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Development of Digital Twins for Urban Water Systems

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Abstract

Purpose: This paper provides an overview of the emerging concept of digital twins (DTs) for urban water systems (UWS), drawing from literature review, stakeholder interviews, and analysis of ongoing DT implementation at the utility company VCS Denmark (VCS).

Methodology: Within the realm of UWS, DTs are situated across various levels, including component, unit process/operation, hydraulic structure, treatment plant, system, city, and societal levels. A UWS DT is described as a structured virtual representation of the physical system's elements and dynamics, organized in a star-structure format with interconnected features linked by data connections conforming to open data standards.

Findings: This modular structure facilitates the breakdown of overall functionality into smaller units (features), fostering the emergence of microservices that communicate through data links, primarily facilitated by application programming interfaces (APIs). Integration with the physical system is achieved through simulation models and advanced analytics.

Unique Contribution to theory, practice and policy: The paper suggests distinguishing between living and prototyping DTs, where "living" DTs entail coupling real-time observations from a dynamic physical twin with a simulation model through data links, while prototyping DTs represent system scenarios without direct real-time observation coupling, often used for design or planning purposes. Recognizing the existence of different types of DTs enables the identification of value creation across utility organizations and beyond. Analysis of the DT workflow at VCS underscores the importance of multifunctionality, upgradability, and adaptability in supporting potential value creation throughout the utility company. This study clarifies essential DT terminology for UWS and outlines steps for DT creation by leveraging digital ecosystems (DEs) and adhering to open data standards.

Keywords*:* *Digital Twins, Urban Water System, Simmulation Models, Digital Ecosystem, Advanced Analytics*

Introduction

Digital twins (DTs) are currently garnering increasing attention across various research and industrial sectors. This interest arises from the growing emphasis on digitizing production processes and leveraging data through advanced techniques like machine learning and enhanced visualization. DTs offer a means to support and integrate these elements, with high expectations for productivity gains over the next 5-10 years according to the Gartner hype cycle. I tend product lifetimes by not only focusing on product design but also understanding real-world product performance through continuous data transmission to manufacturers during usage. Today, DTs are being explored in diverse fields such as healthcare, meteorology, education, urban planning, and specifically in urban water systems. The latter is particularly crucial due to substantial investments and the potential consequences of incorrect decisions on public health and the environment. For instance, Danish utilities spend billions annually on urban drainage systems, guided by hydrodynamic models that simulate system behavior in various scenarios. However, ensuring model accuracy through calibration is challenging, resource-intensive, and expensive. Limited sensor coverage and staff availability often restrict calibration efforts to short durations and few measurement points, posing similar challenges in water distribution systems, where leakages drive the need for enhanced monitoring and modeling. This paper primarily investigates DTs in urban drainage systems but offers insights applicable to broader urban water systems engineering. In 2008, VCS Denmark initiated efforts to monitor the performance of its urban drainage system through sensor data and automated daily model runs. Initially, this involved visually comparing model results with measurements from an increasing number of monitoring locations (over 300 by 2021, mainly water level sensors, covering an urban drainage system of 2650 km pipes across 11,500 ha). Despite confidence in these models, discrepancies between simulations and reality became apparent. Recognizing the need for better understanding model performance, VCS sought a method to systematically and consistently quantify model performance, aiming for transparency in model quality. VCS views the tools used in modeling as puzzle pieces that do not yet fully align, resulting in a puzzle that does not adequately reflect reality. These pieces include attributes describing assets, various models for runoff and flow, rainfall data driving simulations, and manual procedures for result analysis and updating system attributes. While these puzzle pieces have been improved over the years with tools from various suppliers, they still do not consistently fit together, indicating that the models' value for planning and design falls short of expectations and that the continuous improvement process needs streamlining. Although many years of observation have resulted in reasonably acceptable models, there is recognized untapped potential for greater value from these data and models. To address these challenges, VCS is exploring the concept of Digital Twins (DTs) for urban water systems, a concept detailed in this paper. This application of the DT concept to urban water systems represents relatively unexplored terrain. Specifically, we introduce the term "living DT" for the urban water system context due to the long-lasting nature and significant temporal and spatial changes of underground infrastructure connected to urban transformations, distinguishing it from other application areas.

