Water Science & Technology

 Water Science & Technology Vol 87 No 7, 1630 doi: 10.2166/wst.2023.079

Chances and barriers of building information modelling in wastewater management

Florian Kretschmer[a,*], S. Franziskowski[a], F. Huber[b] and T. Ertl[a]

[a] University of Natural Resources and Life Sciences, Vienna, Department of Water, Atmosphere and Environment, Institute of Sanitary Engineering and Water Pollution Control, Muthgasse 18, 1190 Vienna, Austria

[b] University of Natural Resources and Life Sciences, Vienna, Department of Landscape, Spatial and Infrastructure Sciences, Institute of Spatial Planning, Environmental Planning and Land Rearrangement, Peter Jordan-Strasse 82, 1190 Vienna, Austria

*Corresponding author. E-mail: florian.kretschmer@boku.ac.at

FK, 0000-0002-7479-2229; FH, 0000-0002-8717-0525; TE, 0000-0001-8099-1403

ABSTRACT

The advancing digitalisation is one of the great challenges of our times. Related activities also concern the wastewater sector. In the field of building construction, one emerging approach is building information modelling (BIM). The presented work investigates to which extent BIM practices have already found their way to wastewater management, and what kind of benefits and constraints are incorporated. Information is collected by means of a literature review and international expert surveys. Results indicate that several BIM-related key elements are already well established in the sector, but not necessarily in the intended manner. Consequently, the digital transition in the wastewater sector is not about replacing existing procedures and techniques but to rethink and optimise them. This primarily concerns data and information management in combination with the application of digital tools. Furthermore, wastewater management requires more integrated approaches, involving interdisciplinary/collaborative concepts and life cycle perspectives. Appropriate change management is necessary to give support and guidance to employees during the transition process. Furthermore, also from the political side, a clear definition and communication of the pursued digital vision is important. This article aims at stimulating discussion and research to optimise wastewater management from the digital perspective.

Key words: data management, digitalisation, digital twin, digital water, integrated planning, sewer operation and maintenance

HIGHLIGHTS

- To cope with today's challenges in the (waste)water sector, digitalisation is considered a suitable tool.
- Building information modelling (BIM) can help to optimise existing working practices and procedures in various ways.
- This article presents and discusses the chances and barriers of BIM to support the digital transition in the wastewater sector.

1. INTRODUCTION

Digital technologies and the related digitalisation of our life are on the advance worldwide, the buzzword used in this context refers to 'Industry 4.0'. In regard to the water sector, Garrido-Berserba *et al.* (2020) speak of the 'fourth revolution'. To cope with the upcoming challenges of digital transformation, the European Union (EU) has declared the current time horizon until 2030 as Europe's Digital Decade (European Commission n.d.a). The (digital) aims of this strategy are based on four core aspects: digital competence, digital infrastructure, and digitalisation of companies and public services. Furthermore, the EU states in its 'Path to the Digital Decade' (European Commission n.d.b), that digital technologies should contribute to a sustainable, circular and climate-neutral economy and society. These goals are aligning with the International Water Association's Digital Water program (IWA n.d.), which intends to facilitate the journey of the water industry toward digital uptake and integration into water services. It is well known that the water sector faces a variety of great challenges today (climate change, increasing urbanisation, flooding, and droughts), and digitalisation is considered to be helpful in addressing them (Valverde-Pérez *et al.* 2021). Although, a re-thinking of the current approach in planning, building, operating, and managing assets and resources might only be one aspect of the required transition. Brink & Weishut (2020) postulate the need to even develop a new vision of society, which should be based on paradigms meeting the requirements of our digital future.

In the field of building construction, the application of Building Information Modelling (BIM) has been evolving in recent years. In general, the BIM concept is based on a continuous elaboration and utilisation of a digital representation of a specific building asset. It aims at the integration of all relevant professional fields during the entire life span of the related construction (planning, construction, operation and maintenance, and demolition). In European countries with high digital competitiveness (Scandinavian countries, Great Britain, the Netherlands) BIM is already strongly promoted (Bris & Cabolis 2021). However, even beyond these countries, the political will to further introduce this new approach is apparent (EU BIM Task Group n.d.a.). In certain countries (e.g. Denmark and Finland) BIM application is already mandatory, at least for public buildings (Degendorfer 2022). Other countries and/or cities, respectively, have taken the first steps. In this context, we would like to mention the city of Vienna, Austria, which gets funded by the European initiative on 'Urban Innovative Action' (out of 175 applications from 23 EU countries) to implement a digital building permit application for all buildings in the town, public and private ones (BRISE n.d.). However, with regard to (under)ground infrastructure, the application of the BIM approach still seems not very common today. Nevertheless, some initiatives can also be observed in this sector, primarily concerning railways, roads (BMVD (n.d.) BIM4Infra 2020), and, at least to a certain extent, also the water sector (BIM4Water, British Water n.d.).

Due to the application of a digital representation, the BIM approach is closely related to the concept of digital twins (DTs). According to Beetz *et al.* (2020), DTs can be considered as a digital representation of a physical asset. Brink & Weishut (2020) widen this definition also to representations of systems or processes. They state, that '*by definition, every digital twin is linked to a unique physical counterpart and is continuously updated based on relevant frequency and purpose.*' This is aligning with the specific view in the water sector, where, according to Pedersen *et al.* (2021), DTs are considered as combinations of models also including the utilisation of real-time data. In this context, one must add that Witteborg (n.d.) distinguishes between the 'as-built' digital twin (DT) and the 'what-if' simulation twin. Valverde-Pérez *et al.* (2021) refer to DTs for operational use and for planning, design, construction, or investment purposes, respectively. Finally, the integration of various DTs might result in an entire ecosystem of DTs (Beetz *et al.* 2020).

Recent research in the field of BIM and DT applications has, in general, a strong focus on the integration of BIM and GIS for combining information from both perspectives, buildings, and their adjacent environment (Liu *et al.* 2019; Wang *et al.* 2019). More specifically, the development of conceptual and/or semantic models aims at further integrating stormwater and wastewater infrastructure into BIM-related concepts, or, at least, provides the basis for related subsequent steps (Bock & Michaelis 2019; Prenner *et al.* 2021). Chapman *et al.* (2020) present a possible application of the BIM approach in underground pipe construction and management. In regard to DTs, Pedersen *et al.* (2021) investigate the possible role of DTs in the urban water sector. Valverde-Pérez *et al.* (2021) present two examples of DT application in sanitary engineering. One refers to improved control of combined sewer overflow events, and the other to optimised wastewater inflow management at a water resource recovery facility. Torfs *et al.* (2022) address various questions in regard to DT transformation at water resource recovery facilities (WRRFs).

