The uptake of digital twins in delivering infrastructure sector projects

Uptake of Digital Twins in delivering infrastructure sector projects

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Abstract

Purpose: The anticipated strong growth of the infrastructure industry over the coming decades will require more modern, digital approaches to create data-centric infrastructure that allows infrastructure to be monitored and managed throughout its lifecycle. Digital Twins (DTs) are currently at an early stage in terms of their implementation on infrastructure projects across the United Kingdom (UK). The purpose of this paper is to evaluate the current uptake of DTs in delivering infrastructure sector projects and how DTs can help contribute towards strengthening the industry.

Design/methodology/approach: A systematic Literature Review approach has been conducted with the research questions derived from the PRISMA article screening tool. In addition to this, inclusion and exclusion criteria have been used to screen irrelevant information and help streamline research documents. Following a screening of relevant information, 36 pieces of literature were reviewed in order to identify the key drivers, barriers, enabling technologies, and use cases.

Findings: DTs have the potential to transform asset design, production, and maintenance. However, to further advance the digital innovation in the UK infrastructure sector, further study is necessary. An emerging technology must be considered on a broader scale than just its technical aspects, particularly when it comes to DTs. With enabling technologies such as the Internet of Things (IoT), sensors, and Artificial Intelligence (AI), the uptake of DTs appears promising. While current literature indicates that DTs offer clear benefits in the infrastructure sector, the uptake is low and hindered by both technical and non-technical challenges.

Originality/value: This paper provides a rich insight into the understanding and awareness of the DTs in delivering infrastructure sector projects and how the infrastructure sector has evolved in order to develop new ways of designing, constructing, operating and monitoring infrastructure assets. This study contributes towards informing leaders in the sector of the current uptake of DTs within the UK's infrastructure sector as well as how DTs can contribute towards strengthening the industry.

Keywords: Artificial Intelligence, Digital Twins, Digitalisation, Infrastructure Sector.

Introduction

The UK infrastructure sector (water, transport, energy, smart cities, telecommunication, and waste management) is moving towards advancing digitalisation to deliver more complex, resilient and sustainable infrastructure projects (Gürdür Broo *et al.,* 2022). It is forecasted in the National Infrastructure and Construction Pipeline (2021) that £649 Billion will be invested into UK infrastructure over the coming decade, demonstrating the industry's expected growth. Digital transformation needs to be considered alongside the outcomes needed in society characterised by the United Nations Sustainability Development Goals (IPA, 2021) in order to maximise the impact and unlock the value of this future investment, when making decisions on how infrastructure is constructed, maintained, and renewed.

The National Infrastructure Commission (2017) highlighted the emerging technologies that had the most potential in optimising the performance, management and maintenance of existing and future infrastructure assets to support the nation's economy, with DTs being a primary focus. Since DT in the infrastructure sector is a developing concept, there is no generally recognised definition (Broo and Schooling, 2021). The UK's Nation Digital Twin programme (NDTp) refers to a DT as a "realistic digital representation of assets, processes, or systems", which represents the real-world behaviours of the physical system through data-connection (CDBB, 2020; NIC 2017). However, several studies (Pregnolato *et al.,* 2022; Boje *et al.,* 2020) argue that the transition of this technology into the infrastructure sector is not well defined.

Passive infrastructure assets can be turned into data-centric systems of systems with DTs improving the flow of information and operations (Gürdür Broo *et al.,* 2022). With the integration of enabling technologies, such as sensors, IoT, data analytics, AI and Machine Learning (ML), DTs can create dynamic digital models that can monitor, inform, and update the physical asset from various sources (Pregnolato *et al.,* 2022). According to Lu et al. (2019), DTs will simulate, predict the performance and future state of its physical equivalent, which will in turn provide smarter decision-making capabilities and data-driven infrastructure. Similarly, Pregnolato *et al.* (2022) states that when all systems are connected in the built environment an DT can then be achieved. In contrast to other digital representations of infrastructure assets, such as Building Information Modelling (BIM), DTs change and evolve alongside their physical counterparts throughout their lifecycle, based on the synchronisation between the physical asset, process or system and its DT (Pregnolato *et al.,* 2022).

In order to improve infrastructure efficiency, resilience, and sustainability, DTs enable the acquisition and integration of data to optimise the performance of infrastructure throughout its lifecycle (Gürdür Broo *et al.,* 2022). DTs provide organisations with more opportunities for resource conservation during the design development phase, as well as the capability to conduct proactive multi-directional analysis during the operation phase, when integrated with the latest enabling technologies and influential data analytics algorithms (Gürdür Broo *et al.,* 2022; Grieves and Vickers, 2017). For instance, DTs can be used to analyse data and detect anomalies in asset performance to help identify ways to improve maintenance strategies and reduce costs (Pregnolato *et al.,* 2022).