Creating a Digital Twin (DT) for an urban water system might appear daunting to some, especially considering that many utility companies have yet to extensively deploy sensors within their systems, which are essential for constructing a functional DT. While some utility companies utilize hydraulic models of their systems to a certain extent, these models require enhancements to fully exploit their potential, as discussed earlier in relation to VCS. Despite the challenges associated with developing and maintaining costly models and sensor networks, optimizing the output and generated value is crucial. In this paper, we endeavor to shed light on the multifaceted value that a DT can bring to water utility organizations and regulatory authorities.

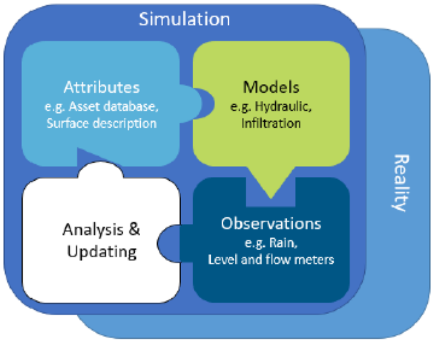


Figure 1. Pieces in a puzzle that illustrates how different elements play together in the simulation process to reproduce reality. Sometimes the pieces do not properly fit.

The objectives of this paper are as follows:

1. Introduce the concept and relevant terminology concerning DTs in urban water systems.

2. Identify the value creation potential for various needs from the perspectives of utility companies and regulatory authorities.

3. Analyze and illustrate the workflow and dataflow involved in constructing and managing a functional DT within the context of VCS, aiming to foster greater international exchange of ideas and experiences.

II. Overview of the Digital Twin Concept

A. *Literature Study*

The concept of DTs has undergone rapid evolution in the past decade, driven by the vision of Industry 4.0 and advancements such as more affordable sensors and faster data processing. Our literature review indicates a significant surge in interest in DTs in recent years, evidenced by a growing number of papers. While research on DTs is prominent in water-related fields, there is a scarcity of structured definitions of DTs. Although scientific papers delve into DTs within water-related research, industries and consulting firms frequently extol the benefits of digital twins in professional publications and on their websites. While some utility companies employ a structured approach to DTs, their findings are often not published in scientific journals, hence not reflected in Scopus statistics. To underscore the widespread adoption of DTs beyond academia, a relative trend analysis of Google searches demonstrates a substantial increase in overall interest in DTs over the past five years.

The VCS Service Area and Utility Organization

VCS, a water and wastewater utility company situated in Funen, Denmark, serves a service area covering 757 square kilometers in the lowlands, predominantly below 80 meters above sea level, with the majority below 40 meters above sea level. The region experiences an average annual rainfall of 700 millimeters. VCS is responsible for producing and distributing 10 million cubic meters of water annually. However, there are other private water firms supplying water to settlements outside the major urban centers within the service area. VCS oversees stormwater and wastewater management for approximately 230,000 residents and industrial facilities in the municipalities of Odense and Nordfyn, which are the owners of VCS. These municipalities also serve as authorities for approving the environmental impacts of VCS operations and its recipients. Additionally, eight water resource recovery facilities (WRRFs) treat 28 million cubic meters of wastewater annually in the area. The organizational structure of VCS comprises three main departments related to Distribution Territories (DTs): Operation and Maintenance, Investments and Business Development (including planning, design, construction, and documentation), and Customers and Communications. The municipality's external department, Authorities, also plays a role in DTs, focusing on documenting the utility company's environmental footprint and acting as regulatory authorities for VCS. All four departments share responsibilities related to water production, distribution, wastewater and stormwater collection, and wastewater treatment.

Overview of the Digital Twin Concept

Presently, the scientific literature lacks a definitive agreement on the definition of the term "DT," leading to its widespread and imprecise application and a weakening of the terminology associated with DT concepts. Models are significant components within DT frameworks, yet, as outlined later, a DT encompasses numerous attributes, including simulation models. A DT can span various professional domains and serve diverse objectives. Given its relatively recent emergence in urban water systems engineering, exploring how other industries define DTs could provide valuable insights.

