Deliverable

D2.4 Cloud-based business model analysis

Project Acronym:	DUET	
Project title:	Digital Urban European Twins	
Grant Agreement No.	870697	
Website:	www.digitalurbantwins.eu	
Version:	1.0	
Date:	5th of June 2021	
Responsible Partner:	IMEC	
Contributing Partners:	imec-SMIT	
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Dissemination Level:	Public	X
	Confidential – only consortium members and European Commission	

This project has received financial support from the European Union's Horizon 2020 Programme under grant agreement no. 870697

Revision History

Revision	Date	Author	Organization	Description
0.1	20.12.2019	Ruben D'Hauwers	imec-SMIT	Initial structure
0.2	10.1.2021	Ruben D'Hauwers	imec-SMIT	Table of content
0.3	26.3.2021	Ruben D'Hauwers	imec-SMIT	Version 1
0.4	21.4.2021	Ruben D'Hauwers	imec-SMIT	Version 2: ready for review
0.5	25.5.2021	Andrew Stott	Dirdigeng	External review
0.6	26.5.2021	Ruben D'Hauwers & Marina Klitsi	imec-SMIT, ATC	Version 3 Integrate first feedback of expert reviewers
0.7	30.5.2021	Yannis Charalabidis	Aegean	External Review
0.8	31.05.2021	Pieter Morlion	MORE LION	External review
0.9	04.06.2021	Lieven Raes	AIV	Final review
1.0	05.06.2021	Ruben D'Hauwers & Nils Walravens	imec-SMIT	Final version

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Executive Summary

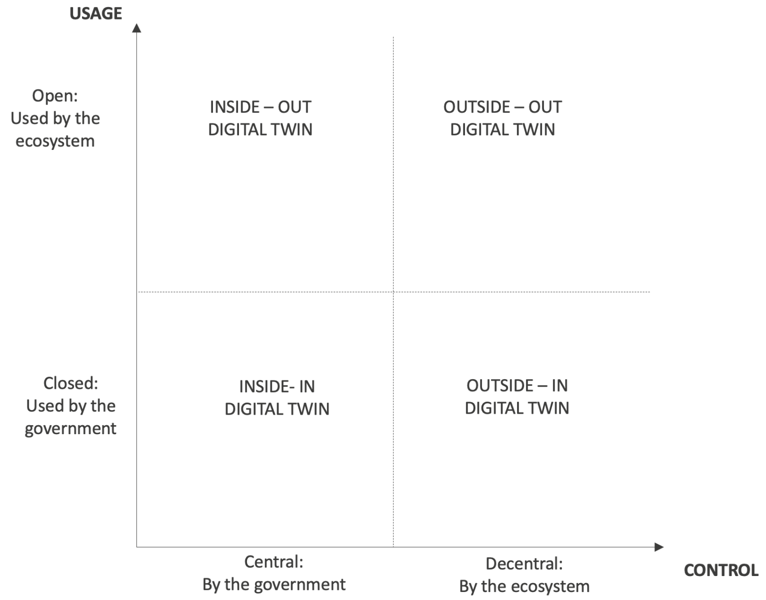
In order to define how cloud services can support Urban Digital Twins, the goal of this deliverable is to look into the business models of digital twins, which challenges they face and, based on this analysis, to determine the requirements for a cloud infrastructure to support the development of Urban Digital Twins. Based on experience in DUET pilot sites and interviews with different existing Digital Twins, to build sustainable and exploitable Digital Twins, a major challenge breaking data silos data, and the collaboration with the ecosystem regarding enabling the availability of data, as well as the handling of the data in a data ecosystem. To determine requirements for cloud business models, an analysis is required exploring the business models of Urban Digital Twins, zooming in on 1) the network level of the business model of an Urban Digital Twin and 2) on the fact it is operating in a data ecosystem. We examined the business models of established and innovative business practices of existing Digital Twins, in order to distil key insights relevant for the sustainability and exploitation of DUET.

In order to determine business requirements for cloud solutions for Urban Digital Twins, a business model analysis of existing urban Digital Twins is performed in order to determine the different challenges the Urban Digital Twins face. The authors examined the business models of established and innovative business practices of existing Digital Twins focused on the specificities of acting in a data ecosystem. These result in scenarios for different types of Urban Digital Twins and their related challenges. These challenges result in the business requirements for future and current cloud services related to Urban Digital Twins.

Five Digital Twin initiatives were interviewed and analysed. The selection of the Digital Twins was based on geographical spread, business model complexity, and the availability of direct contacts. The Digital Twins were analysed based on the business model parameters **value** (Is the Digital Twin used in a closed model by the government, or in an open model by the ecosystem?) and **control** (Are the data resources controlled in a central or decentralized way?). Four different types of Digital Twins were analysed based on their business model characteristics (use cases, added value, data type, data owner and controller, control mechanism). Lastly, **business requirements** were drawn from each type of Digital Twin based on the Data Sharing Business Model framework of D'Hauwers and Walravens (2021).

The four different types of Digital Twins (Figure 1) are the following: an **Inside-In Urban Digital Twin** which is used for policymaking based on governmental data resources. The government is controlling the data resource. Second, an **Inside-Out Urban Digital Twin** is used to engage with the ecosystem-based on governmental data resources. The government is controlling the data resources. An **Outside-Out Urban Digital Twin** is used to engage with the ecosystem-based on data resources of the ecosystem. The government is controlling the data resources. Last, the **Outside-In Urban Digital Twin** is used for policymaking based on data resources of the ecosystem. The government is controlling the data resources.

Figure 1: Urban Digital Twin: business model scenarios



Based on the conversations with the existing Digital Twins and the DUET pilot sites, one of the core challenges of any type of Urban Digital Twin is **data governance**, and this is the foundation for developing the Digital Twin. It concerns the organization of the governmental departments, and the changing workflows. It also concerns setting up a shared Digital Twin architecture encompassing different departments, requiring the introduction of data standards. Thirdly, it includes the quality and availability of data. Thus, data governance is the basis of any Digital Twin. Once a data governance is set in place, the next challenge is how to **open up the data** to the entire ecosystem in the case of the Outside-Out and Inside-Out Digital Twin, which requires a classification system of the data to determine which data can be shared with the ecosystem, and which needs to remain closed, as well as an identity management solution. **Ecosystem governance and trust** is the last challenge when the data supply and control of the data includes increasingly the ecosystem in the cases of the Outside-Out and the Outside-In Digital Twin, another new challenge is the governance of the ecosystem, ensuring trusted data ecosystems and ecosystem governance models.

Some of these challenges can be solved through cloud solutions: the **business requirements** are to connect the **(internal and external) data sources, to harmonise the data** among the different stakeholders and solutions which **prevent vendor lock-in** for the Urban Digital Twins.

These scenarios and business requirements are used as a basis for the task 7.6 on Exploitation and commercialization of DUET in two distinct ways:

- For cities: a **Maturity Model for Urban Digital Twins** to identify which types of business models they want to follow
- For cloud service providers: **Requirements for cloud solutions** supporting Urban Digital Twins

1. Introduction

As a cloud infrastructure will never consist of one physical or business entity, collaboration, interoperability, and (economic) sustainability are key variables in this space. In order to define how cloud services can support Urban Digital Twins, the goal of this deliverable is to look into the business models of digital twins, which challenges they face and, based on this analysis, to determine the requirements for a cloud infrastructure to support the development of Urban Digital Twins. Therefore, an analysis is required, exploring the business models of Urban Digital Twins, zooming in on the network level of the business model of an Urban Digital Twin and on the exchanges of data.

In order to determine business requirements for cloud solutions for Urban Digital Twins, a business model analysis of existing urban Digital Twins is performed in order to determine the different challenges the Urban Digital Twins face. We examined the business models of established and innovative business practices of existing Digital Twins focused on the specificities of acting in a data ecosystem. These result in scenarios for different types of Urban Digital Twins and their related challenges. These challenges result in the business requirements for future and current cloud services related to Urban Digital Twins.

The work performed in this deliverable (D2.4) will feed business requirements directly into the exploitation scenarios developed in task 7.4 on the sustainability and exploitation of DUET (D7.6). Section 2 of this document describes the methodology used to select the Digital Twins as well as the analytical frameworks utilized. Section 3 describes the business model analysis performed, which led to the categorisation of 4 different types of Digital Twins. In Section 4, the business requirements are discussed based on the different types of Digital Twins which serve as requirements for cloud business models. Section 5 concludes this document.

2. Methodology

2.1 Selection of Digital Twin projects

To select the Digital Twins to be interviewed, a shortlist of 25 public sector Digital Twins across Europe, Asia, North America, and Australia was prepared. An initial analysis of the Digital Twins was made based on desk research, where the purpose of the Digital Twin, stakeholders involved, data sources, and the business model complexity were assessed. An overview was also made on the available information online and the possibility to connect to the Digital Twin, which can be found in annex 1.

The selection of the final 5 Digital Twin cases for a deep dive was based on the geographical spread across Europe (by including, as much as possible, cities from different countries within Europe) and whether data ecosystems were involved, which data types were used, and the number of stakeholders involved. Two cases from the Netherlands were selected as the complexity of the business model of the two cases were rather distinct and thus it was interesting to include both. The availability of direct contacts to connect to the Digital Twin was also taken into account.

Table 1: Overview of selected Digital Twins

Name	Country	Purpose	Type of data	Link
Helsinki	Finland	Decision making and open innovation, especially to reach sustainability goals	Public data and private data	https://kartta.hel.fi/3d/atlas/#/
Örebro	Sweden	Decision making and citizen participation	Public data and private data	No website
Rotterdam	Netherlands	Map changing city environment in social, physical and digital dimension	Public and private data in the data ecosystem	https://www.3drotterdam.nl/#/
Vienna	Austria	Linking data to break silos, develop an urban planning process are the basis for simulations and analytics in a multitude of use cases	Public data	No open version
Amsterdam	Netherlands	Facilitate the use of the Digital Twin by providing a Plug and Play Digital Twin environment for end users	Public data	https://3d.amsterdam.nl/web/app/index.html

2.2 Methodology of analysis

In order to analyze the different Digital Twins, three different methodological steps were used. In 2.2.1, an overview is given on how different Digital Twin business model scenarios are created. To describe the characteristics of the Digital Twin scenario, an introduction is given for which characteristics were analysed in 2.2.2. In 2.2.3 an overview is provided for the framework used to develop the interview questionnaire.

2.2.1 Digital Twin business model scenarios

In the business model literature there is no common definition for the term of business models. A distinction can be made between authors that define a business model mostly on the level of the firm (Rappa, 2000; Osterwalder, 2004) while others define it at the network level (Weil & Vitale, 2001; Al-Debei & Avison, 2010; Timmers, 1998). On the firm level, questions arise on who the customers are, what the value proposition is, which activities need to be performed and what are the revenue models (Osterwalder, 2004). On the network level of the firm, the main questions to be solved are connected with shifting firm boundaries, exploring the relationships that exist between actors in complex value networks and the roles they may play (Walravens & Ballon, 2013).