Despite the significance of DTs, the uptake of this technology is unclear in the infrastructure sector and needs to be established in order to shed light on how the sector can integrate this technology onto existing and future infrastructure projects. The adoption of digital technologies in the infrastructure sector has not always been straightforward, consistent, and efficient, which has resulted in limited benefits and a waste of valuable resources. For example, DTs are often confused with BIM, therefore, differentiation between digital models and digital replications may need to be established, i.e., DTs of infrastructure need to be recognised as a powerful lifecycle management initiative (Gürdür Broo *et al.,* 2022; Jiang *et al.*, 2021). Moreover, most existing infrastructure assets are faced with challenges, such as ageing and unforeseeable occurrences, that are vulnerable to asset failure (Pregnolato *et al.,* 2022).

With this background, the aim of this study is to evaluate the uptake of DTs in delivering UK infrastructure projects. Understanding how the UK infrastructure sector perceive and act on DTs, the various components that enable DTs and the wider national context of this.

Research Gap

There is a lot of information about the technical application of DTs and its supporting role in various industries, however, it appears to be deficient in the infrastructure sector. With particular focus to the UK infrastructure sector published literature in relation to the uptake of this technology are not clearly presented with literature specifically relating to its status in the industry. There is a lack of exploration into the current uptake of DTs and strategies in the UK infrastructure sector.

To provide a sustainable, resilient, and efficient infrastructure asset throughout its entire lifecycle, DTs can take advantage of a number of different technologies. In the UK infrastructure sector, most information about DTs is published by parties who have implemented their own DT as part of a project or at a prototype stage, which results in partially biased information and lack of critical evaluation. Nevertheless, it provides insight into how DTs can be adopted, as well as an understanding of the potential requirements necessary for successful implementation. A critical appraisal of these requirements is required in order to provide an unbiased assessment.

In the development of any new initiative, research is essential to ensure that all aspects are considered, followed by continuous challenge and improvement in order to facilitate an efficient implementation. While there is some research undertaken within the infrastructure sector that recognises the benefits, significance and technical considerations of DTs, little research has been conducted to assess how this technology is faring and how projects are implementing DTs. This could imply that the infrastructure sector is still in its infancy, as indicated by several studies (Gürdür Broo et al., 2022; Pregnolato et al., 2022), when implementing DTs. Thus, there exists a gap in both practice and assessment in regard to the alignment of DTs.

Research Methodology

It was a challenging task to review literature on this topic since it is a relatively recent technology introduced within the infrastructure sector. Implementing a new technology requires an understanding of its status, the reasons for implementing it, the benefits it brings, and the challenges it poses. The scope of the literature review was to review the status of DTs in the UK infrastructure sector. As a means of enabling a systematic understanding of the topic, the following questions were developed: How would a DT be defined from infrastructure sector perspective?; What is the level of awareness of DTs within the infrastructure sector?; What is the usage of enabling technologies of DTs?; What is the potential-use cases of DTs within infrastructure sector?; What are the potential barriers to implementation of DTs in the infrastructure sector?; and Is there a need to develop a framework for successful integration of DTs in the UK infrastructure sector?.

A systematic review is used for this paper to review relevant literature guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement to evaluate whether the findings of the review can be trusted and are applicable. This systematic review was reported in accordance with the PRISMA statement to ensure transparency and comprehensiveness of the review findings that clearly address the purpose of this study (BMJ, 2021). The papers were selected based on the research questions and inclusion criteria. Data extraction and analysis were then conducted to evaluate the quality and validity of the studies. The systematic review findings were then reviewed and interpreted. Accordingly, the results have been analysed and reported based on the research questions.

Initial scoping was conducted using the search terms ("digital twins" OR "digitalisation") AND ("infrastructure sector" OR "civil engineering" OR "building information modelling") AND ("united kingdom") to identify relevant electronic databases and journals to be used for the literature search. Following the initial scoping, electronic databases Science Direct, The University of Wolverhampton library, Google Scholar and ICE Virtual Library were selected for this literature search. The databases selected for this review have a high reputation and a wide range of citations which relate to the topic under review.

In order to conduct a comprehensive search across all 4 databases, the following key words were used: ("digital twins" OR "digitalisation") AND ("infrastructure sector" OR "civil engineering" OR "building information modelling" OR "railway" OR "smart city" OR "water" OR transport OR "energy" OR "telecommunication" OR "waste management") AND ("united kingdom" OR "britain" OR "england" OR "scotland" OR "wales" OR "northern island").

An advanced search tool was used during the extraction of studies to identify only English-language studies published between January 2011 and December 2022 (the last 11 years). The reason for this is that this is the year digitisation began to significantly develop within the infrastructure sector, and as technology is a rapidly evolving field; therefore, it is important to avoid discussing outdated technologies. Moreover, only published articles, government reports, and websites were selected for inclusion in the review.

