrial estates, accessibility of top economic centres or logistics functions and use of buildings	(LCB, 2023)	1 Digital model
10	Virtual Zeeland	Province of Zeeland	Province of Zeeland	Provides insight into land use and flood risk	(Virtual Zeeland, 2023)	1 Digital model
11	Rotterdam 3D	Rotterdam	Municipality of Rotterdam / Tygron	City planning: 3D map buildings, roads, vegetation, subsurface	(Municipality of Rotterdam, 2023)	1 Digital model

12	3D Utrecht	Utrecht	Municipality of Utrecht / Unity	City planning: 3D map buildings, roads, vegetation, subsurface	(Municipality of Utrecht, 2023)	1	Digital model
13	Zwolle Digital Twin	Zwolle	Land registry	City planning: 3D map buildings, roads, vegetation, subsurface	(Municipality of Zwolle, 2023)	1	Digital model
14	3D City Model	Eindhoven	Municipality of Eindhoven / ESRI	Interactive digital twin to calculate and visualize policy choices	(ESRI, 2021)	2	Digital generator
15	Geoenvironment	The Netherlands	Geodan	Calculate noise pollution	(Geodan, 2023)	2	Digital generator
16	Breda & Den Bosch Smart city monitor	Breda and Den Bosch	Municipality of Breda, 's-Hertogenbosch Argaleo, Geodan, JADS, BUAS	Crowd and traffic management for bicycle traffic with real-time information	(Smart city monitor, 2023)	3	Digital shadow
17	Den Bosch Crowd Management Dashboard	Den Bosch	Municipality of 's-Hertogenbosch and Argaleo	Real-time crowd management	(Argaleo, 2023)	3	Digital shadow
18	The Hague Digital Twin	The Hague	Municipality of The Hague and Argaleo	Monitoring flows of pedestrians and cyclists	(OTAR, 2021)	3	Digital shadow
19	Digital twin Deventer by Tauw	Deventer	Municipality of Deventer, Tygron, Tauw, Esri	Free drawing, heat stress	(Tygron, 2023)	3	Digital shadow
20	Nijmegen 3D Twin City	Nijmegen	Nijmegen, Police, Safety Region, Four-day celebrations, Esri	Event permits, crowd management for events, preparation of security services	(ESRI, 2021)	3	Digital shadow
21	Tygron Platform	on request	Tygron	Urban planning platform with features such as environmental impact assessments, traffic analysis and scenario analysis	(Tygron, 2023)	3	Digital shadow
22	Urban Strategy	on request	TNO	Predictive twin for transport demand, emissions, topology, noise and energy consumption	(TNO, 2023)	3	Digital shadow

What is striking in graph 1 is that more than half (thirteen out of twenty-two), according to, are actually digital models, which mainly focus on visualizing data by plotting it on a (3D) map. Two examples are classified as digital generators used for simulations that are interactive to some extent. For seven, there is some automatic connection with (almost) real-time data, of which four twins are used to monitor groups of pedestrians or cyclists. Tygron and TNO use their twins for traffic analyses, with Tygron also making drawings and experimenting with possibilities in the twin. However, none of the twins use automatic data flows that meet the Grieves definition. This raises the question of whether the current urban digital twins in the Netherlands can really be considered digital twins.

GRAPH 1: DISTRIBUTION OF URBAN DIGITAL TWIN LEVELS IN THE NETHERLANDS

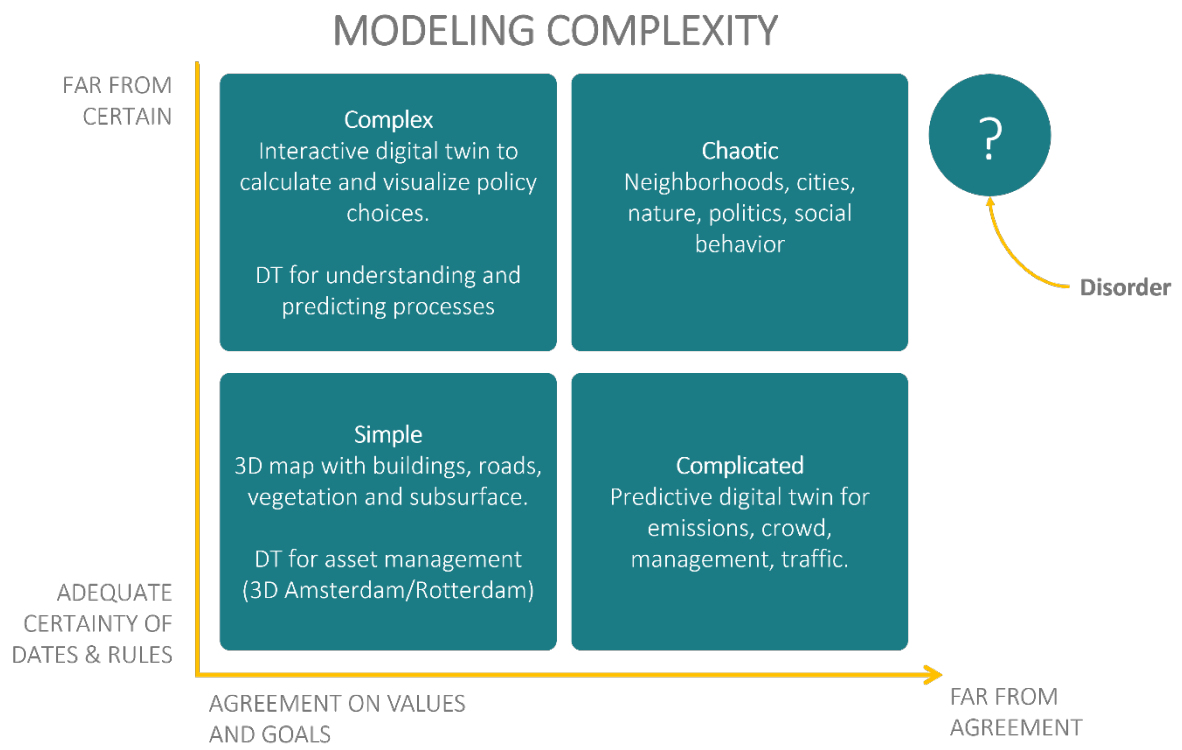


Why is it so difficult to reach those higher levels? And is it actually desirable to have an urban digital twin that processes data and then acts fully automatically? To understand this better, we have found out what role complexity plays.

1.3 Complexity model

Stacey (2002) developed the Complexity Model, also known as the Cynefin Framework. This model is intended to support decision-making and, with some adjustments, is surprisingly useful for showing the extent to which a digital twin can now provide insight into complexity. The framework classifies problems and situations into five domains, each with different characteristics and approaches. We start at the bottom left with “Simple”:

FIGURE 4: STACY'S COMPLEXITY MODEL, ADAPTED FOR URBAN DIGITAL TWINS



Simple: In this domain, the relationships are clear and predictable. Problems are *well-structured* and can be addressed with best practices and known solutions. There is a high degree of certainty about the data and rules, and there is agreement about the values and goals. This also makes it logical that the majority of 'twins' are currently digital models because compared to 'generators,' 'shadows' and digital twins, it is relatively simple. Public national data that is generally accepted, such as the BAG, is often used as the standard for the model. This way, we know quite accurately where houses are located, where roads run, and how big the trees are. Examples of this are 3D Rotterdam, 3D Amsterdam and NL3D. Many of these digital models look similar and have similar functions because they are often built on the same types of data sets that are highly available and reliable. Currently, this data mainly consists of buildings and their function, bridges, canals, vegetation, and, in some cases, the subsurface. These are static artifacts that have limited mutual influence. Hence, you do not have to calculate with it, and this often limits the function of visualizing data.

Complex: In this domain, we look to the future; this will always be a form of forecasting, but with proper agreement on values and goals, it can be useful, such as SMART-defined long-term policy challenges. These are *moderately structured target problems* with a low degree of data certainty because they involve hypothetical situations, and the models are based on historical data. Within this complexity, it is possible to experiment, learn by doing, and make iterative adjustments to determine which strategy best fits to achieve the desired values and goals. This is the domain of digital 'generators,' and these have already proven effective in some areas. Geodan uses its digital 'generator' to calculate and predict

noise pollution, while Eindhoven is working on a 'generator' to calculate integrated policy choices. What we see is that current 'generators' often perform well on specific subtopics, provided the results are validated over time with historical data. Building 'generators' without good data or the ability to validate future results is not very effective due to the large number of assumptions that need to be made, and it always remains an “estimate guess at best.”

