Defining Digital Twin Use Cases in the AECO Industry – A Data Schema

Zahra Ghorbani, zxg120@psu.edu
PhD Candidate, Department of Architectural Engineering, University Park, PA, USA

Kimon Onuma, ko@onuma.com
Founder and President, ONUMA Inc, USA

John Messner, jim101@psu.edu
Charles and Elinor Matts Professor, Department of Architectural Engineering, University Park, PA, USA

Abstract
In recent years, Digital Twins (DTs) have emerged as an influential and transformational digital technology in the Architecture, Engineering, Construction, and Operations (AECO) industry. This concept has gained traction among researchers and industry practitioners, reflecting its growing importance and relevance in digital transformation in this domain. Use cases play a pivotal role in implementing DTs. Recognizing the crucial role that use cases play, their definition becomes a key point in ensuring the implementation and effectiveness of Digital Twins in the AECO industry. However, there is no formal schema for DT use case definition in the AECO industry. This research aims to bridge this gap by proposing a schema for defining DT use cases through the analysis of BIM use case schemas and DT use case definitions from other industries. Moreover, attributes were added from DT definitions and frameworks. The schema was validated through a focus group and sample use cases.

Keywords: AECO; Construction; Digital Twins; Digital Transformation; Use Cases; Use Case Definition; Standards

1 Introduction

Digital Twins (DTs) have emerged as a pivotal technology in various industries, revolutionizing the way assets are designed, constructed, and operated. DTs have gained significant attention in the Architecture, Engineering, Construction, and Operations (AECO) industry in recent years (Foudah et al 2024). DTs offer many opportunities throughout the asset lifecycle, from design (Arowoiya et al 2024) to construction (Su et al 2023) to operations (Zhang et al 2023). In the AECO domain, a Digital Twin of an asset is defined as "*a fit-for-purpose and intelligent virtual representation of it synchronized at specific frequencies, with an existing or planned connection between the virtual and physical twin that may include analysis and the ability to actuate physical changes from the virtual twin"* (Ghorbani & Messner 2024). Throughout the lifecycle of an asset, DTs play a critical role. They can facilitate informed decision-making during the design phase (Lu et al 2020), optimize construction processes, streamline commissioning processes, and optimize operations (Zhao et al 2022). The versatility of DTs in the AECO sector underscores their potential to drive innovation and efficiency throughout the lifecycle of assets.

The essence of a DT, as defined by Ghorbani and Messner (2024), lies in its purpose-driven definition, underscoring the importance of use cases (NIBS 2024). In the context of the paper, a

use case is a specific scenario or example that shows how DTs can be used in real-world situations within the AECO industry. It describes the purpose, steps, and outcomes of using DTs to solve a particular problem or achieve a certain goal. Use cases serve as the foundation of DTs, delineating the functionalities essential for building a DT, such as purpose, methods, and outputs. Despite their significance, the absence of clear standards within the AECO domain for defining and documenting DT use cases impedes their widespread adoption. This paper focuses on DT use case standardization, emphasizing the pivotal role of standardization in facilitating reusability, reliability, and scalability and a common understanding of the use cases.

Background

Given that DT is a novel and influential concept in the AECO industry without established use case definitions, we explored building information modeling (BIM) use case definition schemas as a point of departure due to their similarities and initial model content for creating DTs. Additionally, we investigated DT use case definitions from other industries, such as manufacturing, and incorporated the insights into our study.

1.1 BIM Use Case Definition Structures

There are four BIM use case definitions structures identified in the industry, namely buildingSMART International (bSI) use case management tool (bSI 2017), ISO 29481-3 2022: Building information models – Information Delivery Manual (IDM) – Part 3: Data Schema (ISO 29481-3 2022), US National BIM Standard V4 Use Case Definition (NBIMS-US™ v4 2024), and BIMe use case template (*BIMe Initiative,v12* 2016). ISO 29481-3 is a BIM standard that includes data schema for the development of an information delivery manual (IDM). The attributes to define a BIM use case include use, local project phase, standard project phase, summary, description, aim and scope, limitations, benefits, required competencies, outcomes, actor, construction entity, general, region, business rule, user-defined property, classification, information requirements, required resources, and references. US - NBIMS BIM Use Definition Module is a BIM standard with a specific module for BIM use definitions. The attributes for defining a BIM use include ID/version, name, definition, author, considerations/commentary, potential benefits, methods/tools, competencies, inputs, outputs, related terms, BIM use case example (methods and outcomes), predecessor BIM use(s), successor BIM use(s), and resources. The buildingSMART International Use Case Management tool is a BIM tool created by buildingSMART Switzerland. The objective of this tool is to facilitate the sharing of insights gained from both completed and ongoing BIM projects among professionals. Although there is no formal documentation of attributes and their definitions, the attributes were extracted from the tutorial available on the bSI website. These use case attributes include version number, identifier, GUID, title, abbreviation, lifecycle stage(s) (local), lifecycle stage(s) (global), short text, description, aim and scope, objectives, author, project group, partners, main discipline(s) (local), main discipline(s) (global), project status, maturity level, reference(s), publisher, referenced use cases, management summary, libraries, tag(s), copyright, and case type. The BIMe use case template is a BIM template document that includes a name, extended description, purposes, software tools, activity flow list, acknowledgments, endnotes, and bibliography. In comparison to previously discussed tools and standards, the BIMe tool collects much less information about a BIM use case.