In comparison to other sectors and countries, the published literature on DTs in the UK infrastructure sector has been underrepresented, primarily because it is an evolving topic and there is a lack of relevant publications. Consequently, additional reports, articles, and datasheets were obtained from other sources. Other sources include the UK government, the Centre for Digital Built Britain, Arup, and the National BIM Report.

Following the inclusion and exclusion criteria shown in Table 1, the literature retrieved was thoroughly screened and reviewed to ensure relevance and to reduce the likelihood of biased information being presented. As shown in Table 1, the following inclusion and exclusion criteria were used to filter out irrelevant studies and were then screened for duplicate entries. Due to the use of several databases, it was more likely that some articles had been published in more than one database. The titles and abstracts were screened for eligibility after the duplicates were identified and removed. After identifying the studies that met the pre-defined inclusion and exclusion criteria, a review was conducted.

Table 1 – Inclusion and Exclusion Criteria

	Inclusion Criteria	**Exclusion Criteria**
Date	Data collection carried out between January 2011 – December 2022	Data collection carried out before January 2011
Geographic location	United Kingdom, Britain, England, Scotland, Wales, Northern Island	All other geographical locations or no specific involvement from the United Kingdom
Language	English	Papers not in English

Type	Published Articles, Reports, Research Papers	Blogs, Book reviews, Dissertations, Duplicated Publications
Publications	Published Textbooks, Peer Reviewed Journals, Government Report and Websites, Conference Proceedings, Organisational Published Reports, Industry Specific Articles, Websites	Discussion Forums, Papers focussing on DT in other industries other than the infrastructure sect√or
Participants	Industry Professionals, Public or Private Organisations contributing to the analysis and Information of DTs in the UK specific to the Infrastructure Sector	Non-UK Based Organisations and Researchers
Design	Quantitative, Qualitative, Case Studies using validated Methodology, Surveys	
Focus	Is the information relevant to DTs in the infrastructure sector? Does the information contribute to the study of DTs in the infrastructure sector?	Information with limited or no relationship related to the infrastructure sector or United Kingdom

During the extraction of the possible papers to be used in the study an advanced screening tool, PRISMA, was used to ensure the identified literature was appropriately filtered, associated to the topic and as per the inclusion and exclusion criteria (listed in Table 1). Based on the screening process, 36 studies were determined to be eligible for analysis and were subsequently included in this systematic review (see Figure 1).