More complicated is the domain in which cause-and-effect relationships are present, but they are not always clearly visible. For example, we see that it gets busier during an event, but when is it too busy? And is 45,000 people a lot, too many? Are there too many everywhere? With *these moderately structured resource problems* - with reasonable certainty about the data and rules- you can map the crowds in real-time. This is necessary because people have difficulty imagining large numbers and because the concept of "too busy" is subjective. To reach a consensus, it may be useful to simulate this based on near-real-time data. This is useful for moving elements with large numbers or constantly changing contexts, such as traffic, events, or weather. Because busyness is subjective and context-dependent, expertise remains necessary to translate the results into actions. This is the domain of digital shadows. Examples of this are the smart city monitor of Den Bosch and Breda, as well as the yet to be developed Nijmegen 3D Twin City for the Four Days Marches.

Chaotic: This domain lacks order and stability. It is a phase of crisis and urgent action for complex, *unstructured wicked problems* that cannot be simulated with standard data, such as (political) behaviour. There are no insightful cause-and-effect relationships, and quick decisions have to be made about processes that we cannot reliably simulate. Which level of the digital twin pipeline does this actually belong to? Actually none. This does not mean you cannot do anything. For example, the military uses wargames to devise cause-and-effect relationships. These serious games can contribute to providing insight into the problem. To a certain extent, this can be based on data, but often, there is more reliance on scenarios/narratives that can occur in the real world. This remains a human job, and perhaps that is a good thing.

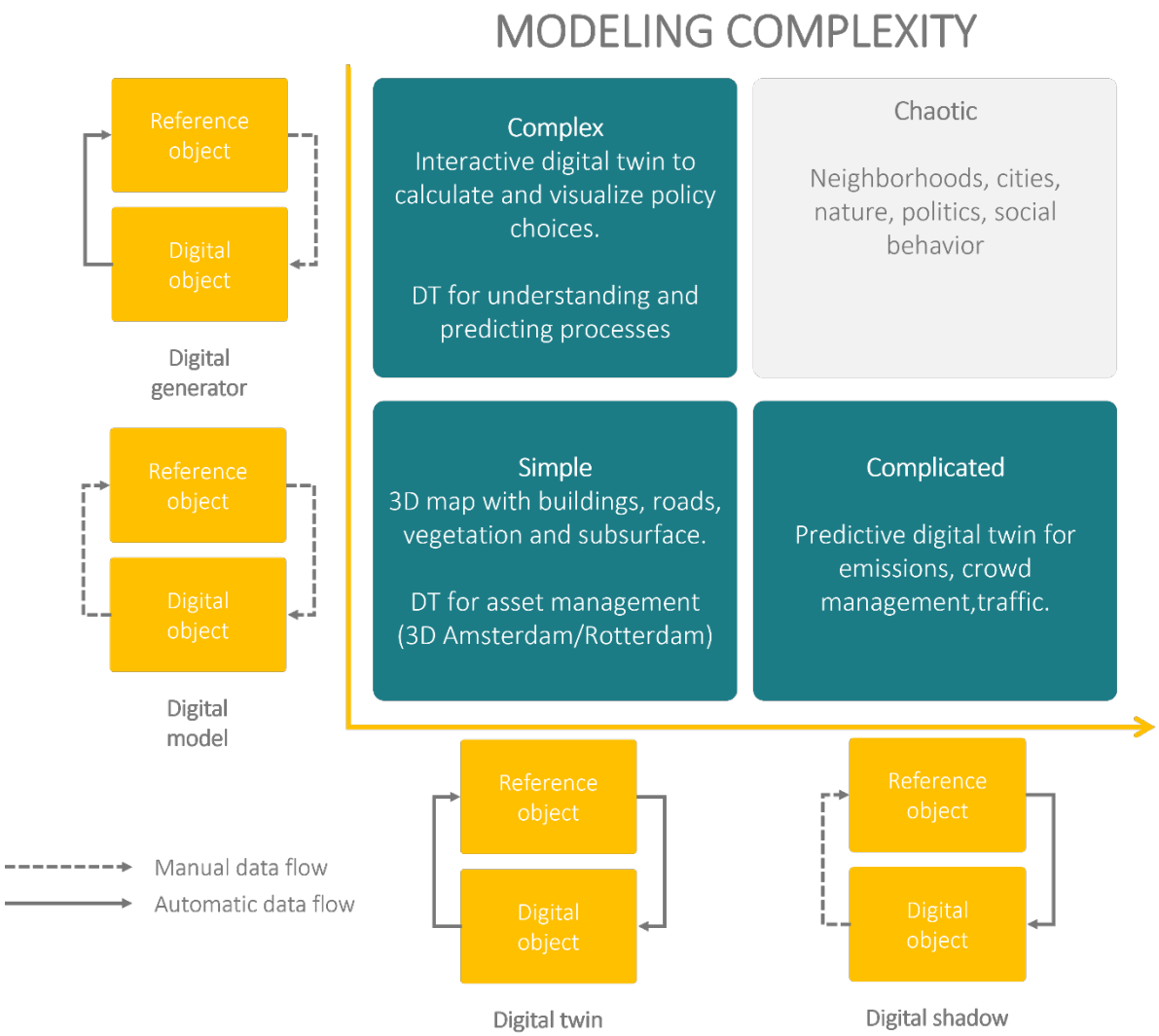
Where are the autonomous digital twins in this story? We believe that these can only be applied in situations where there is a high degree of agreement on values and goals, complete certainty of data and rules, and a situation where we can let the twin make automatic choices. This concerns a number of cases in the simple domain. They often focus on management. For example, how can you direct as much traffic as possible per hour past the traffic lights?

Disorder? In this domain, one does not know which of the other four domains applies. It can arise when people have no idea how to handle a situation or when there is a chaotic transition between the other domains. If you are in the realm of disorder, the key is to get out of it as quickly as possible. When it comes to urban digital twins, we recommend asking yourself the following questions:

Question 1. What do I want to make clear?
Question 2. Is it something static, future-oriented, something moving, or something chaotic?
Question 3. Is there agreement about the purpose of this insight?
Question 4. Is there reliable data available to provide insight into this?

Depending on your answer, you will end up in one of these four domains, or you will have to look for better data or more consensus. This sounds easier than it is. Gaining consensus is not just about getting the right data/figures. It is about bringing together different perspectives, backgrounds, and interests of the parties involved, which can lead to conflicting positions and opinions. More complex topics and uncertainty do not make it easier.

FIGURE 5: STACY'S COMPLEXITY MODEL AND THE DIGITAL TWIN PIPELINE



Obtaining better data also brings challenges that can often be attributed to limited data governance and data management. Data is often collected to a limited extent, is dated, or not validated. In addition, data is often spread between different parties, and in practice, they still find it difficult to process it jointly. Data is sometimes seen as (unused) capital, and you do not just give your capital away. You want something in return. Several participants in this study confirm this. It is striking that those who work most on building twins are often the least likely to see data as a problem. One of the interviewees put this aptly: "*First, I'm going to see if we have it ourselves. If not, I'll see if a partner has it. If they do not have it either, we will see how expensive it is to collect that data ourselves, and otherwise, we will buy it. If purchasing proves to be too expensive, we will collect it ourselves if we really need the data*." Good available data remains a challenge. This is a challenge that the participants view very differently, as shown in Chapter 2.

We have summarized Stacey's urban digital twin pipeline and custom Cynefin framework in the model below. The urban digital twin pipeline remains hierarchical because you need the underlying techniques to move up a level. However, a higher level is not always better. It is about what kind of complexity you want to understand.

1.4 Conclusion: Complexity in the world and concepts; What are digital twins?

What does the urban digital twin pipeline look like?

The urban digital twin pipeline contains six steps for the development of digital twins for urban systems: data collection, data spaces, digital models, digital generators, digital shadows, and autonomous digital twins. Data collection and data spaces form the preconditions, while, in practice, the other steps are often used as a collective name for urban digital twins. However, there are differences between these steps. For example, digital models focus on visualizing static information with manual data flows. Digital generators also perform automatic simulations based on manual data input. Digital shadows use real-time data that must be interpreted manually by humans, and digital twins that meet Grieves' definition are completely autonomous. This hierarchical structure implies that each step builds on the underlying techniques from visualization to simulation, partial automation to full automation, and each new step adds new functions. The choice of the correct level depends on the complexity of the system to be modelled.