A. *Definitions—Digital Twins as an Open Feature-Based Concept*

The concept of Digital Twins (DTs) began to take shape around the turn of the millennium, initially focusing on Product Lifecycle Management. This involved transferring performance data from physical space to virtual space and sending control or maintenance information in the opposite direction. Despite numerous review papers on DTs, there has been no consistent definition. This paper adopts the definition outlined in the Introduction, drawing primarily from the work of Grieves and Vickers (2017), Autiosalo et al. (2020), and Wright and Davidson (2020). According to Grieves and Vickers (2017), there are two main types of DTs: Prototypes and Instances. Prototypes are used to optimize final designs, particularly beneficial for complex and costly products where physical experiments are impractical. Instances refer to products that have left the factory and provide information on their performance outside production lines. DTs can be predictive or interrogative depending on their purpose. Prototypes are predictive but not interrogative, whereas Instances can be both predictive (e.g., predicting wear and tear) and interrogative (responding to real-time data about the physical twin's condition). Autiosalo et al. (2020) expanded on this framework by identifying various features that describe DTs' technical functionalities. These features include data link, coupling, identifier, security, data storage, user interface, simulation model, analysis, artificial intelligence, and computation. While not all features need to be present, their importance varies depending on the application area. Wright and Davidson (2020) emphasized the dynamic nature of physical objects, underscoring the necessity of updating and adjusting DTs based on data from each physical twin. They highlighted the critical role of "coupling" between the DT and the physical twin. In the context of urban water systems, we propose defining a DT as a systematic virtual representation of the system's elements and dynamics. This representation comprises various features organized in a star-structure, similar to Autiosalo et al. (2020). We stress the inclusion of an ever-changing physical twin, connected via the coupling feature, which makes the DT dynamic or "living." This term denotes DTs that reflect the real-time state of the system, striving for accurate replication of reality. The features outlined in the conceptual framework correspond to different aspects of the DTs, with models playing a significant role in processing data from the physical twin. Further details on the features and the rationale behind the framework are provided by Autiosalo et al. (2020).

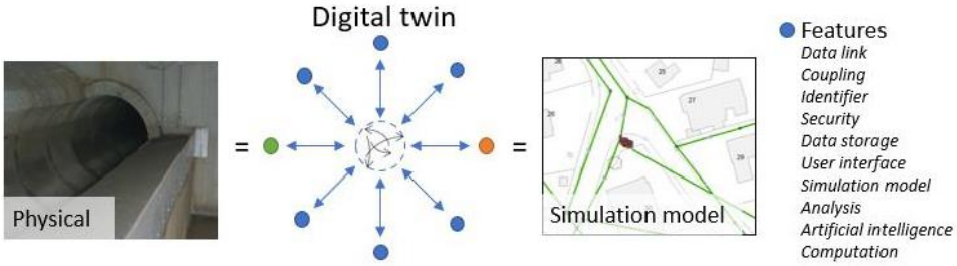


Fig-2. Illustration of the concept of digital twin (DT) for urban water systems. The DT consists of a virtual part linked to a list of features and a physical counterpart. The continuous coupling to the physical twin is important to make it a “living” DT, and simulation models play an important role in urban water systems (here exemplified by a distributed urban drainage system model). Blue dot refers to the feature data link, which is the center of a star structure surrounded by other features. Green dot refers to the feature coupling, and Orange dot refers to the feature simulation model.

B. Value Creation in Digital Ecosystems through Digital Twins

The concept of digital ecosystems (DEs) can be broadly defined as "distributed, adaptive, open socio-technical systems with the properties of self-organization, scalability, and sustainability inspired from natural ecosystems". Recently, the World Economic Forum (WEF) has advocated for this concept . DEs consist of various modular parts that work together as a cohesive unit, aiming to enhance value for end-users, aligning with the definition of a Digital Twin (DT) as a star-structure (Figure 2). The DE thrives on flexibility, collaboration, and open standards, enabling multiple third parties to easily engage as partners in delivering a DT for mutual benefit. This poses a challenge to traditional corporate structures that typically prioritize providing proprietary products and services covering all end-user functions, as DEs instead demand openness and governance to facilitate collaboration among diverse users and companies [28]. Water utility companies heavily rely on many such products and services, and their role in fostering the future development of DT products and services in alignment with DE principles is crucial. DEs facilitate interactions between various disciplines including computer science, data science, and water domain knowledge, all of which are historically essential for creating sustainable solutions in hydroinformatics.

