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Digital Twins for the Built Environment

A Position Paper on Integrating BIM and Digital Twin

NIBS Digital Twin Integration Subcommittee
June 25, 2024

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Attributions

This paper was written by the National Institute of Building Science's (NIBS) Digital Twin Integration Subcommittee (DTI-S) and approved by the NIBS Digital Technology Council Board of Direction. The DTI-S consists of members from academia, industry, and government in the Architecture, Engineering, Construction, and Operations (AECO) industry who have various levels of knowledge either of BIM or Digital Twin.

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The DTI-S is grateful to these contributing members, and to the additional unnamed members whose continued interest through many meetings supported and propelled the momentum of this effort. Thank you!

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Executive Summary

Integrating Building Information Management (BIM) and Digital Twin presents a groundbreaking opportunity for the AECO industry, setting the stage for innovation, efficiency, and collaboration. This Position Paper envisions a future where BIM and Digital Twin coexist and synergize to drive sustainability and enhance operational performance. By identifying this opportunity, the DTI-S is not merely adapting to digital transformation, it is participating in it by offering the industry a plan for advancement that leverages the full spectrum of digital capabilities.

This Position Paper aims to demystify the relationship between BIM and Digital Twin and showcase how through strategic integration, leaders, technologists, and practitioners can accelerate significant industry-wide change. This paper advocates for the symbiotic adoption of BIM and Digital Twin in the AECO industry, emphasizing implementation in accordance with established standards. The positions discussed here present a focused message to decision-makers, providing insight and urging changes to drive industry advancement and collaboration.

The Importance of Integration

The introduction of Digital Twin to the AECO industry has generated significant excitement and speculation. Amid this enthusiasm, a prevalent challenge persists:

> *There is a need for more clarity regarding the Digital Twin concept and its relationship to BIM*.

Despite the established presence of BIM in the industry, the ambiguity between BIM and Digital Twin has led to confusion, leaving stakeholders uncertain about their interchangeability. Acknowledging this issue, this Position Paper aims to bring clarity to the relationship between BIM and Digital Twin. By addressing fundamental questions, our objectives are to define the relationship between BIM and Digital Twin, create value, enhance understanding, remove uncertainties, and facilitate informed decision-making within the AECO industry.

The Audience for this Paper

The Position Paper is designed to cater to a diverse audience within the AECO industry. It addresses the needs and interests of three main audiences: executive leaders, technologists, and practitioners.

- For **executive leaders**, the paper explores the transformative potential of BIM and Digital Twin. It explores the strategic implications of these technologies for decision-making within their organizations.
- For **technologists**, the paper provides a thorough investigation into the technological intricacies of BIM and Digital Twin. It offers insights into cutting-edge technological advancements and opportunities for innovation.
- For **practitioners** in the AECO industry, the paper serves as an informative resource. It sheds light on the profound impact of Digital Twin and its relationship with BIM, fostering a comprehensive understanding of the evolving landscape.

One demonstration of using insights from this paper follows:

> *An **executive leader** needs to create a society name to professionally use as a common and public term for a future team. In reading this paper, they come across the Public Perception positions in sections 2.4.1 (Groups and Organizations) through to 2.4.4 (Tools and Practices). Here they make the following observations:*
>
> *If the acronym of the title is the same as (or similar to) another complimentary organization or concept – perhaps by calling themselves the "Neural Infrastructure and Buildings Society" (aka NIBS), or by using any non-"Digital Twin" term that results in "DT" (at this point in the digital twin hype cycle) – it will:*
>
> - *confuse new practitioners coming to the effort,*
> - *impact the relationships between any organizations with mutual interest in the term, and*
> - *impact the opinions of supporters who may perceive the decision as ill-advised at best, dismissive most likely, and even potentially disingenuous at worst.*
>
> *Realizing the nuanced impacts of a potential mistake, the **executive leader** then directs their team to read and align with this paper. In doing so, volunteer **technologists** and **practitioners** supporting the development of this new society begin to identify opportunities to improve their efforts. They observe where mis-aligned definitions are leading to breakdowns in collaborative discussions, and where use cases can constructively leverage the BIM and Digital Twin relationship in digital transformation.*

The Top-Level Position on Integrating BIM and Digital Twin

The Subcommittee holds the position that the BIM and Digital Twin relationship is:

(a) Integrative and not duplicative,
(b) Commonly misunderstood, and
(c) Uniquely well suited for solving substantial AECO issues and avoiding pitfalls.

This is therefore an opportunity to reinforce the "BIM and Digital Twin relationship" as vital to digital transformation in the AECO industry. This position is established after scrutinizing the relationship through the lenses of Public Perception, Use Cases, Execution, and Data Frameworks (see Figure 1).

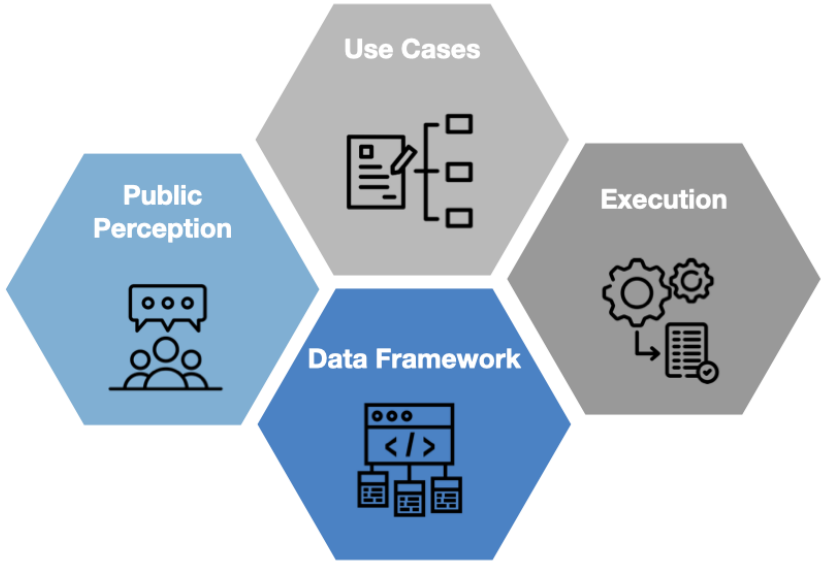

Figure 1 – The main components of the paper: Public Perception, Use Cases, Execution, and Data Framework.

Through the **Public Perception** lens, the Subcommittee considers the ubiquitous role that the general public plays in shaping policy for the integration of BIM and Digital Twin. Though these stakeholders are unlikely to be aware of technical discussions such as this paper, they indirectly have a substantial impact on efforts like it. It is logically argued that the general public is overlooked as a source of confusion, miscommunication, and uncertainty, and that as a result, efforts to integrate established BIM practices with disruptive Digital Twin approaches depend heavily on how the general public perceives and interacts with the built environment. There are several non-AECO industries that are widely inconsistent about communicating the nature of Digital Twin, and that this messaging (coupled with the hype surrounding general innovation) is now impacting the AECO Industry's enduring BIM implementation effort. As a result, the Subcommittee contends that public perception should be leveraged to reduce delay and confusion, and to enhance the effectiveness of BIM and Digital Twin integration.

Through the **Use Cases** lens, the Subcommittee considers the practical application of BIM and Digital Twin approaches, showcasing how both revolutionize the life cycle of built spaces and the natural environment. The Subcommittee recognizes the transformative potential of BIM and Digital Twin and advocates for their collective adoption in sustainable and efficient development. Clear and well-defined use cases are key to the successful implementation of BIM and Digital Twin.

Through the **Execution** lens, the Subcommittee explores how BIM and Digital Twin can be executed by harnessing their differences. The position on integrating BIM and Digital Twin execution planning establishes that synergy is realized by embracing and operationalizing their distinct characteristics and execution approaches. This is based on the recognition that BIM Models generally provide detailed, robust, and static asset representations that digital twins can animate and operationalize. The Subcommittee believes that there can be a practical strategy for leveraging BIM as a "foundational structure" upon which AECO digital twins are built.

Through the **Data Framework** lens, the Subcommittee delineates a dynamic way to manage and harness data vital for the evolution of BIM and Digital Twin. The framework identifies strategies for immediate implementation and projects a forward-looking trajectory. It is responsive and expansive, readily absorbing new insights and adapting to the evolving landscape of challenges and opportunities. While BIM excels at robust information, Digital Twin thrives on change; together, they form a comprehensive vision more significant than the sum of its parts. While BIM offers a foundational digital structure, Digital Twin can build on it, making the structure come alive with real-time data. The key is to understand and respect the strengths of each, while leveraging their capabilities to the fullest.

I. Introduction

1. Introduction

In the rapidly evolving landscape of AECO practices, the advent of the Digital Twin concept has sparked considerable excitement and speculation. Amid the hype, however, a challenge persists: there is a lack of clarity surrounding what constitutes a "digital twin", how one can be uniquely leveraged, and why – as an approach – its benefits stand out in driving support for investment. While Building Information Management (BIM) has established itself as a familiar and widely adopted concept within the industry, the ambiguity between BIM (including BIM Models) and Digital Twin (including digital twins) has given rise to confusion. Many stakeholders are left wondering if they are interchangeable terms or distinctly different entities.

Recognizing this issue, this paper presents a position on clarifying the relationship between BIM and Digital Twin. By addressing these fundamental questions, our aim is to provide an understanding, dispel uncertainties, and pave the way for informed decision-making within the AECO industry. This paper examines the complexities surrounding the adoption and integration of BIM and Digital Twin and how they relate to existing standards. The Subcommittee's goal is to advocate for the symbiotic adoption of BIM and Digital Twin in the AECO industry while ensuring that they are implemented in accordance with established standards. This Position Paper provides a focused message to decision-makers to drive this necessary change.

1.1. Definitions of BIM and Digital Twin

As the focus of the Subcommittee and the Position Paper is the relationship between BIM and Digital Twin, the following definitions are provided in this context and for the AECO industry.

BIM

The concept of BIM has been developed to apply to three facets of building and managing facilities:

1. **Building Information Management (BIM)**: functions of controlling the acquisition, analysis, retention, retrieval, and distribution of built environment asset information all within an information processing system.