How are urban digital twins concretely applied in the Netherlands, and how do these applications connect to the different steps of the digital twin pipeline?

In the Netherlands, 22 applications of urban digital twins have been identified and classified according to the urban digital twin pipeline. The applications range from digital models for visualization to more advanced digital generators and digital shadows. The current focus in the Netherlands seems to be on static 3D visualization of buildings, roads, vegetation, and subsurface (13/22). This is because the data is relatively readily available. Based on Matos et al. (2022) and Ortt and Tiihonen (2022) and the 29 expert interviews, two examples (2/22) of digital generators were found that are concerned with simulating noise and policy goals. Seven of the twelve cases concern digital shadows because they use some degree of real-time information, especially for simulating events and traffic. No examples were found that met Grieves' definition of a digital twin. The examples of the Tygron platform and TNO's Urban Strategy Index currently seem to be best able to simulate a number of urban processes, and the Den Bosch company Argaleo stands out for its focus on visualization.

What kind of complexity can the current generation of urban digital twins handle?

The modified Cynefin Framework distinguishes between four domains. In "Simple," with clear agreement of values and goals and reasonable certainty of data, we mainly work on digital models for the visualization of static objects. This is relatively easy, which makes it logical that there are mainly digital models in the Netherlands. "Complex" is about the future through the use of digital generators for iterative simulations for policy choices, for example. For this, you need consensus on the values and goals. Future information is, by definition, uncertain because it concerns the future, but historical data that is validated can provide insights. In "Complicated", digital shadows use real-time data and simulations to analyse moving objects, such as people and traffic, or changing contexts, such as weather. Autonomous digital twins are only suitable for domains with high agreement, data certainty, and limited impact. This framework guides the choice of digital twin types based on complexity. Reaching consensus on values and goals and improving the certainty of data and rules remain crucial challenges that need to be addressed to realize the full potential of urban digital twins. They depend on a collaborative approach with sufficient multidisciplinary disciplines and organized stakeholder management.

Making (common) sense of urban digital twins

2 Making (common) sense of urban digital twins

Common sense refers to knowledge of the commons, i.e., the shared knowledge, instead of the general knowledge as we know it in the Netherlands. What knowledge is shared and is not controversial? Where do opinions differ about digital twins? This chapter explores the common sense about digital twins through a Q study.

2.1 Method

Within this study, 29 participants were asked about their ideas regarding urban digital twins using the "Q-method". The Q-method has been developed to provide insight into ideas and perceptions about "boundary concepts". The term "Boundary concepts" was introduced by sociologists Susan Leigh Star and James Griesemer in the context of studies of science and technology. This term is used to describe objects or ideas that have the potential to connect different communities, disciplines, or perspectives. However, to achieve this, they must start speaking the same language. That is why we have designed the following tailor-made Q-study on urban digital twins.

Research procedure:

The Q methodology includes the following steps:

1. First, we conducted a systematic literature review to generate the “Q-set” for urban digital twins. A standard Q-set consists of 30-50 statements. Based on the literature review, 41 statements were tested and selected during several internal workshops.
2. We then selected participants through the BrabantStad partnership, and the Smart City Ecosystem based on their knowledge level and background. This resulted in 29 participants who were interviewed during the period April – July 2023.
3. The participants completed the Q methodology individually using an online platform in collaboration with the researcher(s). Within this platform, they were asked to perform a "Q-sort", ranking the statements on a quasi-normal distribution as in visualization 6 (Q scale,-3 to +3, strongly disagree- strongly agree).
4. Participants were asked to explain the underlying reasons behind their choices. All interviews were recorded, automatically transcribed, manually coded, and analysed.
5. Statistical analysis was carried out based on the Q-sort, using "inverse factor analysis". Inverse factor analysis is a correlational statistical technique used to find patterns in participants' responses.
6. Based on the inverse factor analysis and the analysed interviews, frames were manually constructed to represent the different and similar ideas about urban digital twins.

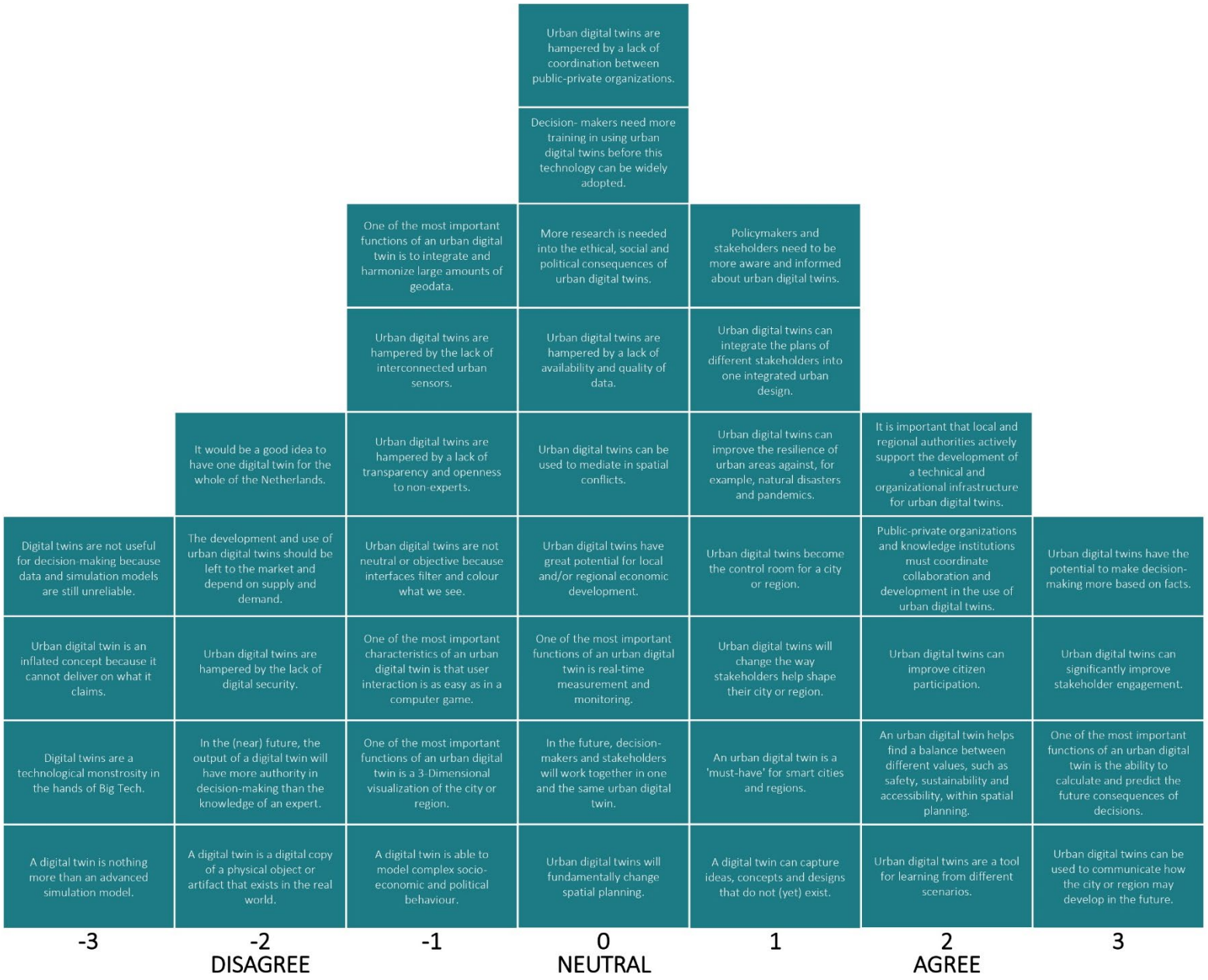


FIGURE 6: Q SORT - TECHNO-UTOPIANS

2.2 Results

Twenty-nine participants took part in the Q sorting and the subsequent in-depth interview. Participants were between 27 and 62 years old. Twenty-three identified as male, four as female, and two chose not to share their gender. Participants were allowed to share their own level of understanding about urban digital twins: two participants claimed to know almost everything, sixteen knew a lot about it, nine had quite a bit of knowledge about it, and one knew a few things. Twenty-three participants work in the public sector, mainly civil servants at municipalities in North Brabant: three work for private organizations, two in knowledge institutions, and one in a non-profit organization. A full list of the participants and their institutional affiliations can be found on the back of the report.