Given the focus on data ecosystems in Urban Digital Twins, the network level approach of business modelling provides a framework for analysing the business models for Urban Digital Twins. The overarching questions concern "Who controls the value network and the overall system design" and "Is substantial value being produced by this model (Ballon, 2007). The questions that arise specifically on data ecosystems are, on the control side what the data sources are (Kampfer (2019); Hartman (2014)) and who controls and owns the data (Gelhaar, 2021). On the value side, the major applications of the usage of the data (Kampfer, 2019), who the target customer and who is using the data (Hartman, 2014) and what the added value activities are related to the data (Hartman, 2014) are the major questions.

Different scenarios were made for identifying different types of urban Digital Twins based on network-level business model parameters of control and value. The specific variables that are used for building the scenarios are:

- Value (indicated by usage): Which actors will use the Urban Digital Twin? To whom is the added value addressed?
- Control: Who controls the data resources?

The scenarios are used to identify the different roles and activities of a Digital Twin related to creating value and controlling the data resources. Furthermore, the scenarios were used to identify the challenges and the related (cloud) requirements, which are specific to the type of Digital Twin. The scenarios lead to four different types of Digital Twins.

2.2.2 Business model analysis

In each business model scenario, the characteristics of the Digital Twin are analysed in order to clarify how the Digital Twin is set up. The characteristics are based on parameters defined by Hartman (2014), Kampfer (2019), Gelhaar (2021), Ballon (2007) and D'Hauwers and Walravens (2021).

On the **value parameters,** the following characteristics are described:

- *Purpose:* The reason why the Digital Twin exists.

- *User:* Who is the user of the Digital Twin (a single firm or organization, the value chain, or entire ecosystem).
- *Value* proposition: Provision of (raw) data, information, and knowledge or a product or service.
- *Added value activities:* Generation, processing analysis, and visualization of data.

The **control parameters** describe the following characteristics:

- *Data type:* Governmental open data, governmental closed data, commercial data, personal data.
- *Data owner and data controller*: Who owns the data and who controls the data.
- *Control technical requirements*: A single organization, the technology provider, or the ecosystem.

3. Business Model Scenarios and Analysis

3.1 Urban Digital Twin Business Model Scenarios

As discussed in 2.2.2, scenarios were built to determine the business model of the urban Digital Twins. The parameters on which the scenarios were built are the following:

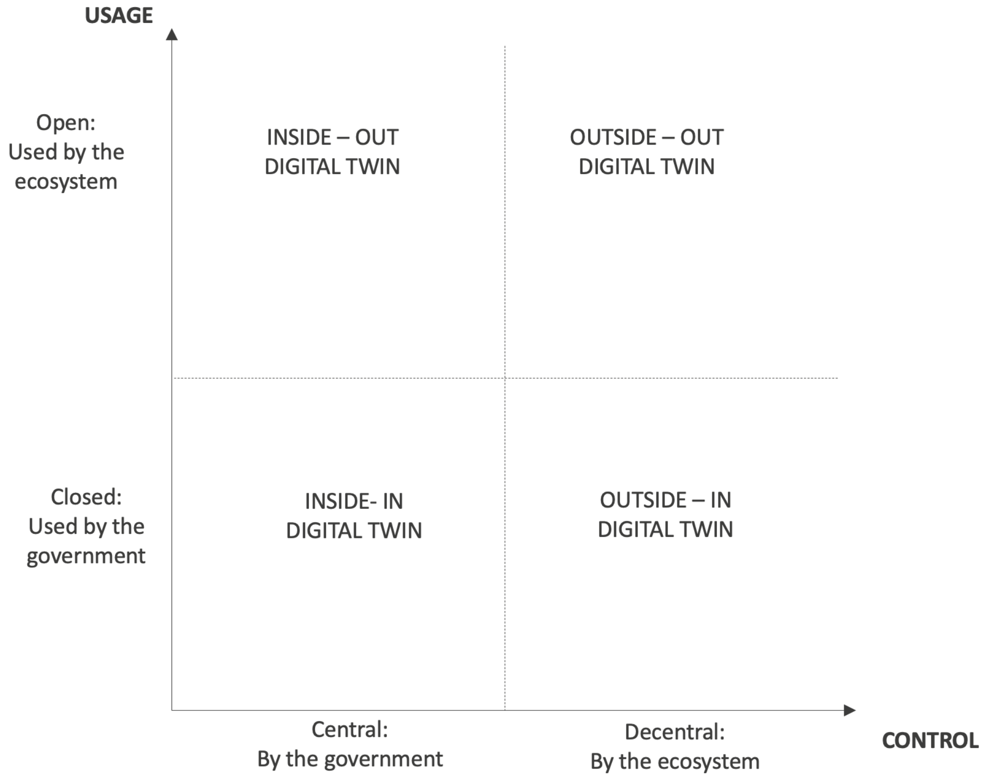
The **value proposition** (D'Hauwers, Walravens,2021) parameter identifies by which actors the Digital Twin will be utilized. It could be **used by the government**, where the Digital Twin is used purely for policy making for the government in a **closed model**. If the Digital Twin is **used by the ecosystem**: the Digital Twin is utilized by different actors in the data ecosystem, for example, citizen participation, for decision making in companies or citizens, in an **open model**. In figure 1, the y-axis moves from a closed model (solely used by the government) towards an open model (the data is open for anyone in the ecosystem).

The **control parameters** identify who controls data resources and the technological infrastructure (Gelhaar, 2020). If control is **central,** the data resources are **controlled by the government**. The government is in this case also responsible for purchasing private data when required in bilateral agreements. If control is **decentral,** the data resources are controlled by the data ecosystem, in which case different actors in the data ecosystem are controlling the data resources and technology. Different actors serve in this case as data sources in an ecosystem. The different players in the data ecosystem can provide their conditions for sharing the data and control their data themselves. In figure 1, The x-axis of control moves from a central control (the government controls their own data resources) towards a diffuse, decentral model of control (different stakeholders in the ecosystem provide their data and control their own data).

This mapping results in four scenarios as shown in figure 1 and discussed below:

- Inside-in Urban Digital Twin
- Inside-Out Urban Digital Twin
- Outside-Out Urban Digital Twin
- Outside-In Urban Digital Twin

Figure 2: Urban Digital Twin - business model scenarios



The different scenarios are discussed in sections 3.2, 3.3,3.4, and 3.5 with the following characteristics. An overview of the characteristics can be found in figure 2.

Figure 3: Urban Digital Twin -characteristics

	Inside - In Digital Twin	Inside – Out Digital Twin	Outside – In Digital Twin	Outside – Out Digital Twin
Purpose	Policy Making	Open innovation Citizen Participation	Policy Making	Open innovation Citzen Participation
User	Government	Data Ecosystem	Government	Data Ecosystem
Data Type	Governmental data Purchased commercial data	Governmental data Purchased commercial data	Governmental Commercial data Personal data	Governmental Commercial data Personal data
Data Control	Government	Government	Data Ecosystem	Data Ecosystem
Use Case Examples	Vienna	Helsinki, Örebro, Vienna, Amsterdam	Rotterdam, Örebro	Rotterdam, Örebro, Vienna (future)

3.2 Inside-In Urban Digital Twin

3.2.1 Digital Twin Business Model Analysis

The purpose of an Inside-In Digital Twin is to support the **policy making of the government**, which is oriented purely on the internal governmental decision process. Thus, the urban Digital Twin is not open to the ecosystem. A Digital Twin can aid the decision process by **visualizing data in the real world for policymakers**, and thus can result in a better **decision process** when it is included in governmental planning for e.g. urban planning, climate change policies, and mobility policies.

The added value of the Digital Twin is to **gather data** from different governmental sources, **process data** in order to structure the data into a city data model and **visualize the data i**n a real-world environment. In some cases, the Digital Twins also allow making policy simulations. The value is mainly created internally in the government for decision making, risk prevention, reaching policy goals, ... Thus, the revenue model is also focused on capturing value within the government: there is no direct financial return for the service.

In the Inside-In Urban Digital Twin, the city pays for the technological infrastructure and for the structuring and gathering of data, as the value also returns to the city.

In this scenario, the **data source is mainly governmentally owned data**, such as satellite pictures, laser beams, Building Information Management (BIM) data, point clouds, and other geodata such as telecom data, traffic data, and energy data. The data is often generated and collected by the government, and when needed **purchased from private companies**. In case when the government becomes the owner of the data and thus also controls the data, and who can access the data. In case when the government only has a license to use the data purchased from public procurement, it would be considered an Outside-In Digital Twin.

The control of the technology used to develop the Digital Twin is controlled by the government. In most cases, they c**ombine different open-source software** into what is required for a Digital Twin. Most cities prefer **not**

to purchase proprietary technological solutions from technology providers, as this limits the possibilities to **adapt to changing requirements.**

3.2.2 Digital Twin: Vienna use case

The Vienna (Austria) Digital Twin is a good example of an Inside-In Urban Digital Twin. The purpose of the Vienna Digital Twin is to transfer data from reality to the virtual space in order to aid **decision makers and planners in their policy making process**.

The main use cases in Vienna (see table 2) are the ability to make **simulations, to link the data between different data sources and to facilitate the urban planning decision process**. The value is created internally in the government, as it improves decision making, ensures risk prevention, facilitates reaching policy goals, improves processes and reduces cost for future use cases. As the use is primarily internal, the **revenue model is based on creating internal value** and use without any monetary reward. The costs are covered from the GeoTWIN department paid from **governmental funds**.

Table 2: Use case value proposition, capturing and revenue model in Vienna

Use Case	Actor	Value proposition	Value captured	Revenue Model
Simulations (Solar potential, Flood protection,..)	Governmental official responsible for renewable energy, water management	Make simulations to ensure where solar panels/ water management can be improved. Forecast disruptive events	Improved decision making Risk prevention Facilitate reaching the (climate) goals	Internal use in government Costs covered by GeoTwin department
Linked Data (City Information Model)	Officials working in data department, geodata department	Improved data governance, structuring, enables to support additional future use cases	Reduced costs to structure data Reduced time Enable future use cases	Internal use in government Costs covered by GeoTwin department
Urban Planning process	Urban planning officials, contributors on urban projects	Simulate planning of projects Better decision making	Improved decision making	Internal use in government Costs covered by GeoTwin department

The Urban Digital Twin of Vienna (Lehner and Dorffner, 2020) is currently in the prototype phase. Therefore, one of the primary goals in Vienna is to break data silos within the government by linking data of different governmental sources. Second, the urban Digital Twin of Vienna is first to be used in the urban planning process, and the goal is to aid in the development of new projects. It can showcase the effect of new infrastructure that is built and is used for simulations, such as for the development of the new SeeStadt Aspern urban development project and the North and North-West Train station area. Finally, the linking of the data and the urban planning process is the basis to enable analysis and simulations to make city-scale simulations such as climate, pollution, solar potential, flooding scenarios of the Danube.