   Note: *within BIM, 'building' refers to the process of building an asset, not a specific type of facility (i.e. not "a building"). BIM is a function that can be implemented across all types of built environment assets, including buildings, bridges, highways, tunnels, process plants, landscape, and other infrastructure and facility types.*

2. **Building Information Model ("[BIM] Model")**: a shared digital representation of physical and functional characteristics of a built environment asset.

   Note: Adapted from NBIMS V4. Added the word "BIM" to the acronym. *Many uses of "BIM" interchangeably refer to management, models, or modeling, so the word "Model" is used here to reduce the miscommunication and conflict that is often observed when discussing BIM. Further, because the focus of this paper is on the relationship between BIM and Digital Twin as concepts, the text will explicitly use BIM Model where it applies.*

3. **Building Information Modeling ("[BIM] Modeling")**: generating and using a shared digital representation of a built asset to facilitate design, construction, and operation processes to form

a reliable basis for decisions.

> Note: Adapted from NBIMS V4. Added the word "BIM" to the acronym. *As with BIM Model, the word "Modeling" is used here to reduce the miscommunication and conflict that is often observed when discussing BIM. Further, because the focus of this paper is on the relationship between BIM and Digital Twin as concepts, the text will explicitly use BIM Modeling where it applies.*

Digital Twin

Digital Twins surfaced before the turn of the century and have been adopted in many industries since then (e.g., Manufacturing, Healthcare, etc.). Because it has developed with such diversity, its definition has generated significant controversy. This section will explore and discuss various aspect of defining Digital Twin that have yet to be established in the AECO industry.

The Digital Twin Consortium (DTC) definition is:

> *A Digital Twin is a virtual representation of real-world entities and processes, synchronized at a specified frequency and fidelity.*

The DTC continues by adding:

- *Digital Twin Systems* ***transform business by accelerating holistic understanding, optimal decision-making, and effective action.***
- *Digital Twins use real-time and historical data to represent the past and present and simulate predicted futures.*
- *Digital Twins are motivated by outcomes, tailored to use cases, powered by integration, built on data, guided by domain knowledge, and implemented in IT/OT systems. [23]*

While this paper uses the above definition as a basis for discussion, it also introduces a definition specific to the AECO industry using the domain language. Building toward this, the positions herein also use a definition that:

- [A] Applies specifically to an identified need for the AECO industry to rely on defined use cases.
- [B] Articulates the multiple frequency requirements within complex, multipurpose facility systems.
- [C] Accounts for multiphase planning processes that require development of the digital model prior to constructing its physical twin (coincidentally aligning more closely with BIM methodologies).
- [D] Aligns to non-AECO industry definitions that require simulation.
- [E] Assimilates existing technologies that are AECO equivalents to digital twins and are used to actuate physical assets (such as building automation systems (BAS), environmental management control systems (EMCS), supervisory control and data acquisition (SCADA) systems, etc.).

The modifications for these considerations are color-coded and underlined in the following single sentence definition, and are not intended to conflict with any components of the DTC definition:

> *A Digital Twin [A] of an asset is a [A] fit-for-purpose and [A] intelligent virtual representation of it synchronized at specific [B] frequencies, [C] with an existing or planned connection between the virtual and physical twin that [D] may include analysis and [E] the ability to actuate physical changes from the virtual twin. [2]*

These two definitions are compatible, and work to express different facets of the same technology.

Categories of a Digital Twin

This second definition also expressly accommodates digital twins that are created at different stages of an asset's life cycle and with different levels of integration between digital and physical environments. Throughout this paper, the following classification system for types of digital twin is used where it adds context and value. Based on the level of integration between digital and physical twins, this classification system consists of three categories: Digital Twin Prototype (DTP), Digital Shadow (DS), and Cyber-Physical System (CPS) as shown in Figure 2 below.

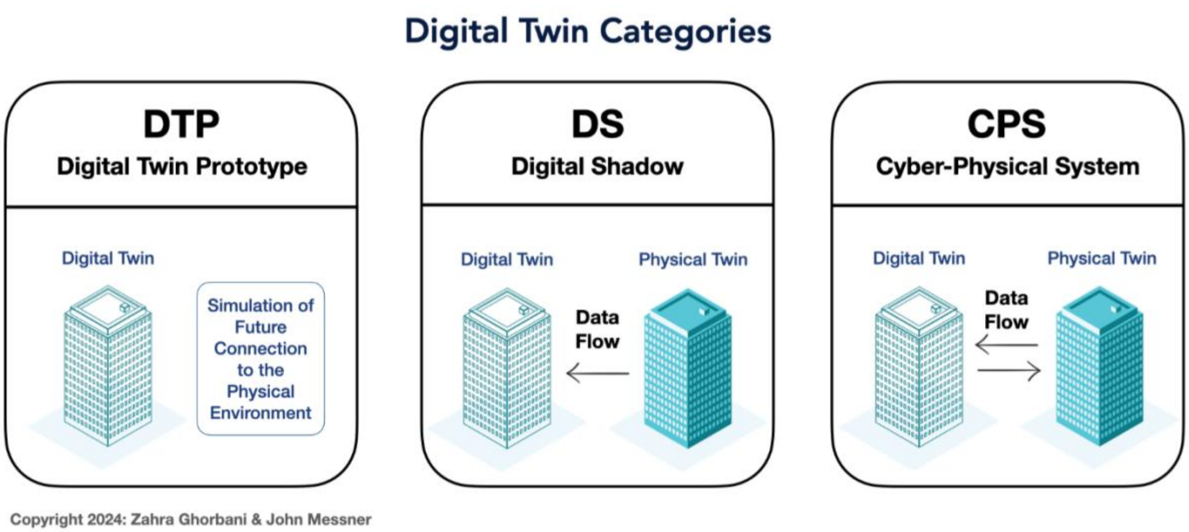

Figure 2 – Digital Twin categories [2]

> *A Digital Twin Prototype (DTP) is a virtual representation of an asset designed to be connected to the physical asset in the future.*
>
> *A Digital Shadow (DS) is a virtual representation of a built asset with data flow from the asset to its Digital Twin.*
>
> *A Cyber-Physical System (CPS) is a virtual representation of an asset with bi-directional data flow between the digital and physical twins, often including an actuation layer. [2]*

<u>Chair's Editorial Comment</u>

This editorial comment has been added to transparently highlight and address a complex issue: there was no full consensus on the definitions above. There was a surprisingly significant controversy that these terms stirred up. Though they were developed rigorously from doctoral research into multiple industries, being academically defined does not mean that they will integrate well without compromise or debate. The truth is that many AECO professionals have terms they work with and have defended, but none that are universally adopted for communicating the concepts conveyed by DTP, DS, and CPS. In this regard (among many), the AECO industry lacks effective cohesion.

There is an unfortunate risk in proceeding without a clear consensus, namely that the terms in this paper will conflict with the experiences, beliefs, and/or convictions of some (if not many). But after hearing opinions from across the spectrum, as the Chair, <u>I individually made the call</u>. Though there are valid reasons for and against, the core of my decision was based on the clear, positive signal received from a large segment of our membership: many experienced professionals who were newly introduced to the concept of Digital Twin found that DTP, DS, and CPS provided the balance between clarity and application that they had been looking for. "Many" that is, though regrettably not "all".

And so right or wrong, but in keeping with the insights generated by this Subcommittee, these terms are used here in deference to advancing multi-industry interoperability, promoting collaboration and intra-industry cohesion, and supporting those who are new to this cross-discipline community.

Note that Figure 2 illustrates a specific example (i.e., a building) and its relationship to the intersection of BIM and Digital Twin. A fundamental concept introduced is the dynamic coexistence of these Digital Twin categories (i.e., DTP, DS, CPS) within a single asset. This paper underscores the notion that a single asset can concurrently integrate all three categories, and their significance is contingent upon the specific use case at hand. Emphasizing "equal importance", this approach dispels the notion that one category overshadows the others. In practical scenarios, a building may have a CPS of the Building Automation System (BAS) that interacts with building systems for the physical environment. Simultaneously, there could be a DTP simulating future scenarios that do not exist yet.

This nuanced understanding emphasizes that these categories are not hierarchically structured, and these different categories of digital twins can harmoniously coexist, operating synergistically to address diverse use cases within the built environment.

1.2. Discussions on BIM and Digital Twin

The discussion on the relationship between BIM and Digital Twin is gaining traction in the AECO industry, resulting in publications. However, there are few peer-reviewed publications that discuss the correlation between them.

Peer-reviewed publications have examined the relationship between BIM and Digital Twin [3-5]. Some perceive Digital Twin as a progression of BIM [3], while others mention that BIM is a separate entity that can be leveraged to create Digital Twin [4-5]. Another category of papers considers BIM as a component of Digital Twin [6-9]. However, none of these studies have expressly examined the nuances of the relationship between BIM and Digital Twin.

In addition, there are a number of blog posts and articles that present individuals' opinions on this matter, some being opinion pieces published on software vendors' websites or online magazines. While many of these sources are not peer-reviewed and have not gone through any technical review, they are valuable as an indication of an increasing interest in the topic, and they have an impact on degree of communication experienced in discussions on the topic.

For a complete review of the literature, refer to **Appendix B: Literature Review**.

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II. Positions on Public Perception

2. Public Perception

A growing body of literature indicates that interest in this technology within the AECO industry is increasing, and as a result, the idea that the general public has a growing interest in Digital Twin is becoming an important factor to take note for the industry. It is a demand that drives vendor investment. Members of the Subcommittee have experienced that collaborative efforts to assess use cases and address the general public's demand are often underfunded and easily overshadowed by well-funded and uncoordinated vendor sales pitches. In the absence of clear incentives to collaborate on coordinated messaging, businesses invest heavily in marketing innovative concepts directly to consumers who seek novel solutions. As a result, they end up creating new terms, forms, and structures that compete with policy-shaping efforts for the general public's attention and use.

2.1. Audience Intent

For the target audiences of this paper, the following describes how this section's insights are intended to be received.

- Leaders / Policy Makers
  The general public will continue to be a source of disruption in the relationship between BIM and Digital Twin because of an influx of targeted messaging from a wide range of Digital Twin business sectors outside of the AECO industry.

