Digital Twin Technology: Vision and Challenges

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***Abstract*—The construction industry has greatly evolved over the past decade, with the onset of emerging technologies. One such technology is the Digital Twin, which is the virtual replica of a physical entity existing in the real world, enabling real-time monitoring and analysis of construction projects. Looking at the research recently conducted over the past few years, the extent to which Digital Twin technology can be implemented within the construction industry has been discussed in this paper, along with the challenges faced while doing so. This paper aims to employ Digital Twin technology in the construction domain and then analyze the benefits and technical challenges associated. In turn, the usage of Digital Twins in the construction industry is discussed, especially looking at the validation and testing of structures, while taking into consideration that this technology is quite recent; therefore, certain issues and challenges arose while creating a DT, revolving around integration and visualization. Therefore, we were able to build a Digital Twin to an extent after encountering various limitations.**

***Index Terms*—Digital Twin, construction industry, validation and testing, challenges**

I. Introduction

In today's world, technology has made significant advancements to simplify everyday life. One such innovation is the Digital Twin (DT), which is a virtual replica or model of a real-world physical entity, interconnected through the exchange of data. This means that the virtual copy has the same characteristics as the physical entity and vice versa. [1] Digital Twins have various applications across industries such as construction, robotics, education, healthcare, and more.

The use of Digital Twins holds great potential in the construction industry. DTs can enhance performance and productivity by providing a virtual replica for testing purposes, which reduces the time and costs of projects. [2] However, implementing a Digital Twin presents several challenges, as it is a relatively recent and abstract concept that has not been extensively explored. Creating a Digital Twin can be achieved using tools like Microsoft Azure and its features to demonstrate its potential and benefits, especially for testing and validation purposes. Nevertheless, there are only a few tools available for implementing a Digital Twin, and these have limited features, making it difficult to fully utilize the functions of a Digital Twin.

II. Literature Review

Exploring the origin of digital twin technology, researchers analyzed different types of digital twins and their potential. They found many advantages associated with the use of digital twins, such as simulation and prediction capabilities, along with forensic troubleshooting, record-keeping, decreased costs, and increased outputs. However, they discovered that there were several limitations to using Digital Twins as well, as there is a lack of clear understanding of the concept, a lack of standards and regulations, and increased time and costs. [1]

Moreover, the applications and practicality of Digital Twins were pondered upon, analyzing the notion of an Augmented digital twin as the basis of the Human Digital Twin (HDT). Researchers found that building an HDT is possible if there are adequate technological developments and progressions, and that HDT can be utilized in human full lifecycle management. The challenges while creating an HDT should also be considered, as they include the complications of humans, the hassle involved in modelling and data analysis, alongside ethical and legal issues. [2]

Looking at the construction industry, different emerging technologies were used while developing Digital Twins. The research found that Digital Twins can be implemented at various levels of granularity of the construction industry ecosystem, and they have the potential to enhance productivity and performance through successful decision-making brought about by optimized processes. However, future research should be undertaken on various technologies for transmission within the layers and data processing. Moreover, this study in particular was limited to the technologies of Digital Twins and lacked research on organizational aspects, along with having publications obtained from only seven keywords used for searching. [3]

Adding on, DT application in the construction industry was discussed, as researchers found that the industry is faced with numerous challenges including low productivity, lack of research and development, and poor technology advancements. They also deduced that DT technology has the potential to transform the construction industry and provide responses to some of its challenges. At its present state, a Digital Twin is synonymous with a BIM model within the construction industry. The databases Scopus, Web of Science, and ScienceDirect were used for the search. This study recommends the use of a variety of data sets and a more extensive range of literature. [4]

On the other hand, an experiment was conducted utilizing different sensor reading instances, to create and test a limited Digital Twin of a building facade. Researchers deduced that based on their successful experiment, future research can be carried out to implement a more comprehensive Digital Twin of a building interior while utilizing the benefits of using Digital Twins. It is to be noted however, that their study posed several limitations as there was a limited sensor network and only three environmental parameters for sensing, as their experiment was conducted on a small scale. [5]