Based on the results, three statistically significant frames have been identified, which together explain 54% of the variance in views on urban digital twins, namely:

1. Techno-utopianism in urban governance.
2. Rethinking data-based decision-making – the critical perspective.
3. Integrators of digital twins in the real world.

Based on the data, two more frames were developed that are not statistically significant. Namely:

4. Pragmatic data pushers
5. Conflict simulators.

The addition of the last two frames provides an explained variance of 64% but frames 4 and 5 have not been further elaborated in this report because they are not significant.

The examined statements and an average rank per statement and frame are shown in Table 2 under the heading “ideal rank”. Table 2 shows the correlations between the participant and each frame. Of the 29 participants, 27 showed significant overlap in beliefs with one frame, explaining 53% of the total variance in beliefs. The ambiguous factors, which fall within multiple frames, are listed separately. Table 3 presents the correlation between the factors. A high number indicates higher similarity between perspectives. This suggests some overlap between the different frames, indicating that the variations in the conceptual approach to urban digital twins are not radically separated. A description of each frame is added below the tables.

TABLE 2: AVERAGE RANK OF THE STATEMENTS PER FRAME FROM HIGHEST TO LOWEST

No	Statement		Ideal rank		
		Avg	1	2	3
F3	One of the most important functions of an urban digital twin is the ability to calculate and predict the future consequences of decisions.	1.62	3	0	2
P8	Urban digital twins can be used to communicate how the city or region may develop in the future.	1.55	3	0	2
P7	Urban digital twins can improve citizen participation.	1.45	2	1	3
P2	Urban digital twins are a tool for learning from different scenarios.	1.41	2	2	2
I3	Urban digital twins will change the way stakeholders help shape their city or region.	1.31	1	2	3
P10	Urban digital twins have the potential to make decision-making more based on facts.	1.17	3	-2	2
P9	Urban digital twins can significantly improve stakeholder engagement.	1.03	3	0	1
S5	Public-private organizations and knowledge institutions must coordinate collaboration and development in the use of urban digital twins.	0.93	2	1	0
P3	An urban digital twin helps find a balance between different values, such as safety, sustainability, and accessibility, within spatial planning.	0.9	2	0	1
S6	It is important that local and regional authorities actively support the development of a technical and organizational infrastructure for urban digital twins.	0.83	2	1	-1

S3	More research is needed into the ethical, social, and political consequences of urban digital twins.	0.76	0	3	0
S2	Policymakers and stakeholders need to be more aware and informed about urban digital twins.	0.66	1	2	-1
S4	Decision-makers need more training in using urban digital twins before this technology can be widely adopted.	0.62	0	3	0
F5	One of the most important functions of an urban digital twin is to integrate and harmonize large amounts of geodata.	0.55	-1	-1	3
P6	Urban digital twins can integrate the plans of different stakeholders into one integrated urban design.	0.55	1	0	1
D3	A digital twin can capture ideas, concepts, and designs that do not (yet) exist.	0.38	1	0	1
P11	Urban digital twins can be used to mediate spatial conflicts.	0.28	0	-1	1
C3	Urban digital twins are hampered by a lack of availability and quality of data.	0.28	0	3	-1
I2	Urban digital twins will fundamentally change spatial planning.	0.21	0	-1	1
P4	Urban digital twins have great potential for local and/or regional economic development.	0.14	0	1	0
I1	An urban digital twin is a 'must-have' for smart cities and regions.	0	1	-3	0
I4	In the future, decision-makers and stakeholders will work together in one and the same urban digital twin.	0	0	1	0
C1	Urban digital twins are not neutral or objective because interfaces filter and colour what we see.	0	-1	3	-2
P5	Urban digital twins can improve the resilience of urban areas against, for example, natural disasters and pandemics.	-0.03	1	0	-2
F1	One of the most important functions of an urban digital twin is a 3-Dimensional visualization of the city or region.	-0.14	-1	0	2
F4	One of the most important characteristics of an urban digital twin is that user interaction is as easy as in a computer game.	-0.21	-1	0	1
D2	A digital twin is a digital copy of a physical object or artifact that exists in the real world.	-0.31	-2	-2	3
C6	Urban digital twins are hampered by a lack of coordination between public and private organisations.	-0.34	0	1	-2
C7	Urban digital twins are hampered by a lack of transparency and openness to non-experts.	-0.38	-1	1	0
P1	Urban digital twins become the control room for a city or region.	-0.48	1	-3	0
F2	One of the most important functions of an urban digital twin is real-time measurement and monitoring.	-0.59	0	-2	-1
C4	Urban digital twins are hampered by the lack of digital security.	-1.03	-2	-1	-1
C8	Urban digital twins are hampered by the lack of interconnected urban sensors.	-1.1	-1	-1	-2
C2	Urban digital twin is an inflated concept because it cannot deliver on what it claims.	-1.17	-3	2	-2
S7	It would be a good idea to have one digital twin for the whole of the Netherlands.	-1.24	-2	-3	0
C5	Digital twins are not useful for decision-making because data and simulation models are still unreliable.	-1.31	-3	2	-3
D1	A digital twin is nothing more than an advanced simulation model.	-1.41	-3	-1	-1
D4	A digital twin is able to model complex socio-economic and political behaviour.	-1.45	-1	-1	-3
I5	In the (near) future, the output of a digital twin will have more authority in decision-making than the knowledge of an expert.	-1.45	-2	-2	-1
S1	The development and use of urban digital twins should be left to the market and depend on supply and demand.	-1.9	-2	-3	-3
D5	Digital twins are a technological monstrosity in the hands of Big Tech.	-2.07	-3	-2	-3

Factor 1: Techno-utopianism in urban governance

Fifteen participants scored significantly on frame one, including eleven people working for the public sector, three with a research background, and two people from the private sector. Together, they shared a view on urban digital twins with the following exclusively positive statements: *urban digital twins have the potential to improve the quality of decision-making by calculating and predicting future consequences of decisions* (F3, +3). *The belief is that this will significantly improve stakeholder engagement* (P9, +3) and *help find a balance between different values such as safety, sustainability, and accessibility* (P3, +2).

The techno-utopians emphasize that (regional) governments must actively support the development of the technical and organizational infrastructure for urban digital twins (S6, +2) to stimulate research and innovation by private organizations and knowledge institutions. They see the importance of this collaboration in coordinating the development and use of urban digital twins (S5, +2). The interviews show that there is often a gap between the needs of the municipality and the offer from the developer.

They also emphasize that a digital twin must be more than an advanced simulation model (D1,-3). Visualizing and simulating are not enough (digital modal and generator). You must also be able to calculate interactively with real-time data. They also think this is possible. The techno-utopians strongly disagree with the statement that urban digital twins are an inflated concept that cannot deliver on what it claims (C2,-3) and see limited risk in hindering transparency and openness to non-experts (C7,-1).

Based on the interviews, it becomes clear that the central point of this frame revolves around its positive impact on decision-making. In a world with increasingly complex urban challenges, urban digital twins can be used as a tool to address this complexity. Despite their imperfections, urban digital twins can be exploited, and there are already some reliable examples. One participant acknowledges the criticism but argues that urban digital twins will be better than the current way of working, which is also biased and influenced by subjectivity.

Frame 1 represents the largest group of individuals with a shared viewpoint within this study. The group has high expectations but may underestimate the risk of the lack of transparency and openness to non-experts.

Frame 2: Rethinking data-based decision-making, critical perspective

Frame 2 shows a significant correlation with five participants, consisting of four civil servants and one researcher. Two of them are actively involved in ethical issues surrounding new technologies. These critics are a lot more concerned than the techno-utopians.

A major concern is that urban digital twins are not neutral because interfaces always filter and colour what we see (C1, +3). For the virtual green experience, for example, it matters how big and green the trees are in the 3D model. They believe that the availability and quality of data hinder the development of digital twins (C3, +3). Because they find the quality of the data limited, they doubt whether urban digital twins can provide insight into the complexity of our world. After all, what you do not know or see is often forgotten in decision-making. That is why they also doubt whether urban digital twins have the potential to really base decision-making more on facts (P10,-2).

They fear that these risks are not considered by the people who work with them. Therefore, users need to receive more training before urban digital twins can be widely adopted (S4, +3), and they need to be more aware of the potential risks of using digital twins (S2, +2). These risks are not yet clear enough. Therefore, more research is needed into the ethical, social, and political consequences of urban digital twins (S3, +2).