  Leaders and policy makers are encouraged to read this Position on Public Perception to ensure that high-level and long-term investment strategies account for this uncertainty, and that policy-shaping actions can be taken to reduce confusion, conflict, and delay.

- Technologists
  The general public will continue to be a source of product and feature requirement conflicts because of both the ill-informed demand signals received by owners/investors and the marketing efforts vendors make to entice them through these signals.

  Technologists are encouraged to read this Position on Public Perception to ensure that this "push and pull" dynamic is understood and leveraged to improve communication and better deliver integrated solutions for end users.

- Practitioners
  The general public will continue to be a source of new practitioners for design, engineering, labor, and more. With these entrants into the AECO industry comes their technology-related habits, preconceptions, biases, and ambitions.

  Both new and experienced practitioners are encouraged to read this Position on Public Perception to ensure that sources of confusion are understood, recognized, and addressed when encountered, and that personal actions are shaped to foster healthy dialog, encourage full participation, and amplify the benefits of a diverse array of perspectives.

2.2. The Importance of Public Perception

The Subcommittee holds the position that:

(1) The general public's[1] perception is undervalued as an essential and influential component of BIM and Digital Twin integration efforts,

(2) The general public's perception has not been leveraged to align these two approaches, and

(3) The impact of addressing the general public's perception collaboratively can be instrumental in efficiently managing an unavoidable disruptive transformation of the AECO industry.

2.3. Logic of the Position

In developing the above positions, a relationship emerged: through a chain of five critical concepts, the perception of the general public has an impact on industry cohesion because opinions bias risk, and risk tolerance informs capital investments within organizations throughout industry. Figure 3 visually describes the logic of this impact within a single organization, though does not suggest that a single organization's impact alone is substantially relevant to industry cohesion.

Figure 3 – The impact of public perception on industry cohesion (through a single organization)

This logic is expanded on in Section 2.5 (Extended Discussion) to encompass the entire AECO industry by the sheer number of organizations the general public affects. As a result, the following sub-positions on public perception should be considered in order to leverage this insight and generate a positive transformational effect on the industry as a whole.

2.4. Sub-Positions on Public Perception

The Subcommittee's Position on Public Perception relies on the following specific concepts the team identified across four topic areas. Significant discussion and debate have identified that the topic areas are woven through with a common thread: support for integration exists and is based on relatability, compatibility, motivation, and experience.

[1] Members of the general public may be unaware of BIM or DT concept but can still drive demand because non-technical users expect businesses to provide features based on unintended sources of information (such as word-of-mouth or entertainment media).

2.4.1. Groups and Organizations

<u>The groups and organizations that shape policy for BIM and Digital Twin practitioners across communities are prolific, engaged, and seek collaboration.</u>

Though more is needed, there exists within most BIM and Digital Twin groups and organizations a clear understanding of the benefits they provide, a sincere openness to diversity, and a drive for inclusivity. In shaping policy, they have leveraged shared purposes and motivations, applied them across national boundaries and cultural divides, and created an ecosystem of innovation ripe for integration.

The BIM and Digital Twin communities in the AECO industry often overlap in their mutual desire to digitally enhance asset management and capability delivery, as well as the motivation to pursue transformative innovations passionately. For BIM practitioners and stakeholders, there are volumes of experience and policy resources built over decades of implementation that have been tested and established. For Digital Twin practitioners and stakeholders, there is exceptionalism in their ability to drive and motivate the general public through a digital-native[2] friendly style of design, communication, and engagement, as well as in collaboration with other industries that can drive innovative approaches.

2.4.2. Current State of Definitions

<u>General understanding of BIM and Digital Twin definitions is evolving towards maturity, and practitioners are aware of the need to improve communication and comprehension across the industry.</u>

Digital Twin organizations engaged in policy-shaping are at a stage of development where definitions across industries are still forming, and BIM organizations engaged in policy-shaping are becoming aware of the need to address ambiguous technical definitions[3] that burden discourse and investment. This flexibility supports the Subcommittee's position because it suggests these groups and organizations are primed to accept impactful and transformational reframing of established definitions. In other words: for the right reasons, they are prepared to discuss changes in long-established terms and definitions.

The communities across BIM and Digital Twin practitioners have valuable and relatable concepts that are consumable if communicated clearly. They are at a justifiable time for change if the need is formally recognized and supported, and they have learned valuable lessons for simplifying communication with all audiences if effectively organized. Given the nature of their exceptionally

[2] "Digital-native" refers to individuals born into an era of digital technology, having only experiences in a world influenced by computers or the internet.

[3] For context, three examples of "ambiguous technical definitions" are provided: (1) the three formal meanings for the "M" in BIM (management, modelling, and model), (2) the divergent interpretations of "building" in the BIM acronym as a verb or a noun, and (3) the subtle differences between the "D" in the three common breakdowns of LOD (detail, development, or design).

compatible goals, it is the Subcommittee's position that the communities across BIM and Digital Twin practitioners are experienced, resourced, and prepared for changes to definitions so long as they are made in concert.

2.4.3. Influential Forces of Change

<u>There are forces impacting the general public's perception of BIM and Digital Twin that remain overlooked in many professional discussions on the relationship between these two approaches.</u>

Cross-industry marketing, national adoption, and entertainment media are three monolithic examples of impact forces that can support a well-integrated relationship between BIM and Digital Twin.

- <u>Cross-Industry Marketing</u>
  Through marketing and general messaging from outside the AECO industry, digital twins demonstrated in other industries (e.g., Aerospace, Manufacturing, and Medical) have an influence on the general public's opinion. Leveraged in concert, these influences can be impactful if deliberately used to drive interoperability, pool lessons learned, and amplify communication efforts.

- <u>National Adoption</u>
  As a relatively monolithic customer the United States Federal Government has an ability to impact national adoption and accelerate the rate of industry change through the sheer magnitude of its federal infrastructure contracts and the regulations it maintains.

- <u>Entertainment Media</u>
  Though never mentioned by name, BIM and Digital Twin benefit from popular media and entertainment as high-budget computer graphics and engaging scenarios viscerally demonstrate the value of digitized real-world assets, thereby driving demand for digital integration and organizational transformation.

Leveraging impact forces such as these through influence, development, or study can meet a demand that is currently undersupplied. This "supply and demand" imbalance proves there is value in integrating BIM and Digital Twin, and the Subcommittee argues it can drive industry investment.

2.4.4. Tools and Practices

<u>The tools and practices supporting BIM and Digital Twin integration bring a previously disengaged sector of the public into "participatory management" of an asset's operational life cycle, imparting new caretaker responsibilities on an industry where technical maturity is often already expressed.</u>

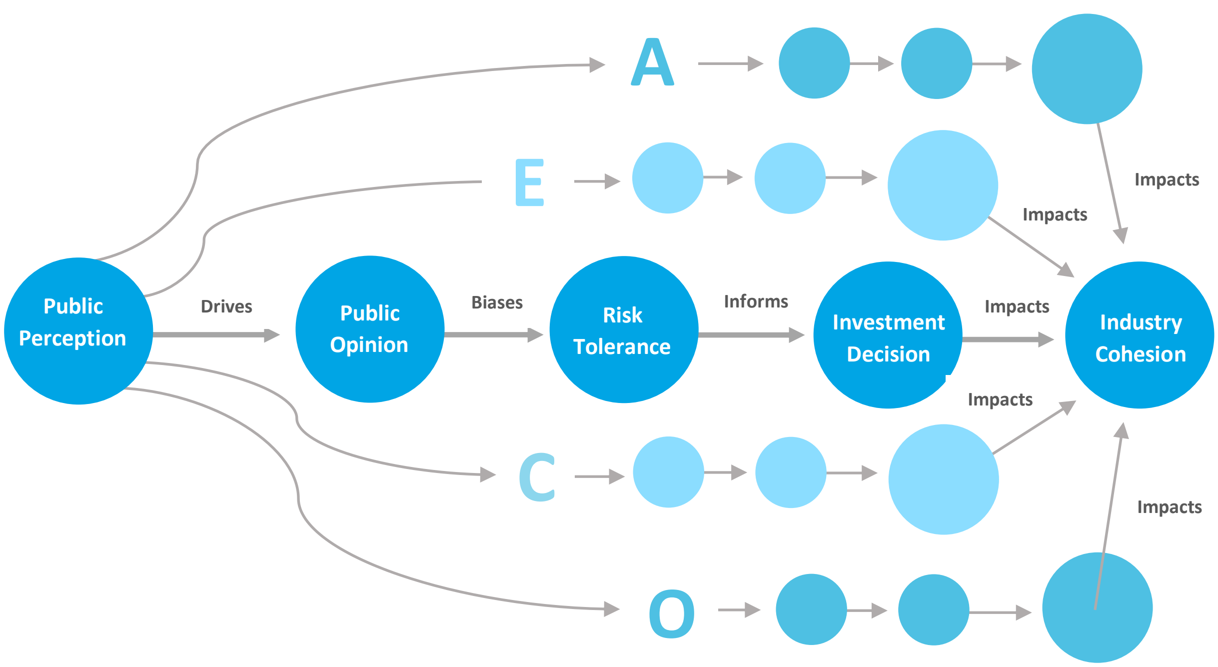
Since the late 20th century, BIM has enabled practitioners and direct stakeholders to coordinate better design and construction by focusing the AECO industry on evolving the tools and practices they depend on. Outside of this core technical community however, public audiences have rarely (if ever) needed awareness of the highly technical applications, regulations, and approaches used to implement BIM practices.

In contrast, Digital Twin focuses heavily on mainstream accessibility by attempting to interact directly with the general public and achieve delivery of insights through digital tools that interface with end users. Examples of these users can be librarians who monitor humidity for book preservation purposes, or stock clerks who benefit from real-time location mapping and inventory monitoring in facilities. This contrast highlights the extensive consumer reach of digital products and suggests that the circumstances are right for supplying this new degree of digital delivery. But, in rushing to meet this demand, it should be noted that there is also a substantial risk that hasty technological change can fatigue the general public and expose them to security and privacy issues[4].

2.5. Extended Discussion

The cohesiveness of an industry is evident in its ability to act as a united whole. For example, the ability of an industry to authoritatively establish and abide by definitions can be evidence for or provide metrics regarding the degree of an industry's level of cohesion. The greater the disarray, confusion, miscommunication, and fragmentation in an industry, the less cohesive that industry is and the less likely it will be in rapidly responding to changes in the technological landscape.

