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A Blueprint for Creating Digital Twins for Transportation Assets: an Application for Highway Engineering

A. Ammar[1], B. Bhatt[2], G. Dadi[1] and H. Nassereddine[1]

[1]Department of Civil Engineering, University of Kentucky
Lexington, United States
[2]Department of Computer Science, University of Kentucky
Lexington, United States

Abstract

The concept of Digital Twins originated in aerospace engineering, however, after several researchers and practitioners realized the capabilities of the technology, the Digital Twins concept emerged in other industries including manufacturing, healthcare, and the architecture, engineering, and construction industry. While the technology has several capabilities and a wide range of applications, a critical condition for its successful implementation is the identification of its purpose. Digital Twins have the potential to leverage the value of data and transform data into useful information to inform decision making, while keeping the asset condition updated in a real-time manner, allowing for conducting preventive maintenance and future predictions. Since Digital Twins with its capabilities can act as a holistic information management strategy, state Departments of Transportation (DOTs) in the United States can adopt and implement this technology to manage and maintain transportation assets. This paper contributes to the body of knowledge by further emphasizing the value of implementing Digital Twins for transportation asset data management, an application necessary for building and maintaining sustainable and resilient infrastructure systems by focusing on the added value of integrating heterogeneous and multi-sourced data to better understand the project concepts. Furthermore, this paper presents the structural blueprint of an integrated Building Information Modeling (BIM) and Geographic Information System (GIS), in addition to semantic web technologies with the aid of the Internet of Things (IoT), and real-

time data collected by sensors to develop and deploy an actual Digital Twin prototype for a transportation asset that state DOTs can adopt and implement. Such implementation of Digital Twins is envisioned to allow DOTs to harness the value of collected data, release data from the isolated silos, and seamlessly share them within different divisions to support reliable and high-quality decision-making.

Keywords: digital twins, asset data management, departments of transportation, Building Information Modeling, Geographic Information System, ArcGIS GeoBIM.

1 Introduction

The Center for Digital Built Britain defines Digital Twins as "a realistic digital representation of assets, processes or systems in the built or natural environment. What distinguishes a digital twin from any other digital model or replica is its connection to its physical twin" [1]. The authors of [2] investigated the different Digital Twins capabilities in the built environment from a practitioner's perspective, and identified seven Digital Twins capabilities, namely: increased transparency of information: real-time monitoring, analysis, and feedback; better stakeholder collaboration; advanced preventive measures; advanced what-if scenario analysis and simulations; real-time tracking; and higher accuracy, explained through 40 applications. Moreover, and because of such capabilities, Digital Twin represents an innovative solution for asset management since it can leverage the value of asset data throughout the asset lifecycle by collecting and integrating asset data to improve the asset condition and support decision-making and resources allocation [3] [4].

In the United States, state Departments of Transportation (DOTs) are responsible for managing and maintaining transportation assets. Every year state DOTs conduct hundreds of projects, such as creating new roads and making changes to existing ones. Thus, each asset will have several revision versions, resulting in massive amounts of data that state DOTs should handle [5]. The data handling challenge is amplified by the wide variety of assets, their expansion over a vast network, the deterioration of the transportation system, limited funds, and the increasing demand for a user-oriented performance system [6]. As such, several DOTs are establishing a vision for implementing Digital Twins as an information management strategy to connect the enterprise asset information to a geospatial model of the individual physical assets. It is expected that implementing Digital Twins for asset data management will support the documentation of the updated asset condition of the designed assets as well as the as-built assets and therefore fill the gap in the information, which will allow for conducting complex and comprehensive data analysis and support decision making to enhance highway safety, optimize mobility, and maintain transportation infrastructure systems to extend their long-term service life [7]. Therefore, this paper aims to provide a blueprint for a Digital Twins structure that DOTs can implement as a holistic transportation asset data management strategy. The proposed blueprint depicts the process for extracting necessary asset information, linking the extracted information to the geospatial model of the asset and the surrounding environment, and integrating real-time data by integrating sensors and semantic web technologies.