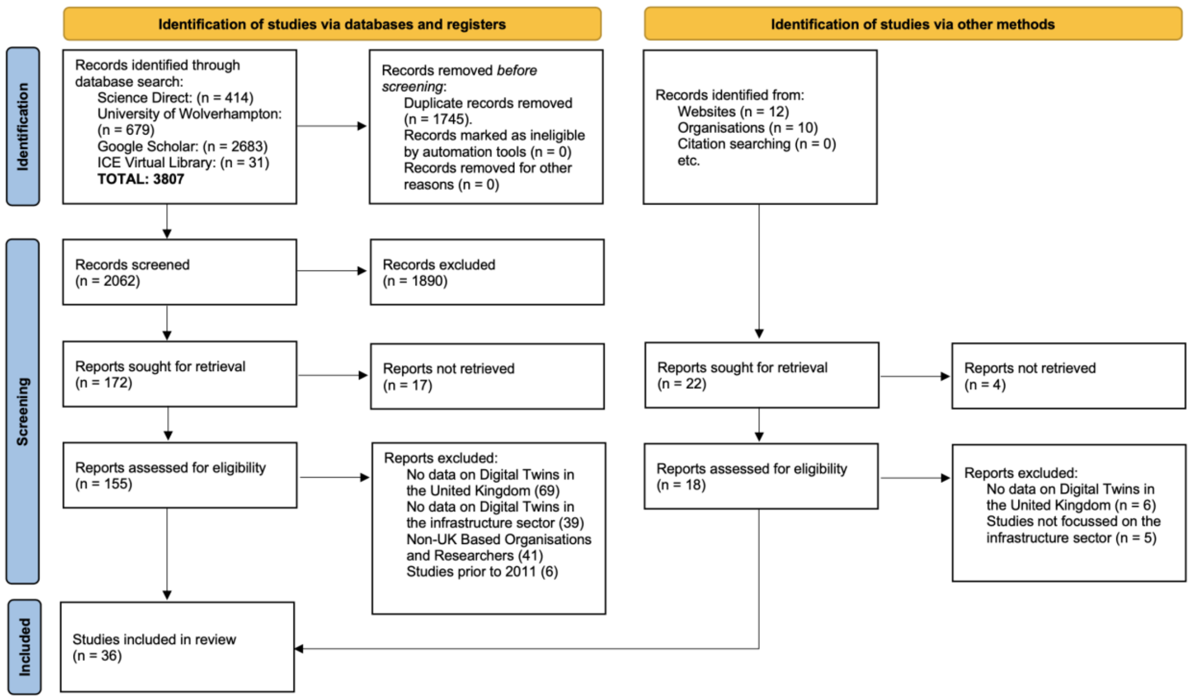

Figure 1 – PRISMA screening process

Results and Discussion

Overview of DTs in the UK infrastructure sector

The UK is challenged with increasing economic uncertainty, population growth and climate change issues, which is putting significant pressure on infrastructure. In order to address this, the UK's infrastructure needs to become smarter and integrated as part of an optimised system to achieve increased efficiency. The NIC's Data for the Public Good (2018) study identified that there is "limited understanding about the way the UK's infrastructure works as a system". The UK's National Digital Twin programme (CDBB, 2020) was launched to implement the key recommendations of the study. It identified the importance of establishing a National DT, an ecosystem of DTs, sharing infrastructure information to support the planning, predicting, and understanding of infrastructure assets. However, it importantly implies that a Nation's DT does not represent a whole nation's infrastructure in one federated model. Instead, how it is made up of individual DTs constructed at various scales (Lu *et al.,* 2020). Followed by "The Gemini Principles" which aim to form consensus on DTs in the built environment (Bolton *et al.,* 2018). Despite the awareness of the benefits this technology has, there is no clear indication of how well this technology is being adopted on infrastructure projects to assist with its implementation.

According to existing concepts, a DTs consists of three components: the physical entity that exists within the physical environment, the virtual entity that exists within the virtual environment, and the data linking between the physical and virtual environments (Boje *et al.,* 2020; CDBB, 2020; Grieves and Vickers, 2017). It should be noted that Jiang *et al.* (2021) argues that there are five parts comprising a physical part, a virtual (digital) part, connections, data, and services, which demonstrates the uncertainties as to the clarity of a DTs in the infrastructure sector. The five components of a DTs represent a more comprehensive understanding of how each part contributes to a DTs functionality.

Pregnolato *et al.* (2022) recognises that industry and literature must identify and resolve conflicting definitions and undefined processes associated with DT development, specifically in relation to existing infrastructure that may not be digitally represented. However, Jiang *et al.* (2021) argues that by leveraging sensors and IoT, DTs can be used to inspect and assist existing projects. The ambiguity regarding DTs in the infrastructure sector and what it can do for digital advancement is evident from this.

The usage of enabling technologies of DTs

This section discusses the technologies that constitute the core of the DTs model as identified in multiple sources of literature (refer to Table 2). It also provides a thorough understanding of the current usage of technologies that enable the advances of DTs in the infrastructure sector. It has been identified in current literature that there are various key usages of enabling technologies for DTs. For example, in the infrastructure sector, it is suggested that the outset and modelling capability of a DTs starts with BIM and continues with integrating further enabling technologies such as sensors, Big Data, IoT and AI (Pregnolato *et al.,* 2022).

Table 2 – Enabling technologies considered important to a DT in the infrastructure sector, extracted from multiple literature sources.

Reference	What enabling technologies are considered as being part of a DT?					
	BIM	Sensors	Big Data	IoT	AI	ML
Arup, 2019	√	√	√	√	√	√
Boje et al., 2020	√	√	√	√	√	√
Gürdür Broo et al., 2022	√	√		√	√	√
Hall and Pesenti, 2017		√		√	√	√
Jiang et al., 2021	√	√	√	√	√	√
Lu et al., 2019	√	√		√	√	√
Lu et al., 2020	√	√	√	√	√	√

Lu et al., 2021	√	√		√	√	√
McMillan and Varga, 2022		√			√	√
Pregnolato et al., 2022	√	√	√	√	√	√
Valerio, 2021		√	√	√		√
Wan et al., 2019					√	√
Zambrano et al., 2022		√		√	√	√

DTs and BIM

The widespread acknowledgement of BIM has enhanced the digitisation of existing and future infrastructure processes. Enhanced data-driven applications for BIM will increase its capabilities to further support the industry and researchers explore the latest technological advances such as the IoT, sensors, Big Data, and AI (Pregnolato *et al.,* 2022).

The infrastructure sector is looking at enhancing its digital technology capabilities which is why it is important to look at where we currently are in terms of digital representation on projects. The scope of DTs is broader than that of BIM due to the richness of the information and analytical capability that it possesses (Lu *et al.,* 2021). While BIM enables a standardised semantic representation of building systems and components using procedures, technologies, and data schemas (Pregnolato *et al.,* 2022; Boje *et al.,* 2020). By connecting digital and physical assets, a DT can also transmit data in at least a single direction, monitoring the physical asset in real-time (Lu *et al.,* 2021). These recent studies have begun to stipulate insight into how DTs provide a holistic view of the physical asset compared to BIM.

Some researchers, such as Gürdür Broo *et al.* (2022) and Pregnolato *et al.* (2022), propose methods for the development of BIM-centred DTs to expedite data interaction and analysis in order to greater recognise, predict, and optimise the physical process. Similarly, Jiang *et al.* (2021) concurs that a DT typically forms when virtual models are connected to their applicable physical components in BIM applications, during the development of the associated 3D models for the targeted physical component. Yet, Boje *et al.* (2020) contends that BIM is not fully semantically covered in some areas, “requiring a holistic, scalable semantic approach” that considers data dynamically at various stages.