Figure 4 (below) expands section 2.3's logic to show that even though the general public does not substantially impact AECO cohesion through a single organization (Figure 3), it does so collectively across the many organizations that constitute the entire industry. In this case, the general public's perception drives and biases risk tolerance across organizations of architects, engineers, construction contractors, owners, and more.



[4] Example: a popular mapping company used driver location services on phones for their internal systems, exposing the public – who were unfamiliar with the technology – to privacy and security risks that were not well-understood.

Figure 4 – The Impact of public perception on industry cohesion (collectively through many organizations)

If the relationship between BIM and Digital Twin is left to develop organically without coordination or facilitation, the AECO industry risks further loss of cohesion through substantial confusion, worsening barriers to entry and adoption, poorly informed investment decision-making, and fragmented efforts to transform organizations and communities. Through facilitation, organizations like NIBS and the Digital Twin Consortium are successfully mitigating these risks: when discussions directly address the general public's beliefs, interpretations, and common assumptions, the industry gains tools for cohesive improvement. One manifestation of this is the formation of DTI-S itself.

These insights suggest significant value in directly and deliberatively addressing the general public's perception to integrate BIM and Digital Twin technologies, policies, and practices.

The Subcommittee sees that after nearly 50 years, BIM development is coinciding with the social emergence of Digital Twin as a named concept – backed by substantial demand – to culminate in a tipping point: the AECO industry is at a threshold in which key organizations can leverage the general public's demand and maturity to refine BIM standards, tools, and practices. Focusing on the digital needs of end users will enable BIM to support and improve Digital Twin efforts in how their use cases are identified, their execution is conducted, and their data frameworks are integrated into an organization. By doing so across the AECO industry, organizations can responsibly phase in digitally integrated facilities to support effective decision-making through a synthesis of BIM and Digital Twin approaches.

III. Positions on Use Cases

3. Use Cases

Having reviewed the definitions and foundations of BIM and Digital Twin, the Subcommittee acknowledges the public's escalating demand for clarity and tangible benefits from these advanced technologies. While the intricacies of BIM and Digital Twin might appear overwhelming, it is through their practical, real-world applications that their true potential is unveiled. As the paper transitions to use cases, positions are introduced that make these concepts accessible to leaders, technologists, and practitioners, and dissect the complexities of the overall ecosystem. These practical applications and strategies support the standardization of BIM and Digital Twin and pave the way for a deeper comprehension of the technical discussions on required data frameworks and BIM and Digital Twin execution.

3.1. Audience Intent

For the target audiences of this paper, the following describes how this section's insights are intended to be received.

- <u>Leaders / Policy Makers</u>
  Use cases will be the key drivers for making investment in BIM and Digital Twin technologies, guiding decision-makers towards strategic allocation of resources.

  Leaders and policy makers are encouraged to read this Position on Use Cases to identify how their strategic business needs may be translated into actionable applications across the entire asset life cycle. Understanding the use cases is imperative for identifying opportunities to leverage technology and innovation effectively, thereby shaping environments in line with broader societal and economic objectives and ensuring long-term sustainability and resilience.

- <u>Technologists</u>
  Use cases will be a foundational step for technologists in comprehending the diverse applications of BIM and Digital Twin within the AECO industry, providing them with valuable insights into the practical needs of stakeholders.

  Technologists are encouraged to read this Position on Use Cases to ensure that their technology solutions are not only robust but also aligned with the specific requirements of different use cases. By understanding the varied applications of BIM and Digital Twin, technologists can tailor their solutions to provide the necessary capabilities, ultimately enabling leaders and practitioners to achieve their goals effectively. This alignment fosters innovation and drives the industry towards more efficient and sustainable practices.

- <u>Practitioners</u>
  Use cases will empower practitioners to translate conceptual ideas into tangible assets that generate value and address societal needs, serving as a roadmap for practical implementation.

  Practitioners are encouraged to read this Position on Use Cases to learn how to better evaluate the feasibility of their projects and connect them with broader strategic goals. Their pivotal role lies in aligning business objectives with practical use cases, identifying areas where BIM and Digital Twin can create the most significant benefit. By leveraging these technologies effectively, practitioners contribute to the creation of sustainable and resilient built environments that enrich lives and foster community well-being.

3.2. The Importance of Use Cases

The Subcommittee holds the position that:

(1) Use cases are the cornerstone of BIM and Digital Twin, and

(2) Establishing clear and well-defined use cases is significant as the foundation for successful BIM and Digital Twin integration.

3.3. Logic of the Position

Before a single tool is chosen or an application is deployed, use cases stand at the forefront of a BIM and Digital Twin strategy. Use cases are narratives that preface technology selection, acting as both the story that inspires development and the requirement against which the implementation is tested. They are distinct from the actual deployment of BIM and Digital Twin technologies, serving as an illustration of foundational elements that inform and shape implementation. This precise sequence ensures that use cases are not an afterthought but a prelude to implementation, allowing for a more targeted and story-driven development process. By establishing use cases early on, a detailed framework is created for what BIM Models and digital twins need to achieve—providing a clear, testable objective that stands apart from the technologies. This approach assures that when BIM and Digital Twin Solutions are eventually selected and operationalized, they are not merely sophisticated technologies, but purpose-driven solutions tested against the specific narratives and specifications of pre-defined use cases.

3.4. Sub-Positions on Use Cases

The Subcommittee's Position on Use Cases relies on specific concepts the team identified across four topic areas (outlined below).

3.4.1. Use Case Applicability

<u>Use cases offer the clarity and direction needed to maneuver within a complex digital ecosystem and to extract maximum value.</u>

The relationship between BIM and Digital Twin relies on a data framework tied to the clarity of Use Cases. BIM concentrates on a project's design, construction as a DTP, and operation stages as a DS or CPS. It is detailed and exhaustive. On the other hand, Digital Twin extends far beyond a representation of physical assets. They serve as digital replicas, constantly evolving and synchronizing with other systems such as DS and CPS. The spectrum of Digital Twin is vast, encompassing countless potential nodes and interactions. While a strength, this vastness necessitates crafting specific and focused use cases to harness Digital Twin's full potential. For example, during design a BIM is used to define a vision of a future building as a DTP, then when the building is under construction DS and CPS can be used to track material delivery to create the physical asset. After construction is completed, the full DTP, DS, and CPS can be used to synchronize the physical asset to the Digital Twin.

This intricate relationship between BIM and Digital Twin, which supports infinite use cases through dynamic, two-way communication within cyber-physical systems, is illustrated in Figure 5. This showcases the extensive network of interactions between physical and digital realms, emphasizing the limitless potential of Digital Twins and BIM.

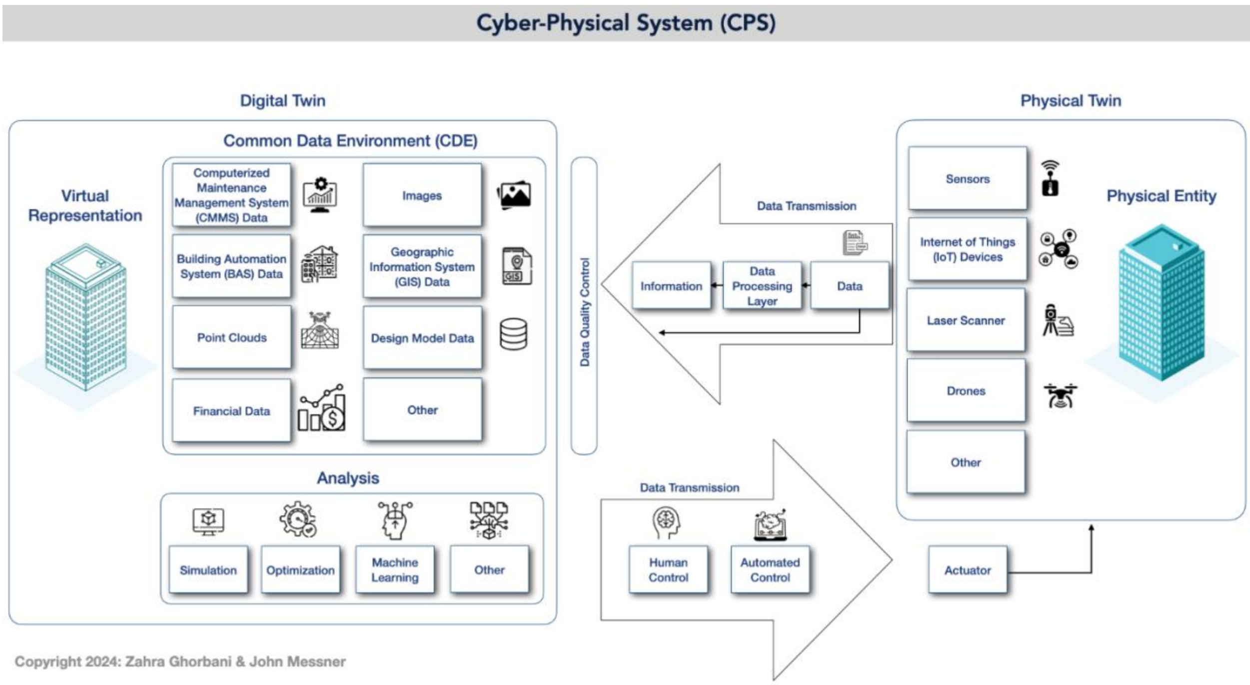


Figure 5 –As a DTP and DS of a BIM preconstruction evolves into a constructed asset CPS uses are enabled.[2]

When a digital twin of an electrical utility system connects with a Digital Twin of a facility's mechanical system, the synchronization goes beyond mere data sharing. This interaction aims to optimize energy use, benefiting the facility and the broader community as a CPS. The data from this interaction can then be integrated into a property owner's dashboard, providing insights into building performance, ensuring loaned asset value, fostering trust, and expanding the Digital Twin ecosystem. Through use cases, a dynamic ecosystem is created that harnesses the full potential of both BIM and Digital Twin.