IV. Digital Twins for Water and Wastewater Systems

Digital Twins (DTs) for urban water systems are a relatively novel concept in academic discourse. A recent report on digital water by the International Water Association (IWA) highlighted DTs as a tool for digitizing utility companies but did not offer a standardized definition. The DT group within the SWAN industry network proposed a visual representation to define the DT concept for water and wastewater systems, emphasizing data integration, analytics (both data-driven and physics-based models), and visualization as crucial components of a DT. These elements are deemed essential for water treatment and distribution systems, with particular emphasis on hydraulic accuracy and the use of short time steps. Therrien et al. (2020) discussed the DT concept from the perspective of Wastewater Resource Recovery Facilities (WRRFs), suggesting that key components of a DT include a virtual system capable of simulating a physical system, measurements, real-time data exchange, predictions, and intelligent actions. The authors underscored the urgent need for consensus on the necessary components to designate a digital system as a DT to prevent misapplication of this powerful concept. They noted that efforts toward consensus-building in the realm of water and wastewater networks have already commenced.

A. Living Digital Twins for Water Distribution and Urban Drainage Systems

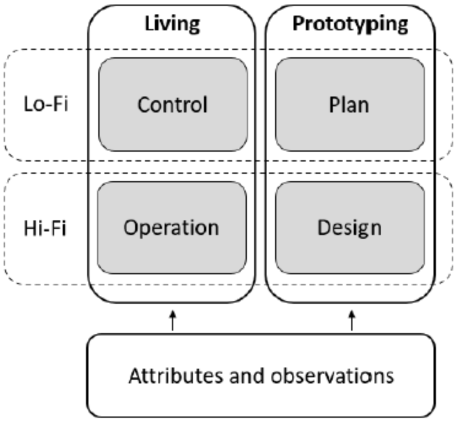
Urban water systems are unique in their composition and characterized by constant change and renewal. One cannot clearly define the lifetime of an urban water system because such a system never truly dies (except in the case of natural disasters, war, or political decisions to move an entire city). The attribute data and structure of the DT must be continuously adjusted to reflect reality because reality changes in both time and space. Urban water systems are, furthermore, typically unique and complex infrastructural systems whose components are interlinked and, to a large extent, placed underground. These systems are, therefore, complicated to repair or renovate in the event of a failure and are also difficult to monitor. This makes DTs for urban water systems fundamentally different from DTs at the plant, process, product, and component levels. For DTs at the component level in the water sector, several pump manufacturers have begun to use DTs to optimize their products' value propositions for customers. However, for an urban water system, we must consider a whole system and not just a component, which changes how the DT is perceived. Not all features that are interesting from a component perspective are necessary from a system perspective, and vice versa. In the water distribution industry, DTs have been known for several years, with some utility companies either already running a DT or having started their journey towards one, e.g., Global Omnium in Valencia, Spain, Consorci d'Aigües de Tarragona in Spain, Portsmouth Water and Anglian Water in the UK, and Halifax in Canada. The goal of these DTs is primarily to reduce water leakage by analyzing data through models and to predict the risk of pipe breaks occurring to ultimately provide better service to their customers. The purpose may also involve diagnosis of the pumps in the system, as done in Gwinnett County, Georgia, USA. By diagnosing pumps at the system level, the purpose is the same as that of a pump manufacturer investigating its product but with added opportunities to extract other information at the system-level that is not known to the component manufacturers. Water distribution systems are characterized as closed systems with repetitive daily demand patterns and typically with more sensors installed compared to urban drainage systems (e.g., flow meters in the system installed to find leakages). They are, however, more difficult to inspect due to the smaller diameter of the pipes, and therefore errors in the pipe system have to be identified indirectly by interpreting model and sensor data, which is a strong motivation for acquiring a DT.

The complexity of urban drainage systems is compounded by the stochastic and temporally and spatially variable nature of rainfall inputs, along with dependencies on past weather events and other time-varying factors. These complexities pose challenges to urban hydrology and rainfall-runoff modeling, areas still under intense research. Additionally, underground pipes in poor condition can lead to increased infiltration or exfiltration. Unlike distribution networks, urban drainage systems typically lack extensive sensor monitoring, making it difficult for current simulation models to accurately capture all processes. This underscores the importance of learning from observations and establishing a Digital Twin (DT). Complex systems that evolve over time stand to benefit significantly from a DT, as noted by Wright and Davidson (2020), While a SCADA (supervisory control and data acquisition) system theoretically could function as a dynamic DT by storing and visualizing data and executing actions based on control rules, it often lacks the features of simulation models and advanced analytics. Furthermore, SCADA systems are typically closed to non-experts, limiting their interpretation as true DTs.