With the addition of BIM, multi-disciplinary design and asset data can be federated enabling the prospect of achieving a single source of truth in the form of one model (Seabright *et al.,* 2022). This is currently known as the “UK BIM Framework”, previously known as BIM Level 2 (NBS, 2020), allowing all information to be captured at the design and construction phase of a project. However, it is also argued that the construction supply chain has reaped little advantage from it so far (Boje *et al.,* 2020). Conversely, challenges to this development, as identified in the 10th Annual BIM Report (2020), suggest the following: that BIM is a developing technology itself, with 73% of respondents reporting that they are currently aware of and use BIM; and the low incidence of retroactively incorporating BIM into existing assets. It raises the question if the industry is still looking at implementing BIM how it will move forward and adopt a more complex technology such as DTs.

DTs and Sensors

Any system capable of autonomous decision-making must be able to transmit data “in real-time or near-real-time” (Zambrano *et al.,* 2022). Sensors connect scattered assets into a unified unit to gather and store data, so that constant communication between them and the virtual model is possible (Pregnolato *et al.,* 2022). Despite the fact that many of these studies consider sensor device data as a source of real-time data, the types of sensors and networks depending on the type of infrastructure is neglected (Boje *et al.,* 2020).

Pregnolato *et al.* (2022) compares the use of physical sensors with virtual sensors, highlighting the importance of deploying sensors in a way that allows the physical server to perform the data analysis. Boje *et al.* (2020) identified many key challenges associated with the use of sensors with DTs. These include "demanding a successful integration of sensors of different capabilities, reading frequencies, accuracies, their respective locations and the interdependencies between sensor clusters and network" (Boje *et al.,* 2020). The research literature suggests that IoT can be used to capture sensor data. However, a primarily unfamiliar area is the sensor dynamics depending on the DT application and their interoperability with other DT components (Boje *et al.,* 2020).

DTs and IoT

In order to facilitate interaction between physical entities and virtual models, highly effective communication platforms with real-time updates need to be used. The IoT combines sensors, cloud storage, and Big Data analytics to function as a viable communication platform.

Many studies include IoT as a component of DTs since it can work with many protocols and environments, provide real-time sensor connectivity and distribute data in various formats. For example, Network Rail has deployed 3000 IoT devices to connect all the smart devices (Valerio, 2021) to allow them to interact and collect data (Seabright *et al.,* 2022). Although the railway maintenance strategy does not specifically look at a DT, the IoT shows the potential to be used as part of a DT. Integrating IoT allows the physical and virtual worlds to be interconnected (Boje *et al.,* 2020), which provides the foundation for a DT. Nevertheless, there are many uncertainties about how this data will be managed in the future, particularly in terms of data collection (Arup, 2019). For the IoT to be implemented in the form of a DT, a data acquisition system must be developed (Lu *et al.,* 2019). Furthermore, since the infrastructure assets are dispersed, they must be scalable to support assets at building levels and upload data from distributed sensors (Lu *et al.,* 2019). Whilst also focusing on accuracy, privacy and security, storage and the protection and the exchange of that data (Arup, 2019). IoT is clearly shown to have a firm stance, especially in terms of how infrastructure assets are managed, allowing data transfer between physical and digital assets. However, the challenges of implementing this crucial enabler render it necessary to develop an IoT-enabled wireless sensor network (WSN) (Lu *et al.,* 2020). An example of a WSN is a collection of wireless sensors that monitor and record the environment and equipment conditions (Lu *et al.,* 2020). Therefore, with the use of the IoT, the data from the sensors can be integrated allowing information to be used effectively without any intervention from the user (Seabright *et al.,* 2022).

DTs and AI

Advances in AI have enabled better insights into the analysis of physical assets, enabling previously unavailable data to be accessed (Arup, 2019). AI learns efficiently from numerous sources of data and detects inconsistencies using the DT. Pregnolato *et al.* (2022) suggests that the capability to use this knowledge for autonomous decision-making would advance the application of DTs. DT systems with AI-enabled decision-making and data analysis capabilities would significantly improve the intelligence of data and model integration layers (Lu *et al.,* 2019).