3.4.2. State of Standards

<u>Existing BIM and data interoperability standards provide a foundation for supporting Digital Twin use cases, and synchronization through a CPS to harness current frameworks while remaining open to integrating future advancements.</u>

This approach ensures that deployment builds on proven, established protocols, allowing for immediate implementation and scalable growth as new standards emerge.

Existing BIM standards from NIBS (such as National BIM Standard - United States® Version 4) and buildingSmart International (bSI) form the backbone of a unified data framework where they can anchor a cohesive BIM and Digital Twin ecosystem. Specifically, ISO 19650 enables tracking spaces, systems, and assets. This is further enriched by BIM standards such as Industry Foundation Classes

(IFC) and Construction to Operations Building information exchange (COBie), which, with their structured ontologies, create pathways for Digital Twin applications. For instance, an asset within a building space can easily incorporate attributes like sensors, facilitating intricate data interactions and synchronization through a DS and CPS.

The inherent complexity and diversity of Digital Twin approaches, unlike the homogeneous nature of BIM Modeling, curates a collection of diverse use cases, each adopting specific standards tailored to its components, negating the singular, all-encompassing Digital Twin standard. In this Digital Twin landscape, resources such as the Capabilities Periodic Table[5] from the Digital Twin Consortium become pivotal, providing insights into aspects like data streaming and processing, bridging BIM with advanced domains like data services, intelligence that includes Artificial Intelligence (AI) and machine learning, all while respecting the bespoke nature of individual Digital Twin use cases and enabling DS and CPS.

Addressing the Absence of Standards

Though established industry BIM standards play a pivotal role for users, navigating the intricate web of digital twins necessitates a more granular approach when a standard is absent. Rather than seeking a macro-standardization across the entirety of Digital Twin, the focus can shift towards ensuring seamless microtransactions—essentially, the handshake and synchronization protocols for a DS and CPS at the device and inter-device levels, encompassing various wireless protocols and data translation protocols. While the absence of a standard should not hinder BIM and Digital Twin initiatives, the micro-level transactions provide an approach to maintaining interoperability and functionality across diverse devices and platforms without the complexity of overarching standardization. Referencing the DTP, DS, and CPS in the use of these exchanges and synchronization reinforces the synergy between BIM and DT. This approach is illustrated in Figure 6, emphasizing the importance of industry standards as a foundation and data framework for BIM and Digital Twin use cases that expand beyond BIM use cases.

[5] Digital Twin Consortium Capabilities Periodic Table

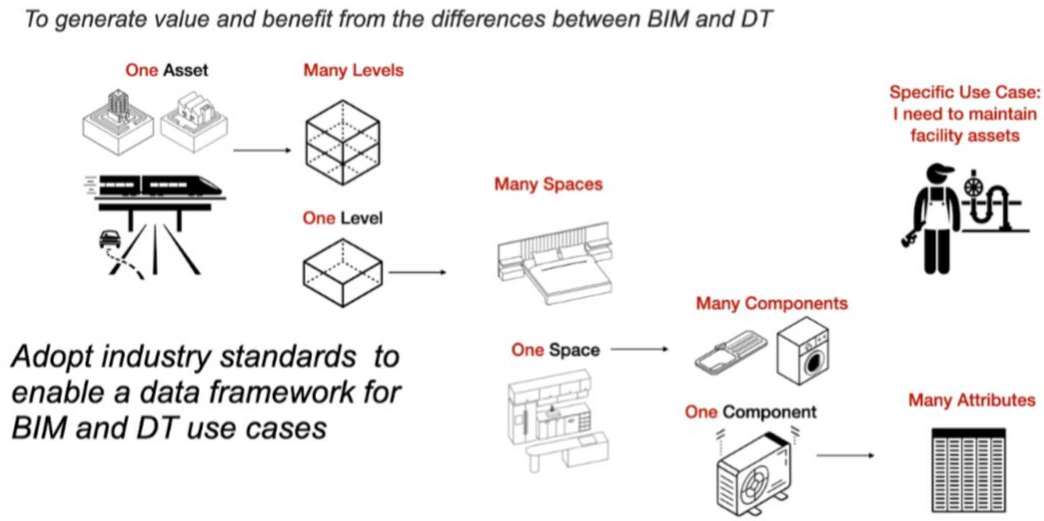


Figure 6 – Use existing industry standards to execute BIM and DT use cases. ©ONUMA, Inc. 2024

3.4.3. Physical-Digital Relationship

<u>Choosing the right solution for an intended use case depends on understanding the ways BIM and Digital Twin address the physical-digital data synchronization.</u>

The data synchronization between physical and digital entities differs in a BIM Model compared to a Digital Twin. The output of using BIM and Digital Twins is also different. See Figure 7.

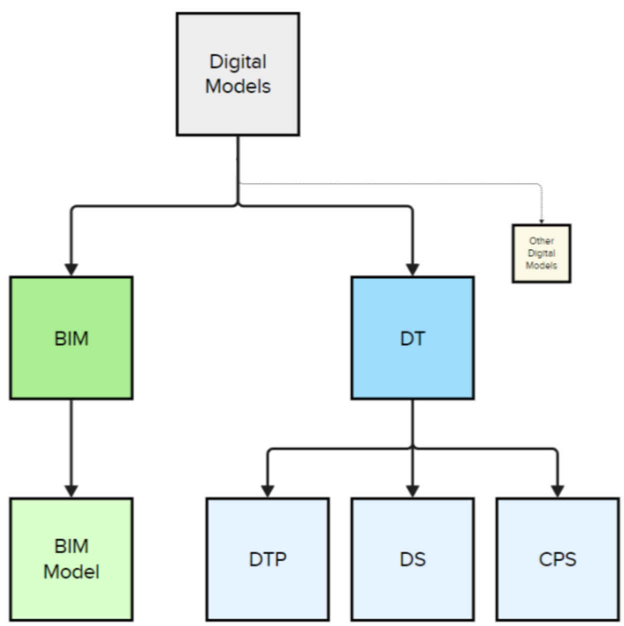


Figure 7 – Relationship between different types of digital models.

Unlike BIM, a BIM and Digital Twin solution can be capable of providing a seamless bi-directional synchronization at specific frequencies between the virtual and physical twin entities to support DS and CPS. See Figure 2.

In the context of the built environment, both BIM Models and digital twins serve as virtual representations of a physical asset. The relationship between the physical and digital entities can be discussed in terms of a unidirectional vs. bidirectional connection, manual vs. automated data flow, and as-designed vs. as-built representation. A BIM Model, as a digitally constructed object, mostly offers unidirectional and manual connections, meaning there is typically no data flow from the physical asset back to the model.

In contrast to BIM, the Digital Twin approach can establish a bidirectional connection between physical and digital entities. However, such a connection may not always be desirable for all Digital Twin use cases or relevant to every phase of an asset's life cycle, especially since the physical asset may not fully exist during the design and construction phases. Regardless, a Digital Twin solution can be capable of establishing a bidirectional connection when necessary. Moreover, a digital twin's data flow is more digitally automated than in a BIM Model, both from the physical-to-digital side (leveraging a robust Internet of Things [IoT] network) and from the digital-to-physical side (utilizing building and infrastructure automation capabilities integrated within the Digital Twin solution).

IV. Positions on Execution

4. Execution

To transition from the conceptual scaffolding of use cases into the tangible realm of execution, the Subcommittee presents concepts that fully realize the potential of BIM and Digital Twin. This section is where theoretical meets practical, articulating the minimum viable product for a BIM and Digital Twin solution which aims to support the asset life cycle through agility and simplicity. It becomes an enabler, providing a structured landscape for intelligent systems to interpret, learn, and act upon. As the BIM and Digital Twin ecosystems evolve and are supported by human expertise, they simultaneously lay the groundwork for advanced use cases, enhancing the AECO industry's capacity for innovation and informed decision-making. A cohesive data framework can transform the complexity of a system of systems into a streamlined conduit for both human intelligence and innovation within the AECO sector.

Execution is highly specific, designed to realize use cases by providing a detailed roadmap that ensures each step taken is in direct service to these scenarios. This planning approach is particularly crucial in the AECO industry, where the diversity of potential use cases requires a disciplined focus to avoid a one-size-fits-all mindset, which could dilute the effectiveness of digital strategies. As the execution layer is unfolded, the way is also paved for the subsequent section on data frameworks. The aim is to construct the synergistic interplay between BIM and Digital Twin, underpinned by the use cases that inform them and the execution strategies that operationalize them.

4.1. Audience Intent

For the target audiences of this paper, the following describes how this section's insights are intended to be received.

- <u>Leaders / Policy Makers</u>
  Execution will play a crucial role in driving the adoption of BIM and Digital Twin within the AECO industry, shaping the future of the built environment.

  Leaders and policy are encouraged to read this Position on Execution to ensure that their strategic vision is effectively translated into actionable plans and initiatives. By focusing on strategic execution, leaders can ensure that environments are built upon foundations of innovation and sustainability, and foster long-term resilience and prosperity.

- <u>Technologists</u>
  Execution will involve developing an integrated system of systems to support diverse stakeholder applications, showcasing the transformative potential of BIM and Digital Twin.

  Technologists are encouraged to read this Position on Execution to ensure that their solutions prioritize seamless integration aligned with organizational goals. By emphasizing strategic implementation, technologists can advance the industry while meeting evolving needs and driving positive change in the built environment. This focus on execution ensures that technological solutions not only meet current requirements but also lay the groundwork for future advancements.

- Practitioners
  Execution will emphasize practitioners' pivotal role in implementing BIM and Digital Twin initiatives, leveraging their expertise to guide practical applications through implementation processes.

  Practitioners are encouraged to read this Position on Execution to ensure that they understand the terminologies and methodologies essential for successful project delivery. By embracing BIM and Digital Twin principles, practitioners contribute to the creation of spaces and assets that not only enhance lives but also sustain the environment.

4.2. The Importance of Execution

The Subcommittee holds the position that:

(1) BIM and Digital Twin can be executed by harnessing the differences between both, and

(2) BIM can serve as a basis for delivering digital twins by streamlining execution.

4.3. Logic of the Position

The position on integrating BIM and Digital Twin execution establishes that a synergy is realized by embracing and operationalizing their distinct characteristics and execution approaches. This follows from recognizing that BIM provides a robust, static asset representation that Digital Twin can bring to life, and so the Subcommittee sees a strategy that leverages BIM as a "foundational structure" upon which AECO Digital Twin systems are layered.