Exploring Digital Twins for construction site logistics, logistics processes were looked at which are characterized by very limited visibility and inefficient organization. Researchers analyzed the exploitation of the prototype DSS to perform extensive simulations and to leverage the transformational benefits of smart silos and support planners in their operational and strategic decision-making. They found that by transforming "dumb" silos into smart data processing units a new logistics system can be established which can directly reduce costs. The installation of the sensors enables permanent silo tracking and threshold-based filling. However, retaining a naive threshold-based replenishment policy does not necessarily lead to cost reductions. Although the PDP as well as the IRP are established problem classes in research, the complexity of the embedded dynamic optimization problem should be noted. [6]

The integration of deep learning and digital twins towards Construction 4.0 was also looked into. A DL-integrated DT model facilitating Construction 4.0 incorporated cognitive abilities to detect complex and unpredictable actions and reasoning about dynamic process optimization strategies to support decision-making. This study in particular was limited in its insight due to the small number of specialists from various industry sectors who participated in it. [7]

Combining the Internet of Things (IoT), Building Information Modeling (BIM), and Digital Twin in the Construction Industry, there was a research study conducted. Failures of integration and collaboration, which are crucial for enhancing and regulating the value stream, were recognized as a core reason for performance concerns. Using BIM, DT, and IoT in the construction sector might be seen as one of the most effective and impactful approaches to achieving "Smart Construction 4.0", involving a strong integration of data, processes, knowledge, and stakeholders. However, the research limits the scope of the reviewed Building Information Modeling, Internet of Things, and Digital Twin literature by concentrating exclusively on academic papers obtained from the Web of Science database. [8]

The analysis of Building Information Modelling (BIM) expanded into how it provides procedures, technologies, and data schemas enabling a standardized semantic representation of building components and systems. The concept of a Digital Twin conveys a more holistic socio-technical and process-oriented characterisation of the complex artefacts involved by leveraging the synchronicity of the cyber-physical bi-directional data flows. The research also explored the standardization for seamless data exchange among different Digital Twin systems. This research presented a Comprehensive Digital Transformation (CDT) framework, drawing from an analysis of 196 research articles. While it does not cover all aspects of nD BIM and Digital Transformation, in-depth analysis highlights key future research areas. Challenges like cybersecurity in large-scale infrastructure remain prominent. [9]

Further research provided references for upcoming applications of Digital Twins in many sectors, analyzing the functions, fields of application, and development patterns of digital twins. Researchers found that Augmented Reality (AR) has the potential to break down the boundaries that traditionally separated the physical world from the virtual world created by computers. It does this by bridging the gap between the two, making interactions more seamless. By enhancing people's senses of sight, sound, and touch, AR will break the boundary between the human and virtual world, strengthen the integration of the human and virtual world, and further blur the boundary between the real world and the virtual world generated by the computer, so that people can break through. [10]

A framework was proposed by researchers for analyzing and supervising the development of Digital Twins. They observed that the majority of researchers think that the development of digital technology is accelerating. Moreover, several construction-related industries are ready to adopt digital technologies and advanced controls with the capability to exact change within a construction project on the building site. As a consequence, the modern tools and systems that have developed into the Digital Twin system can find customized applications in the construction sector, but they are usually confronted with significant challenges related to delocalized work environments and the specifics of construction project management that emphasize safety, material consumption, and deadlines as opposed to the high capability and low variability that occurs in the production sector. [11]

Moreover, it was discussed that the Digital Twin is rapidly being adopted in multiple sectors and that the technology has the potential to leverage construction data. This paper synthesized the current state of practice of Digital Twin in construction by reviewing the extant literature and proposing a framework that classifies the level of integration in construction into three subcategories namely: Digital Model, Digital Shadow, and Digital Twin. It was deduced that although the construction industry is often labelled as conservative regarding potential advancements in technology and technological applications, it has made significant strides over the past few decades to improve information management through the use of Building Information Modeling. The analysis of the framework showed that although construction has made significant strides by going beyond the Digital Model, the application of Digital Twin is still not fully accomplished in the construction industry. [12]

Depicting the workflow for a digital twin construction (DTC) information system, researchers have extended the existing understanding of DTs in the construction industry. Their research built on existing concepts and ideas of BIM, lean project management systems, and artificial intelligence to create a means of construction while applying DT information systems to achieve closed-loop control systems, providing necessary information and control concepts for DTC. After careful analysis, they proposed a DTC information system workflow, deducing that DTC is not just an extension of BMI but also an extensive mode of construction that prioritizes closing control loops. [13]