The ability for AI to provide and maintain infrastructure services will become increasingly crucial as systems become more complex, interconnected, and digital (McMillan and Varga, 2022; Hall and Pesenti, 2017). Combining DTs with information and communication technologies, as well as advanced analytics algorithms, such as AI, enables societies to sustain physical resources during the lifecycle of an infrastructure project and perform diagnostic and prognostic analysis while the infrastructure is in operation (Lu *et al.,* 2020). Wan *et al.* (2019) suggests that with the use of AI, the DT could have the potential to generate new knowledge that matches or even exceeds the existing knowledge of the physical asset. In theory, the DT could, therefore, indicate how to plan and manage cities ahead of their implementation (Wan *et al.,* 2019). AI is currently adopted in the railway sector as a predictive maintenance tool (Valerio, 2021). The Intelligent Infrastructure (II) programme was launched to improve services for passenger and freight customers (Seabright *et al.,* 2022). For example, a digital representation of track data is used to monitor and predict potential repairs in advance. AI forms an essential part of a DT as it incorporates physical and virtual capabilities that are the basis of any DT.

However, McMillan and Varga (2022) argue that AI applications in infrastructure systems are, at present, isolated. Therefore, it is somewhat unclear how AI will be used in the infrastructure sector, since DTs is still a developing technology. Nevertheless, it is also likely that the application of AI in infrastructure systems will develop as they become progressively digitalised, offering high-level information outputs and autonomous predictions for AI applications (McMillan and Varga, 2022).

Potential-use cases of DTs within the UK infrastructure sector

Smart Cities

A smart city is becoming increasingly connected with the use of DTs through IoT (Fuller *et al.,* 2020; Arup, 2019;) and their potential for improved efficiency is growing every year. Moreover, the added inclusion of AI would be required to deliver greater energy efficiency and lower operational costs (Boje *et al.,* 2020; Howell *et al.,* 2017). An accurate DT of a city is sustained by taking advantage of the data collected in smart cities and integrating them into an urban DT and its respective integrated systems (Ferré-Bigorra *et al.,* 2022). Independent urban DTs of diverse assets must collaborate and communicate with one another in order for a smart city to function effectively (Pregnolato *et al.,* 2022). They must also provide inputs to a "central decision-making "hub" or city level decision-makers" (Pregnolato *et al.,* 2022).

Through data exchange, the DTs can represent the city model realistically and its systems as accurately as possible. Data exchange can lead to increased benefits in the management and operations of urban infrastructure (Ferré-Bigorra *et al.,* 2022). A number of applications of DTs are proposed within the smart city context, such as planning city vulnerability, facilitating de-risked decision-making, identifying potential environmental concerns, or recommending a concept for integrating the latest enabling technologies to support the physical asset (Gürdür Broo *et al.,* 2022).

The case study of the Intersection Bridge 5 (IB5) was implemented to develop a DT of a physical asset. Identifying what information could be needed in the future (Gürdür Broo *et al.,* 2022). The sensor system installed was designed to be used during the construction and operation stages of the project. By doing so, it could reveal whether the asset was structurally integral which could serve as a basis for making comparisons during operations and subsequent repairs.

Water

Water infrastructure systems are critical in delivering goods and services that the population rely on. However, planning and managing these systems is particularly challenging due to the scale, complexity, lifecycle, and crucial significance of the service they deliver (Savić, 2022). DTs are increasingly being applied in the water sector to increase the energy efficiency of these systems and it can also be used as an "decision-support tools for operational water system management" (Savić, 2022). For example, detecting pressure increases in pipe systems or leakages within the network. According to Ramos *et al.* (2022), a DT in conjunction with an optimisation system can result in water savings of up to 28% by detecting leaks, thereby improving the overall efficiency of the system. In England and Wales over 3000 million litres of water is lost due to leakages (UK Water, 2022), therefore optimising the system using DTs could provide better management of the pressure and flow, and significantly enhance the systems reliability and the operation flexibility.

To enable the vision of a DT it firstly needs to be looked at for an individual asset to understand how all components are integrated and how the DT can be utilised to create an optimised system. The failure of the Tadcaster Bridge (2015) is a case that is looked at how a DT could have been used to increase flood resilience (Pregnolato *et al.,* 2022; CDBB, 2020). It also demonstrates how assets currently maintained do not have the capability to detect asset defects or failures at the right time. If a DT was deployed for the physical asset of the bridge the change in flood level could have been detected in advance to avoid the complete failure of the structure (Pregnolato *et al.,* 2022). Especially considering the current climate change challenges and subsequently increased rate of flooding, DTs have the ability to optimise infrastructure built and proactively maintain them in accordance with the current climate challenges that may arise.

The potential barriers to implementation of DTs in the infrastructure sector

Table 3 – The potential barriers to implementation of DTs in the infrastructure sector

Barrier	Description	Reference
Limited government support	Policy outcomes must be delivered by DT technology in order for this technology to be useful and effective.	Ferré-Bigorra et al., (2022); Wan et al., (2019)
Lack of published literature on the DT topic	Publications on DT technology is low which may be attributed to its low implementation and awareness.	Jones et al., (2020); Lamb (2019)
Low interoperability	DT models require a large number of interconnected systems with contrasting dimensions that are determined by the scale and rate of change of the particular type of infrastructure.	Ferré-Bigorra et al., (2022); Wan et al., (2019)
Lack of case studies to demonstrate the practical application of a DT	In order to adopt a new technology an assessment of cost and benefits is crucial to drive the industry into enhancing the current technologies used. An evaluation of costs the associated advantages is critical for understanding and appreciating the practical applications of a DT, thereby justifying their scope.	Jones et al., (2020); Pregnolato et al., (2022)