This underpins the Subcommittee's belief that BIM's comprehensive modeling capabilities, when used as a scaffold for digital twins, can streamline the execution process, ensuring a seamless transition from static design to dynamic operation. Such integration fosters a cohesive digital ecosystem where BIM and Digital Twin capabilities coexist and enhance one another, driving efficiency and innovation. This logic is the cornerstone for the detailed execution strategies that follow, each aimed at harmonizing intended use cases, and integrating workflows to capitalize on the unique strengths of BIM and Digital Twin.

4.4. Sub-Positions on Execution

The Subcommittee's Position on Execution relies on specific concepts the team identified across six topic areas:

4.4.1. Agility and Simplicity

<u>Agility and simplicity are foundational for BIM and Digital Twin, ensuring a modular and user-friendly framework that simplifies complex AECO processes and enables synchronization.</u>

This position promotes a scalable and adaptable system of systems, facilitating innovation and accessibility across the AECO industry, and creating value for the public.

Digital twins make complex processes simple, even though the overall ecosystem can be infinitely complex. BIM Models used in the AECO industry are complex by design since the industry is complex. Typical BIM applications are monolithic and require specialized training. Digital Twin is also complex but simplified by treating the whole as a composable system of systems.

The Digital Twin Consortium White Paper, **Digital Twin System Interoperability Framework**, describes it as follows:

- *A key tenet of this Interoperability Framework is that all entities requiring interoperability (including assets) need to be viewed and represented as systems.*
- *By viewing everything that needs to interoperate as a system, everything becomes simply composable and connectable into dynamic, multi-level, systems of systems.*
- *All entities (systems) are inherently composable to create digital threads and system-of-systems that are critical to Digital Twins.*

At the heart of a synchronized BIM and Digital Twin ecosystem lies a commitment to simplicity and agility. Anchoring the data framework with these two principles ensures it remains adaptable, intuitive, user-friendly, and composable for future use cases.

While the evolution and maturity of BIM and Digital Twin underscore the importance of a robust data framework, complexity should never be a barrier to its adoption. The system of systems approach for Digital Twin enables infinite complexity to be solved by the nodes of composable parts. In response to this driving need, today's dynamic digital landscape is characterized by easily developed apps and AI tools. This trend signals a strong public demand for clarity that can only be implemented reliably by practitioners who are given straightforward and intuitive standards. Meeting this demand means crafting a data framework that democratizes access and benefits for all today.

Data standards for BIM already lay a solid foundation. These standards, which facilitate data sharing across both proprietary and open platforms, can be harnessed and extended to accommodate the unique requirements of Digital Twin. BIM data exchanges are typically transactional, reflecting specific project milestones. Examples include the transition of IFC data between the design and construction phases or the handover of IFC/COBie data to operations for individual buildings. Recognizing and leveraging these transaction points can provide a roadmap for integrating the Digital Twin approach into the workflow and enabling synchronization of systems.

4.4.2. Minimum Viable Products (MVP)

<u>A Digital Twin solution's MVP aims to leverage the fundamental capabilities that encapsulate the essence of Digital Twin use cases.</u>

When it comes to adopting and implementing new technology, a common starting point is defining a minimum viable product (MVP). This approach strikes a balance between cost and value. Successfully executing a minimum viable digital twin not only showcases the feasibility and potential of Digital Twin, but also lays the foundation for more sophisticated applications down the road. Within the realm of Digital Twin, a BIM and Digital Twin MVP offers a scalable, adaptable, and cost-effective solution. Its primary objective is to establish a functional BIM and Digital Twin that delivers maximum value based on the users' primary defined uses.

It is crucial to distinguish that the MVP is a property of a Digital Twin solution rather than the Digital Twin itself. The MVP refers to the essential features and capabilities of a Digital Twin solution rather than the sheer number of elements in the Digital Twin. The specific physical asset elements incorporated into the Digital Twin are determined by its intended Digital Twin uses and an organization's strategic asset management planning.

Given this understanding of Digital Twin MVP, it is imperative for practitioners to link their desired BIM and Digital Twin uses with the necessary capabilities. Among the few existing references, the DTC Capability Periodic Table may be used as a foundational guide to learn about Digital Twin-applicable capabilities.

Finally, to elucidate the relationship between BIM and Digital Twin in this context, it can be posited that BIM Modeling is enabled by Digital Twin solutions. In essence, a digital twin, being a system of systems, inherently supports certain capabilities. At the same time, it enables the synchronization of capabilities from various information systems, including BIM capabilities.

4.4.3. Asset Life-Cycle Management

<u>BIM and Digital Twin have data-centric processes that can be utilized across all phases of an asset's life cycle.</u>

Historically, it is important to note that both technologies have increasingly demonstrated their versatility across all phases of an asset's life cycle. For instance, in the operational phase, BIM has found uses through initiatives like BIM-FM (Facilities Management), aiding in tasks such as asset maintenance scheduling and space utilization planning. Similarly, digital twins have proven to be invaluable during the design and construction phases by enabling tasks such as developing design proforma, utilizing AI-driven generative design techniques, and facilitating value engineering for various design alternatives. Additionally, the construction team may implement a digital twin (or multiple independent digital twins) for automated jobsite productivity analysis, construction sequencing optimization, and automated quality control.

Understanding the comprehensive life cycle applications of BIM and Digital Twin enables strategic selection of the most suitable technology solutions tailored to specific requirements. Moreover, this knowledge fosters innovation by inspiring the development of novel use cases for BIM and Digital Twin across different phases of asset life cycle. By leveraging these technologies effectively, stakeholders can enhance collaboration, streamline processes, and ultimately deliver more successful projects.

4.4.4. Scalability

<u>A BIM Model is generally focused on a "single capital asset" while a digital twin is generally intended to expand the horizon to a broader scale.</u>

When discussing BIM as a model, typically the focus is on a single capital asset like a bridge, a single building, or a building system. Even though a federated model can be created containing multiple assets, it still requires a manual process where each BIM model is individually integrated. On the other hand, the Digital Twin approach is capable of managing many integrated assets, including buildings and infrastructure across a portfolio. This allows for seamless asset data extraction and aggregation as well as better interoperability between multiple assets. Although the current cloud-based BIM tools aim to close such scalability gaps between BIM and Digital Twin, the emerging Digital Twin solutions show higher fidelity when working with large-scale portfolio models.

Also, a property owner typically manages numerous assets scattered across a portfolio and each asset can signify a unique investment and a distinct set of business objectives. To manage this, specific business processes and rules have been crafted. While BIM captures the structural nuances of every building, it might fall short of encapsulating the complexities of these business processes across a portfolio of assets.

The BIM and Digital Twin data framework are connected through a system of systems and Digital Thread[6] (which is a digital representation of a [product's lifecycle](), from design to manufacturing to maintenance and beyond), that enable end-users to not only capture the physical attributes of assets but also seamlessly intertwine with their business processes, making them intrinsically synchronized to each asset. Imagine a dynamic checklist for every property, ensuring its alignment with your overarching mission throughout its life cycle, optimizing value from its inception to eventual evolution. Particularly for natural systems in an owner's portfolio, like landscape, the Digital Thread offers a unique advantage. The feedback loop inherent to the Digital Twin is uniquely equipped to ensure the success and fulfillment of that particular type of asset.

Expectation: the emerging Digital Twin solutions should support the interoperability between different data sources regardless of the solution used to develop and host those digital twins. This interconnected approach, which enhances asset management by integrating business processes and physical attributes, is illustrated in Figure 8, highlighting how a unified digital framework ensures both agility and scalability, while expanding the focus from single assets to the entire lifecycle of linked systems.

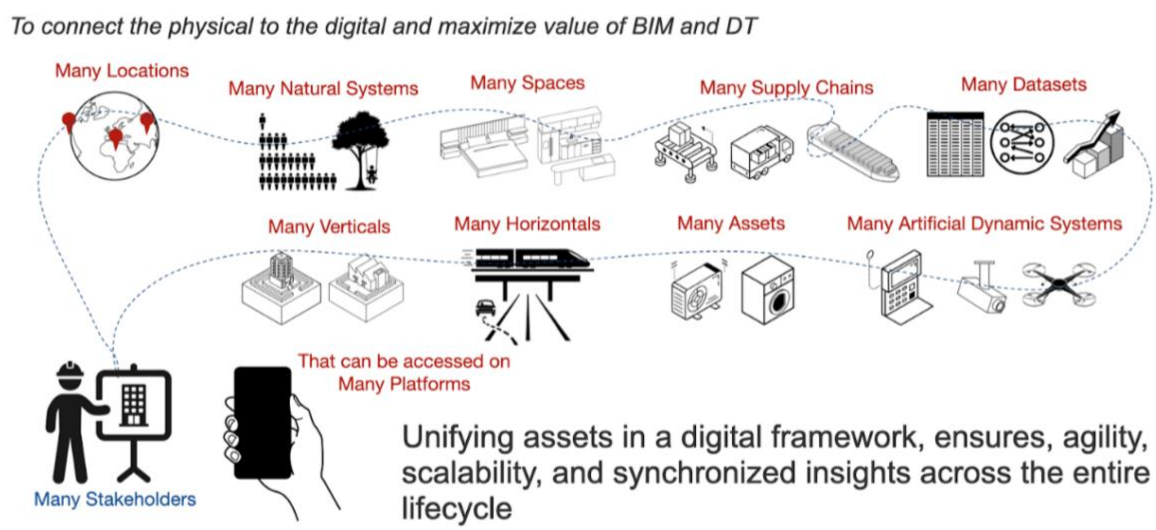


Figure 8 – Expand the horizon from single assets to lifecycle of assets and linked systems. ©ONUMA, Inc. 2024

[6] A Digital Thread example can be seen at https://www.ibm.com/blog/digital-thread-vs-digital-twin/

4.4.5. The Creation of BIM and Digital Twin

<u>Though similar in terms of their use cases, BIM and Digital Twin are very different in terms of how they use data frameworks to deliver those use cases.</u>

BIM technology has evolved through a bottom-up approach, whereas Digital Twin has developed through a top-down approach. As BIM has evolved, there has been a steady and continuous emergence of diverse use cases for BIM, each boasting its own distinct workflow and data requirements. Moreover, BIM execution expanded its applicability from the design phase into the construction and later operation phase of a project. However, the overlaps among these developed workflows, coupled with frequent reworks during execution of a new use case and inefficiencies in data exchange, have often driven the industry to establish BIM standards and execution plans that do not emphasize the data pipeline between upstream or downstream phases. The result is a perception that delivery of operational use cases is an “afterthought.”