The critics do not believe that urban digital twins are a monstrosity in the hands of Big Tech (D5,-2). Instead, they are mainly concerned about the techno-fixation. It is often sold and purchased as a must-have for a smart city (S1,-3), and they fear that the twin will eventually be seen as a control room for the city (P1,-3), while the concept is currently still limited and cannot deliver what it promises (C2, +2). And for what purpose? Optimize even more and focus on growth? One of the participants put it succinctly: "*We should not want to become a smart city at all".* What he wants to work on is a 'wise city' - a city that does not focus on technology, optimization, and growth but on making society increasingly liveable.

Although this group does not represent a large number of individuals, this perspective adds a valuable element that deserves attention in the development of urban digital twins. The individuals in this group are genuinely concerned about the ethical, social, and political implications surrounding this new technology. They see it as a technology pushed by the industry and question whether it really contributes substantially to the problems of residents in their city. They see it as an expensive project with mediocre results and risks for personal data, privacy, security, and the reliability of the algorithms. For example, bias and institutional discrimination, such as the algorithm of the benefits affair, are mentioned within this frame.

Frame 3: Real-World Integrators of digital twins

Seven participants fit into frame three: six working for municipalities and one from the academic world. They see a digital twin as a digital copy of an object or artifact that exists in the real world (D2, +3) and that can help improve citizen participation with the visualization capabilities of digital models and generators (P7, +3). Therefore, they see 3D visualization as one of the most important functions of the digital twin (F1, +2). To make the 3D model really useful for participation, they attach great importance to integrating and harmonizing large amounts of geodata (F5, +3) and also see the representation of that data as objective (C1,-2). This is what an urban digital twin promises and delivers in their eyes (C2, -2). Of all frames, they also have the greatest doubts about the possibility of modelling complex socio-economic and political behaviour (D4,-3). However, they do see other simulated models, such as traffic, as reliable (C5,-3).

From the conversations with the experts, it becomes clear that there is some optimism towards digital twins, but that they do not see it as the solution for everything. For certain topics, much insight can be generated with limited simulation. What was striking is that the people within this frame are actively involved in the implementation of digital twins. That may also explain why they emphasize visualization. That is what most digital twins now focus on, and with adjustments, this can be used for participation. They also say that the data does not have to be perfect as long as you are transparent about it. It is not as if classic decision-making is always correct and perfectly substantiated. A digital twin makes validation of the information possible by validating historical data and predictions. As a result, the models are getting better, and it will eventually be possible to switch from visualization to simulation. They find it less relevant whether this should also take place in real-time (F2,-1).

Similarities and differences between the frames

The frames provide insight into how differently urban digital twins are viewed in the region. The correlation scores given in Table 3 give an idea of the differences between the frames. As it became clear from the interpretations of the frames, the techno-utopians and integrators view urban digital twins from a completely different perspective than the critics. There is a correlation of 0.18 between the techno-utopians and the critics. This indicates that there is less than 18% overlap between frames 1 and 2. The differences between frames 3 and 2 are even greater (0.08). There is more overlap between frames 1 and 3: they agree with each other in 60% of the cases. What does this mean?

TABLE 3: CORRELATION BETWEEN FRAMES

Frames	Frame 1	Frame 2	Frame 3
Frame 1: Techno-utopianism in urban governance.	1	0.18	0.60
Frame 2: Rethinking data-based decision-making – the critical perspective	0.18	1	0.08
Frame 3: Integrators of digital twins in the real world.	0.60	0.08	1

Frame 1 Techno-utopianism * Frame 2 Critical perspective

The techno-utopians and the critics do not agree on much (0.18), but they do agree on some topics (difference from ideal rank = 0). Both groups see urban digital twins as a valuable tool for learning from different scenarios (P2, +2) and see the importance of integrating and harmonizing large amounts of geodata as one of the less important functions of an urban digital twin (F5,-1). Both see a digital twin as more than a digital copy of a physical object or artifact that exists in the real world (D2,-2). They see the hindrance of interconnected urban sensors as limited (C8,-1). They doubt whether it is possible to model complex socio-economic and political behaviour (D4,-1). They also do not see it as realistic that in the future urban digital twins will have more authority in decision-making than an expert (I5,-2).

This is where the similarities end, and the following statements stand out (difference from ideal rank = >4). The critics, unlike the utopians, for example, do not believe that an urban digital twin has the potential to make decision-making more based on facts (P10, +3/-2) and do not see it as a necessity for smart cities and regions (S1, + 1/-3). They also warn about the subjectivity of interfaces and fear that it will be seen as a control room for the city (C1,-1/+3, P1, +1/-3). They view digital twins as an inflated concept that is unusable for decision-making due to unreliable data and simulation models (C2,-3/+2, C5,-3/+2).

Frame 1 Techno-utopianism * Frame 3 Integrators

Techno-utopians and integrators have similar perspectives (0.60). The statements below are closest to each other (difference between ideal rank = 0) and mainly contain fairly ambiguous topics. Both groups feel little urgency for more research into the ethical, social, and political consequences of urban digital twins (S3, 0). They see training in its use as a limited problem (S4, 0) and the economic potential of twinning as a side issue (P4, 0). They also attach less importance to working together in the same urban digital twin (I4, 0), for example, to record concepts that do not yet exist (D3, 1) and to integrate the plans of different stakeholders into one integrated design (P6, 1). What they are more vocal about is their confidence that digital twins are reliable enough to support decision-making (C5,-3). They reject the idea that the technological monstrosity is in the hands of Big Tech (D5,-3).

Where do they really differ from each other? It is no surprise that one group sees it as a tool for calculating scenarios. In contrast, the other sees it more as a data space (F5, +1/-3) for visualizing the current environment in 3D (D2,-2/+3) to promote participation- simulating versus visualising, and modelling complexity versus participation.

Frame 2 Critical perspective * Frame 3 Integrators

Despite the overall low overlap (0.08) between the perceptions of critics and integrators, they agree on the following position (difference of ideal rank = 0): both recognize that this technology is a valuable tool for learning from different scenarios (P2, 2). digital security (C4,-1) is the only statement on which there is consensus among all frames, and they share limited concerns. They view a digital twin as more than an advanced simulation model (D1,-1). Both strongly disagree that the development of urban digital twins should be left to the market (S1,-3).

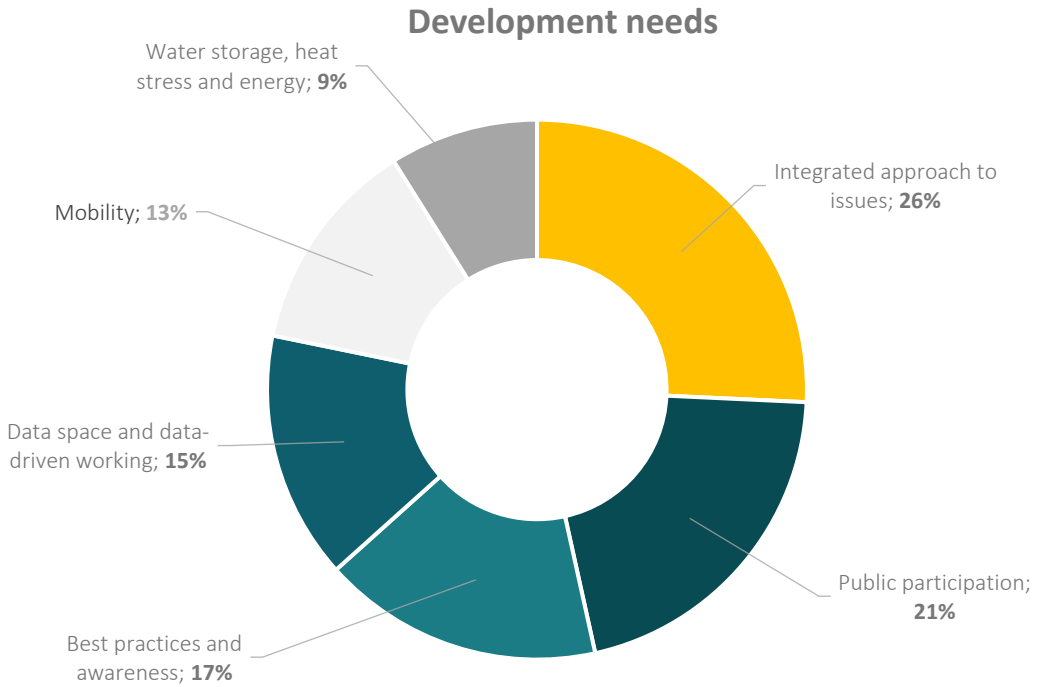
The differences between the two groups are greater. They each have a different view on the potential of digital twins to base decision-making more on facts (P10,-2/+2), and the critics attach less importance to having (access to) large amounts of geodata (F5,-1/ +3). While the integrators consider the data to be good enough, the critics (C3, 3/-1) doubt whether the data through the interfaces is objective (C1, 3/-2) and usable for decision-making due to the still unreliable data and simulation models (C5, 2/-3).