In order to develop the Digital Twin, an urban city model - a **city information model** - needs to be developed in order to link geodata to the model in one central database. Different **data gathered by the city** through terrestrial surveying, photogrammetry are captured. The model also aims to link databases from different governmental departments to the city model, such as data of the solar potential, climate data, flooding, etc. In the future, sensor and IoT data might also be added.

The city information model aims to **integrate different commercial open-source software**, like e.g. for 3D modelling, building a city map, fuelling data, and adding building blocks. One of the major goals of the GeoTWIN[1] project is to integrate the different software into one model that can be used by the city.

3.3 Inside-Out Urban Digital Twin

3.3.1 Digital Twin Business Model Analysis

The purpose of an Inside-Out urban Digital Twin is to support the **policy making of the government and by including the ecosystem in the process and drive co-innovation**, which is oriented to engaging the ecosystem to innovate with the data of the urban Digital Twin. Thus, the Digital Twin is open to the ecosystem. An urban Digital Twin can aid the decision process by **visualizing data in the real world for policymakers and for the ecosystem**, and thus can result in a better **decision process** when it is included in governmental planning for e.g. urban planning, climate change policies, and mobility policies. Opening the city model data for the wider public can also **support innovation in the ecosystem,** e.g., start-ups could use the data to build products.

The added value of the Digital Twin is to **gather data** from different governmental sources, **process data** in order to structure the data into a city data model and **visualize the data i**n a real-world environment. In some cases, the Digital Twins also allow making **simulations** of a policy decision. The data can also be opened for the wider public to be used in innovative projects.

In the Inside-Out Urban Digital Twin, the city pays for the technological infrastructure and for the structuring and gathering of data, as it concerns public value. Therefore, the Inside-Out Urban Digital Twin could use governmental funding for the opening of the Digital Twin to the ecosystem.

As described above in the Inside-In Urban Digital Twin, the **data source is mainly governmentally owned data**. The data is often generated and collected by the government, and when needed **purchased from private companies**. In this case, the government also needs to decide on which data can be **open, and which data cannot be shared with the wider public**. Reasons for not sharing the data can be because the data is sensitive, can pose negative effects on society when it comes into the wrong hands or simply because there are no use cases.

The technology used to develop the Digital Twin is controlled by the government. Similar to the Inside-In Urban Digital Twin, the cities prefer not to purchase proprietary solutions.

[1] https://link.springer.com/article/10.1007/s41064-020-00101-4

3.3.2. Digital Twin: Örebro use case

The Örebro Digital Twin is used for internal use cases, such as for urban planning (see below), thus as an Inside-In Digital Twin, but an important goal of the Digital Twin is to visualize data of the city to improve decision making and to include citizens in the decision-making of the city. In the future, it also might include data from the overall ecosystem, and thus will also be an example of the Outside-Out Digital Twin.

Table 3: Use case value proposition, capturing and revenue model in Örebro

Use Case	Actor	Value proposition	Value captured	Revenue Model
Citizen participation	Citizen	Simulations to improve communication to citizens on project	External: Increased interest by citizens in urban project, Internal: better feedback capturing on urban projects, more engagement	Free for citizens Internal use in government Costs covered by Digital Twin department

The Digital Twin is used for participation in order to ensure that people can better imagine what the impact would be of urban planning projects, and in the future, it might include gamification to increase the participation of citizens. Based on the data source, this could also be an example of an Outside-Out Digital Twin use case. In this case, the use of the Digital Twin is for citizens, but the value mainly returns to the city as it can capture better feedback from citizens and have more engagement with citizens. The value is captured mainly internally, and the Digital Twin department covers the costs for development.

In order to develop the Digital Twin, geodata needs to be linked to a central **city information model**. Different **data gathered by the city** are captured. The model also aims to link databases from different governmental departments to the city model and sensors which capture information in real-time.

3.3.3. Digital Twin: Helsinki use case

The Helsinki (Finland) Digital Twin is another example of Inside-Out Urban Digital Twin. Most parts of the Digital Twin are open data and can be accessed, used and shared by citizens and the overall ecosystem. Citizens can be included in the decision process, can receive advice based on the information, and can also innovate with the city.

Table 4: Use case value proposition, capturing and revenue model in Helsinki

Use Case	Actor	Value proposition	Value captured	Revenue Model
Energy & Climate Atlas (energy data, solar panels, CO2 emissions,..)	Real estate companies, researchers, city planning, citizens,..	E.g. Solar panels: give advise by real estate companies to improve renovations E.g. Information tol for energy, heating and cooling companies	External: Improved service provision for companies, better decision making Internal: Improved services of the city, reach climate goals	Free for citizens and actors (?) Cost covered by governmental funds
Hackathon and co-innovation	Universities, startups, citizens	Access to data to innovate e.g. open data and 5G challenge, to use	External: access to data, create new innovations	Free for users City provides a prize for challenges

		geodata to build an AR application	Internal: Provide data, create innovation, "open by default' principle	Cost covered by governmental funds

The main applications of the Digital Twin are the Helsinki Energy and Climate Atlas, which is an open web service, built on a semantic Digital Twin model. It has four service modules: energy data, solar energy, heat demand, and geo-energy. It can be used by companies, real estate developers, city planners, and building users. It is used by an energy advisory agency that advises people on renovations or on whether or not to install solar panels. Another use case is to open the data of the city model for companies, who can innovate using the data of the city. This was used in a challenge to how companies could use open data and 5G mobile networks, and how augmented reality could be useful in this challenge. The value for the government is mainly to reach policy goals and to engage the ecosystem to innovate. The costs are covered by governmental funds.

The city has two different models - a reality model[2] and a CityGML[3] model - with different formats where data is linked to the different data sources, ranging from point clouds, oblique images, GIS DataBases, registers, IFC/BIM, and new geodata from sensors, mobile phones, ... Most of the data is gathered by the city, from different city departments, or, if needed, purchased from private companies.

The city information model aims to **integrate different commercial open-source software**. The city wants to remain independent from big closed systems where it would not have any control over the components, which would reduce the ability to adapt based on the changing environment.

3.3.4. Digital Twin: Amsterdam use case

The aim of 3D Amsterdam (Netherlands) is to operate in a Plug & Play Digital Twin with a 3D platform to facilitate easy functionality by end users. The objective is to disclose 3D data, visualize the data in 3D and to add open source functionalities such as download and upload functions, drag and dropping of datasheets and the ability to make simulations. Thus, the role of the 3D Amsterdam is to provide an infrastructure for players in the ecosystem to use the Digital Twin.

Table 5: Use case value proposition, capturing and revenue model in Amsterdam

Use Case	Actor	Value proposition	Value captured	Revenue Model
Plug and play ecosystem	Developers, startups, geodata companies,..	Tools for companies, actors to make their own simulations and use the digital twin	External: innovation, improved services, better urban decision making Internal: Reach policy goals	Free for citizens and actors (?) Cost covered by governmental funds

[2] Reality modelling is the process of capturing the physical reality of an infrastructure asset, creating a representation of it, and maintaining it through continuous surveys

[3] CityGML is an open data model and XML-based format for the storage and exchange of virtual 3D city models

A city data platform has been developed with APIs, mainly based on the Dutch basic registrations data of the city of Amsterdam, which is available already as 2D data on the website of Amsterdam. The data that is being used is mainly data, which is available in the government, structured, and consisting of buildings, trees, bridges, water flows, the sewage system etc. The data and functionalities included in the Digital Twin are open by default.

The added value of the Urban Digital Twin is to visualize already available and opened data, as it provides the infrastructure for the Urban Digital Twin. Users can drag and drop a file in the Urban Digital Twin 3D environment to make a thematic 3D map or make simulations themselves with the Digital Twin. Some use cases of 3D Amsterdam are to show the impact of a requested building permit on its surroundings, helping the process of granting it, visualizations of thematic data and traffic flows or to give insight in the relationship between above ground urban developments and the underground infrastructure and soil.

3.3.5. Digital Twin: Vienna use case

In the case of the Urban Digital Twin of Vienna, a lot of geographic base data is published as open data. As Vienna is currently in the prototype phase of the Urban Digital Twin, the data is not published yet in the Digital Twin. Yet, if in the future the underlying data is open data, those parts of the Digital Twin will be opened. This can for example be used by technical companies, urban planners, researchers, GIS consultants, and interested citizens.

One use case (table 6) that is implemented already is the use case where the city communicates the urban planning process through a Digital Twin with citizens. The value is created internally in the government, as it improves the quality and involvement of stakeholders in the urban planning process, and externally as it increases the involvement of citizens in urban projects. As the information is shared with citizens for free, the **revenue model is based on creating internal value** and use without any monetary reward. The costs are covered from the GeoTWIN department paid from **governmental funds**.

Table 6: Use case value proposition, capturing and revenue model in Vienna (2)

Use Case	Actor	Value	Value captured	Revenue Model
Communicate the Urban Planning Process	Citizens	Simulations to improve communication to citizens on project	External: Increased interest by citizens in urban project, Internal: better feedback capturing on urban projects	Free for citizens Internal use in government Costs covered by GeoTwin department

3.4 Outside-Out Urban Digital Twin

3.4.1 Digital Twin Business Model Analysis

The purpose of an Outside-Out Urban Digital Twin is to support the policy making of government by including the ecosystem in the decision process, and also to drive co-innovation, which is oriented to engaging the ecosystem to innovate with the data of the urban Digital Twin. Thus, the Digital Twin is open to the ecosystem. An urban Digital Twin can aid the decision process by **visualizing data in the real world for policymakers and for the ecosystem**, and thus can result in a better **decision process** when it is included in governmental planning, e.g., urban planning, climate change policies, and mobility policies. Opening the city model data for the wider public can also **support innovation in the ecosystem.**

The added value of the Digital Twin is to **gather data** from different governmental sources, **process data** in order to structure the data into a city data model and **visualize the data** in a real-world environment. In some cases, the Digital Twins also allow making **simulations** of a policy. The data can also be opened for the wider public to be used in innovative projects.

In the Outside-Out Urban Digital Twin, the city pays for the technological infrastructure and for the structuring and gathering of data. As it concerns public value, the Outside-Out Urban Digital Twin could use governmental funding for the opening of the Digital Twin to the ecosystem. In the future and for some use cases the ecosystem could also be paid for data by other actors in the ecosystem if the value mainly returns to them.