Expanding on the previous research, a data-driven circular construction was explored and researchers provided evidence that digital data templates (DDT) and digital building logbooks (DBL) are important components for increased growth of the DTC during the construction process lifecycle. They also found that the best use of data will be important for the future of the construction industry, to which DDT and DBL contribute, yet little importance has been given to these two concepts. Therefore to increase the understanding of DDT and DBL, the researchers developed the "Digital data-driven concept". However, they were limited in the sense that they discussed how DDT, DBL, and DTC should be further integrated in future research other than their own. [14]

Developing an integrated Digital Twin and blockchain framework, researchers explored traceable data communication to address the issue of ineffective communication and collaboration within fragmented stakeholders. After testing the framework, they found that it brought about the traceability of data transactions, contributing to accountable and responsible project-related information sharing between stakeholders, and also realizing the potential of blockchain in Digital Twin technology. However, since blockchain is not efficient when it comes to data storage due to its inherent nature, its framework may be limited and ineffective in some ways. Moreover, there is still no proof that all real-time data on a DT can be shared, while being traceable, on the blockchain with limited storage. [15]

Creating a digital mapping model of the corresponding shop floor, a Shop-floor Digital Twin (SDT) was developed to improve production reliability and efficiency in a shop while monitoring the floors. Moreover, a five-dimensional approach of SDT, a DT-based 3D visual and real-time monitoring approach, and a Markov chain-based prediction approach are proposed, to foresee and monitor shop-floor operating status based on the SDT that was set up. A case study also verified the practicability and feasibility of the proposed approach. This proposed solution, however, has several constraints such as the prediction methods need improvement and the application scope needs expansion and improvement. Additionally, the whole concept of a Shop-floor DT is still quite abstract and new so it is difficult to implement. [16]

III. Methodology

A. Design

We selected a benchmark research paper, which aimed to build a sensor network to develop a real-time Digital Twin by analyzing specific environmental factors in the surroundings of the building. Moreover, there were three environmental parameters set i.e. light, temperature, and humidity. This paper in particular utilized the external environment and its associated parameters. [5]

Keeping this paper as a starting point, we decided to model the building interior instead and chose our university's basement II in the CS block, to model the Digital Twin after. We evaluated the possible parameters that could be found inside the basement model and decided to split the model into five parts: Basement, Offices, Lobby, Passageways, and CS Lab 6, effectively creating a relationship in turn.

Our aim was to create an application based on the construction industry, to create a Digital Twin, and to find out whether the proposed architecture is feasible to be constructed or not.

B. Implementation

The first step was to create the front-end of the application having the User Interface (UI), which will ask for input from the user in terms of the parameters that we have defined such as the size of the room, the walls, etc. A core technology we used while developing the front-end was HTML Pug.

The application in turn will take the inputs and generate a Digital Twin having the same characteristics of the architecture, based on the inputs given. All kinds of testing would produce the same results in the Digital Twin as in the proposed architecture if built.

Next, we set parameters for the building facade model along with the models of the lobby, office, passageway, and computer lab and the relationship was created between these five models through the building facade. JSON files were created for each model based on Digital Twin Definition Language (DTDL). Then, in Azure Digital Twins Explorer we uploaded these five models with multiple instances created.

Moreover, we designed a 3D model of our university's Basement II on SketchUp by utilizing its functions and imported it into Blender to produce the .glb file, since that was available in Sketchup and not Blender. We exported the .glb file into Azure Digital Twins for 3D scenes and created a container on Azure for it. Once the 3D scene model was imported, links were created with feasibility checks and conditions according to the parameters set according to our university basement architecture, such as whether the inputs were insufficient, within range, or exceeding.

Therefore, the generated Digital Twin was a replica of the proposed architecture that the user intends to build or renovate, and the output would tell the user whether their architecture is feasible for them to construct or renovate, or not. The final deliverable was the application that we created which had the Digital Twin and its interface on Microsoft Azure, along with a frontend resembling the UI.