The techno-utopians, critics, and integrators, therefore, view urban digital twins differently. Not one perspective is right. The techno-utopians call for experiments. The critics contribute by asking the right questions and keeping the utopians on their toes, and the integrators try to make it applicable. These frames have different standards and fears regarding data. What they have in common is that they look for solutions to navigate the complexity and believe that humans, in combination with twins, can potentially contribute to this. That raises the question: *What needs do they think twins can contribute to*? We explored this in the next chapter.

2.3 What development needs are there in North Brabant?

After the Q study, the 29 participants were asked what they encountered when working with urban digital twins, which problems they thought could provide a solution to, and what role they saw for BrabantStad. The interviews were recorded, automatically transcribed, and manually coded. All 29 participants (D1-29) were given a number, and their answers were summarized and sometimes elaborated with a quote, followed by the number. The needs were then clustered into the six themes below.

CHART 2: DEVELOPMENT NEEDS OF PARTICIPANTS



Integrated approach to issues and coordination with stakeholders

What is reflected in 26% of the conversations is the great need for integrated insight into complex issues. Many of the topics mentioned are also reflected in the other topics, but what these 26% have in

common is the integrated approach to those issues. There is a "*gigantic housing construction demand* D1". This will result in population growth, but it is not clear what the impact will be on mobility growth in a province that is already bogged down by traffic jams. In addition, there is the climate adaptation issue within which cities, but especially stony cities such as Den Bosch and Breda, must green up for the benefit of water storage and heat stress. On top of that, there is an ongoing energy transition. Space in cities is scarce, and all these issues claim the same limited square meters, but the interconnection is missing. There are often different "silos" within a municipality that work on these issues, using different tools and data to generate insights that fit the challenges their division addresses. Urban digital twins have the ability to harmonize all this data from different domains to address the space scarcity issue cities are increasingly facing. Sharing and standardizing data is essential for accelerating transitions and achieving a solid foundation for decision-making that can break down silos with common ground to enable effective collaboration. (D25: "*What I am convinced of is that we need a twin where you translate different ambitions into KPIs that are ultimately tested in the choices you make and scenarios that you develop for the future of your city. There, I really see that it will help us make better integrated and more realistic choices. A DT does not give the optimal result but provides direction ... what are the buttons that you can turn? That is also what you want - to get a feeling for where I can make the choices that best contribute to my objectives.").*

Citizen participation and transparency

Of all participants, 21% see potential in the use of digital twins for participation. "*Now a sounding board evening and some sessions are often organized. […]That is, of course, also very important and good, but perhaps this type of instrumentation offers more possibilities for that* " (D3). "*It helped enormously to have the conversation when the plans were visualized, but the conversation also became very quickly, banal, of a meter here and a meter there - I would like to have something in-between. A twin with which you can not only see what is there now but also one in which you can sketch in an accessible way*" (D3). It does not have to be on the square meter, and it can be generic because the focus must be on co-creation. It would be nice if you could also show different scenarios with it in the future. What does the maximum density scenario look like? One with only shared mobility? Or the district that can store the most water?

The interviewees emphasized that it is essential to know what application options are available and how they can be used. There is still limited insight into this. That is not surprising because, as Table 1 shows, there are only a few twins who can do that. Tygron's twins seem to come closest.

Best practices and awareness

Of all participants, 17% indicate a need for best practices and awareness. "*We are really still in a pioneering phase" (D1). "We tested our digital skills within the organization. You can then give a score on a scale of 0 to 5, but we have not even achieved a score of 1*" (D11&D15).

What often happens within an organization is that some people are really involved, and others are indirectly involved (D1). This is understandable because "*many people think yes, far from my bed show* (D2)" because they do not know what they can do with it. People are often already too occupied with their other responsibilities. This limits knowledge and experimentation to a few people. Moreover, those who work on the development are often not the same people who have to use the twin in their daily work. D23, from one of the better-known digital twins, indicated that approximately 300 people in their organization would benefit from the current twin, while the average number of weekly users has been only 3. This shows that there is much experimenting going on in Brabant, but this is done by a relatively small group of people. Based on this research, we estimate that the number of people in Brabant actively working on urban digital twins is no more than 60. These people are spread across different organizations. Sometimes, you have a single pioneer, and sometimes, there is a team of at most ten people. As a result, knowledge remains limited, and people do not always learn from each other, which

makes it difficult to move beyond ad-hoc experiments. This emphasizes the need for more best practices, awareness, and learning to work with digital twins.

Learning to work with a twin should not be in the form of a course, should not only focus on working with one specific twin because this is too limited, and should not involve only the group that has to work with it regularly (D25). Instead, it must be part of the work processes, and the people working on the more complex issues must have easy access to the data and be able to actually work with it (D6): "*Because decisions are often made based on gut feeling. The idea that you work from a common data environment is a task for a municipality, and a DT is a tool for that* (D6)."

Joint data space and data-driven working

There is, therefore, a need (15%) for a central data space where data is brought together and shared. The lack of such a technological infrastructure is experienced as a challenge for data integration, data sharing and sandbox experiments. Data quality verification is important, but it does not prevent you from getting started and gaining experience. The interviews also show that data-driven working entails operational challenges. The crucial role of high-quality data, integrating diverse data sources, and overcoming disciplinary silos is consistently emphasized. Depending on the subject, the availability of data is not always there. The implementation of a data space must, as mentioned, also be accompanied by a restructuring of work processes. This new data-driven approach requires a paradigm shift and requires better access to data.

In addition to the operational aspects, the importance of political assurance, awareness, and the formation of expert teams for digital twins is highlighted. Various interviews highlight the importance of experimenting and daring to make mistakes, where practical experience with urban digital twins is seen as a learning tool. This experience is also necessary because data literacy is explicitly seen as a challenge (D6: "*Having civil servants do data-driven work that requires a different paradigm*"). People outside the data world often struggle with information overload and understanding metadata. What numbers are there, and what do they mean? It requires a different way of thinking and approaching issues and a belief that data-driven working methods can help.

Cycling, mobility, and transport

Of all participants, 13% associate digital twins with mobility. "*Where are the people, and where do they want to go?*" Three trends can be distinguished within this framework: long-term strategic planning, operational monitoring, and local optimization.

Long-term strategic planning sees mobility as more than just urban. People move between cities and the countryside. "*This is an issue that is very important for the province as a whole* (D2)." How do you ensure that Brabant remains accessible while cities become more crowded, and the countryside has fewer bus services due to declining income? Which factors can be influenced? These abstract major issues require more insight into current traffic flows, where digital twins may be able to provide a solution. Within cities, some participants work with TNO's Urban Strategy Index, "*particularly based on mobility issues and exploring certain measures, and that is quite a task because it shows you that it is not a tool that you can simply use at all levels* (D26)."

At the operational level, much experimentation is already being done by looking both back and forward in the short term, such as with the Smart City Monitor twin from Argaleo. An interesting issue would be how the crowds in a city can be influenced, for example, by means of lighting after a football match.

The benefit of local optimization lies mainly in learning the possibilities of the "*playground of sensors* (D2)". How can you make an intersection safer where many pedestrians cross? What types of cars are there? "*I have doubts about whether it should be 3D* (D26)."

Water storage, heat stress, and energy

In urban areas, such as Breda and Den Bosch, there is a significant degree of petrification. This brings challenges, such as flooding and heat stress. There is a need for a way to visualize and calculate what is cost-effectively possible to make cities greener and, therefore, more resilient. Mobility plays an important role in achieving these goals and is considered a way to finance this. An aspect that is often overlooked but of great importance is the underground electricity network. Mapping this network is important to avoid unnecessary costs. Accurately mapping the electricity network and ensuring that this information is always up-to-date remains a challenge.

2.4 Conclusion: Making (common) sense of urban digital twins

What perceptions do policymakers, academics, and companies have about the impact and value of urban digital twins – What are the similarities and differences in perceptions?