In this scenario, the **data source is from the data ecosystem**, which combines data from governmental data sources, satellite pictures, laser beams, Building Information Management (BIM) data, point clouds, and other geodata such as telecom data, traffic data, and energy data. The data is often generated and collected by the government, and when needed **purchased from private companies**. In case when the government only has a license to use the data purchased from public procurement, it would be considered an Outside-Out Digital Twin. The data can also be obtained from the ecosystem, which could be done through a marketplace or through the engagement of different actors in the ecosystem. The ecosystem is the owner of the data and thus also controls the data, and who can access the data. This means that the actor can own the data and can decide which data will be opened for the Digital Twin, under which conditions. In this case, the different actors need to decide for themselves which data can be **open, and which data cannot be shared with the wider public**.

The control of the technology used to develop the Digital Twin is controlled by the government but could be transferred to the ecosystem if this would be required in later stages. The government is often the initial innovator due to the investment requirements. In most cases, they **combine different open-source software** into what is required for a Digital Twin. Similar to the Inside-In and Inside-Out Urban Digital Twin, the cities prefer not to purchase proprietary solutions.

3.4.2. Digital Twin: Rotterdam and Örebro Digital Twin

The Rotterdam (Netherlands) Digital Twin aims to integrate changing city dimensions from a social and physical construct towards a social, physical, and digital construct. The urban Digital Twin aims to integrate a digital view of the reality of the city, serving as the base for smart solutions. Therefore, it aims to set up the **digital infrastructure for a data ecosystem** in Rotterdam to bring different actors together through the Digital Twin and the open urban platform by sharing data within the ecosystem. The Örebro Digital Twin aims to set up a data ecosystem called Linked Örebro, which is still under development. The Digital Twin is mainly used to engage the ecosystem, with different use cases. It engages with the ecosystem, as it provides **data insights for different players in the ecosystem** to make their own decisions (e.g. information on building permits, support the firefighting department to indicate emergencies,...), and to engage citizens in participation in urban construction processes (an AR application on construction sites, citizen participation by allowing to give feedback on plans). Some use cases of the Rotterdam Digital Twin also fit under the type of the Outside-In Urban Digital Twin, as it is also used for the government to make **policy decisions** (a flooding simulation use case) in an internally governmental use case.

The main use cases in Rotterdam (see table 7) are the ability to **provide feedback on building, visualise citizen projects and participation.** The value is created externally to the citizens, as the citizen can provide feedback and receive feedback on projects in the city, and they can also engage more with the digital twin. For the government, this can improve decision making, improves processes and reduces cost for future use cases. As the use is primarily **provided for free to the citizens**, the **revenue model is based on creating internal value** and use without a direct financial exchange. The costs are covered from the Digital Twin department paid from **governmental funds**.

Table 7: Use case value proposition, capturing and revenue model in Rotterdam

Use Case	Actor	Value proposition	Value captured	Revenue Model
Building Permits	Citizens who want to request a permit	Quick feedback on whether a citizen will receive a permit	Citizen: quick feedback Government: reduced governmental time spent , better service	Free for city Costs covered by Digital Twin department
Visualise citizen building projects	Citizens with a building project	Visualise the building project in the 3D model of the city	Citizen: Better idea on what the project will look like in real life Government: Create excitement about city 3D model	Free for citizens. Costs covered by Digital Twin department
Participation	Citizens who want to give feedback on urban project	Informing citizens about urban development projects	Citizen: Better visualisation of the city project Government: Improved decision making, receive feedback from the citizens	Free for citizen Costs covered by Digital Twin department

In Örebro (Table 8), we can observe two similar use cases. In the building permits use case, citizens also might be able to get feedback on their own plans if they would request building permission, by adding their own file and to receive whether it conforms to the urban plans made by the city. This use case is free for the city, but it can reduce governmental time spent on a better service delivery. In another use case, geodata is coupled from different (internal and external) data sources to improve urban planning. The goal is also to include building companies, architects, as it can help to create a common spatial view on the buildings in the urban space. The coupling of the data reduces the data costs for future and can improve urban planning. It is an internal use case by the government, and also brings value for the stakeholders. The main costs are covered by the government, but some actors could potentially have to pay for access to the data.

Table 8: Use case value proposition, capturing and revenue model in Örebro (2)

Use Case	Actor	Value proposition	Value captured	Revenue Model
Building Permits	Citizens who want to request a permit	Quick feedback on whether a citizen will receive a permit	Citizen: quick feedback Government: reduced governmental time spent , better service	Free for city Costs covered by Digital Twin department
Coupling geodata for simulations in urban planning	Building companies, city architects, urban planning	Create a common spatial view op buildings, … to improve urban planning	Reduced costs to structure data for future use cases Improved urban planning	Internal use in government and external by stakeholders Costs covered by Digital Twin department Actors could pay for access to data

The added value of the Digital Twin is to **gather data** from ecosystem players, **process data** in order to structure the data into a city data model and **visualize the data** in a real-world environment.

Rotterdam aims to set up a data ecosystem called the **Open Urban Platform, and Örebro the platform "Linked Örebro".** In these data ecosystems, the added value of the city is to connect different actors, to develop the platform, to own the platform, and to invest in the initial stages. After the first phase of setting up the platform, it might be transferred to the ecosystem itself. Once the platform is operational, the city and the data ecosystem will be able to act as a data provider, developer, user, and customer of the digital data ecosystem. Thus, the data sources of the urban Digital Twin will be governmental data, as well as data from the data ecosystem gathered from the open urban platform.

The city of **Rotterdam aims to not be dependent on the platforms of large companies** and wants to remain in **control over the technological infrastructure and the used standards** of the Digital Twin and open urban platform. They develop **Minimal Interoperability Mechanisms (MIM)** based on open standards consisting of a marketplace, the Digital Twin, an API strategy, data storage, privacy, metadata, and a governance model.

3.5 Outside-In Urban Digital Twin

3.5.1 Digital Twin Business Model characteristics

The purpose of an Outside-In Urban Digital Twin is to support **policy making of government**, which is oriented purely on the internal governmental decision process. Thus, the Digital Twin is not open to the ecosystem. A Digital Twin can aid the decision process by **visualizing data in the real world for policymakers**, and thus can result in a better **decision process** when it is included in governmental planning for e.g. urban planning, climate change policies, and mobility policies.

In the Outside-In Urban Digital Twin, the city pays for the technological infrastructure and for the structuring and gathering of data, as the value also returns to the city.

In this scenario, similar to the Outside-Out Urban Digital Twin, the **data source is from the data ecosystem**, which combines data from governmental data sources, satellite pictures, laser beams, Building Information Management (BIM) data, point clouds, and other geodata such as telecom data, traffic data, and energy data. The data is often generated and collected by the government, and when needed **purchased from private companies**. In case when the government only has a license to use the data purchased from public procurement, it would be considered an Outside-Out Digital Twin. The data can also be obtained from the ecosystem, which could be done through a marketplace or through the engagement of different actors in the ecosystem. The ecosystem is the owner of the data and thus also controls the data, and who can access the data.

3.5.2. Digital Twin: Örebro and Rotterdam

Some of the use cases of Örebro and Rotterdam could fit within the Outside-In Urban Digital Twin. If the data is obtained from the data ecosystem, and the Digital Twin is used for governmental decision-making, it could be an example of an Outside-In Urban Digital Twin. Within the five investigated Digital Twin cities, this type of Digital Twin was less prevalent, even though Örebro and Rotterdam might exhibit some relevant characteristics in some use cases. In Örebro this could be the case in the future, when the Linked Örebro data ecosystem will serve as a data input for the Digital Twin, for use cases related to urban planning. In the case of Rotterdam, this is the case for e.g., the flooding simulation use case when it is used for making governmental decisions based on the data.

The main use case in Rotterdam (see table 9) is to warn the emergency services in case of an event. This increases the response time, which will improve the emergency services for the citizens who are in danger. The service is free for citizens, who will cover the main costs for the services is unclear at this moment but could be brought back to the emergency services who want to improve the services, or the Digital Twin department who is developing the Digital Twin. The costs are covered from the Digital Twin department paid from **governmental funds**.

Table 9: Use case value proposition, capturing and revenue model in Rotterdam (2)

Use Case	Actor	Value proposition	Value captured	Revenue Model
Flooding: Safety Warning Use Case	Firefighting department, Emergency services	Quick information for emergency services on when intervention is required	Citizen: quick response in emergency Government/ emergency: quick response time, improved communication	Free for citizen Costs covered by Digital Twin department (?) Emergency services (?) [4]

[4] The actor that would cover the costs could not be validated at the time of the deliverable with the city of Rotterdam

In Örebro, one use case is to visualise sensor data in order to improve among other governmental services, such as improved traffic lights. This is useful for the traffic management department and other governmental actors, which could help to adapt traffic lights based on the traffic. This could provide benefits for traffic flow and improve services. This service would be paid by the government.

Table 10: Use case value proposition, capturing and revenue model in Örebro (3)

Use Case	Actor	Value proposition	Value captured	Revenue Model
Visualising sensor data (real-time) (e.g. improved traffic lights)	Traffic management Other Governmental actors	MConnect data based on traffic to adapt traffic lights	Improved traffic Improved decision making Improved governmental services	Internal use in government Costs covered by Digital Twin department