Summarising the above, one can state that the discussion about digitalisation in general and about BIM-related approaches and DTs in specific has undoubtfully arrived in the (waste)water sector, at least in certain areas and at the case study level. However, when discussing the potential of the latter concepts to support the transition in the sector, one should keep existing and well-established practices and concepts in mind. To cast more light on this issue, the presented work investigates (1) to which extent BIM (and DT) approaches have already been introduced to the wastewater sector (possibly under different terms), and (2) what chances and barriers are related to the practical implementation of BIM (and DT) approaches in wastewater management. As a result, this article highlights and structures related core aspects to provide orientation for further discussion and research as well as for implementation of improvements in wastewater management towards a digital future.

2. METHODS

2.1. Definition of terms and BIM core elements

A literature review in the discussed field reveals, that the considered approaches of BIM (and DTs) often have more than one definition. Consequently, interdisciplinary collaboration is aggravated due to the lack of a common language and interpretation. In the following, we display definitions from different sources. To create a common understanding, we briefly summarise the various interpretations at the end of this sub-chapter. In addition, we derive core elements of BIM for providing a clear framework for our investigations. This is aligning with the recommendation of buildingSMART Austria (n.d.), who recommends, when starting a new project, to accurately define the BIM terms and the associated expectations of all stakeholders to ensure clear communication and thus efficient collaboration.

Basically, the term BIM itself continues to evolve over the years and is thus best understood as an '*expression of digital innovation*' across the construction industry and the overall built environment (BIM Dictionary 2021).

In EN ISO 19650 part 1, BIM refers to the '*use of a shared digital representation of a built Asset to facilitate design, construction and operation processes to form a reliable basis for decisions.*'

The EU BIM Task Group (n.d.b.) postulates the following definition: '*(…). BIM is a strategic enabler for improving decision making for both buildings and public infrastructure assets across the whole life cycle. It applies to new build projects; and crucially, BIM supports the renovation, refurbishment and maintenance of the built environment – the largest share of the sector*'.

For the US National Institute of Building Sciences (2007) '*a BIM is a digital representation of physical and functional characteristics of a facility. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its life cycle from inception onward. A basic premise of BIM is a collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or modify information in the BIM to support and reflect the roles of that stakeholder*'.

In the construction industry, a '*Digital Twin typically refers to a data-rich 3D model – of a building for example – that represents, reacts to, and can cause changes in the Physical Twin, the actual building*' (BIM Dictionary 2019).

BuildingSMART International (Beetz *et al.* 2020) provides the following definition: '*A digital twin (DT) - also referred to as digital shadow, digital replica or digital mirror – is a digital representation of a physical asset. Linked to each other, the physical and digital twins regularly exchange data throughout the PBOD* (plan-build-operate-decommission, explanatory note) *life cycle and use phase. Technology like AI* (artificial intelligence, explanatory note)*, machine learning, sensors and IoT* (Internet of Things, explanatory note) *allow for dynamic data gathering and right-time data exchange to take place*'.

In addition, Wright & Davidson (2020) emphasise that a DT without a physical twin is just a model. Furthermore, they underline that the use of evolving data means a key strength of the DT approach according to deliver an accurate description of objects that change over time.

Summarising the above, BIM represents a model-based and object-orientated data management approach involving all relevant 'trades' (stakeholders) over the entire lifespan of an asset. It shall provide the basis for better-informed (improved) decision-making to ensure the efficiency of assets in every use phase. A DT can be understood as a digital replication (not necessarily in the form of a 3D model) of an asset including physical (base) and constantly updated operational data (static and dynamic/functional data). In this connection, the BIM model is to be understood as a DT, which contains mainly static data of the concerned asset.

Finally, to put these different aspects in a nutshell, we conclude the following four core elements of BIM providing the frame-work for our further investigations: (1) model-based data/information management, (2) application of a digital representation of physical assets (DT), (3) stakeholder management/collaboration, and (4) a life cycle perspective.

2.2. Methodological approach

The methods used to answer the questions about the current state of BIM applications in the wastewater sector and the related chances and barriers are literature review, questionnaire-based qualitative expert interviews, and content analysis of interview protocols. Figure 1 outlines the used approach, which is divided into the three depicted steps: preparation, interrogation and evaluation.

In step 1 (preparation), common definitions for BIM (and DT) are collected and used to derive core elements of the BIM concept (compare Section 2.1). In the following, those core elements serve as a (thematic) framework for structuring the presentation and discussion of results. For the preparation of the questionnaire, we used existing interview protocols with five Austrian experts from different professional fields in the water sector (civil engineers and utility operators) presented by Kammerlander & Ladinig (2018). A content analysis of these protocols was made to derive the most urgent BIM-related topics/contents to be addressed in the intended interviews. A review of recent international literature supported this preparatory work. While the previous work by Kammerlander & Ladinig (2018) interviewed experts not having BIM implemented in their daily business, the current approach is different. International interview partners (from the Netherlands, Switzerland, Germany, and Austria) were selected based on their BIM expertise from their daily practice, their involvement in research projects as well as their contribution to working groups concerning BIM (e. g. regarding standardisation). We chose two interviewees (IP 2 and IP 3) with central roles in German and Swiss working groups for BIM in the wastewater sector. IP 1 is a