2 Methods

The three essential elements of Digital Twins are the physical environment, the digital environment, and the data connecting them. As such, the successful creation and implementation of the Digital Twins concept is initially established by defining the different data sources. Data sources can be internal or external and may exist in different file formats such as unstructured data (e.g., text, images, or documents), semi-structured data (e.g., XML, JSON and CSV files, or Google Sheet files), and structured data (e.g., data extracted from a database).

Building Information Modeling (BIM) can provide rich geometric and semantic asset data including but not limited to asset models (i.e., available 2D models or 3D models), asset specification, required level of details, asset documentation, data schemes, and ontologies. Additionally, the Geographic Information System (GIS) can integrate many types of data while analyzing the spatial location of the asset and organizing layers of information into visualizations using maps and 3D scenes. Moreover, GIS can handle and process spatial data of the individual physical asset, system of assets, and the surrounding environment. The integration of asset data extracted from BIM and GIS can provide a digital representation of the asset architectural entity and will support the management of spatial information of the asset and the surrounding environment, thus providing a better understanding of how the individual physical asset or system of assets interact with its surrounding. The integration of data extracted from BIM and GIS does not require any data transfer, rather it will be conducted via ArcGIS GeoBIM. ArcGIS GeoBIM is an innovative, web-based solution that allows the collaboration of information extracted from BIM models in a geographic context. GeoBIM supports the integration and visualization of GIS data with engineering documents to simplify coordinated decision-making across different project teams [8].

Moreover, as a Digital Twin model should always reflect the real state of the physical model, real-time data can be collected using sensors to ensure a continuous flow of real-time data. With the advancement of semantic web technologies, and the use of Application Programming Interfaces (APIs) to link data from heterogeneous sources, the bidirectional information exchange between the physical asset and its digital replica can be established, thus, enabling the adoption and implementation of Digital Twins for transportation asset data management.

3 Results

Data extracted from BIM is represented through Industry Foundation Classes (IFC), an open data model adopted in the architecture, engineering, and construction industry for information exchange; developed by buildingSMART as an EXPREESS-based file [9]. While the data extracted from GIS is represented through City Geography Markup Language (CityGML) defined in Extensible Markup Language (XML) format, and considered the most detailed exchange standard of urban geospatial data [10]. GeoBIM can support IFC files and different GIS data formats and is capable of

supporting the visualization of geographic features and BIM objects side by side to show the relative context of the projects [8]. Moreover, an additional capability of GeoBIM is integrating links from Autodesk BIM 360 or Autodesk Construction Cloud with data features in ArcGIS Web Maps and Web scenes [8].

However, sensors planted in the physical environment to collect information about the asset condition in real-time will have internet connectivity and therefore data collected by sensors can be sent to the cloud by adopting the Internet of Things (IoT) technology. The smart IoT gateway will act as a communication bridge. After this internet communication is achieved, a custom API will be created that will request and send certain types of data from the sensor to the cloud. With the GeoBIM capability of reading links from the cloud, data collected from sensors will be integrated and will be visualized in addition to the BIM objects and geographic features of the asset and the surrounding environment. The proposed integration of heterogeneous and multi-sourced data will allow for the creation of a Digital Twin of assets that is continuously updated with comprehensive and high-quality data in a real-time manner. This Digital Twin can be used to conduct predictive maintenance, what-if analysis, and improve the operation of the asset operation and use cycle.

A Digital Twin preliminary prototype for signs - an asset that is critical for traffic control and management - will be created. The sensors will continuously measure the sign retroreflectivity (i.e., the day and night retroreflectivity) since signs should be retroreflective or illuminated to show the same shape and similar color by both day and night. Retro-reflectivity is a ratio of the amount of light returned from a sign versus the amount hitting the sign. The detailed process of creating a Digital Twin for signs is illustrated in Figure 1.