In comparison to such organic technology developments, Digital Twin leans toward a more standardized approach from the outset. It provides data strategies that support consistent data utilization and interoperability throughout a project’s life cycle. Furthermore, Digital Twin benefits from an independent data layer (digital thread) and application layer which enables delivering integrated workflows with focus on the organizational aspects and capabilities to support all intended use cases.

The Subcommittee considers Digital Twin as a technology approach with all related practical knowledge, processes, capabilities, and tools. However, as a system of systems, Digital Twin is not a new digital technology providing new capabilities, but rather it allows for new integrations between several systems (fault detection and diagnostics, Building Information Management, Energy Management Systems, etc.) based on the intended uses. In this regard, Digital Twin and its associated technologies can be considered as a significant advancement beyond BIM as it supports application modularity and provides better workflows and infrastructure for data governance across phases of asset life cycles for enhanced digital delivery in the AECO industry.

4.4.6. Expanding the Horizon: Integrating Broad Intelligence in BIM and Digital Twin

<u>Now is the time to spearhead the use of artificial intelligence (AI) to enrich BIM and Digital Twin utilization.</u>

The AECO industry has long leveraged data intelligence in designing and engineering our surroundings, well before the advent of BIM and Digital Twin. The distinction made by this position is that the data-rich environment of BIM aligns with the Digital Twin approach to enable the use of the latest in AI.

The value of BIM and Digital Twin enhances the intelligence captured within BIM. This framework is articulated through business rules, prediction, AI, machine learning, automated processes, and human insights.

This approach to intelligence enables a more nuanced application of BIM and a collaborative environment where machines and humans work together. By tapping into AI, BIM data can be transformed from low-frequency, manually updated, project-centric information into a dynamic, interactive, and persistently relevant digital twins. This improves decision-making throughout the life cycle of assets.

An example of this approach is applying design and construction intelligence to the operations of assets. Here, an intelligence framework allows for the strategic application of AI, machines, and human intellect to interpret and leverage engineering principles and physics, enhancing facility management, predictive maintenance, and overall asset performance.

Failing to lead in this domain risks ceding control to others who may not fully grasp the potential of the industry. By guiding the development of BIM and Digital Twin, it is ensured that Use-Cases are amplified through the data in BIM, offering a broader view of the intelligence enabled by Digital Twin.

Takeaways on BIM and Digital Twin Intelligence

The integration of BIM and Digital Twin with broad intelligence using Digital Twin Platforms (DTP), Digital Shadows (DS), and Cyber-Physical Systems (CPS) is unlocking opportunities in the AECO industry that neither BIM nor DT could achieve alone. This synergy is transforming project management and design by merging human expertise with AI, enabling the analysis of vast datasets for innovation and efficiency.

Automation through DS enhances BIM accuracy and compliance, while the combination of CPS with DT allows for real-time updates to as-built models, facilitating quicker and more informed decision-making. Predictive analytics applied to maintenance and work orders identifies potential issues early on, demonstrating how deep data analysis can proactively manage assets in ways not possible before.

Rethinking construction and maintenance processes through CPS leads to more efficient methodologies, utilizing data patterns to optimize task sequences. This blend of BIM and DT with advanced intelligence technologies heralds a new era of efficiency, innovation, and proactive problem-solving.

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V. Positions on Data Frameworks

5. Data Frameworks

Transitioning from the execution of BIM and Digital Twin approaches – where their unique capabilities are operationalized – now data frameworks and the 'system of systems' are addressed as a pivotal shift that extends the utility of BIM and Digital Twin to support use cases. In the context of BIM and Digital Twin, Data Standards serve as the building blocks, providing the necessary protocols and formats for data creation, storage, and exchange.

However, a data framework goes beyond that and defines how these standards synchronize within a larger ecosystem. It outlines the relationships and workflows that enable disparate systems to work together, supporting a range of use cases across the asset life cycle. While Data Standards ensure uniformity and compatibility, the data framework integrates these standards into a coherent, flexible system that can grow and adapt over time.

This framework addresses the characteristics of BIM and Digital Twin data layer, detailing the Data Requirements, Data Structure, and the processes of Decoupling Data and Exchanging Information—all within the bounds of existing industry standards.

5.1. Audience Intent

For the target audiences of this paper, the following describes how this section's insights are intended to be received.

- Leaders / Policy Makers
  Data frameworks will provide leaders with practical knowledge on understanding data flow within organizations and leveraging data for informed decision-making.

  Leaders and policy makers are encouraged to read this Position on Data Frameworks to ensure that they grasp the fundamental requirements for data-driven collaboration and communication. By embracing data frameworks, leaders can effectively harness the full potential of BIM and Digital Twin, driving organizational efficiency and innovation.

- Technologists
  Data frameworks will emphasize the critical need for creating open data platforms that integrate BIM and Digital Twin data with life cycle insights, highlighting their pivotal role in enhancing project outcomes.

  Technologists are encouraged to read this Position on Data Frameworks to ensure that they understand the importance of synchronization between BIM and Digital Twin as well as the key elements of a robust data framework that supports interoperability during all phases of built environment projects. By prioritizing open data platforms, technologists can facilitate collaboration and innovation, driving industry-wide advancement and transformation.

- Practitioners
  Data frameworks will be a prerequisite for successful deployment of BIM with digital twins, extending practitioners' influence beyond project delivery and empowering them to shape asset life cycles.

Practitioners are encouraged to read this Position on Data Frameworks to ensure that they recognize the importance of leveraging data to optimize project outcomes and enhance asset performance. By integrating BIM and Digital Twin data, practitioners contribute to the long-term sustainability and effectiveness of assets, driving value for clients and communities alike.

5.2. The Importance of Data Frameworks

The Subcommittee holds the position that:

(1) There are synergies between the BIM and Digital Twin data frameworks

(2) Combining BIM and Digital Twin synthesizes a value greater than the sum of its parts.

5.3. Logic of the Position

A data framework is essential for capturing the multi-dimensional nature of BIM Models and digital twins. BIM provides a granular, relatively static model of a capital asset – a snapshot in time – while the Digital Twin approach brings the BIM Model into the continuum of the asset's life cycle, introducing a dynamic element that reflects real-world changes synchronized over time. Combining these frameworks does not merely bring data together; it creates a sophisticated description of the asset, one that changes over time as the asset takes on new characteristics, uses, and forms. This continuous alignment enhances decision-making and operational efficiency through relevance and context.

The logic extends to the data framework that is not rigid blocks, but malleable entities within a digital ecosystem, capable of evolving with the assets they represent. Underpinning this is the assumption that *while BIM excels at organizing relationships and processes, Digital Twin thrives on sustaining data connections and change*. Together, they form a comprehensive vision more significant than the sum of its parts. With this foundational understanding, a discussion of the individual positions that substantiate this high-level stance is provided below.

5.4. Sub-Positions on Data Frameworks

The Subcommittee's Position on Data Frameworks relies on specific concepts the team identified across four topic areas (outlined below).

5.4.1. Data Requirements

A fundamental difference between BIM and Digital Twin execution is in the nature of their static and dynamic data requirements.

To successfully integrate BIM and Digital Twin, understanding their differences in terms of data requirements is needed, since BIM deliverables do not necessarily provide all data required for a given Digital Twin use case.

A data-rich BIM Model encompasses static data such as spatial data providing details about element positioning, geometric data covering the exact shapes and sizes of elements, and asset attributes highlighting the specifics like materials used, manufacturer details, and more. When considering the ISO 19650 categorization of information (organizational, project, and asset information), a BIM Model primarily offers the attributes of an asset. Therefore, a BIM deliverable typically comprises the BIM Model and other supplemental data documents to fulfill users' data requirements (such as technical manuals and specifications).

In a Digital Twin implementation, not only is relatively static attribute data gathered as a DTP, like a BIM Model, but also dynamic data using devices like IoT sensors and control systems as a DS or CPS. The dynamic data is sourced from the built assets, such as building systems and occupants. This data provides insights that are immediate and ongoing, reflecting the real-time performance of building systems, the patterns of occupants, and even immediate environmental impacts. Ultimately, data requirements are determined by the intended Digital Twin uses, and all essential data are synchronized through the digital thread at a specified frequency and fidelity.

In essence, while BIM offers a foundational digital structure, Digital Twin can build on it, making the structure animated with real-time data and beyond. The key is to understand and respect the strengths of each while leveraging their capabilities to the fullest.

5.4.2. Data Structure

<u>BIM can be used as a basis for executing Digital Twin.</u>

BIM and Digital Twin can work hand in hand to effectively deliver a range of uses. However, to seamlessly integrate them into a company's technology stack, it is crucial to understand the prerequisites for employing BIM within a Digital Twin framework. First, it is worth noting that BIM might not encompass all the information needed for the successful operation, management, and optimization of an asset. For instance, even though a BIM Model could include technical information like the sequence of operation or the capacity of HVAC equipment, it typically does not. This is the type of information that a facility manager needs for effective HVAC control and monitoring and useful for DS and CPS digital twins. Furthermore, not every Digital Twin use necessitates data typically provided by BIM, such as elements' geometrical and spatial attributes.

Another significant difference lies in a BIM Model's inherent structure or ontology versus a Digital Twin. The structure of BIM is typically more hierarchical, rooted in a parent-child relationship among the model's elements. For example, the category of HVAC systems might encompass subcategories like air handlers, which can further house distinct types of air handling units (AHU). In contrast, a Digital Twin adopts node and edge model, allowing the establishment of diverse, many-to-many relationships between elements. Such a setup enables linking an AHU with variables like occupancy schedules and real-time Indoor Air Quality (IAQ) data, enhancing the potential for performance optimization. As a system of systems, a Digital Twin goes beyond the project focus of BIM and with connections to the environment, entire cities, and the world.