1.2 Digital Twin Use Case Definition Structures

We have also investigated DT use case definitions in other industries (e.g., Manufacturing) and included the one schema in the literature. Shao (2021) studied three DT use case scenarios in Manufacturing and presented a framework to document these use cases. They also investigated how the ISO 23247 standard series can streamline the implementation of these DT use cases. The attributes for DT use case definition include ID, use case name, application field, lifecycle phase(s)

coverage, status, scope, initial (problem) situation, objective(s), short description, stakeholders, key technologies, and relevant standards. Although they present the use cases through this template, they do not provide any formal definition for the attributes.

2 Methodology

The research methodology for this paper included defining the scope, identifying and analyzing existing use case definition schemas, identifying other use case attributes, and validating and documenting the proposed DT use case schema (see Figure 1).

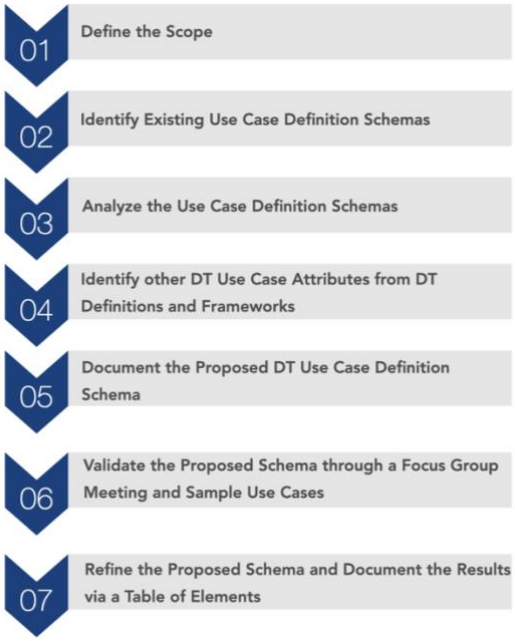

Figure 1. Research Methods Design

2.1 Define scope

This study's scope is limited to the AECO industry, with a focus on the DT definition outlined by Ghorbani & Messner (2024). This targeted scope ensures a concentrated analysis of DT within a specific context, enabling a nuanced understanding of its applicability within the AECO industry.

2.2 Identify existing use case definition schemas

In the initial phase, existing DT use case definition schemas were studied. No DT use case definition was found within the AECO industry and only one DT use case definition example was found in the manufacturing industry. Given the absence of DT use case definitions, building information modeling (BIM) use case definition schemas were investigated due to the conceptual overlaps between BIM and DTs. Schemas were drawn from established standards where available, supplemented by template documents in the absence of formal definitions within standards.

2.3 Analyze the existing BIM use case definition schemas

A comprehensive analysis of existing BIM use case definitions was conducted to determine their applicability to DTs. This analysis aimed to be exhaustive, incorporating all pertinent attributes to DTs while excluding elements deemed irrelevant. Through this process, the

suitability of BIM use case definitions for DTs was investigated, laying the ground for subsequent refinement.

2.4 Identify other DT use case attributes from DT definition and frameworks

Given the limited DT-specific use case definition schemas, additional attributes were extracted from DT definitions and frameworks to augment the analysis. This step was crucial in enriching the understanding of DTs and ensuring a comprehensive assessment of their use case requirements within the AECO industry.

2.5 Validate the proposed DT use case definition schema through a focus group meeting and sample use cases

The proposed use case definition schema was validated through a focus group meeting comprising seven industry members, four of whom were actively involved in DT projects. The meeting was conducted online through Zoom and lasted 1.5 hours. During the meeting, the underlying structure for DT use case definitions was explained (e.g., use case title structure) as well as the DT use case definition schema. Using a Mural online collaborative tool, comments were documented and further analyzed, guiding modifications to refine the use case definition schema in alignment with expert feedback.