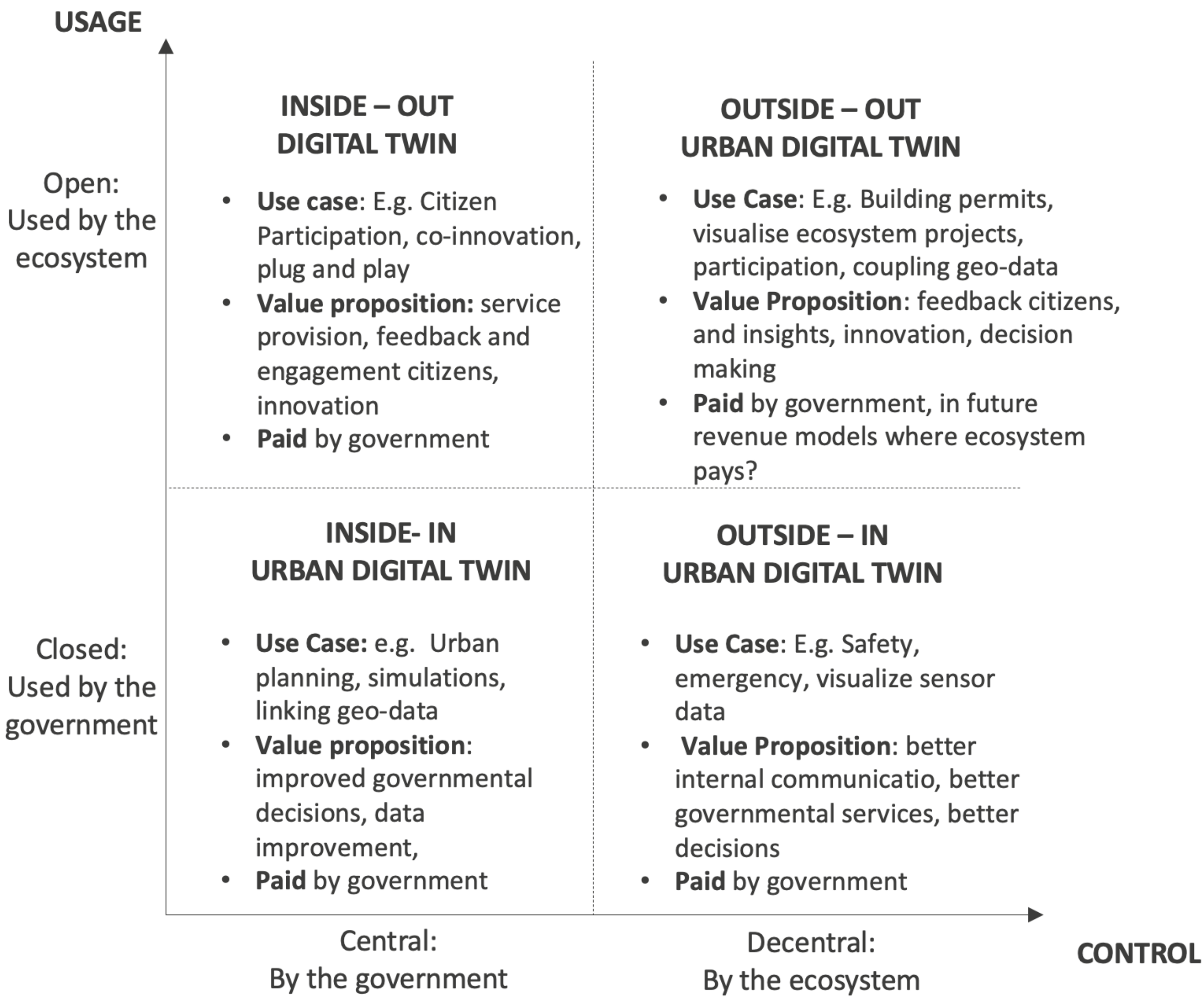
3.6 Value Proposition and revenue model of Urban Digital Twins

The figure 3 provides an overview of how the different Urban Digital Twin types create value.

The **value is internal (for the government) in the Inside-In and Outside-Out urban Digital Twin**, and can concern improved governmental decisions, improve the data in the government, improve the communication, improve governmental services. In these cases, the Urban Digital Twins will always be paid by the government, as it can provide internal value. Thus, governmental departments will allocate budgets in order to reach their policy goals.

In the cases of the **Inside-Out and Outside-Out Urban Digital Twin, the value can be internal (for the government) and external (to the ecosystem)**. Internal value can be a better service provision, reaching policy goals, improvement engagement and feedback of citizens. External value (for the ecosystem) can be for the citizens (to improve their decisions and get information and provide feedback) or by NGOs, companies in order to provide a better service offering to their customers. In these cases, in most of the Urban Digital Twin the government mostly still pays for the Urban Digital Twin, as it is used to reach their policy goals. In the future alternative revenue models could be identified when value is created for alternative stakeholders who would receive sufficient value to be willing to pay. In some cases, this could be for access to data, for a better service delivery or for access to use the Urban Digital Twin infrastructure (such as in the Plug and Play example).

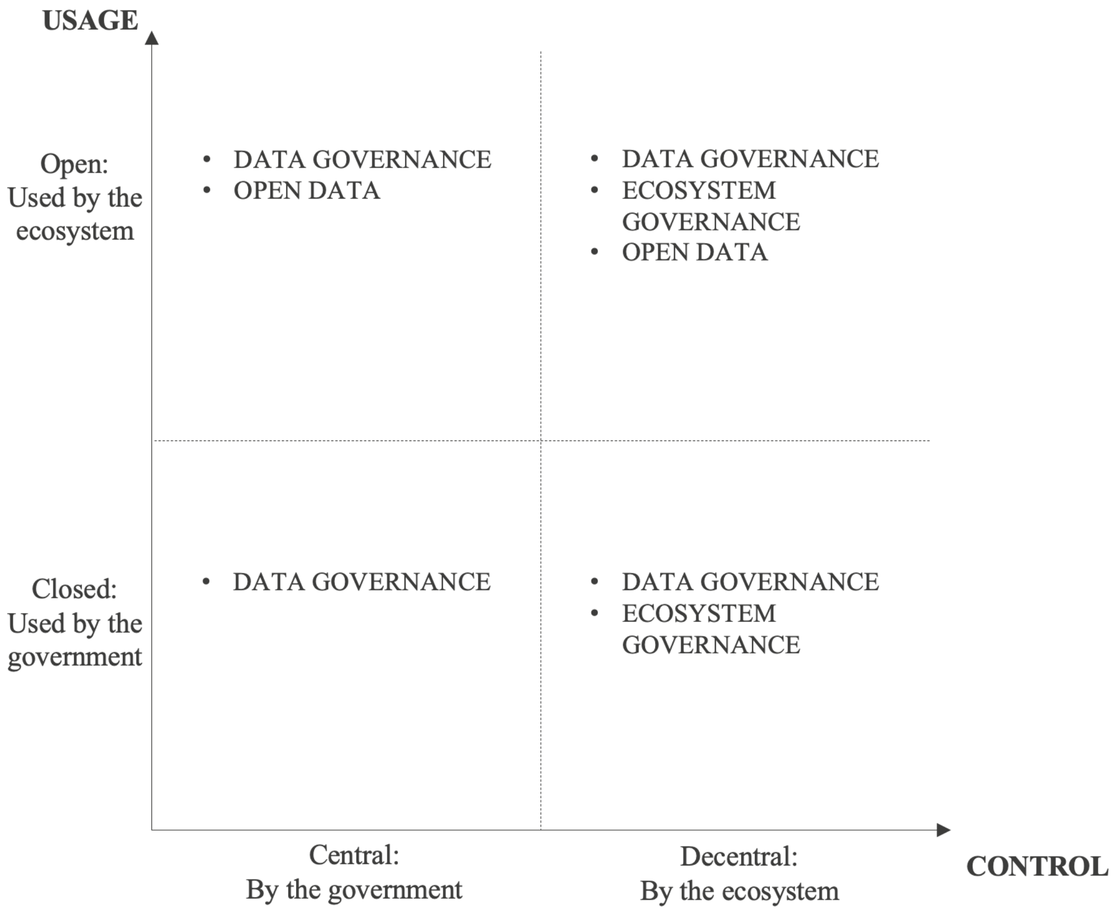
Figure 4: Value creation and capturing in Urban Digital Twins



4. Urban Digital Twin challenges in the business model scenarios

Based on the business model scenarios, different challenges can be identified in each type of Urban Digital Twin (figure 4) throughout the interviews with the Digital Twins and the DUET experience. The basic challenge, which is the core for each business model scenario, is **data governance**. Having a structured information model and data governance is a key component of the entire Digital Twin development and is thus a challenge which is a basic requirement for its development. When the **data is opened to the ecosystem**, decisions need to be made on which data can be shared with the ecosystem, and which data not. When the ecosystem is controlled by the ecosystem, and the data input is performed by the ecosystem, another challenge arises regarding **ecosystem governance**. The different challenges are discussed more in depth in the following sections 4.1 Data Governance, 4.2 Open Urban Digital Twin and 4.3 Ecosystem Governance.

Figure 5: Urban Digital Twin challenges



An overview of these challenges is shown in Table 11.

Table 11: Summary of challenges in Urban Digital Twins

Type of Challenge	Challenge	Description
Data governance	Organization	Establishing new workflows and collaboration between different departments
	Digital Twin infrastructure and vendor lock-in	The cities require a Digital Twin infrastructure. Yet, the trade-off on whether to develop services themselves vs. to purchase services internally is challenging.
	Data Availability	Structuring data and ensuring the quality of data
Open Digital Twin	Classification of data	Classification of data in data which is open and closed
	Identity Management	Identify who can access the data
Ecosystem Governance	Role of government	From a passive to an active role in the ecosystem
	Trust	Governance models to ensure trust in the ecosystem
	Collaboration model	Collaboration models regarding data ownership, access, and standards within the ecosystem

4.1. Data governance

Organization

The collaboration between and within departments is one of the major challenges when developing a Digital Twin. The shift towards an urban Digital Twin requires a cultural change. It requires not only to adopt new technology but also to adopt entirely new ways of working with completely different workflows compared to the past. New workflows are required in order to link the data and the databases, we have to establish a novel system. It also requires collaborating with different departments who are not always willing to adapt their current way of working, and they need to be convinced to change their workflows and to adopt the new standards. Additionally, new competencies are required which might currently not be present in the city.

Digital Twin architecture and the risk of vendor lock-in

The data needs to be structured into a novel city information model, but there are **no standards yet to implement this**. CityGML is the only **standard** for city models, but it is not complete, and not all the standards of 3D classification are ready as there are no international standards yet. Additionally, there is no software yet which can cover the whole range of CityGML definitions.The different Urban Digital Twins are concerned about which cloud and other technological services to purchase at which providers. They are very aware of the threats of vendor lock-in. Most Urban Digital Twins aim to not be dependent on the platforms of large companies and want to remain in control over the technological infrastructure and the used standards of the Digital Twin and open urban platform. Yet, when these components are developed in-house, this leads to a considerable amount of time and effort spent on developing their own infrastructure and reduced economies of scale.

Data availability and quality

A lot of the data that needs to feed into the architecture is of l**ow quality and is unstructured data** that is spread in the whole organization in different departments. It requires a lot of manual work and collaboration between the entire organization to structure the data. In some cases, the data does not exist or is not qualitative enough and needs to be purchased.

4.2 Open Urban Digital Twin

Classification of open data

In order to open data, a **classification of data** is required which determines which data can be **opened**, and which data needs to remain **closed.** This depends on the confidentiality, correctness, and availability of the data. This depends also on the type of data, as **governmental data** is often seen as data which needs to be 'as open as it can be', whilst some data can be too sensitive to share (e.g. in the case of water piping data this can only be shared on a certain LOD level). In the case of commercial data, the sharing of the data depends on the conditions of the company. In the case of personal, privacy-sensitive data this needs to comply with the GDPR, and some cities even require to set up an ethical commission which needs to determine whether the data can be shared based on what will happen with the data and which data is required.

Identity Management

The **identity management** of the data determines who can access the data, and who can share the data. The city also needs to be able to control what happens with data on the level of the data source.

Open Data Standards

Often data can be opened by cities or companies but in formats unreadable for the entity who wants to utilise the data, or it might require licences to specific software which is not utilised by everyone and is therefore not useful. Therefore, there is a need for agreements on open data standards for opening Digital Twin data. Additionally, there is no (national or international) standard yet on visualization rules of 3D data. When offering 3D data models on a public 3D Digital Twin, a city has to come up with their own rules to make the data visually understandable to prevent wrong interpretations.