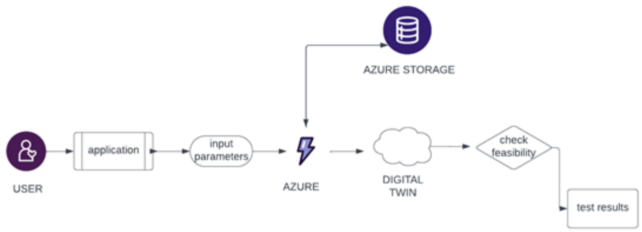

Fig. 1. Block Diagram of the application

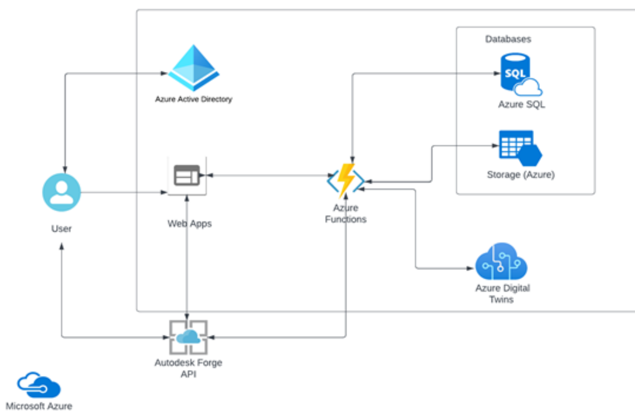

Fig. 2. Architecture Diagram of the application. Adapted from [17]

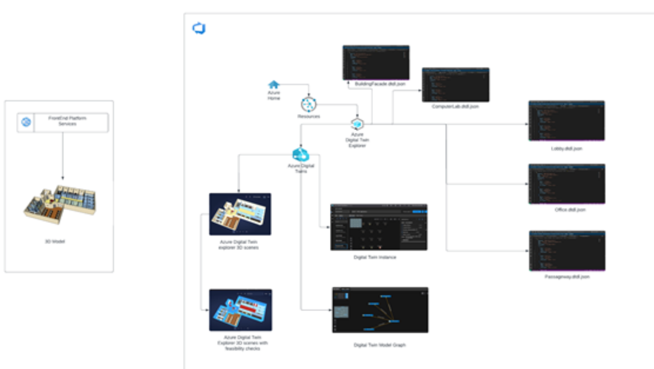

Fig. 3. System Diagram of the application

IV. Testing and Evaluation

A. Parameters

For the overall Digital Twin, we created DTDL models and the related Digital Twin instances of the overall Basement, Offices, Lobby, Passageways and Computer Lab. Below is a complete list of parameters that we defined for each Digital Twin instance:

BuildingTwin:

- Height of room
- Length of room
- Width of room
- Number of entrances/exits
- Wall paint

LobbyTwin:

- Width of room
- Length of room
- Number of doors
- Number of lights
- Flooring

PassagewayTwin:

- Length of room
- Width of room
- Number of people

OfficeTwin:

- Length of room
- Width of room
- Number of glass divisions
- Number of doors
- Flooring
- Number of lights
- Number of people

LabTwin:

- Length of room
- Width of room
- Number of doors
- Number of lights

B. Feasibility Checks

The following shows some of the feasibility checks we set for the Digital Twin instances on Azure Digital Twins. BuildingTwin:

1. WallHeight
   - Height within range: 30-50 ft
   - Height exceeded: 51- infinity ft
   - Height insufficient: -infinity to 29 ft
2. BasementLength
   - Length within range: 70-90 ft
   - Length exceeded: 91-infinity ft
   - Length insufficient: -infinity to 69 ft
3. BasementWidth
   - Width within range: 90-110 ft
   - Width exceeded: 111 to infinity ft
   - Width insufficient: -infinity to 89 ft
4. Exit/entrances
   - Number of exit/entrances within range: 1-2
   - Number of exit/entrances exceeded: 3 to infinity
   - Number of exit/entrances insufficient: -infinity to 0

OfficeTwin:
Office1:
1. LengthOfRoom
   - Length within range: 22-26 ft
   - Length exceeded: 27 to infinity ft
   - Length insufficient: -infinity to 21 ft
2. WidthOfRoom
   - Width within range: 9-13 ft
   - Width exceeded: 14 to infinity ft
   - Width insufficient: -infinity to 8 ft
3. Obstruction
   - No obstruction: 0 to 6 people
   - Obstruction detected: 7 to infinity people
4. GlassDivisions
   - Glass division within range: 2 to 3
   - Glass divisions exceeded: 4 to infinity
   - Glass divisions insufficient: -infinity to 1
5. NumberOfDoors
   - Doors within range: 1 to 2
   - Doors within range: 1 to 2
   - Doors insufficient: -infinity to 0
6. NumberOfLights
   - Lights within range: 1 to 3
   - Lights exceeded: 4 to infinity
   - Insufficient lights: -infinity to 0