2.6 Refine the proposed schema and document the results via a table of elements

Two additional attributes were added to the list, incorporating the focus group meeting results. Moreover, possible values were added for each attribute. The final results were documented in a table of elements, including DT use case attributes, their data formats, examples, notes, and references. This comprehensive documentation is a foundation for defining DT use cases in the AECO industry, providing a structured framework for future research and implementation endeavors.

3 Analysis of Existing DT and BIM Use Case Definition Approaches

We analyzed the four commonly used BIM use case definitions in the industry (namely, buildingSMART International use case management tool, ISO 29481-3, US- NBIMS V4 Use Case Definition, and BIMe use case template) as well as the DT use case definition schema from manufacturing. During the analysis, we investigated the relevance of the attributes to DT use cases in the AECO industry and documented the ones that are applicable. After analyzing all the schemas, we compiled all the attributes that apply to DTs from the five studied schemas (see Table 1).

4 Proposed DT Use Case Definition Schema

In addition to the attributes identified in the previous section through analysis of existing BIM and DT use case schemas, six attributes were added to the proposed schema from the DT definition and framework, including DT category, frequency of updates, DTC capabilities, graphical system architecture, system level, and owner. The final proposed DT use case definition schema is presented in Table 2, along with descriptions for each element. The table also includes example entries for a sample DT use case focused on capturing building conditions to analyze building conditions using a database. This example is from an actual DT Use Case implemented within the California Community Colleges using a DT platform from Onuma Inc. by one of the authors. It is presented to demonstrate the use of the data schema.

Table 1. Use case attributes from the identified use case definition structures (and how each attribute appears in the identified schemas)

Attribute	NIST DT Use Case Template	NBIMS V4 BIM Use Schema	ISO 29481-3 (IDM)	bSI Use Case Management Tool	BIMe Use Case Template
ID	ID	ID	X	Identifier; GUID	X
Name	Use Case Name	Name	Use	Title	Name
Lifecycle Phase(s)	Lifecycle Stage(s)/Phase(s) Coverage	X	Local Project Phase; Standard Project Phase	Local Project Phase; Standard Project Phase	X
Short Description	Short Description	Definition	Summary; Description	Short Text; Description	Extended Description
Scope	Scope	X	Scope	Scope	X
Objective(s)	Objective(s)	X	Aim	Aim; Objectives	Purposes
Initial (Problem) Situation	Initial Problem/ Situation	X	X	X	X
Considerations	X	Considerations/ Commentary	Limitations	X	X
Potential Benefits	X	Potential Benefits	Benefits	X	X
Method(s)	Key Technologies	Methods/Tools	X	X	Software/ Tools
Input(s)	X	Inputs	X	X	X
Output(s)	X	Outputs	Outcomes	X	X
Stakeholders	Stakeholders	X	Actor	Project Group	X
Status	Status	X	X	Project Status	X
Relevant Standards	Relevant Standards	X	X	Referenced Standards	X
Related Terms	X	Related Terms	X		X
Referenced Use Cases	X	BIM Use Case Example	X	Referenced Use Cases	X
Predecessor DT Use Case	X	Predecessor BIM Use(s)	X	X	X
Successor DT Use Case	X	Successor BIM Use(s)	X	X	X
Resource(s)	X	Resources	Required Resources	References	Bibliography
Author	X	Author	X	Author	X

Table 2. DT Use Case Definition Attributes

Attribute	Description	Field Type	Rule	Example
ID	Unique identifier for the DT use case (adapted from NBIMS-US™ v4)	Numeric	-	001
Name	Title of the DT Use Case	Text	Format: Use Name + to + Output + Using + Method	Capture building conditions to analyze building conditions using the FUSION database
Lifecycle Phase	Lifecycle phase of the DT	Text	Acceptable values: Planning; Design; Construction; Operations	Operations
Short Description	Concise description of DT use case (adapted from NBIMS-US™ v4)	Text	Should not be more than 150 words.	FUSION (Facilities Utilization, Space Inventory Options Net) is a database of over 90 million square feet of California Community College facilities that tracks the condition assessments and develops cost modeling for maintenance projects, enabling colleges to plan budgets and help facilitate the passing of much-needed bond measures. The FUSION project team is comprised of representatives from California's 72 community college districts, FoundationCCC, and the California Community Colleges Chancellor's Office.
Scope	Scope of the use case	Text	Should not be more than 150 words.	Provide space inventory data with a user interface to view, maintain, and analyze for multiple uses. Maintain web API links so other systems can see the same data. Maintain inventory by having field teams update data, import new buildings, and remove buildings and spaces that are no longer at the colleges.
Objective(s)	Objective of the use case	Text	Should include at least one objective for each use case.	Maintain source data for buildings and spaces to be used as inventory and decision-making for projects.