4.3 Ecosystem governance

Governance Model

Working with a completely different model which gives more control to the ecosystem, requires a drastically changing role of the government. It needs to move from a more passive role towards taking an active role in the ecosystem and positioning the government and the data ecosystem actively. It requires a governance model for the ecosystem and a role definition for the government. Different activities will be required to facilitate the supply and demand of data in a marketplace, and additional services (such as data storage, geocoding...). Additionally, there is a role for marketplace governance who guards the balance between the commercial exploitation and the societally responsible behaviour of actors in the ecosystem. Additionally, when the Urban Digital Twin is offered to the ecosystem as an infrastructure for the end users, questions arise on who gains value, who adds value and who owns the results of the outcome of the Urban Digital Twin. Therefore, when opening the Digital Twin to the ecosystem there can be questions on what the role of the city government, beneficiaries and contributors of the Urban Digital Twin are.

Trusted data ecosystem

A Urban Digital Twin with a surrounding data ecosystem needs a governance model which ensures trust in the ecosystem. The data ecosystem needs to be willing to open the data, require clear data ownership rules, which ensure control over the data resources, and to set up conditions based on which the data can be shared. The trust between the data ecosystem is according to the interviewed Digital Twins one of the largest challenges to be overcome in the Outside-Out and Outside-In urban Digital Twin. In order to set this up, collaboration models need to be set up regarding the ownership of data, access to data, and open standards adoption by the ecosystem.

4.4 Cloud Business Requirements

Based on the challenges addressed in 4.1, 4.2 and 4.3, this section aims to translate these challenges into cloud business requirements. Some of the challenges the Urban Digital Twins face relate to the governance of the data, of the organisation within the cities and of the ecosystem around the Urban Digital Twin. These challenges cannot be addressed through Cloud Solutions, and require **internal solutions performed by the city.**

Other challenges can be seen as **requirements for Cloud solutions for Urban Digital Twins**. Thus, DUET could provide technological cloud components which would enable the cities to focus on their internal challenges. In the centralized model where the government controls the data, the data will be gathered from different internal cloud servers which can be seen as internal data silos within the government. If it is gathered in a decentralized model where the data is controlled by the ecosystem, it will need to combine the access of data among different data silos in the ecosystem. Due to these silos, both in the centralised and decentralised models, cloud solutions can provide a solution for the cities. The main challenges that can be addressed through cloud solutions are:

Table 12: Cloud business requirements

Challenge	Description	Requirement
Data Availability and Quality	(Internal and external) Data silos	Cloud Native Brokers
Standardisation of data and 3D modelling	Unreadable formats and licenses which are not readable. No 3D standards yet.	Harmonisation of the data
Digital Twin Infrastructure without risk of vendor lock-In	Digital Twin infrastructure which reduces the risk of vendor-lock ins	Provide tools to develop the Digital Twin internally. Provide tools (standardisation, procurement, exportation of the data) to avoid vendor lock-in

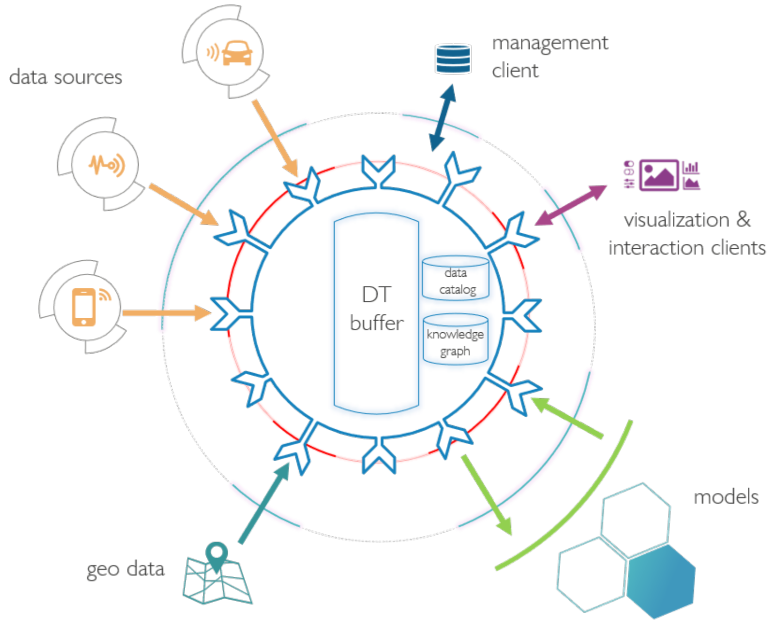
Several initiatives such as GAIA-X[5] could provide an offering to the European market which will also be useful in the Cloud Strategy of Urban Digital Twins. Additionally, policies and programs such as Schrems II[6], EU Cloud Rulebook[7], the (proposal of the) Data Governance Act[8] provide a framework to overcome these challenges and need to be followed up.

Within DUET, these requirements will also be partially taken into account by developing different (technical) cloud tools as part of the cloud platform which can help the cities to address these requirements, such as those described below. The core DUET components are connected in the "DUET T-Cell", which is a cloud-based platform which aims to support Urban Digital Twins to connect with h external systems like IoT data sources, models or apps, through a set of specialised Gateways, and is elaborated on in D5.1. System Architecture & Implementation Plan These core components constitute the "DUET T-Cell", (Figure 5).

- A set of Gateway components that lay on the edge of the DUET cell and control the data flow in and out of the cell
- A message streaming platform that allows components to exchange data and events in an asynchronous manner
- A data catalogue for registering different kind of data sources
- A management module that controls the users, access rights and various configurations of the DUET platform

[5] https://www.gaia-x.eu/pdf/Gaia-X_Architecture_Document_2103.pdf
[6] https://www.europarl.europa.eu/RegData/etudes/ATAG/2020/652073/EPRS_ATA(2020)652073_EN.pdf
[7] https://digital-strategy.ec.europa.eu/en/policies/cloud-computing
[8] https://digital-strategy.ec.europa.eu/en/library/proposal-regulation-european-data-governance-data-governance-act

Figure 6: The DUET T-Cell Architecture

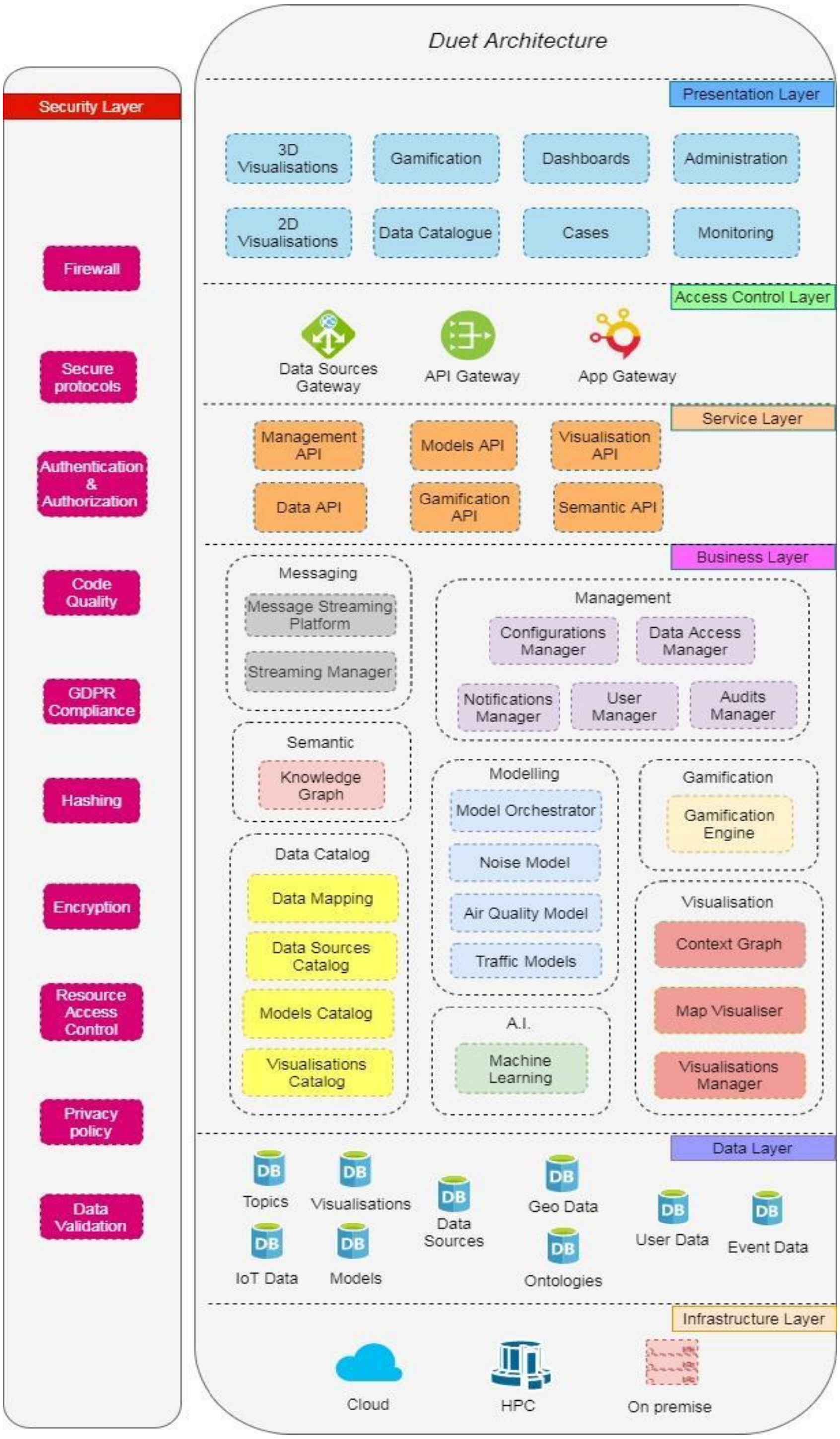


The DUET platform follows a layered architecture pattern (figure 6), thus the system's components are divided into multiple distinct layers, each responsible for a specific set of functionalities. By convention, the layers interact with each other in a top-down manner, with each layer being able to access all layers below.