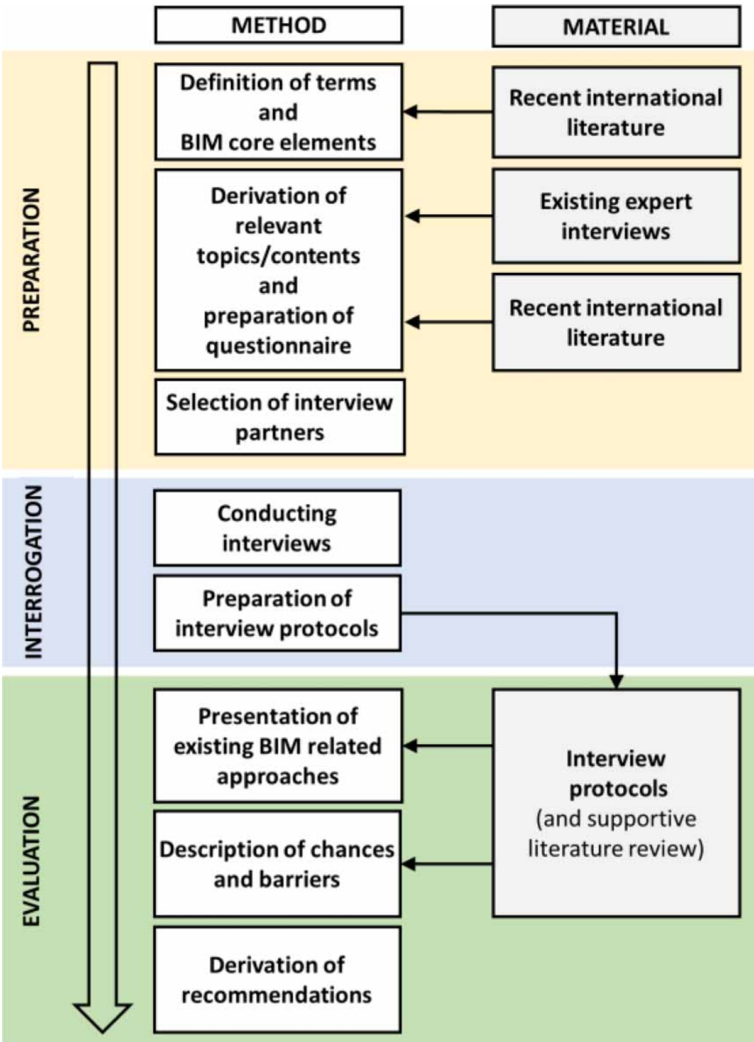

Figure 1 | Methodological approach including working steps and materials used (own presentation).

core representative of the buildingSMART International 'Digital Twins Working Group (DTWG)' (with a European focus). IP 5 brings in the view from daily practice, as he is CEO of an international sewer rehabilitation company. Finally, IP 4 and IP 6 were part of an Austrian national research project regarding the application of augmented reality and BIM in special wastewater (sewer) structures. While IP 4 represents the perspective of (sanitary) engineering office/consultancy, IP 6 gives his view from a wastewater operational standpoint. With this pool of interviewees, we believe to cover all phases of the plan-built-operate life cycle in wastewater management to give first, exploratory but representative answers to our proposed questions.

In step 2 (interrogation), the experts were interviewed on the following topics/contents obtained from the previous working step (relevant topics/contents): (1) the role of the government in digital transformation, (2) practical application of BIM in wastewater management, (3) barriers in the application of BIM in wastewater management, (4) interfaces and standards, and (5) BIM and DT in wastewater asset operation (sewers and wastewater treatment plants (WWTPs)). All interviews were carried out in a qualitative way, where the questionnaire served as a guiding document. Additionally, all interviews were recorded and fully transcribed for interview partner approval and subsequent evaluation.

In step 3 (evaluation), the conducted interviews were evaluated by means of content analysis of the prepared protocols. This work was done in a hermeneutic approach conducting a repeated analysis of the material, but with changing focus depending on the research aim (existing BIM approaches in wastewater management, related chances, and barriers). The obtained results were supplemented by a further in-depth literature review to gather conclusive information on the current state of BIM in the field of wastewater management and the related chances and barriers to its practical application. Finally, this information was used to derive general recommendations and highlight further discussion and research demands.

3. RESULTS AND DISCUSSION

3.1. BIM-related approaches in recent wastewater management

The results obtained from expert interviews and literature review confirm that certain aspects of the BIM approach have already found their way into modern wastewater management. To make a clear connection between recent practices and the BIM concept, we structure the results orientating on the previously defined four BIM core elements: (1) model-based data/information management, (2) application of a digital representation of physical assets (DT), (3) stakeholder management/collaboration, and (4) life cycle perspective. Hereby, we highlight relevant outcomes from the interviews in the related thematic sections. For completing the picture in areas less covered by the interviews, we additionally refer to international literature. However, aspects considered common sense in the field of wastewater management are not indicated with specific sources.

Data collection and processing as well as the application of digital tools have a long tradition in wastewater management. This concerns continuous (online) wastewater quantity and quality measurements in WWTPs, e.g. in the form of supervisory control and data acquisition (SCADA) systems and, to a minor extent, related monitoring approaches in sewer systems (primarily in the context of real-time control (RTC) and combined sewer overflow management). In regard to sewer systems, recurrent inspection and condition assessment of existing assets as the basis for continuous operation and maintenance (cleaning, rehabilitation) is a common practice. State-of-the-art data management makes use of computer-based operation control at WWTPs and geographic information systems (GIS) for sewer systems. To provide further insight into system behaviour, model applications for simulating runoff and sewer flow and/or sewage treatment are well recognised and used.

The current approach of digital and object-based storage/mapping/representation of sewer networks in database software and/or model applications, not only includes the location of the different segments but also their specific constructional and even operational condition/characteristics already contain aspects of the BIM concept. Furthermore, the documented 'as built' information certainly provides an appropriate foundation for the elaboration of 'digital twins' for sewer system management (IP 4 2022). The same can be stated for WWTPs, although digital management of structural data still plays a minor role compared to the use of operational one (IP 2 2022).

Today, data storage mostly happens in utility-specific 'silos', from where it is difficult to share with in-sector project partners and/or other disciplines. A continuous, database-centred workflow ('one-stop-shop') through the entire lifespan of the different assets still shows great optimisation potential. In regard to sewer operation and maintenance, data exchange (between wastewater utility and service provider) for sewer cleaning and inspection activities already seems more evolved compared to those related to sewer rehabilitation planning. This might be explained through the availability of specific data exchange formats (e.g. European standard EN 13508-2 provides a standardised coding system for visual sewer inspection). In wastewater treatment, planning, operation, and maintenance also often involve various disciplines. Also here, standardised data formats could help to make data management and exchange more efficient, within the wastewater sector and beyond. In this regard, Söbke *et al.* (2021) present a semantic model for describing WWTPs assets and processes in a standardised way following the internationally recognised BIM IFC format.

Concerning stakeholder collaboration, the relevance and added value of the BIM approach in projects are usually closely linked to their complexity and the number of actors involved (IP 1 2021). In regard to sewer network expansion and rehabilitation, projects are usually handled by a single planner (service provider), who coordinates the contractor(s) and reports to the client (wastewater utility) directly. In this case, only a few other trades (stakeholders) are involved. This fact can be seen as one of the reasons, why BIM has not yet gained momentum in this field. The more complex the project and its set-up becomes, the more advantages of applying the BIM approach might be seen by the project participants. Nevertheless, one has to keep in mind, that the recent concepts for network expansion and rehabilitation planning are practicable and thus well established, this was also confirmed during interviews (IP 3 2022).