Initial Problem	The problem or situation that drives the DT use case.	Text	Should not be more than 150 words.	The Foundation for California Community Colleges needs an authoritative source of buildings and spaces for their colleges statewide, totaling 90 million square feet. The inventory needs additional attributes such as room type, number of desks or stations, and facility condition. There is a need to understand the current inventory to budget for future capital projects and be able to have a consistent way statewide to see the same information.
Considerations	Information on how to apply and/or when to use the DT use case (adapted from NBIMS-US™ v4).	Text	-	Measures should be taken regarding the cyber security of the DT to make sure all the data is secure.
Potential Benefits	Potential gains achieved on a project or within an organization from adopting the DT use case. (adapted from NBIMS-US™ v4)	Text	-	Authoritative source data of 90 million square feet of buildings, spaces, and attributes (not many owners have this)
Method(s)	Methods used to implement the DT use case.	Text	Methods could be digital (e.g., software) or physical (e.g., sensors). For each use case, at least one type of method should be included.	FUSION Building and Space Inventory Database to track existing inventory that is updated on a regular basis and linked to location through GIS. The same underlying data is also used for capital planning to define and plan future needs.
Input(s)	A list of example deliverables that enable the DT use case (adapted from NBIMS-US™ v4).	Text	-	Updated space inventory data of name, ID, area, space type, facility condition, system condition, current value, replacement value.
Output(s)	A list of example deliverables generated by the DT use case (adapted from NBIMS-US™ v4).	Text	-	Statewide authoritative source data, dashboards of inventory, and web API for other apps to use the same authoritative source data.
Stakeholder(s)	Stakeholders involved in the DT use case	Text	-	The college administration, state of California taxpayers, planners, and facility administrators.
Status	Status of the use case	Text	Acceptable values: Concept; Under development;	Operational

			Prototype implementation; Operational; Decommissioned.	
Relevant Standard(s)	Relevant standards used for the use case implementation	Text	-	RESTful WebServices, JSON
Related Terms	Synonyms or other widely used terms for similar DT use cases (adapted from NBIMS-US™ v4).	Text	-	Monitor building conditions
Predecessor Use Case(s)	DT use case(s) that are implemented prior to this DT use case (adapted from NBIMS-US™ v4).	Text	Format: Use Name + to + Output + Using + Method	N/A
Successor Use Case(s)	DT use case(s) that are implemented after this DT use case (adapted from NBIMS-US™ v4).	Text	Format: Use Name + to + Output + Using + Method	Analyze building conditions to optimize building operations using BIM Genie and FUSION
Resources	Implementation guides, case standards, and studies that provide more details on the DT use case (adapted from NBIMS-US™ v4).	Text	-	Digital Twin Consortium Periodic Table
DT Category	DT category based on the level of integration between digital and physical environment	Text	Acceptable values: Digital Twin Prototype; Digital Shadow; Cyber-Physical System. (Ghorbani & Messner 2024)	Digital Shadow
Frequency of Updates (for Each Data Source)	The frequency at which each data source(s) within the digital twin is updated.	Text	Format: Source 1: frequency of updates; Source 2: frequency of updates … Source n: frequency of updates	FUSION: Real-time
DTC Capabilities	Capabilities needed to enable the use case from Digital Twin	Text	Should follow the format of the DTC Periodic Table:	13-DS.DS-DS. Data Services: Domain Specific Data Management,

	Consortium (DTC) Capabilities Periodic Table (CPT)		https://www.digitaltwinconsortium.org/initiatives/capabilities-periodic-table/	23-IC.SR-IC. Intelligence: Search, 55-MG.DG-MG. Management: Data Governance, 58-TW.SC-TW. Trustworthiness: Security
Graphical System Architecture	Link to the DT system architecture.	Image	Acceptable formats: .png; .jpg; .jpeg	CaliforniaCommunityCollege_SystemArchitecture.jpeg
System Level		Text	Acceptable values: Component; Building System; Building; Campus	Campus
Author	The individual or organization that identified, documented, and consolidated the DT use case in the current form. (adapted from NBIMS-US™ v4)	Text	-	Kimon Onuma
Owner	Owner of the DT.	Text	-	Foundation for California Community Colleges - Funded by each Community College at the State Level