The layers are described as follows:

- **Presentation Layer:** Contains all the User Interfaces and Visualization Modules that help the user to get all the information that the DUET platform offers in an easy (self-explanatory), efficient, and enjoyable (user-friendly) way.
- **Access Control Layer:** Contains all the necessary Gateway components, for controlling the data flow in and out of the platform
- **Service Layer**: The layer that exposes the core components' functionalities as a set of APIs
- **Business Layer:** It encapsulates all the business logic of the system that tackles the user needs.
- **Data Layer**: This layer consists of the logical set where all the heterogeneous data sources are archived. It is comprised of repositories holding information about the events of the system, the data sources, the ontologies, the users etc
- **Infrastructure Layer:** It consists of the physical or virtual servers of the platform and the relevant supporting tools.
- **Security Layer**: A vertical layer that implements the necessary security measures for all the other layers

Figure 7: High level architecture of the platform



This provides a solution for the Cloud Business requirements which are discussed below. More specifically, in each challenge, we make the connection with a specific DUET component which provides a potential solution.

Cloud native brokers

In order to connect data sources, a digital component which connects data sources of cities (internally) and with data sources of the ecosystem (externally), which are called cloud native brokers. They can be seen as APIs which will configure and connect the different infrastructures. In the City of Things in Antwerp, a "context broker" has already enabled digital twins to connect different data sources, among others in a water use case[9]. The context broker enables the digital twin to send and receive data in a structured way, which ensures readability.

Within DUET, the **Data Source Gateway** which is mainly responsible to control the data flow from the IoT sources will be developed. The Data Sources Gateway consists of a set of specialised connectors based on the type of data exchanged, that receive data from IoT sources and forward the data to the Message Streaming Platform of the DUET system (more information in the DUET D5.1).

Harmonization of data

Harmonization of data requires building standards of data (inter)nationally, to ensure all the data is structured in the same way. Microsoft and OASC have set up a Minimal Interoperable Mechanism (MIM) together as a Digital Twin Definition Language (DTDL)[10][1] for models, not exclusively for Azure Digital Twins.

Within DUET, the **Knowledge Graph** will be developed which contains a formal semantic definition of data offered through the registered data sources and as such may assist in providing validation components to ensure that published data conforms to these definitions. It makes the information offered through the data APIs searchable and allows the creation of a navigable structure on top of registered data sources (more information in the DUET D3.8).

Vendor lock-in versus Developing own solution

Different Digital Twins aim to develop their own solutions running on cloud solutions, as they do not want to depend on the proprietary solutions of large Chinese or American solutions. They do this to keep control over the data and the solutions. Yet, this poses different challenges, as it reduces the economies of scale, as the city might not be the best player to build these technologies themselves. Cloud solutions are required which reduce the vendor-lock in effect, and still ensure economies of scale. As an example, GAIA-X aims to achieve a distributed type of ownership across different actors in an independent way. Thus, actors can collaborate around in a decentralized/federated ecosystem.

Solutions in DUET that could be developed can deal with these challenges in two distinct ways:

1. To provide cities with **enabling tools to build an Urban Digital Twin** themselves to achieve economies of scale

Cities can use tools that DUET deploys in its cloud based platform. This concerns modules that can store and edit data, such as:

[9] https://www.imeccityofthings.be/nl/blog/schaalbare-architectuur-voor-internet-of-water-flanders

[10] https://docs.microsoft.com/en-us/azure/digital-twins/concepts-models

- The Data Catalogue: The Data catalogue is the main metadata repository and a key component of the project. It provides to the users all the necessary interfaces that allows them to register their data sources, models and visualisations. It also offers to the system, mapping capabilities between different interpretations of data (more information on D5.1 and D3.1)
- The User Manager: The User Manager provides authentication and authorization mechanisms based on Json Web Tokens. This includes different functionalities for users such as user registration, user profile editing, role and user group definition and user assignment which also support in permissions definition (more information on D5.1 and D3.1).

In general, the DUET components are being implemented in such a way that are not dependent on cloud providers and tools i.e., Azure, keycloak, CKAN etc. For each tool there is a provided connector or a new one is needed to be implemented, without however affecting the basic functionalities of the components and UIs.

2. To provide cities, if they decide to work with a vendor, with **tools to avoid vendor lock-in**

To avoid vendor lock-in, technological tools will most probably not be sufficient. Cities need tools to arm them in negotiations with technological providers. This is currently not developed in the project DUET. Different tools could be:

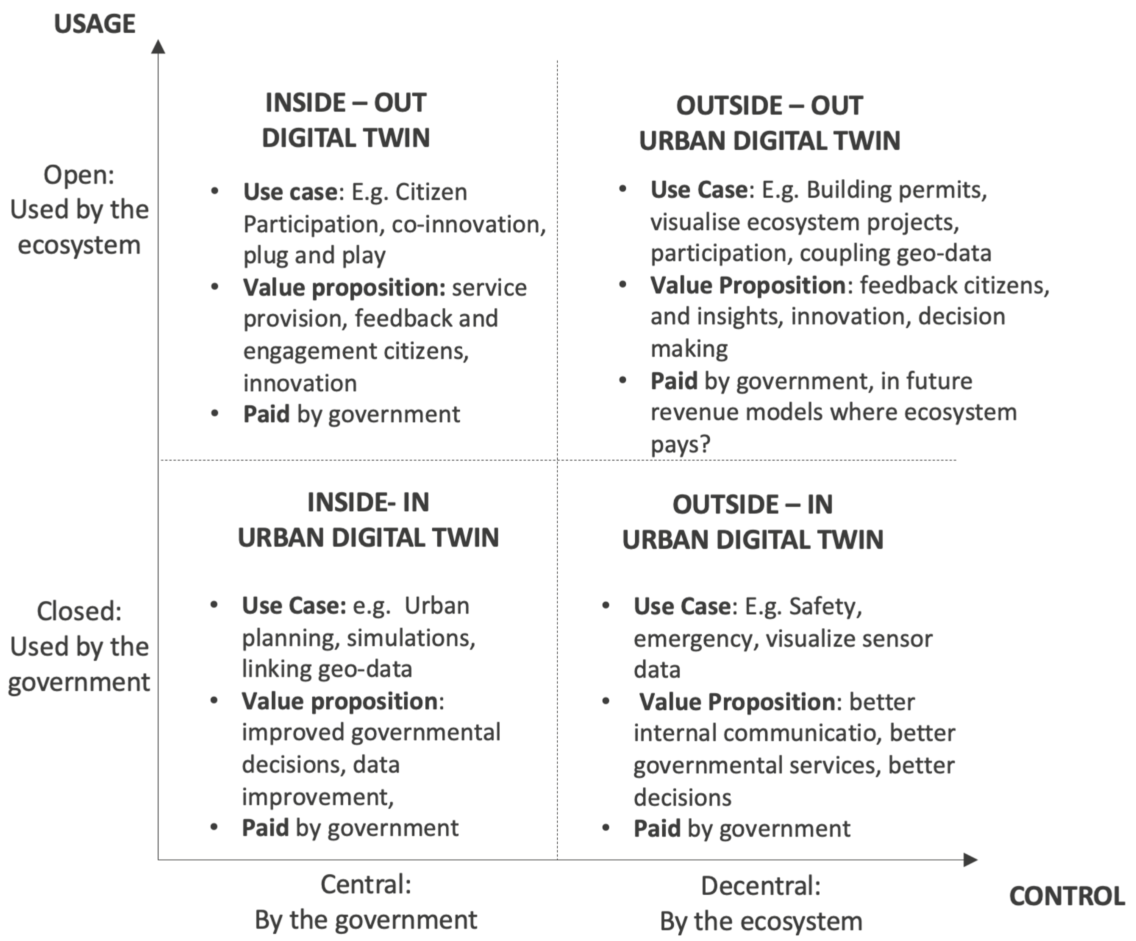
- Support to write tender with conditions which avoid vendor lock-in. This way the cities can include these documents in negotiations with technology providers. This could include a clause which requests technology providers to ensure data export functionality, which ensures that governments can easily change towards another provider.
- Standardisation and harmonisation of the data (see above in other requirements)

5. Conclusion

The outcomes of the Cloud Based Business Model analysis can be utilised in DUET in two distinct ways, from the perspective of the pilot cities and Urban Digital Twins, and from the perspective of Cloud Solution providers.

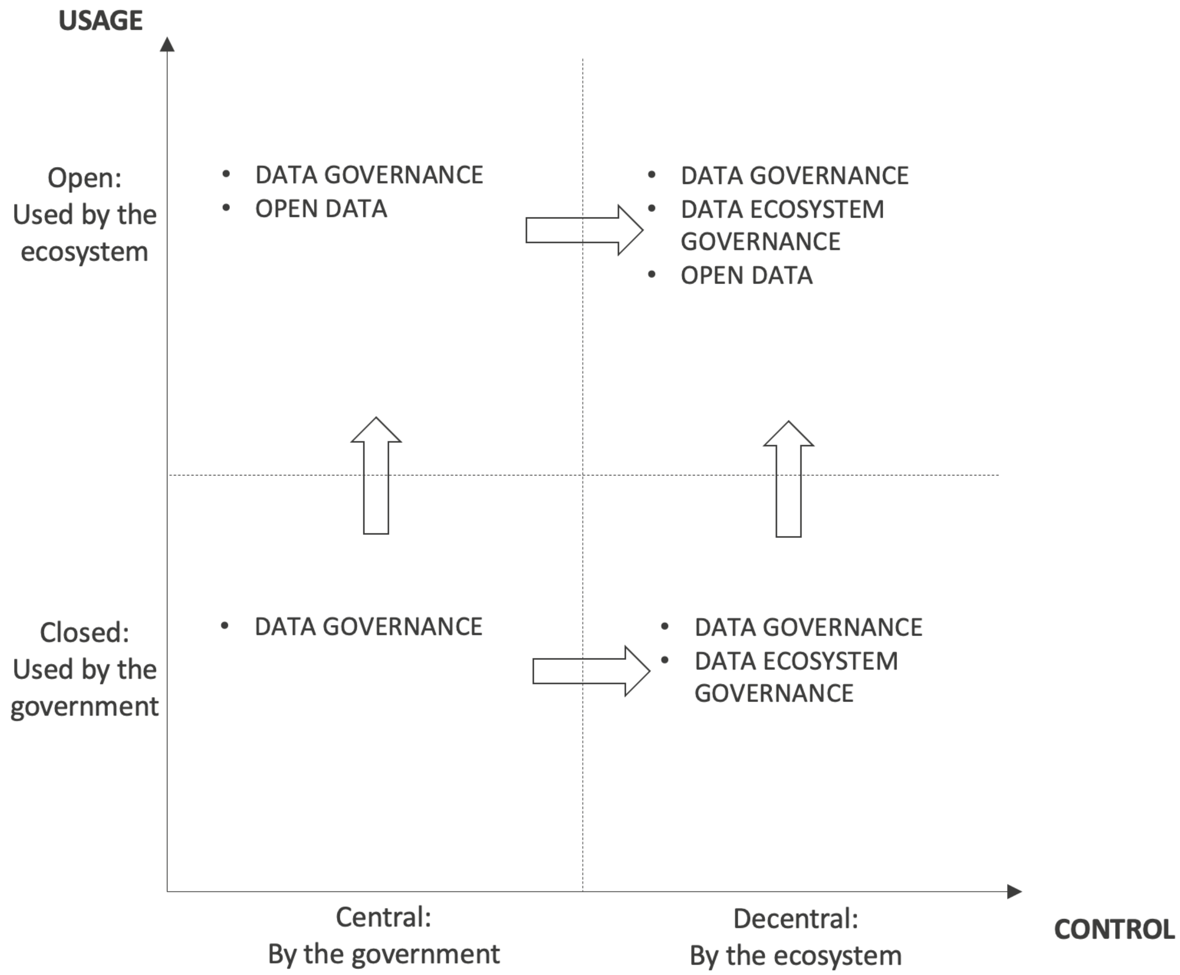
First, **for cities**, the Business Model Analysis concluded that cities have a **choice between different types of Digital Twins (Inside-In, Inside-Out, Outside-Out and Outside-In**), which all have a different (data) business model. This choice depends on the desired purpose, the data that needs to be included in the Digital Twin and the maturity of the Digital Twin. The four types of Digital Twins can co-exist, as it depends on the use case and not on the city. Thus, in one city there can be the need for both an Inside-In Digital Twin for policy purposes, and an Outside-Out Digital Twin for ecosystem purposes. The value can be created internally for the government (in the Inside-In and Outside Out Digital Twins), and in these cases the government also pays for the Digital Twin. In the Inside-Out and Outside-Out Digital Twin, the value can be internal (government) and external (for the ecosystem). In most of the cases, the government pays for the development and services from governmental funds, but in the future alternative revenue models could be identified where actors in the ecosystems (such as citizens, companies, NGOs...) would also pay for the use of the Urban Digital Twin infrastructure, for the access to the data or for the results.