The integrated and interdisciplinary (collaborative) working approach in terms of common data environments and collaboration formats can be considered another core feature of the BIM approach. But the interdisciplinary collaboration of different network operators (e.g. joint infrastructure rehabilitation of sewer operators, and water suppliers) sharing their common underground space is still not very common today. The interviews confirm, that one of the main benefits of planning and construction of buildings, the preview and prevention of collisions of different working tasks in time and space seems not to play an important role in sewer construction but only for WWTPs and special sewer buildings/assets as pumping stations and combined sewer overflows. The reason could be found in the fact, that the latter involves different professional fields, e. g. construction, mechanical, and electrical engineering, who cannot work fully independently from each other (IP 4 2022). Consequently, the application of BIM at WWTPs and more complex sewer structures are perceived as more suitable than it appears for 'common' sewer pipe systems.

Finally, entire life cycle concepts seem not very common in the wastewater sector today. In sewer operation and maintenance (cleaning, inspection, rehabilitation), current asset management practices often have referred to periods of less than a decade. The reason for that might be found in proactive sewer inspection routines often based on return intervals of 10 years. Although recent approaches (in the context of sewer rehabilitation planning) such as sewer deterioration modelling and asset (residual) value estimation methods open the perspective to a broader temporal range, related discussions still appear rather academic and practical applications remain very uncommon. In regard to WWTPs, related asset management approaches even seem more short-term driven today. Nevertheless, the benefits the BIM approach could provide for the water sector in terms of life cycle thinking are briefly described and summarised by Suprun *et al.* (2020).

Table 1 summarises the current practices in wastewater management opposing them to BIM core elements.

3.2. Current chances and barriers of BIM implementation

The following sub-chapters present and discuss chances and barriers concerning BIM implementation in the wastewater sector in more detail. To provide orientation for the reader, the presentation and discussion of results, again, refers to the previously defined four BIM core elements again. Although, a clear thematic separation is not always reasonably possible.

3.2.1. Chances

The interviews reveal that the application of the BIM approach is expected to involve, above all, more efficient and transparent working processes implying a better overall work quality. Furthermore, it provides applying companies (service providers) with certain competitive advantages.

In regard to data/information management, IP 1 (2021) states, that the BIM approach makes information transfer far more efficient, which also represents an important step toward a holistic life cycle management. This is primarily achieved due to the fact, that during the BIM process one has to think about creating, storing, and sharing information across multiple stakeholders at an early stage. Within a BIM process, the exact data required and the form in which these data have to be transmitted to the contractor are defined at the outset. Through an appropriately standardised data exchange process the quality of the transferred data can be significantly increased. This is relevant for the wastewater industry, as the structures usually have a variety of technical systems (IP 2 2022).

IP 3 (2022) suggests that the integration of further attributes, for example, in relation to sustainability, depreciation periods, or aging processes of materials and plant components, can offer great added value. This could be used to carry out further

Table 1 | Overview on BIM core elements and related practices in wastewater management (own presentation)

BIM core elements	Current practices
Model-based data/information management	Continuous wastewater quantity and quality monitoring at WWTPs (operational data), recurrent inspection, and condition assessment of sewer systems (structural and operational data) based on standardised data formats.
Application of a digital representation (DT)	Application of computer-based wastewater treatment control and simulation, application of GIS for sewer operation and maintenance, application of hydraulic models for (sewer) runoff simulation.
Stakeholder management/ collaboration	Collaboration between sewer operators and service providers (sewer cleaning, inspection and assessment, rehabilitation planning) partly in a digital way, collaboration for WWTP planning more on a non-digital (manual) basis, cooperation across sectors not well established (rehabilitation planning).
Life cycle perspective	Temporal perspective in sewer operation and management often reduced to periods of less than 10 years, at WWTPs even much shorter, approaches for sewer deterioration modelling and (residual) value estimation refer to longer time spans.

analyses and simulations. IP 5 (2022) can also imagine added value for infrastructure aging modelling through the collected data. This would make it possible to evaluate more sustainably in the future whether a structure is worth preserving.

The obtained knowledge gain and improved understanding in terms of the required data management provides a sound base for the subsequent development of DTs. In this context, the simplest form of a DT is also often called an 'asset-twin' (IP 1 2021), Witteborg (n.d.) refers to the 'as-built' DT. By adding dynamic/functional data, it becomes a virtual replica of a physical situation at a certain moment in time, making the DT also more mature than a BIM model (IP 1 2021). A DT helps to get a more holistic view of a system and helps to understand how it works or could work in different scenarios. This allows for better-informed decisions. In urban water management, a lot of dynamic data is already collected to ensure efficient operation (IP 6 2022). In this context, GIS can already be seen as a good data basis for the creation of a DT.

The application of digital (planning) tools also offers various opportunities for visualisation. For winning project tenders and for promoting the companies'/utilities' own concepts, decision-makers need to be attracted and convinced. Here, visualisation in a 3D model alone can already be extremely supportive, as they help illustrate the construction project, already existing structures or the construction processes (IP 3 2022). Furthermore, complex tasks and individual construction phases can be better visualised through 3D visualisation. This is of particular interest when reconstructing WWTPs, as operations must be upheld here (IP 2 2022). However, visualisation can also support the training of employees for operational purposes due to better-understanding assets related structures and processes (IP 6 2022). In this context, the application of augmented reality is a promising and advancing approach. Moreover, by means of a visual and automated plausibility checks, possible planning errors can be discovered and thus avoided early in the planning process. In this context, collision checks of pipes (or other assets of different 'trades') are considered a great advantage (IP 4 2022). However, for this purpose accurate data in the right level of detail for all installations must be available (IP 4 2022). This is what makes collision checks for sewer network extensions in existing infrastructure so difficult, as precise data on the location of other underground installations are not always available for specific planning purposes (IP 2 2022). Asset information models (AIMs) focusing on operation and maintenance issues would be very helpful for these kinds of projects, as they allow object-based and process-oriented working (IP 5 2022). Consequently, AIMs including the entire urban infrastructure provide the basis required for smart city planning concepts (in an ecosystem of DTs).

According to IP 1 (2021), in BIM-related approaches data and information management shift to the focus of project work. This promises better stakeholder/project participant interaction in the planning and construction phase. However, first one has to overcome the recent practice of managing data in independent 'silos' and implementing a so-called 'single source of truth', which connects/integrates all relevant project data in a common data environment (CDE). In this joint data platform, all planning processes, changes and communication are documented and connected to the BIM model. This approach offers tremendous additional value for everyone involved. It allows efficient coordination and communication between all trades, providing reliability and transparency for all project participants (IP 2 2022). Moreover, if teams and/or participants change during a project, every new member has all information needed at hand at the touch of a button. Furthermore, no subjective knowledge gets lost.