5 Conclusions and Future Work

Digital twins are a new concept within the AECO industry, necessitating the definition of use cases as a foundational step for their successful implementation. Our research underscores the lack of standardized attributes for defining DT use cases in the AECO domain. To address this gap, we analyzed five use case schemas – four BIM use case schemas and one DT use case schema from manufacturing – compiling a set of attributes for DT use cases. Furthermore, we identified other attributes from existing DT definitions and frameworks, ensuring a robust schema. We validated the proposed schema through a focus group meeting with industry experts to confirm their relevance and applicability. Building on our DT use case schema, future work will focus on further validation through practical case studies and extensive industry feedback. The ultimate goal is to establish a standardized approach for defining DT use cases. A standardized approach could facilitate broader adoption and integration by enabling DT developers to clearly define their use cases and share the use cases within their organizations and across the industry. Standardizing the way DT use cases are documented will help practitioners document and communicate DT use cases more effectively. It also helps build a structured repository of DT use cases for the industry to use, providing a valuable resource for reference and inspiration. This repository can play a crucial role in moving the industry forward with DT adoption by offering a clear, organized, and accessible set of use cases that demonstrate the potential applications of DTs. Moreover, a standardized documentation approach assists owners in setting up requirements for DT deliverables, ensuring that projects meet specified criteria and objectives. By fostering consistency and clarity in how DT use cases are presented, we can significantly enhance the overall implementation and impact of DTs in the AECO industry.

Acknowledgments

We would like to thank the industry focus group members, including (but not limited to) Cindy Baldwin, Jerry Schwinghammer, Radu Dicher, and Ralph Kreider.

References

Arowoiya, V. A., Moehler R. C. & Fang Y. (2024). Digital twin technology for thermal comfort and energy efficiency in buildings: A state-of-the-art and future directions. *Energy and Built Environment*, 5 (5). pp. 641–656. https://doi.org/10.1016/j.enbenv.2023.05.004

BIMe Initiative, Model Uses Table - v12. (2016). Melbourne, Australia.

buildingSMART International. (2017). Use Case Management Tool. Accessed May 28, 2024. https://ucm.buildingsmart.org/use-case-management

Foudah, A., Tarek M., Essam S., El Hawary M., Adel K., & Marzouk M. (2024). Digital twin publications in construction (2017–2023): a bibliometrics-based visualization analysis. *Construction Innovation*, ahead-of-print (ahead-of-print). https://doi.org/10.1108/CI-09-2023-0229

Ghorbani, Z. & Messner J. I. (2024). A categorical approach for defining digital twins in the AECO industry. *Journal of Information Technology in Construction (ITcon)*. 29 (10). pp. 198–218. https://doi.org/10.36680/j.itcon.2024.010

ISO 29481-3:2022. (2022). Building information models — Information delivery manual — Part 3: Data Schema. Accessed January 27, 2024. https://www.iso.org/standard/81261.html

Lu, Q., Parlikad A. K., Woodall P., Don Ranasinghe G., Xie X., Liang Z., Konstantinou E., Heaton J. & Schooling J. (2020). Developing a Digital Twin at Building and City Levels: Case Study of West Cambridge Campus. *Journal of Management in Engineering*. 36 (3). pp. 05020004. https://doi.org/10.1061/(ASCE)ME.1943-5479.0000763

NIBS Digital Twin Integration Subcommittee. (2024). Digital Twins for the Built Environment: A Position Paper on Integrating BIM and Digital Twin. National Institute of Building Sciences, Digital Technology Council, https://www.nibs.org/files/pdfs/DigitalTwinsBuiltEnvironment.pdf

Shao, G. (2021). *Use Case Scenarios for Digital Twin Implementation Based on ISO 23247*. National Institute of Standards and Technology. https://doi.org/10.6028/NIST.AMS.400-2

Su, S., Zhong R. Y., Jiang Y., Song J., Fu Y. & Cao H. (2023). Digital twin and its potential applications in construction industry: State-of-art review and a conceptual framework. *Advanced Engineering Informatics*. 57. pp. 102030. https://doi.org/10.1016/j.aei.2023.102030

US-National BIM Standard (NBIMS) Version 4- BIM Use Definition (BUD) Module." (2024). National Institute of Building Sciences. https://www.nibs.org/nbims/v4

Zhang, A., Yang J. & Wang F. (2023). Application and enabling digital twin technologies in the operation and maintenance stage of the AEC industry: A literature review. *Journal of Building Engineering*. 80. pp. 107859. https://doi.org/10.1016/j.jobe.2023.107859

Zhao, J., Feng H., Chen Q. & Garcia de Soto B. (2022). Developing a conceptual framework for the application of digital twin technologies to revamp building operation and maintenance processes. *Journal of Building Engineering*. 49. pp. 104028. https://doi.org/10.1016/j.jobe.2022.104028