Establishing the value of data used in a DT	A DT is supported by the data attributed to the model, if the value of data is degraded it can cause the physical model to not operate efficiently.	Nochta et al., (2021); Pregnolato et al., (2022)
Limited guidance for recognising and capitalising on the wider business prospects	Insufficient consideration has been given to the potential organisational challenges associated with DT implementation. The development of organisational practices that enable DTs and promote technical proficiency among all parties involved in using this technology on projects is necessary.	Gürdür Broo et al., (2022); Jones et al., (2020); Pregnolato et al., (2022);

Table 3 represents an overview of the potential barriers to implementation of DTs in the infrastructure sector. Despite the UK's Governance of the Digital Framework Task Group to create a real policy impact, the implementation of DTs in the infrastructure sector is still unclear. To move forward and validate DTs as a technological advancement an innovative governance framework must be accompanied to provide significant and practical policy visions (Wan *et al.,* 2019). Pregnolato *et al.* (2022) argues that the initial step to enable the vision is to create DTs of individual assets which work as an optimised system, compared to the CDBB (2020) which looks at a National DT.

After conducting a review of current literature, the publications on DTs technology in the infrastructure sector have been observed to be very low which is also supported by Lamb (2019). DT literature has mostly emerged in the past 10 years with 96% of publications appearing since 2016 (Pregnolato *et al.,* 2022). Even so most being related to manufacturing and production (Jones *et al.,* 2020), with little focus in the built environment (Approx. 5%) (Lamb, 2019). This could be attributed to the low implementation of DTs and awareness of DTs.

There are many types of infrastructure affected by a set of systems such as energy, water supply and transportation (Ferré-Bigorra *et al.,* 2022). As a result, DT models require a large number of interconnected systems (Ferré-Bigorra *et al.,* 2022) with contrasting dimensions, that are determined by the scale and rate of change of that particular type of infrastructure (Wan *et al.,* 2019).

It is recognised that the potential barrier for implementation is the lack of case studies that are used to demonstrate the practical application of a DT, this could also be related to the low level of awareness of DTs. Fundamentality in order to adopt a new technology an assessment of cost and benefits is crucial to drive the industry into enhancing the current technologies used (Pregnolato *et al.,* 2022).

In order to justify the scope and development of a DT, the value of information and business models may help to explain how the DT generates value (Pregnolato *et al.,* 2022). It is clear from the usages of DTs that various applications must be supported at once to allow efficient operations and maintenance decisions and to enable predictive analysis (Lu *et al.,* 2019). However, since a DT is supported by the data attributed to the model, if the value of data is degraded it can cause the physical model to not operate efficiently (Lu *et al.,* 2019).

Asset owners and managers can use DTs to improve the operational efficiency of the asset lifecycle and its condition (Pregnolato *et al.,* 2022). Through their detection of anomalies and prediction of asset behaviour, they can offer an enhanced understanding of potential asset risks. In addition, they can facilitate maintenance optimisation, facilitating planned maintenance opportunities to anticipate and prevent failure of the components (Pregnolato *et al.,* 2022). As of present, there is very limited guidance for recognising and capitalising on the wider business prospects associated with this technology (Gürdür Broo *et al.,* 2022), in addition to the associated savings in cost and operational proficiencies (Pregnolato *et al.,* 2022). Similarly, Jones *et al.* (2020) recognises the importance of evaluating costs as well as the benefits accruing from DTs in order to quantify and understand their practical applications. For infrastructure and workflow changes to be justified, a clear understanding of the extent of benefits associated with DTs is necessary for effective application (Jones *et al.,* 2020). Evidence, with the support of business models, may contribute to understanding how DTs generate significance (Pregnolato *et al.,* 2022), thereby justifying their scope and development based on their costs and returns can further support these suggestions.

Conclusion and Recommendations

A DT facilitates the understanding of how various aspects of the infrastructure industry interact. Overall, there is a need to increase awareness regarding the implementation of DTs and their potential impacts on projects, and the cost savings and damage savings they can result in. In practice, the application of DTs is very low and requires further development in order to shed light on their potential to strengthen the infrastructure sector.

DTs have the potential to transform the way assets are designed, produced, and maintained, but to accelerate digital transformation of the UK infrastructure sector, more research is necessary. There is a lot more to consider when considering new technology than just the technology itself especially when looking at DTs. With technologies such as IoT, sensors, and AI, the uptake of DTs looks promising. The current literature shows, however, that despite clear knowledge of the advantages the enabling technologies can offer, the integration within a DT is overlooked. To enable DTs, these technologies need to be integrated rather than used separately. However, an outlining challenge could be for example, upskilling the workforce (Arup, 2019), the loss of productivity caused by learning new software and increased liability if a mistake is made, which are only a fraction of the non-technical factors that need to be considered to enable a new technology.