Figure 8: Use cases, value proposition and revenue models of Urban Digital Twins



This business model typology for Urban Digital Twins can be seen as a Maturity Model (figure 4) which showcases the exploitation scenarios of a Digital Twin, and these can guide the implementation process, as the chosen type has a major impact on the design of the Digital Twin. The Urban Digital Twin Maturity Model will be used in task 7.4 as guidelines for the exploitation models of the pilot sites of DUET, and to identify the exploitation roadmap of the Urban Digital Twin.

Figure 9: Urban Digital Twin Maturity Model



The different challenges differ based on the different types of Digital Twin. The common challenge of any type of Urban Digital Twin is, based on the interviews and the DUET experience, the data governance (organisation, inclusion of data sources, structuring data, overcoming data silos...), and this is the foundation for developing the Digital Twin. Once the data governance is set in place, a next challenge can be to open up the data to the entire ecosystem in the case of the Outside-Out and Inside-Out Digital Twin. When the data supply and control of the data includes increasingly the ecosystem in the cases of the Outside-Out and the Outside-In Digital Twin, another new challenge is the governance of the ecosystem, ensuring trusted data ecosystems and ecosystem governance models.

The models for who is responsible for paying for the Urban Digital Twin are currently not that complex, as in the current situation it concerns mainly governmental funds. In the future, and mainly for the Outside-Out and (to a lesser extent) the Inside-Out Digital Twin, the value returns to the ecosystem. In these cases, other business cases might arise. These business cases will be investigated more in depth in task 7.4 in Deliverable 7.6 on the Exploitation and Commercialisation Strategy of DUET.

Second, for Cloud Solution Providers, the outcomes of the business model analysis shows different **Cloud Business Requirements** which can be developed by DUET. Some of the challenges the different Urban Digital Twins face can be related to the cloud strategy, as different components will need to be developed in order to facilitate the development of the Digital Twins. Therefore, main components are the **harmonization of data, cloud native brokers and the support in moving away from vendor lock-in challenges**. This could be solved through technological solutions which will be developed within DUET, such as a Data Source Gateway, Knowledge Graph, Data Catalogue and/or User Manager. The exploitation of these technologies will be further explored in task 7.4 on the Exploitation and Commercialization Strategy.

Going forward, these insights will need to be taken into account in DUET, because the maturity model (for cities) provides a crucial guideline in determining an exploitation and commercialization strategy for cities. For the Cloud technological solutions, it will also need to investigate how DUET will position themselves in the Urban Digital Twin ecosystem. Therefore, the insights will provide the basis for the task 7.4 on the Exploitation and Commercialization strategy. Deliverable 7.6 on the Exploitation and Commercialization strategy is a first iteration on the maturity Model, and at the end of the project an iteration will be given which explores the potential for commercialization of the project outcomes.

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6. Annex

Annex 1: Overview Digital Twins

Name	Country	Purpose
Chesapeake Conservatory	US	Conservation Innovation Center (CIC) was established in 2013 to use cutting-edge technology to empower data-driven conservation and restoration of a watershed
CityFlows	Flanders, Belgium	CityFlows visualises flows of cars, pedestrians, cyclists... in the city by fusing mobility-related data streams.
Digital Twin Antwerpen	Flanders, Belgium	Forecasting of certain scenarios on traffic, noise and air quality can be predicted in advance with the use of various sensors in the city
Helsinki 3D models	Helsinki, Finland	The city information model allows users to perform a variety of analyses focusing on energy consumption, greenhouse gases or the environmental impacts of traffic
Kalasatama Digital Twin	Finland	The Digital Twins are part of the Smart Kalasatama project which is a platform for innovation and development. In the project, an online platform for activities in Kalasatama and interaction with the residents was built on the 3D model platform.
Welltown Virtual Wellington	Wellington, NewZealand	New Zealand's capital is transformed into the world's first virtual city that you can explore and play as a game.
Virtual Singapore	SIngapore	Government department that offers 3D semantic modelling, in which the meaning of data can be related to the real world, displaying land attributes or the characteristics of different forms of transport, or the components of buildings and infrastructures.
Brisitsh National Digital Twin program	UK	Enable a National Digital Twin – an ecosystem of connected Digital Twins to foster better outcomes from our built environment;
Victoria Digital Twin	Australia	The Digital Twin replicates the real-world Fishermans Bend in a digital format. It supports 4D modelling of a physical asset's design and condition, enabling better decision-making on the management of existing and future infrastructure.
Amaravati Digital Twin	India	New smart city development with an ntire Digital Twin with environmental monitoring, mobility, climate, permit, ...
3D Rotterdam	Nederland	Developing a Digital Twin of the physical city. The primary aim of 'Digital City Rotterdam' is to improve the efficiency of urban planning and management. But at the same time, the city council is on the lookout for applications that will help people integrate the digital world into their real on
Port of Rotterdam Digital Twin	nederland	Real-time access to information enables the Rotterdam Port Authority to better predict visibility and water conditions. It helps lower fuel consumption rates, facilitate cost-effective per-ship payloads and ensure the safe arrival of cargo. All in all, it makes a world of difference.

Newcastle Digital Twin	UK	Computer replica of an entire city will allow experts to perform real-time resilience testing to see how its infrastructure will perform in the face of challenges such as climate change and population growth.
Sphere BIM Digital Twin	Pilots in Austria, Finland, Italy, Netherlands	Demonstrations in 2 new buildings and 2 renovation residential buildings in Finland, Austria, Italy, and the Netherlands. By integrating the platform into the operations of SME contractors, large construction firms, and end-users, we will be able to accurately evaluate performance, obtain real-time feedback, and powerful exploitation.
Virtuella Gothenburg	Sweden	Digital Twin of Gothenburg (under development)
Ecocraft	Netherlands	Children can built a minecrat city, and can see the impact their decisions have on the city
Amsterdam 3D	Netherlands	Digital Twin infrastructure to enable users to visualise city data
Limerick CityxChange	Ireland	Digital Twin part of project on climate - buildings/urban planning/ energy
Örebro Digital Twin	Sweden	Digital Twin with IOT data on urban planning, energy ,... with a focus on data sharing/ First version on Digital Tviling
digital geo twin Vienna	Austria	Linking the objects of the Digital geoTwin with further data and infor- mation, e.g. census data, socio economic data, energy consumption data, maintenance management data, etc., a city information model can be built up to serve as basis for a living Digital Twin of Vienna.
Digital Twining Australia	Australia	Service provider which support organisations to develop Digital Twins
LIST Digital Twin	Luxembourg	Nation wide Digital Twin for luxembourg
Living Lab Digital Twin utretch	Nethderlands	The commune of Utrecht and SPOTinfo explore the Digital Twin concept in a Living Lab
Vlaardingen	Netherlands	A Digital Twin linking policy data with open data. The pilot needs to show whether policymakers can get better insight in the consequences of measures on the physical environment
Den Haag	Netherlands	Basic information on buildings, trees, sewage, buildings is shown in 3D.

Annex 2: Topicguide interviews

What is the rationale for the Digital Twin?

- What is the problem the Digital Twin is solving?
- What is the purpose of the Digital Twin?

Data ecosystem of the Digital Twin?

- Who are the actors in the Digital Twin? (based on the preparatory work)
  - Who are the main data providers?
    - Public
    - Private
  - Who are the users of the Digital Twin?
  - Who are the technology/platform providers?

Data availability of the Digital Twin?

- What is the data required for the Digital Twin?
  - What is the type of data? Also sensitive data (personal/commercial)?
- Is the data readily available?
  - What are the main uncertainties regarding data availability?
    - How is the data quality?
    - Is the data interoperable/readable?
  - What are the implications of the business model?
    - How to overcome sensitivity issues?
    - How to overcome quality issues?
    - Interoperability issues?
- What are the main sources of the data?
  - Private vs public
  - What are the main differences in the different public vs private data?
  - What are the implications of the business model?
- Are the actors open to sharing the data for the Digital Twin? Are there any barriers and drivers to share data with the Digital Twin?
  - Are there any requirements for them to be willing to collaborate, and share data?
  - Do they trust the ecosystem?
    - How does the platform overcome the trust issues of the platform?
  - Do they receive value in return? What is the value?
  - What are the implications of the business model? How are the challenges overcome?

Digital Twin role

- What is the role the Digital Twin plays?
  - Which activities does the DT play?
  - How is the DT positioned in the market (neutral, government, private, intermediary)
  - Is the Digital Twin seen as a trusted intermediary?
    - Do data providers trust to share their data? What are the issues?
    - Do data users trust the results of the Digital Twins? What are the issues?
    - What are the conditions for the Digital Twin in order to be trusted?

- What is the revenue model of the DT?
    - Is there any value sharing with data owners/providers?

Digital Twin and the cloud

- How does the DT make use of the cloud?
    - Own data storage, or using the cloud.
    - Are there any challenges? What are important decisions/trade-offs that were needed to be made?
    - What is the impact on the business model?

Conclusion: Summary of the main business model challenges

- What are the main business challenges?
- What are the main uncertainties to design the Digital Twin business model?
- What is the ideal business model for a Digital Twin?