B. Simulation Models in Living and Prototyping Digital Twins for Urban Drainage Systems

Simulation modeling is a crucial aspect of Digital Twins (DTs), with various simulation models tailored to specific purposes. In this section, we delve deeper into simulation models for urban drainage systems, although these conceptualizations can be extended to other urban water systems. A model is characterized by its representation of the system. A well-defined model can simulate changes within the system and offer realistic outputs regarding the consequences of those changes. The level of detail of the model's elements determines the resolution needed to effectively address a defined problem. This granularity is paramount when selecting or developing a model. For instance, a simplified dynamic representation in a coarse-grained Lo-Fi planning model cannot accurately simulate the intricate dynamics of urban water systems or facilitate the design of hydraulic structures, unlike more sophisticated Hi-Fi models such as distributed hydrodynamic pipe network models and computational fluid dynamics (CFD) models. In a living DT, it's essential to compare the results from the simulation model with observations from the physical system. This comparison must account for changing conditions, as the dynamics of urban drainage systems vary significantly based on weather conditions, ranging from steady wastewater flow during dry weather to sudden downpours causing high peaks, overflows, and flooding in the system. To facilitate comparison between different states, it's crucial to define statistical objective functions that can indicate when and where the models provide sufficient accuracy and where they fall short.

Models can be categorized into living and prototyping, each further subdivided into Lo-Fi and Hi-Fi models (refer to Figure 3. Living models, operating in real-time Decision Tools (DTs), aim to replicate reality with a high degree of accuracy, utilizing near real-time input. These models typically fall into the Hi-Fi category, faithfully reproducing reality with detailed features such as manholes and structures, enabling the extraction of information even from locations where no measurements are available. Simplified Lo-Fi models (also known as surrogate models when derived from Hi-Fi models) find application in control optimization algorithms due to their quicker computation and the potential suitability of their granularity level. This viewpoint aligns with that of Sarni et al. (2019), who discussed operational and control models as inputs to real-time DTs. Inputs are often derived from real-time sources like multiple rain gauges or rainfall-radar systems.Prototyping DTs, on the other hand, serve integrated or strategic planning purposes and the design of future solutions. These DTs primarily focus on system expansion, such as accommodating new urban developments connected to existing urban drainage systems, or retrofitting existing hydraulic structures to enhance performance. Lo-Fi surrogate models are frequently employed for planning but not for design purposes, as Hi-Fi Computational Fluid Dynamics (CFD) models are increasingly preferred for the latter. Input is rarely performed in real-time; instead, historical observations are combined with conceptual models of inputs, and parameters (e.g., synthetic storm events, estimated roughness coefficients) are utilized to extract desired characteristics from attributes and observations.



C. Design Model of *Digital Twins*

Figure 3. Models (grey boxes) applied in urban drainage engineering that can be included as features in a DT depending on the purpose. All models in living DTs are based on data from

attributes and observations via coupling to a physical system. Models in prototyping DTs can learn from living DT models but can also be based on presumptive data about the future. Living and prototyping DTs can include both hi-fidelity (Hi-Fi) models and simplified low-fidelity (Lo-Fi) models.

Living and prototyping DTs both use attributes and observations from the system. Although they differ, insights from one model can inform the other. For instance, refining the operational model can reduce uncertainty, enabling exploration of unknowns. This knowledge can then improve prototyping models for future investments. Thus, VCS emphasizes learning from operational models in living DTs.

V. Dreaming of a Multi-Purpose Living Digital Twin for the Urban Drainage System in VCS Denmark

A. *Multi-Purpose Value Creation across Departmental Silos*

The study investigated the value creation potential of digital technologies (DTs) in VCS through employee interviews across various departments. VCS comprises departments responsible for water production, distribution, urban drainage, wastewater treatment, and involves collaboration with external authorities. Twelve main purposes for implementing DTs were identified, with varying degrees of recognition across organizational units. Interviews revealed differing perspectives among employees regarding potential DT benefits. Some monitor field activities, others manage sensors, and some use hydraulic models. While operational workers use sensor data, they lack confidence in models. Planning and construction staff heavily rely on models and see DTs as enhancing planning tools. There's consensus on the untapped potential of DTs for cross-departmental value creation. A shared DT could enhance transparency and insight into system responses, breaking down barriers between departments. Open discussions about DT confidence could build trust among stakeholders.