It is clear from the research papers discussed that a DTs could provide more insight to how the system of an infrastructure asset work and provide more effective operations and maintenance. However, despite the clear acknowledgement of the requirement to provide data-centric infrastructure no research papers were identified that clearly presented how well this topic was developing in the UK infrastructure sector. In order to further research the uptake of DTs in the infrastructure sector, it is key to look at the viable ways to collate new information in regard to the current uptake of the technology and what can practically enable DTs to be implemented within the infrastructure sector, since there is limited understanding of the current development of implementing DTs. By compiling all of this information, a collation of views, challenges, and what may be hindering the adoption of DTs from different sectors across the industry can be provided.

Business models need employees who can learn, operate, and maintain the DTs, with knowledge of how the enabling technologies are integrated within the system to ensure the most efficiency of the DT (Ferré-Bigorra *et al.,* 2022). As indicated by the research in this paper, a DT involves technologies that are currently developing themselves, therefore, to possibly overcome this new talent with skills to understand the complexity of a DT need to be looked at (Arup, 2019). As well as capitalising on the existing workforce and the involvement from the government through standardisation needs to be addressed (CDBB, 2020).

With particular focus in the UK there is little research relating to the uptake of DTs despite clear knowledge of the benefits a DT can offer. Bridging the gap between where the industry is now in terms of digital representation on projects and where it is going is only supported by the development of live DTs (Gürdür Broo *et al.,* 2022). There are clear advantages of implementing DTs, however the amount of influence stakeholders has over decision-making is unclear from a research perspective. To enable DTs to be implemented there needs to be a clear understanding of what the technology can bring and support in terms of cost and time to provide that initial reach for using DTs, which can then be supported by business models (Pregnolato *et al.,* 2022; Jones *et al.,* 2020).

Theoretical implications

This research studies the uptake of DTs in the UK infrastructure sector using a Systematic Literature Review approach. The context concerning the uptake of DTs in the UK infrastructure sector is limited. The findings presented that the uptake of DTs in the UK infrastructure sector is low. This paper provides a rich insight into the understanding and awareness of the DTs in delivering infrastructure sector projects and the changes that the infrastructure sector has to undertake in order to develop new ways of designing, constructing, operating, and monitoring infrastructure assets. This study contributes towards informing leaders in the sector to understand the current uptake of DTs within the UKs infrastructure sector and how DTs can help contribute towards strengthening the industry.

In order to further research the uptake of DTs in the infrastructure sector, it is key to look at viable ways to collate new information in regard to the current uptake of the technology and what can practically enable DTs to be implemented within the infrastructure sector, since there is limited understanding of the current development of implementing DTs. By compiling all of this information, a collation of views, challenges, and what may be hindering the adoption of DTs in infrastructure can be provided in order to assist the industry in moving forward with this technology.

Practical implications

The study presents suggestions through the values that will impact higher uptake of DTs in the UK infrastructure sector. In spite of the fact that industry is still progressing with digitalisation of infrastructure, there is still much to be achieved to enable effective implementation that can then lead to sustainable infrastructure, safer projects with cost and time benefits, considering that DTs can optimise an infrastructure asset (Jones *et al.,* 2020). Despite the acknowledgement from the government in terms of how DTs can improve the Nation's infrastructure, this does not consider the influence that businesses and stakeholders must have to initiate DTs within infrastructure projects (Pregnolato *et al.,* 2022). This is what enables a National DT (CDBB, 2020), but clear structure in terms of how this is achieved on a project or organisation level is not evident by existing literature and Government policies. As a result of this knowledge, it may be possible for organisations to understand the advantages of the DT technology.

Additionally, a framework could be developed to support the relevant stakeholders and local authorities in strengthening their approach to implementing DTs and improving the industry's transformation to deliver more complex, resilient, and sustainable infrastructure projects

(Gürdür Broo *et al.,* 2022). With this information, DTs within the infrastructure sector could possibly build upon the current initiatives or even support the process of introducing a new standardised approach.

As this study was conducted in the UK, caution should be exercised when generalising the results on an international scale. It should be noted, however, that the findings in the context of the UK infrastructure sector may serve as a stepping stone for future global research regarding DT uptake in the future. Continuous and intensive studies are necessary to ensure the adoption and implementation of DTs within the UK infrastructure sector. In order to shed light on how a DTs truly adds value to the infrastructure sector will only be done by understanding the current uptake and the view of the technology. Future research could, for instance, investigate how DTs can be integrated within the digital workflow of a project from concept to the operations and maintenance stage, which could evaluate the value the DT can bring. Furthermore, utilising enabling technologies and sharing lessons learnt to enable a standardised framework to transition the industry to using a DT as part of their delivery.

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