IP 2 (2022) and IP 3 (2022) emphasise, that due to BIM application, their offices have gained clear competitive advantages, despite the initial workload to implement it. According to them, the transition to BIM is a fundamental change in their working method and cannot be compared to the transition to CAD in the 1990s. Offices that take the step towards BIM now will already be productive using the method in the future, giving them the advantage to react to new needs of the market (IP 3 2022). Also, contributing to the topic through scientific papers, best practices, and working groups lead to good visibility of a company and makes it attractive for new employees (IP 2 2022), especially from young generations with great digital affinity (and extensive environmental awareness).

3.2.2. Barriers

According to the interviewees, the major challenges refer to significant pre-investments, data and information management, specific application constraints in regard to digital tools, and the human factor in general.

Concerning data and information management (standardisation), the experts interviewed currently see their investments in the methodology as advanced payment. Not just the training of their employees, but also the description and digital representation of specific elements/assets costs a lot of time and money (IP 3 2022). In contrast to the building sectors, where appropriate model representations for a broad variety of building assets (walls, doors, windows, etc.) are quite common today, related freely available object-based catalogues/libraries are still largely missing in the wastewater sector. In this context, IP 2 (2022) exemplary describes the need for properly defining flow measurement devices (e. g. magnetic inductive) or gate valves (pneumatic, motorised, manual) for accurate model application. He summarises, that these developments require notable investments of (internal/unpaid) time and money, therefore concerned companies have been resisting for a long time to make these investments freely available to everyone. Concluding, implementing BIM leads to additional and individual investments before it creates added value. The systematic (and public) creation of object catalogues has not yet conclusively started. This task would further require a clear definition on the attributes (information) needed for the different wastewater related objects. In addition, the information should be able to be exchanged efficiently and securely between the various parties involved (IP 2 2022).

Application challenges primarily concern working with new software. Interviewing IP 2 (2022) and IP 3 (2022) revealed, that automated tendering with BIM, although widely common in the building sector (applying BIM), is hardly implemented in their wastewater projects today. According to IP 3 (2022) this cannot yet be automated due to the lack of above-mentioned standardised service/performance requirements. Consequently, complex tenders still have been prepared conventionally, although the related automatisation and optimisation potential due to BIM application is recognised. With standardised specifications of services, the basis for the interconnection of building components and items of the standardised tender specifications can be laid here. Countries that already apply standardised specifications in the wastewater sector have an important advantage in this regard (IP 5 2022).

Furthermore, even automated plan derivation is currently associated with additional manual efforts in adapting the exported drawings (IP 2 2022; IP 3 2022). However, IP 2 (2022) notes, that in the future, BIM approaches and the corresponding software used is no longer intended to map the building assets in 2D, but to visualise the entire process in the model. In this context, he refers to a pilot project at a Swiss wastewater treatment plant, where the dimensioning, planning and construction are entirely based on digital models without applying any paper plans (compare Hunziker Betatech 2021). In contrast, IP 3 (2022) on the other hand emphasises that it is still important to provide 2D plans in the execution of infrastructure projects. He refers to the expected lack of acceptance of new techniques on the construction site. This point also shows the importance of proper change management.

Moreover, the implementation of BIM in wastewater management currently also lacks clear definitions and procedures to facilitate transparent communication between the client (utility) and the contractor (service provider) as well as smooth project development. In the BIM process, two central documents define the related boundary conditions (IP 2 2022): the Employer Information Request (EIR) and the BIM Execution Plan (BEP). Currently, already several expert groups are dealing with this issue and are preparing related documents for the wastewater sector (for Germany DWA 2021, for Switzerland VSA n.d.). The interviews confirmed, that a clear definition of rights and obligations is necessary to be able to continuously work with BIM in the future and without each project having to follow a new approach (IP 2 2022).

In regard to the human factor, one can state that the BIM methodology fundamentally changes the way people work. This can be perceived as a possible barrier/risk for project work. Because the applied method is new for (some of) the people involved, the practical experience is rather limited and learnings happen 'on the go'. These aspects then might result in additional costs, delays or unsatisfied clients (IP 1 2021).

It is obvious, that the human factor plays a major role in the implementation of new approaches. A transition of current work practices can only be successful if it is fully recognised and accepted by the concerned people (project participants). In this context, Witteborg (n.d.) highlights the important role of professional change management as a key success factor. The introduction of new approaches can have an impact on the concerned organisation (redesign of working methods, new work processes and procedures, new job profiles, etc.). Therefore, it is imperative to carefully guide the employees when introducing/adapting the changes. Nevertheless, digitalisation concerns all hierarchies in the wastewater sector. Manny *et al.* (2021) differ three different levels hindering related development: (1) individual (due to lack of visions), (2) organisational (due to lack of resources and/or digital culture), and (3) institutional (due to administrative fragmentation).

Change management also concerns the current approach to decision finding. Studies on the life cycle costs of buildings show that planning and realisation (construction) account for about 20% of the total cost, while the subsequent operation of a building causes over 80% of them (compare IG Lebenszyklus Bau 2016). The BIM approach does not directly aim to reduce planning or construction costs but helps to create the optimal structures/boundary conditions for the operation. Consequently, the client should therefore have the greatest interest in using the BIM method (Nessier & Börrnert 2020). Nevertheless, higher investment costs with the goal to save money in operation are currently no issue in decision-making. Policymakers still need to justify investment costs rather than those for operation (IP 3 2022). This approach cannot be considered contemporary and has thus to be urgently rethought. To provide a holistic and sustainable infrastructure, it is necessary to invest in new approaches and technologies. IP 5 (2022) recognises that the wastewater infrastructure becomes the focus of political decisions only when the facilities reach their limits, for example, due to extreme weather events. IP 6 (2022) notes that innovations in wastewater management are sometimes not forced, also due to budget limitations. Finally, the client will have to demand a BIM application to support and achieve a real transformation (IP 2 2022).

IP 3 (2022) emphasises that operators are particularly interested in the DT for operations. Nevertheless, benefits for operation are currently not taken into account in the project planning phase. This is due in particular to the fact that there are no clear specifications from the operators in this regard (IP 2 2022).