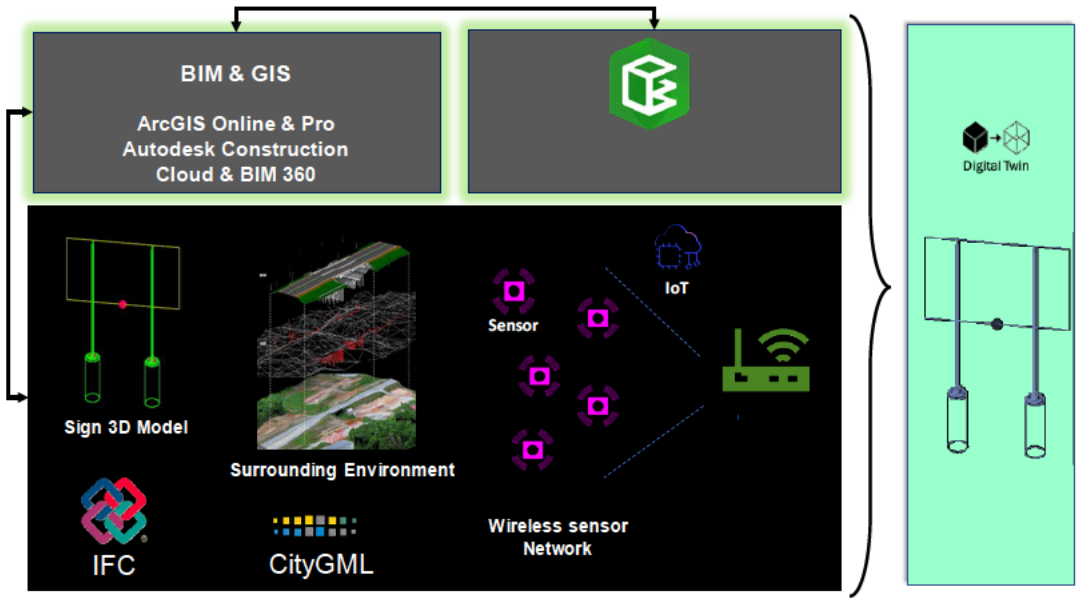

Figure 1. Blueprint for a Digital Twin Structure for an asset.
[Icons are downloaded from Noun Project, where they were created by Insticon (Digital Twin), Lafs (IoT), and Mas Dhimas (Gateway)]

4 Conclusions and Contributions

With the emerging wave of digitizing the built environment and implementing innovative technologies to surpass faced challenges, Departments of Transportation (DOTs) in the United States can benefit from the flowing wave of this paradigm shift and adopt Digital Twins as a holistic information management strategy to help them manage their transportation asset data. DOTs need to harness the value of their asset data, and this can be attained by thinking about the different ways in which the data can be analyzed and used.

With the capabilities of Digital Twins in leveraging the value of data by optimizing its use, Digital Twins can act as a centralized metaverse on the micro and macro level of asset data management. This paper contributed to the body of knowledge by proposing a structural blueprint for creating a Digital Twin for transportation assets. The process begins with identifying different data sources and extracting asset information from IFC files that are linked to the geospatial model of the individual physical asset and the geospatial model of the surrounding environment that can be extracted from CityGML files. Additionally, real-time data can be collected using sensors to ensure a continuous flow of real-time data. Data from the wireless sensor networks with the aid of the IoT technology acting as a communication bridge and adopting custom APIs will be requested and shared with the cloud. ArcGIS GeoBIM, a web-based and innovative solution will allow the integration and visualization of heterogeneous and multi-sourced data. This integration will support the visualization of BIM objects, geographic features and attributes of the asset and the surrounding environment, and real-time asset data side by side which will provide better insights into the project context and will allow the creation of a preliminary Digital Twin of transportation assets. It is worth mentioning that this work is part of an ongoing research effort and future work will adopt this blueprint to develop an actual Digital Twin for a transportation asset that state DOTs can implement and use to support their tasks in managing and maintaining transportation asset data.

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