LabTwin:
1. LengthOfRoom:
   - Length within range: 30-32 ft
   - Length exceeded: 33 to infinity ft
   - Length insufficient: -infinity to 29 ft
2. WidthOfRoom:
   - Width within range: 29-33 ft
   - Width exceeded: 34 to infinity ft
   - Width insufficient: -infinity to 28 ft
3. NumberOfLights:
   - Lights within range: 4 to 8
   - Lights exceeded: 9 to infinity
   - Insufficient lights: -infinity to 3
4. NumberOfDoors:
   - Doors within range: 1 to 2
   - Doors exceeded: 3 to infinity
   - Doors insufficient: -infinity to 0

Therefore after using these parameters for the overall Digital Twin, we were able to successfully create a Digital Twin on the Azure Digital Twins interface where the user could input parameters according to the construction they would like to create, and the Digital Twin would display whether the construction would be feasible or not, by displaying colours such as ‘red’ for exceeded, ‘blue’ for within range, and ‘yellow’ for insufficient. Beyond that, we were quite limited in what we could achieve using the Digital Twin we created, due to various challenges we faced in our project.

Fig. 4. Digital Twin model as created on SketchUp

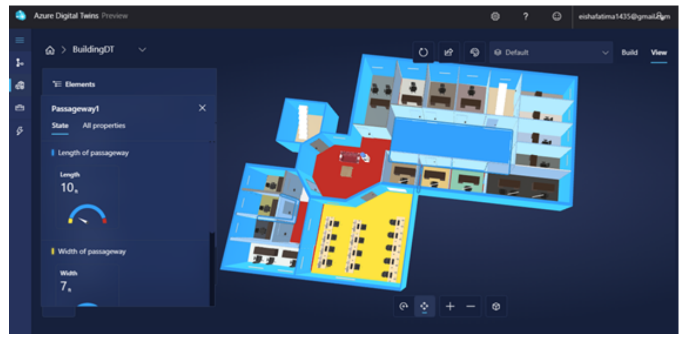

Fig. 5. Digital Twin with feasibility checks on Azure Digital Twins

V. Challenges and Analysis

A. Integration with Microsoft Azure

Our initial plan was to integrate our front-end with the Digital Twin on Azure Digital Twins. However, we faced various obstacles in doing so. Firstly, the frontend libraries or SDKs used to integrate with Azure services were incompatible with the Azure service version. Additionally, the process of integrating the Azure services with frontend applications was hindered by a lack of documentation and resources.

B. Visualising the Digital Twin

Difficulties arose in creating visual effects for the Digital Twin model on the Azure platform due to compatibility issues with other services and limitations imposed by Azure credits. Our goal was to have the parameters input reflect changes in the Digital Twin model, but it was challenging to incorporate visual effects into the model as this feature was not available in Azure Digital Twins. While Azure provides resources and services for creating and distributing models, complex visual effects require more expensive or specialized tools outside of Microsoft Azure. [18]

C. Issue while importing XML file

We considered importing the Digital Twin into an XML file to avoid creating a new model each time the user wanted a new construction. However, we found that Azure Digital Twins does not support this functionality. [19] The only available option was to convert the PNG form of the Digital Twin model to an XML file, which was not relevant to our research.

D. Azure Subscription

As the model was built on Azure Digital Twins, a paid service of Microsoft Azure, we needed a suitable Azure subscription for access to relevant features. However, due to financial constraints and university limitations, we were unable to obtain a subscription with enough features. Additionally, we ran out of Azure credits, which further hindered our implementation capabilities for the Digital Twin.

VI. Conclusion

In summary, this paper focuses on the development and implementation of a Digital Twin based on the user's proposed architecture. The purpose is to assess the feasibility of the user's construction plans and to explore the challenges involved. Creating a Digital Twin would support testing and validation, as well as aid in pre-construction planning and decision-making. Our team successfully designed the front-end and developed the Digital Twin on Azure Digital Twins, which included creating Digital Twin instances and a 3D model of the university basement, along with feasibility checks. However, we encountered challenges such as difficulty integrating the front-end with Azure Digital Twins, visualization issues with the Digital Twin, and problems with creating and importing the Digital Twin into an XML file due to a lack of Azure credits and subscription. We recommend further research to address these limitations in future endeavors.

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