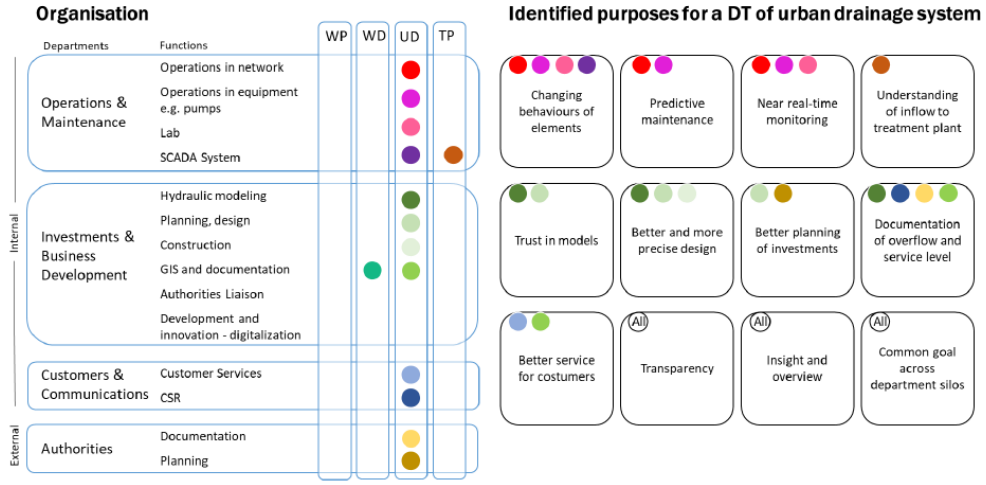


Figure 4. Identified purposes for a DT of the urban drainage system (UDS) from the perspective of different functions in VCS, both internally and externally. The left figure shows the internal

functions classified in departments in VCS, and the external authorities that are contributing to and/or benefitting from a DT of UDS. The right figure illustrates different purposes of a DT of the UDS, as determined by interviewing employees of VCS. The colours indicate which function from the left figure would benefit from a multi-purpose DT of the UDS. WP = water production, WD = water distribution, UD = urban drainage, TP = treatment plant/ water resource recovery facility (WRRF).

Acknowledging every contribution to maintaining a Digital Twin (DT) is vital. The DT can be adapted for various purposes, enhancing its utility within the company. For instance, it can aid in predictive maintenance for equipment operations, potentially reducing overtime spent on repairs during non-working hours. Detecting issues like pump breakdowns or pipe cracks promptly can prevent further complications. These technical applications improve services for staff, customers, and the environment. They align with industrial and water sector objectives and resonate with the predictive and diagnostic functions of DTs as proposed by Grieves and Vickers (2017).

B. The Urban Drainage Living Digital Twin in VCS—Past and Present Implementation

In VCS, the journey towards a Digital Twin (DT) of the urban drainage system commenced in 2008 with the introduction of a concept termed the "day model" (equivalent to an operational model, as depicted in Figure 3). The objective of the "day model" is to monitor, comprehend, and record the performance of the urban drainage system using a high-fidelity hydraulic model fed by data from multiple rain gauges. This model is executed once daily, retrospectively comparing the past 24 hours with data from water level and flow sensors situated at various points within the system. Presently, the model comprises over 31,000 nodes encompassing combined sewer and stormwater systems, and it operates within the hydraulic modeling software Mike Urban. The computational time required for a model run is approximately 2 hours. Various enhancements have been integrated into the evolving DT over time, such as endeavors to simulate infiltration inflow through different methods and the introduction of automated model updating tools. Figure 5. depicts the current setup of the evolving DT in VCS, along with its processes for updating and maintenance, and its relationship with prototyping DTs. The primary objective of the evolving DT is to replicate the physical system as accurately as possible, minimizing uncertainty regarding known processes to identify the remaining unknowns. Through this approach, VCS aims to translate its accumulated knowledge from operating an evolving DT into enhanced insights for the physical system. These insights are utilized to refine tools for predictive maintenance and expand the knowledge base for (prototyping) design and planning DTs.