The participants' perceptions about the impact of the urban digital twins are summarized in three frames where: the techno-utopians and the integrators are the most aligned, and the critical perspective and the integrators are the least aligned.

- **Techno-utopianism:** This group sees urban digital twins as powerful tools for better decision-making and emphasizes the need for collaboration between the public and private sectors. They believe that urban digital twins can have a positive impact but may have little insight into the limitations.
- **Critical perspective:** Critics are concerned that urban digital twins are not neutral and doubt the quality of data, which, in their view, makes urban digital twins of limited use for decision-making. They emphasize the need for ethical research and user education.
- **Integrators:** This group sees urban digital twins as digital copies of real objects and emphasizes 3D visualization and data harmonization. They are less concerned about data quality.

What urban digital twin development needs are there in North Brabant?

1. **An integrated approach to issues and coordination with stakeholders (26%):**
   There is a need for integrated insight into complex issues surrounding housing construction, mobility growth, climate adaptation, and the energy transition.
2. **Citizen participation and transparency (21%):**
   Participants see potential in the use of digital twins for citizen participation. Visualizing and sketching plans can promote conversation between citizens and policymakers and make co-creation more accessible.
3. **Best practices and awareness (17%):**
   Participants emphasized the need for best practices and awareness when working with digital twins. It is noted that many organizations are still in a pioneering phase, and there is a need for more knowledge sharing and awareness of the possibilities of digital twins. Learning to work with digital twins must be integrated into work processes.
4. **Joint data space and data-driven working (15%):**
   There is a demand for a central data space where data can be brought together and shared. The lack of such technological infrastructure is seen as a challenge for data integration and collaboration. Data-driven working requires a shift in thinking and better access to data.
5. **Cycling, mobility, and transport (13%)**
   This includes long-term strategic planning, operational monitoring, and local optimization. Urban digital twins can help understand traffic flows and find solutions to complex mobility issues.
6. **Water storage, heat stress, and energy (9%)**
   There is a need for a way to visualize and calculate what is cost-effectively possible to make cities greener and, therefore, more resilient. The underground electricity network is an important aspect to consider, avoiding costs. Nevertheless, accurately mapping and keeping information up-to-date remains a challenge.

How do we move forward?

3 Working together on urban digital twins

Which cases are interesting for the future?

To understand the logic behind the cases, context is first needed. BrabantStad has asked BUas to investigate the types of urban digital twin cases needs in Brabant. This question arises from the preparation for the Digital Europe call on data spaces for smart communities. What exactly that call will look like depends on the "Preparatory action for the data space for smart communities: DIGITAL-2021-CLOUD-AI-01-PREP-SMART-COMM", the outcomes of which will be presented in the spring of 2024. It is not yet known what the final call text will look like, but an estimate can already be made from the description of the preparatory action, as described below.

Regardless of the call`s content, there must be support for the cases that have been developed. That is why, regardless of the call content, it was decided to interview a large number of stakeholders with an open mind to determine their needs and ambitions, as described in Chapter 2. Making common sense of digital twins. These needs and the call text that has yet to be developed may not always match. That is why BrabantStad has indicated that needs will take precedence over the call. This makes it quite a challenge to translate ideas from 29 interviews and a not yet concrete call into an understandable text with concrete cases that help Brabant move forward. Hence, a modular approach was chosen. Based on the interviews, five cases have been developed that meet the needs of the participants. These five cases are complementary and can also be used separately if they do not fit with the Digital Europe call. The cases are, therefore, not an endpoint of the conversation. They are a starting point for moving forward together.

Call Data Spaces for Smart Communities

The objective of the call is for existing local data ecosystems and public and private stakeholders to jointly develop a data space for sharing large amounts of (European) data. This data space should help to achieve the objectives of the European Green Deal. The EU Green Deal aims to make the European Union climate-neutral by 2050 by reducing net greenhouse gas emissions to zero and taking concrete actions to drastically reduce emissions in various sectors such as energy, transport, agriculture, and industry while stimulating sustainable and green economic growth. There is, therefore, a need for a technical infrastructure for (European) data sharing, such as urban infrastructure, traffic, electricity, pollution, waste management, water, sewage, and extreme weather conditions. Future projects for this call should contain four components:

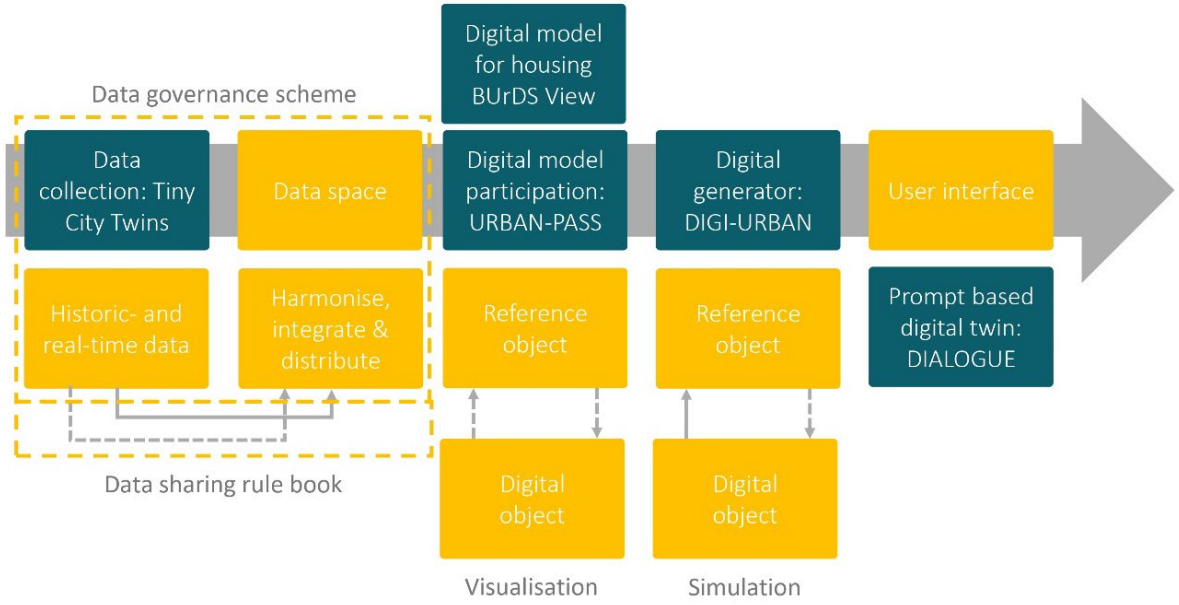
1. The project must bring together stakeholders in the (further) development of a data space and must use a data governance scheme. The preparatory action developed the basis of this governance scheme. This governance scheme contains data standards, rules for the harmonization of user rights, and guidelines to ensure the privacy and reliability of data.
2. Second, the preparatory action should develop a data-sharing rule book that describes how and under what conditions data from the data space should be shared at the EU level to promote commonly agreed tools, standards, templates, and codes of conduct.
3. Third, it must be agreed on how data - relevant to the objectives of the Green Deal, covering urban infrastructure, traffic, electricity, pollution, extreme weather, water, sewage, and waste management - should be shared and used (for example, in a digital twin) by EU cities and communities.
4. Finally, the approach must be tested in an international consortium with pilots involving administrators and citizens.

Likely, the governance scheme, the data sharing rule book, and the European data will not always match the current data and data standards in Dutch cities. It is also likely that the European trend will continue. That is why it is useful to function as a pilot in the final call. If it is decided to participate in the call, a data governance scheme must be used; parties must share data according to the data-sharing rule book;

additional data will be likely needed; this must be brought together in a digital model, and its effectiveness must be tested in international pilot cities. These pilots should focus on planners and citizens. Theory and practice show that these are often different twins. In addition, user interaction must be tested, validated, and improved.

This is quite a task. To make it clear, the steps are shown in visualisation 8.

FIGURE 8: DATA SPACE FOR SMART COMMUNITIES STRUCTURE



The yellow blocks represent the digital twin pipeline. The blue blocks represent the starting points for cases. The cases are briefly described below. All or part of these cases can be implemented in a Digital Europe application. One can also opt to develop the cases individually.