Finally, the interviewees emphasise that the success of BIM application, especially in operation, strongly depends on keeping the model up-to-date. This concern is, anyway, well known from the maintenance of existing GIS databases and hydraulic models. However, data administration ultimately depends on the will of the operator (IP 5 2022), his conviction of the benefits and his inclusion in subsequent works beyond the time frame of a specific project (e. g. model set-up) is crucial. Temporal perspectives certainly have to change towards the building life cycle and not only to specific periods (planning, construction, short-/medium-/long-term operation and maintenance, demolition). Only if all stages of an asset life cycle are considered, the BIM application will develop its full potential.

Concluding these two sub-chapters, Table 2 summarises the current chance and barriers of BIM implementations referring to the BIM core elements.

3.3. Tackling optimisation

The application of the BIM approach concept can provide certain benefits. However, this does not imply, that current, well-established practices must be abandoned. In fact, BIM (and DTs) can rather help to optimise existing methods and take the next step towards digital transformation. Consequently, the upcoming and ongoing digital transition provides a good opportunity for the (waste)water sector for assessing and re-thinking current practices. The overall aim of all related efforts must be seen in making better (informed) decisions.

In regard to increasing complexities in terms of climate change adaption, circular economy, and smart city approaches, current data and information management should be scrutinised. Continued mono-disciplinary ‘silo thinking’ certainly cannot comply with future demands, nevertheless, the development/installation of a single-source-of-truth (either in form of a single or a connected database) will neither happen overnight. In this context, new governance structures to facilitate multi-stakeholder collaboration might be necessary. Communities could set a good example here, as they represent a pivotal point in smart city approaches due to their (administrative) stake in a variety of urban infrastructure systems.

Table 2 | Overview on BIM core elements and related chances and barriers of BIM implementation in wastewater management (own presentation)

BIM core elements	Chances	Barriers
Model-based data/ information management	More efficient and transparent work processes support a better overall work quality and decision finding (due to tailored/standardised data collection and exchange procedures).	Lack of standardised data formats and object catalogues, lack of digital business plans and clearly defined use cases.
Application of a digital representation (DT)	A DT provides a holistic view of a system, clear visualisation supports stakeholder collaboration and training of employees.	Significant pre-investments for new tools, technical constraints of digital tools.
Stakeholder management/ collaboration	Definition of appropriate information management and common data environments facilitates stakeholder collaboration, competitive advantages for BIM applying organisations.	Significant pre-investments for training of employees, lack of clear communication and collaboration procedures, required changes in work culture, lack of a digital vision.
Life cycle perspective	The BIM approach does not only concern planning and construction but also operation and maintenance (bringing operational expenditure to the fore).	Required change in decision finding approaches, need for continuous model update.

The definition of an overall digital business plan and specific (standardised) use cases in wastewater management and beyond, could catalyse strategic data acquisition, provision and management. Obviously, these use cases will not be set in stone but can be continuously updated and further developed according to changing technical, social, and economic factors/boundary conditions. This would also create a common language between the different disciplines, which supports interdisciplinary collaboration by creating well-defined intersection points.

Nevertheless, like in the building construction sector, well-defined catalogues/semantic models of all relevant elements/assets in conventional (grey) and nature-based (blue-green) wastewater management are a vital pre-requisite. In regard to life cycle assessment, this also includes the definition of performance indicators. As mentioned before, first attempts are already documented in the international literature (e.g. conceptual models for green facades). Related activities would also deliver clear definition of terms, which themselves facilitate interdisciplinary communication.

In regard to the development of a new understanding/concept of data management, we suggest a 'demand-orientated' approach. In this context, we consider the term LOIN, level of information need, as crucial. In EN ISO 19650 part 1 LOIN refers to the '*the framework that defines the extent and granularity of information.*' This can be understood as a clear definition of data quantity and quality level(s) for a specific task. In the first step, one should define the specific above-mentioned use cases for a concerned building/infrastructure system. In the context of sewer operation and maintenance one can think of rather simple property development information (on where to connect to the public sewer system), sewer cleaning, sewer inspection, rehabilitation planning, and hydrodynamic modelling. In the second step, for all defined use cases specific data/information requirements have to be assigned, considering data quantity (what data is needed) and quality (what accuracy and frequency) as well as the concerned stakeholders. This approach allows targeted and strategic data acquisition, provision and management (necessary information at the right time) and helps avoid the creation of 'data graveyards' and the often-mentioned 'DRIP phenomenon' (data rich, information poor). In the following, for each use case, a DT can be elaborated for specific planning purposes as well as for continuous operation and maintenance.

The digital modification/transformation of established working structures and procedures can have a strong impact on human resources. Proper change management can help provide a smooth transition. In this context it is crucial, to give orientation to the employees and clearly explain the 'why' of change. Therefore, utilities/companies have to develop and communicate a clear road-map of their (digital) status quo and their intended future role/position. Customised training courses can be very supportive as well.

The demonstration effect of successful implementation examples and best practices from various perspectives (technical, social, governmental) may also not be underestimated. Both large-scale implementations as well as an approach of small steps can support the digital transition. In this context, one can differentiate between 'open big BIM' (multi-stakeholder, multi-software, open data exchange format) and 'little closed BIM' (one stakeholder, one software) approaches. The latter can be considered an appropriate step for first introducing the BIM concept to a utility/company. Nevertheless, further dissemination of all related experiences is imperative.

Finally, it is not only about the utilities/companies, who have to develop and define their future position and role in a digital world. Above all, politics must provide a clear vision of the digital future. If goals are clearly defined and communicated, the challenges of digital transition can be approached target-orientated and thus better overcome.

To conclude the discussion, we want to add one very topical concern: during the preparation of this article, the proposal for the recast of the European directive concerning urban wastewater treatment was published. This draft incorporates very challenging aims for wastewater utilities requesting, among others, integrated water management plans in large agglomerations, energy neutrality of the sector, as well as increased efforts for nitrogen and phosphorus removal and combined sewer overflow reductions. For meeting these goals, a good database and an appropriate information management procedure are essential. We believe that digitalisation is the tool to cope with these challenges. Thereby, the BIM concept and its four presented core elements can provide guidance to develop appropriate solutions for wastewater utilities tailored to their local-specific context.

4. CONCLUSIONS AND OUTLOOK

Digitalisation is advancing in several fields. In the wastewater sector, the application of several digital technologies and related approaches as well as the continuous collection of physical and functional infrastructure data has been common practice. In the context of building construction, the evolvement of the BIM approach, which involves the application of DTs and interdisciplinary collaboration during the entire lifespan of a structure, is gaining importance in recent times. Several BIM working groups in the wastewater sector give clear evidence of the relevance of the topic.