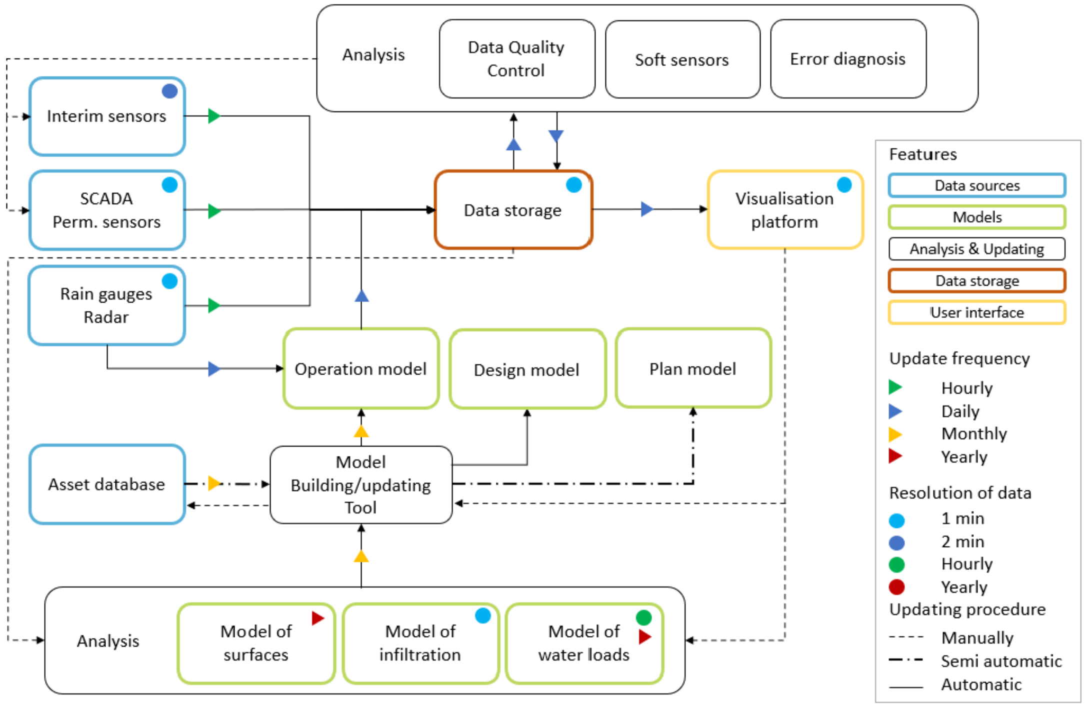


Figure 5. Workflow of the DT environment in VCS with the different features highlighted, including the operational, design, and planning models

In the VCS system, the 'asset database' feature holds attribute data concerning the physical components of the urban drainage system. Additionally, data from various sources such as water level and flow sensors, binary sensors indicating overflow, and rain gauges are stored in databases. Currently, VCS utilizes multiple databases for different purposes, but there is a shift towards consolidating data into a few databases to streamline storage and distribution for various applications. With the advent of more affordable IoT equipment, it is anticipated that an increased volume of observations with varying levels of accuracy will become available in the future. Several functions within VCS contribute to enhancing the quality of both attribute and observational data. Managing this data necessitates a transparent and uniform structure for registration, facilitating the transformation of information into knowledge. Consequently, VCS, along with other Danish utilities, recognizes the importance of standardizing the data storage process. Pedersen et al. describe how attributes and observations are organized within VCS. An integral component of VCS's dynamic digital twin (DT) is the 'model building/updating tool' (MOPS), which facilitates the conversion of an asset database into a model, such as an 'operational model,' semi-automatically. Observational data and model results are stored via cloud data storage and visualized on a platform alongside measurements. Analyzing these results and comparing them with measurements aids in identifying discrepancies between the DT and physical reality, enabling necessary adjustments. VCS currently employs three types of simulation models: operational, design, and planning models. Design and planning models draw insights from operational model runs, which, in turn, can incorporate detailed attributes from design models. Future endeavors may involve integrating design and planning models more extensively into the DT environment, potentially displaying results or conducting simulations directly from the DT user interface. Ensuring a high-quality DT involves engaging various functions within the utility company and considering how the DT can benefit multiple stakeholders without deviating from its original purpose. VCS emphasizes transparency in analyses and tools to facilitate learning and improvement across its model and tool portfolio. Open-standard plug-and-play solutions with logical and efficient workflows, supported by DTs and digital twin environments (DTEs), are preferred by VCS. Notably, the importance of the model building/updating tool, data storage, and data links in facilitating smooth data flow is underscored. This approach differs somewhat from the star structure initially envisioned, emphasizing the iterative nature and time required for developing a DT, alongside the importance of fostering curiosity and a drive for continual enhancement.