3.1 Case 1: Tiny City Twins

Name: Tiny City Twins
Potential partners: Province of North Brabant, B5 / Fontys / BUas

Topic: Real-time data is especially useful for monitoring and adjusting movement in traffic or at events. This requires a specialized data infrastructure with sensors, cameras, and IoT control devices. This is a significant investment and, therefore, not profitable to install throughout the city or proportionately because most planning issues do not require real-time data. What is needed is reliable and available data. Tiny City Twins meets both needs. Instead of equipping the entire city with sensors, Tiny City Twins consists of a movable installation that can collect real-time data in an area, for example, during an event or can carry out counts in an area. The installation can then be moved periodically to map the entire city, piece by piece. This means that the entire city does not have to be equipped with sensors, and real-time data can be collected if necessary. However, it is especially useful to make reliable data available in areas where there is a demand for information. The purpose of this case is to investigate how software and hardware can be set up cheaply, quickly, and well, how this can reliably produce real-time data in a data space, and then how it can be dismantled and moved to the next area - a kind of traveling data circus.

This case contributes to the need for an integrated approach to issues, building a flexible, common data space, and making reliable data available more cheaply.

Demarcation:

- The focus is on building an installation to collect reliable data quickly and cheaply, bringing it together in a data space, and then moving the Tiny City Twin to another area.
- The focus is not on building a digital twin.
- The focus on data collection stems from the need of cities to make reliable data available and cheaper.

3.2 Case 2: BUrDS View

Name: BUrDS View: Built Urban Data Space

Potential partners: Province of North Brabant, B5, Argaleo / Unity platform Amsterdam / Utrecht

Topic: The proposal for this case is to develop a data space with a digital model at the European level. The focus is on housing construction because many urban issues come together within this topic, and many local and international cities feel the pressure of the housing crisis, but an overview is lacking. This includes buildings, functions, roads, vegetation, and subsurface, expanded with information about mobility, accessibility, green quotas, and any necessary permits.

This topic responds to the need for data that helps with an integrated approach. At the same time, experience in working with urban digital twins, municipality-wide, is still limited, which is why this case focuses on current tasks without making it too complicated or complex to gain experience. At the same time, this common data space forms a foundation for further development. This case, therefore, meets the need for an integrated approach, awareness, and data space.

Demarcation:

- The focus is on bringing together (European) data and statically calculating and visualizing reliable information.
- The focus is not on drawing and simulation.
- The focus on the data space arises from the need in cities for FAIR (Findable, Accessible, Interoperable, and Reusable) data to practice data-driven working.
- BUrDS View is a foundation that can be built on later with additional functions, such as in case 4.

3.3 Case 3 URBAN-PASS

Name: URBAN-PASS: Urban Participation and Simulation System
Potential partners: Province of North Brabant, B5, Unity platform / EA games / BUas

Topic: Urban-PASS is a digital model in which citizens can think about development in/of the city through co-creation and participation. People can select an area in a digital model. This is then enlarged and rendered in 3D, after which people can draw in it with a Sims 4-like interface. People can, therefore, place walls, floors, textures, and objects themselves in an accessible interface. You can switch the "with rules" version on and off. Rules restrict you from building too close to a road, for example. Without rules, you can build anywhere within the selected area. The advantage of the no-rules function is that during the participation session, you can have an open conversation about the function of the space. The advantage of playing with rules is that you really look at what is possible and what is not and can also explain this to the group.

This topic responds to the need for data that helps with an integrated approach, participation, and gaining experience with/in working with urban digital twins without making it too complicated or complex.

Demarcation:

- It is more of a sketchbook rather than a reliable digital twin. This is exactly the intention. You want to be able to work creatively and quickly with a large group of people.
- The data does not have to be 100% reliable, but it must provide sufficient context to work with it.
- This case arises from the strong need for participation and the idea that this is a way to future-proof digital twins among the general public and across organizations.

3.4 Case 4 DIGI-URBAN

Name: DIGI-URBAN: Digital Integrated Generator for Urban Applications Network
Potential partners: Province of North Brabant, B5, Tygron / TNO / Argaleo, BUas

Topic: The digital generator for complex change processes. This is the most difficult case because it involves a higher level of twinning. To make this possible, you still have to go through the steps for BUrDS View, but you can also go a step further- combine this with uncertainty margins and simulate it over time. Housing construction is the largest task mentioned. Housing generates traffic. The amount of traffic is partly related to the transport options, and this allows an estimate of the mode of transport per home to be made. Which segment is being built for? How far do these residents live from the station? How many cars are expected per household, and how many parking spaces are required? What material is used for the houses and paving? How much heat does this cause on a hot, normal, and cold day, and if it rains excessively, which areas will be flooded? DIGI-Urban aims to digitally experiment with what an area can look like by developing scenarios. These scenarios are estimates based on historical data and physical models. It can also be used to search for the optimal layout of an area using an AI model. If X number of homes are to be built in the area, X number of parking spaces and greenery must be provided. Which division of the neighbourhood would suit this? It is already possible to allocate an optimal number of parking spaces in the area using AI. The same system is used to divide rooms in buildings. This technology could also work for the layout of a neighbourhood. This ensures higher efficiency when designing the layout - not as a replacement for the planner but as a brainstorming aid for the planner.

This case arises from a need for more integrated work, participation, data-driven work, and insight into mobility and climate.

Demarcation:

- The focus is on bringing together data and statically visualizing reliable information.
- The focus is also on drawing and simulation.
- The focus on the data space arises from the need in cities for accessible, correct information, to gain an idea of what information is available, and to become better at data-driven work.
- The focus on the digital generator arises from the strong need for integrated working and gaining insight into the complexity.
- It may be currently too complex with the limited experience in working with urban digital twins and the large uncertainty margins in the statistical models to calculate scenarios.

3.5 Case 5: DIALOGUE

Name: DIALOGUE: Digital Assistance for LOcating Geo-information in Urban Environments
Potential partners: Province of North Brabant, B5, BUas, Tilburg University

Topic: Many urban digital twins use lists to turn certain layers on and off on a map. This makes searching for the right information in a twin not very user-friendly and becomes more difficult as more data is added. In addition, many people are highly visually oriented. This entails the risk that a layer in a map is misinterpreted due to the lack of context or insight into the underlying data. The success of Google Maps Chat GPT is that it unlocks large amounts of data through a search bar. You ask your question, and you receive the answer visualized in Google Maps and described in Chat GPT. This means the users do not have to search for the answers themselves, and the risk of human errors, such as misinterpreting data, is limited.

Would this also be possible for an urban digital twin? You can train a model on the labelled data in the urban digital twin. You can then use prompts to ask questions such as: "Show me all available construction sites within a 5-kilometer radius of the city centre" or "What is the average income in district X?" The assistant could then answer the question in writing and visualize it.

Potentially, this is a concept that allows professionals to access relevant data quickly and efficiently, as well as a wider audience. City residents, policymakers, and other stakeholders can use the urban digital twin to make more informed decisions on issues such as urban development, environmental aspects, and quality of life.

The idea is to lower the threshold for involvement and participation in the urban planning process while the expertise and data necessary for quality decision-making are immediately available. This is an approach that is both scientifically interesting and socially relevant. In addition, due to the use of AI models, there is a chance that this method will work to improve the interface of multiple urban digital twins.

This case arises from a need for more integrated work, participation, data spaces, data-driven work, and insight into mobility and climate.

Demarcation:

- This concept only works on a dataset labelled by subject and location.
- It is experimental - to our knowledge, this has not been done before - so it is not certain whether it works, but there is great potential.
- The focus is on improving an existing interface, not on developing an urban digital twin.

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Attendees:	Organization	Function
Bertus Rosier	Avans	Project Leader Digital Workshop
Jeroen Weppner	BUas	Business Innovator
Kevin Vermeulen	BUas / Logistics Community Brabant	Event Logistics employee
Hans Teuben	Capgemini	Director Strategy and Innovation
Lex Geervliet	Municipality of Breda	Innovation and Electrical Engineering Advisor
Margriet Heessels	Municipality of Breda	Project Leader Digitization
Maarten van Veen	Municipality of Eindhoven	Strategic Policy Advisor Innovation & Ethics
Michiel Oomen	Municipality of Eindhoven	Program Manager Digital Innovation
Mieke van Schaik	Municipality of Eindhoven	Strategic CIO Advisor & Data Strategy Quartermaster
Pim van de Port	Municipality of Eindhoven	Strategic Information Manager
Ran Haase	Municipality of Eindhoven	Advisor Law & Ethics
Rik van Stiphout	Municipality of Eindhoven	Advisor Innovation and Effect on Society
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