The presented work investigated to what extent BIM-related concepts have already found their way to the wastewater sector, and what potential chances and possible barriers are related to this approach. Investigations reveal, that recent technical implementations primarily concern the planning and construction of WWTPs as well as special structures, e.g. pumping stations. Concerned activities in the field of sewer operation and maintenance are not very widespread today, although some of the current practices already build a bridge to different BIM core elements. Organisational issues concern the collaboration of stakeholders. Within the wastewater sector, this is common practice. In contrast, interdisciplinary cooperation with other sectors (pipe network operators) is still not well established.

Current practices of data management in the wastewater sector involve several data interfaces and storage points (data silos). Furthermore, one can observe a lack of common language, exchange standards and BIM-related object catalogues (for wastewater specific assets). These aspects complicate or even hinder efficient information management and interdisciplinary collaboration. A so-called 'single source of truth', a central aspect of the BIM approach, instead of a variety of different 'data silos' would support data availability in the short way, interdisciplinary information exchange, and the elaboration of DTs. To guarantee efficient and strategic data acquisition, provision and management in the wastewater sector (and beyond), the definition of digital business plans and reconsideration of use cases is recommended. Depending on the specific purpose, requirements for data quantity and quality can be defined. An integrated (holistic) and 'demand-orientated' way of thinking about data considering the level of information need (LOIN) allows efficient information management and helps avoid 'data graveyards'. Finally, this concept provides the relevant data to make better-informed and more transparent decisions.

Emerging approaches such as the smart city and circular economy concepts incorporate high(er) degrees of complexity in regard to data management and interdisciplinary collaboration. Here, the BIM approach and the related application of DTs could provide a solid basis to further evolve wastewater management procedures and to facilitate (standardise) inter- and cross-sectoral (co-)working concepts. Although, the current practices from overground management certainly require some adaption for being applicable in the underground environment. Existing concerns and preconceptions appear comprehensible. From a bottom-up perspective, they can be overcome with good/best practice examples as well as with stakeholder education, knowledge building, and professional change management. However, to cope with the challenges of digital transformation the elaboration of a contemporary, clear and holistic digital vision is also of crucial importance. This also requires top-down efforts. Our article aims at contributing to these two perspectives by stimulating additional discussion and research work to optimise procedures and practices in wastewater management on the continuous journey towards a digital future.

ACKNOWLEDGEMENTS

This article summarises core findings of second author's master thesis quoted as Franziskowsi (2023) in the References section. Intermediate results have been presented at the IWA LESAM 2022 conference. This conference contribution is quoted as Kretschmer *et al.* (2022) in the References section. The authors express many thanks all interview partners for their time and their great and continuous support.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Beetz, J., van Berlo, L., Borrmann, A., Enzer, M., Frey, C., Hartmann, U., Hass, W., Mercer, A., Weiß, F. & Weiß, N. 2020 *Enabling an Ecosystem of Digital Twins*. buildingSMART International.

BIM Dictionary 2019 *BIM Excellence Initiative (BIMe Initiative)*. Available from: https://bimdictionary.com/en/digital-twin/1 (accessed 11 May 2022).

BIM Dictionary 2021 *BIM Excellence Initiative (BIMe Initiative)*. Available from: https://bimdictionary.com/en/building-information-modelling/2 (accessed 11 May 2022)

BMVD (n.d.) BIM4Infra 2020 Digitales Planen und Bauen. Bundesministerium für Verkehr und digitale Infrastruktur. (English translation: *Digital planning and building. Federal Ministry of Transport and Digital Infrastructure*). Available from: https://bim4infra.de/ (accessed 5 May 2022).

Bock, B. & Michaelis, E. 2019 Building Information Modeling in der Abwasserableitung mit openBIM (English translation: *Building information modeling in sewer operation using openBIM*). *WASSER und ABFALL* **5**, 36–42.

Brink, B. & Weishut, J. 2020 *Bits & Pieces – Uniting the Physical and Digital World for A More Sustainable Europe – A Dutch Perspective*. Royal Haskoning DHV Digital.

Bris, A. & Cabolis, C. 2021 *IMD World Digital Competitiveness Ranking 2021*. IMD World Competitiveness Center. Available from: https://www.imd.org/centers/world-competitiveness-center/rankings/world-competitiveness/ (accessed 4 May 2022).

BRISE n.d. *Building Regulations Information for Submission Envolvement*. Available from: https://digitales.wien.gv.at/projekt/brisevienna/ (accessed 27 May 2022).

British Water n.d. *BIM4Water. To Lead the Digital Transformation of the Water Sector Through Better Information Management*. Available from: https://www.britishwater.co.uk/page/BIM4Water (accessed 21 May 2022).

buildingSMART Austria n.d. *Representation of the Global Initiative for Open BIM in Austria*. Available from: https://www.buildingsmart.co.at/ (accessed 10 May 2022).

Chapman, D., Providakis, S. & Rogers, C. 2020 BIM for the underground – an enabler of trenchless construction. *Underground Space* **5**, 354–361.

Degendorfer, C. 2022 *BIM Adoption Nordic Countries*. BIM SPOT GmbH. Available from: https://www.bimspot.io/blogs/bim-adoption-nordic-countries/ (accessed 4 May 2022).

DWA 2021 Merkblatt DWA-M 860-1 – Building Information Modeling (BIM) in der Wasserwirtschaft – Teil 1: Grundlagen – Entwurf Mai 2021 *(English translation:* Building Information Modelling (BIM) in Water Management – Part 1: Basics – Draft May 2021). German Water and Waste Association, Hennef.

EN ISO 19650-1:2018 Organization and digitization of information about buildings and civil engineering works, including building information modelling (BIM) – Information management using building information modelling – Part 1: Concepts and principles.

EU BIM Task Group n.d.a. *Bringing Together National Efforts Into a Common and Aligned European Approach to Develop a World-Class Digital Construction Sector*. Available from: http://www.eubim.eu/ (accessed 25 November 2021).

EU BIM Task Group n.d.b *Handbook for the introduction of Building Information Modelling by the European Public Sector, Strategic action for construction sector performance: driving value, innovation and growth*. Available from: http://www.eubim.eu/handbook/ (accessed 20 March 2023).

European Commission n.d.a. *Europe's Digital Decade: Digital Targets for 2030*. Available from: https://ec.europa.eu/info/strategy/priorities-2019-2024/europe-fit-digital-age/europes-digital-decade-digital-targets-2030_en (accessed 23 November 2021).