C. Future Planned DT Developments in VCS

While VCS currently offers basic analysis tools for all aspects depicted in Figure 6, ongoing enhancements are necessary in the coming years to gradually align with the overarching DT and DTE concept. These improvements should include specialized features focusing on:

Data quality control: While Therrien et al. (2020) provide a guide for performing data quality control for individual sensors, there's a need for features capable of cross-checking data from multiple closely located sensors. This would aid in determining optimal sensor placement and automating data control from numerous levels and flow gauges within the urban drainage system.

Continuous state-dependent error diagnosis: Achieving a living DT capable of describing the physical system with acceptable uncertainty across all locations and objectives is challenging. This is partly due to limited information about assets and dynamics as the system ages, as well as stochastic inputs like rain and water exchange with the environment. Hydrologic signatures may help address the state-dependent nature of differences between models and observations.

Visualization and learning: Utilizing DTs for developing improved planning and desigSn models requires learning from the evolving DT and converting unknown processes into known ones. This process is expected to generate numerous questions and hypotheses for future testing.

Adding more detail: This involves enhancing runoff models, improving representations of hydraulic structures and pump characteristics, exploring unstructured information for new insights, and implementing a balanced alarm system capable of distinguishing critical service alerts from non-critical maintenance notifications.

Improving DT system architecture: Implementing a DE based on open standards for data and standard API solutions is crucial for enhancing the overall DT system architecture. However, there's a risk that the DT may overpromise and underdeliver, potentially leading to skepticism among end-users across various departments and functions within utility companies. Therefore, maintaining close interactions with end-users throughout the process of DT maintenance and development is essential.

Ideally, DTs should possess clear metadata and adhere to open standards orchestrated by the DE. This approach would reduce barriers to entry for entrepreneurs in the water sector, promoting ongoing innovation while also lowering the financial burden of DT construction. Additionally, DTs shouldn't be limited to large utility companies; they should also be accessible and beneficial for smaller utility companies facing similar challenges. Thus, the goal should be to develop a DE that accommodates the needs of both large and small utility companies.

VI. Conclusions

Study: A digital twin (DT) of an urban water system is a virtual representation that systematically captures the system's elements and dynamics through data connections. Key features include data linkage, simulation modeling, analysis, and artificial intelligence. Not all features are necessary for a system to be termed a DT; for instance, a simulation model or a SCADA system alone may not qualify. **Conclusion**: Urban water system DTs can be categorized as living or prototyping. Living DTs closely replicate the physical Study: system's behavior over time, emphasizing coupling and simulation modeling. Prototyping DTs don't replicate every detail but accurately simulate system trends, using either design or planning models. DTs rely on DT environments (DTEs) that adhere to open data standards, fostering innovation and user involvement. This approach aligns with a proposed star structure for DTs, breaking down functionality into manageable units, promoting microservices communication via data links facilitated by APIs. **Recommendations:** This definition of the DT concept for urban water systems clarifies its purpose, aiming to provide a framework for researchers, industry, and utilities to understand and develop DTs effectively, reducing confusion from vague terminology. It emphasizes the importance of nuanced features, highlighting the need for interaction, openness, and transparency in system architecture. By making DTs multipurpose, they can serve various needs within utility organizations, bridging gaps between different departments and functions. A case study at utility company VCS revealed differing perspectives on the urban drainage system, underscoring the potential of a multipurpose DT to integrate these viewpoints. The paper outlines the current workflow of VCS's DT and identifies areas for improvement, such as data quality control and user interface enhancements. It also suggests the broader applicability of DTs and the need for collaboration, openness in data infrastructure, and a shift in traditional business thinking within utility companies.

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