European Commission n.d.b. *Path to the Digital Decade: Governance Framework for 2030*. Available from: https://digital-strategy.ec.europa.eu/en/library/proposal-decision-establishing-2030-policy-programme-path-digital-decade (accessed 5 May 2022).

Franziskowski, S. 2023 *Abwasser 4.0 - Chancen und Herausforderungen der BIM-Methode in der Abwasserwirtschaft* (English translation: Wastewater 4.0 - Chances and Barriers of Building Information Modelling in the wastewater sector). Master Thesis, University of Natural Resources and Life Sciences, Vienna, Austria.

Garrido-Berserba, M., Corominas, L., Cortés, U., Rosso, D. & Poch, M. 2020 The fourth-resvolution in the water sector encounters the digital revolution. *Environmetal Science & Technology* **54**, 4698–4705.

Hunziker Betatech 2021 *ARA Werdhölzli – Rohbau Wird Papierlos Gebaut* (English translation: WWTP Werdhölzli – Paperless Shell Construction). Available from: https://www.hunziker-betatech.ch/de/news/meldungen/ara-werdhoelzli.php (accessed 9 June 2022).

IG Lebenszyklus Bau 2016 *Lebenszykluskostenrechnung in der Vergabe – Leitfaden für die Paketvergabe von Planungsleistungen (English translation: Life Cycle Calcuation in Contracting – Guideline of Cumulated Contracting of Planning Services)*. Vienna, Austria.

IP 1 2021 Digital Director, Engineering Consultancy, buildingSMART representative. Online interview via Zoom, 16 November 2021.

IP 2 2022 Department Manager, Engineering Consultancy, BIM working group member. Online interview via Zoom, 1 February 2022.

IP 3 2022 Managing Director/Co-Owner, Engineering Consultancy, BIM working group member. Online interview via Zoom, 2 March 2022.

IP 4 2022 *Project Manager, Engineering Consultancy*. Online interview via Zoom, 18 March 2022.

IP 5 2022 *CEO, Sewer Rehabilitation Company*. Online interview via Zoom, 4 April 2022.

IP 6 2022 *Department Manager, Wastewater Association*. Online interview via Zoom, 23 May 2022.

IWA n.d. *Digital Water – Get Involved*. International Water Association. Available from: https://iwa-network.org/programs/digital-water/ (accessed 23 November 2021).

Kammerlander, J. & Ladinig, L. 2018 *BIM und Digital Vernetzte Infrastruktur in der Siedlungswasserwirtschaft* (English translation: *BIM and Digitally Connected Infrastructure in Sanitary Engineering)*. *Bachelor Thesis*, University of Natural Resources and Life Sciences, Vienna, Austria.

Kretschmer, F., Franziskowski, S., Huber, F. & Ertl, T. 2022 Chances and Barriers of Building Information Modelling in Sewer Asset Management. In: *Oral Presentation at the Leading Edge Conference for Strategic Asset Management (LESAM)*, May 11–13, Bordeaux, France.

Liu, X., Wang, X., Wright, G., Cheng, J. C. P., Li, X. & Liu, R. 2019 A state-of-the-art review on the integration of building information modelling (BIM) and geographic information system (GIS). *ISPRS International Journal for Geo-Information* **6**, 53.

Manny, L., Duygan, M., Fischer, M. & Rieckermann, J. 2021 *Barriers to the Digital Transformation of Infrastructure Sectors*. Policy Sciences, Springer, Germany.

National Institute of Building Sciences 2007 United States National Building Information Modeling Standard, Version 1 - Part 1: Overview, Principles, and Methodologies. Final Report, December 2007.

Nessier, M. & Börrnert, D. 2020 Digitale ARA-Planung (English translation: digital WWTP planning). *AQUA & GAS* **11**, 14.

Pedersen, A. N., Borup, M., Brink-Kjær, A., Christiansen, L. E. & Mikkelsen, P. S. 2021 Living digital twins of urban water systems: towards multi-purpose value creation using models and sensors. *Water* **13** (5), 592.

Prenner, F., Pucher, B., Zluwa, I., Pitha, U. & Langergraber, G. 2021 Rainwater use for vertical greenery systems: development of a conceptual model for better understanding of processes and influencing factors. *Water* **13**, 1860.

Söbke, H., Peralta, P., Smarsly, K. & Armbruster, M. 2021 An IFC schema extension for BIM-based description of wastewater treatment plants. *Automation in Construction* **129**, 103777.

Suprun, E., Stewart, R. A., Mostafa, S., Sahin, O., Bertone, E., 2020 Integrating lifecycle thinking in asset management through BIM: opportunities for the water sector. In: *The 10th International Conference on Engineering, Project, and Production Management. Lecture Notes in Mechanical Engineering* (Panuwatwanich, K. & Ko, C. H. eds.). Springer, Singapore.

Torfs, E., Nicolaï, N., Daneshgar, S., Copp, J. B., Haimi, H., Ikumi, D., Johnson, B., Plosz, B. B., Snowling, S., Townley, L. R., Valverde-Pérez, B., Vanrolleghem, P. A., Vezzaro, L. & Nopens, I. 2022 The transition of WRRF models to digital twin applications. *Water Science & Technology* **85** (10), 2840–2853.

Valverde-Pérez, B., Johnson, B., Wärff, C., Lumely, D., Torfs, E., Nopens, I. & Townley, L. 2021 *Digital Water – Operational Digital Twins in the Urban Water Sector: Cases Studies*. International Water Association, London, UK.

VSA Verband Schweizer Abwasser- und Gewaesserschutzfachleute (English translation: Association of Swiss Wastewater and Water Protection Professionals) n. d. Projektbeschrieb: BIM-Leitfaden digitale Planung (English translation: Project Description: BIM Digital Planning Guide. Available from: https://vsa.ch/Mediathek/projektbeschrieb-bim-leitfaden-digitale-planung/ (accessed 24 May 2022).

Wang, H., Pan, Y. & Luo, X. 2019 Integration of BIM and GIS in sustainable built environment: a review and bibliometric analysis. *Automation in Construction* **103**, 41–52.

Witteborg n.d. *Digital Twins for Wastewater Infrastructure – A White Paper on the Why, What and How*. Royal Haskoning DHV Digital.

Wright, L. & Davidson, S. 2020 How to tell the difference between a model and a digital twin. *Advanced Modeling and Simulation in Engineering Sciences* **7**, 13.

First received 5 October 2022; accepted in revised form 6 March 2023. Available online 16 March 2023