BIM Models can be leveraged as a basis for Digital Twin deployment. This, however, demands a clear determination of data requirements and, where necessary, the application of data modeling techniques to restructure and align the BIM-derived data with the Digital Twin data framework. This nuanced understanding of data requirements and structures forms the framework for integrating BIM and Digital Twin systems, as depicted in Figure 9. The first diagram illustrates the hierarchical, one-to-many relationship typical of BIM models, while the second showcases the complex, many-to-many node relationships characteristic of Digital Twin frameworks.

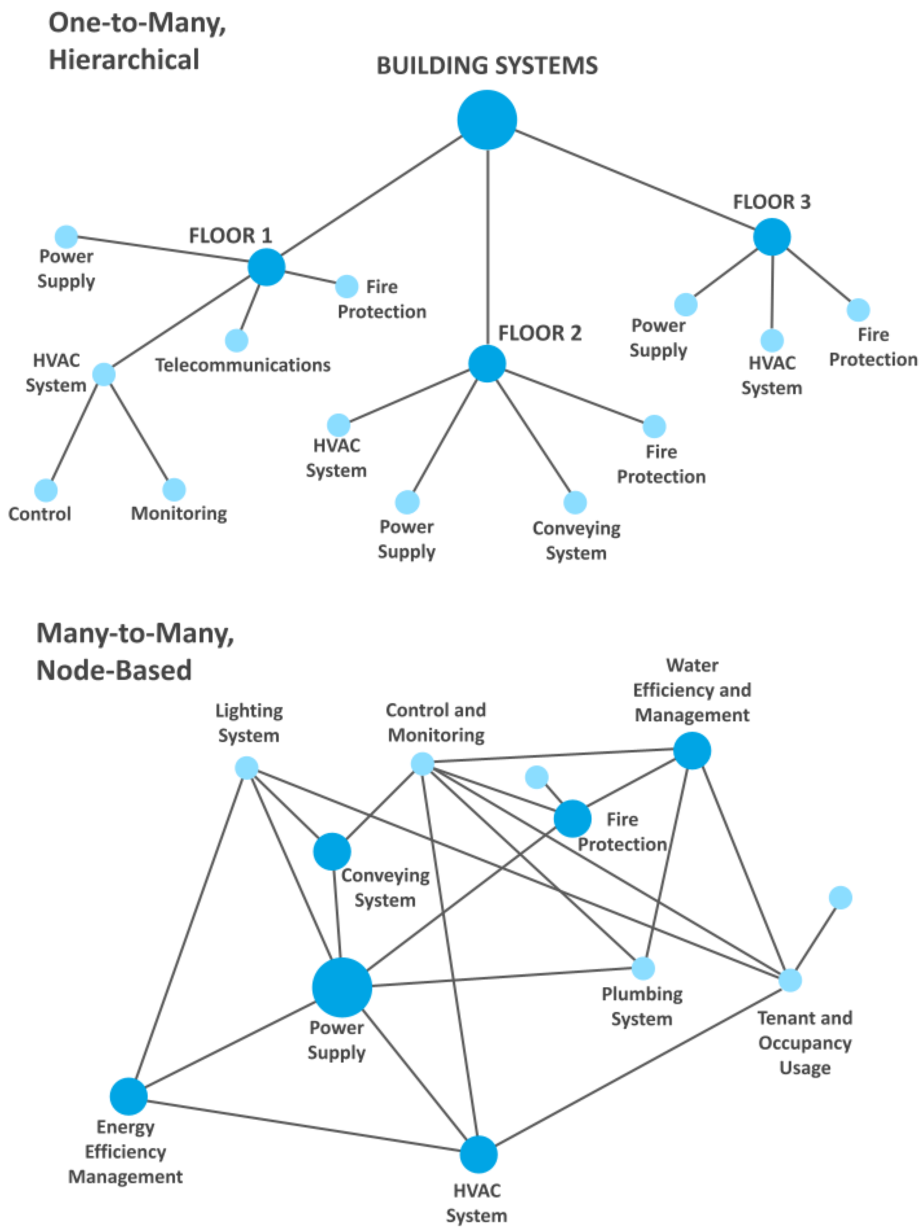

Figure 9 – Comparison between BIM (Above) and Digital Twin (Below) Native Data Structures

5.4.3. Decoupled Data

In the BIM and Digital Twin ecosystem, decoupling emerges as an enhancement from BIM's focus on project-centric workflows and phase-specific model sharing through open standards. This approach, while foundational for specific project phases or team collaborations, often confines the scope of data utility to static exchanges and siloed applications.

Decoupling in the DT context transcends these boundaries, advocating for a dynamic, continuous data interaction across systems enabled by a broad spectrum of data services highlighted in the

Digital Twin Consortium's framework, including synchronization, frequency, fidelity, and data streaming[7]. This capability facilitates a real-time, incremental transfer of data, enhancing the operational agility of Digital Twin and enabling a more nuanced application of BIM data across the entire asset life cycle.

By embracing decoupling, BIM and DT can leverage traditional data-sharing methods and advanced analytics, machine learning, and predictive modeling, which are crucial for optimizing operations, maintenance, and strategic decision-making. This broadens the application of BIM data, moving beyond conventional project timelines to support a wide range of use cases from asset management to sustainability initiatives.

This transition towards a decoupled, dynamic data ecosystem enhances the interoperability and efficiency of Digital Twin. It underscores the need for a more expansive view of BIM's role within the Digital Twin framework, paving the way for innovative applications and operational efficiencies in the built environment.

Takeaways on Decoupled Data

Decoupling data in the framework of the BIM and the Digital Twin ecosystem marks a significant pivot, enabling a seamless association between BIM’s parametric shapes and their physical locations with data that exists beyond the confines of traditional BIM uses. This synchronization of data forms the cornerstone of the digital thread, facilitating a multidimensional flow of insights that Digital Twin exploits across a myriad of applications. By transcending the project-centric nature of BIM, decoupled data empowers insights to traverse not just across various projects but also across regions, countries, and over time, offering a panoramic view of asset management, operational strategy, and sustainability efforts on a global scale. This shift not only amplifies the potential for cross-project intelligence but also enables interconnectedness and efficiency within the built environment. This shift towards a decoupled, dynamic data ecosystem is further illustrated in Figure 10, which delineates the four layers of the data framework: the Use Case Layer, Application Layer, Data Layer, and Information Communication Technology at the base. This framework underscores the importance of separating data from applications, enhancing interoperability and operational efficiency within BIM and Digital Twins.

[7] Continuous, real-time flow of data from various sources into a digital twin system. This concept is crucial for maintaining an up-to-date representation of a physical asset, process, or system in its digital counterpart.

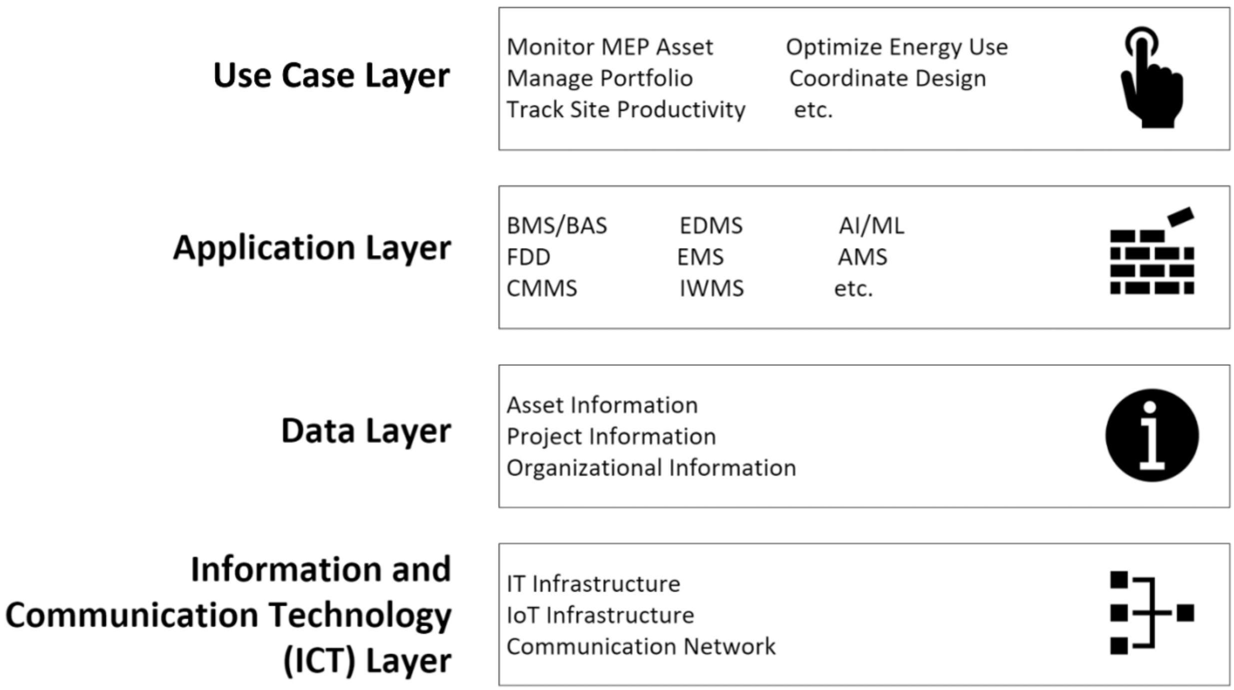

Figure 10 – Data framework to decouple data from applications

5.4.4. Exchanging Information

<u>Information sharing in BIM is based on file exchange using multiple platforms, while in Digital Twin, it is based on digital threads that enable a Digital Twin system of systems.</u>

BIM has transformed the way construction and design professionals collaborate, but its deployment typically necessitates the use of multiple data standards, such as IFC, COBie, and others. These standards facilitate the exchange and interoperability of information between different platforms and tools throughout the design, construction, and operation phases of a project. Given the intricate nature of construction projects and the diverse software ecosystems employed by various stakeholders, this approach to information sharing becomes a pivotal aspect of BIM, ensuring that every member of the project team can seamlessly access and work with the required data regardless of the tools they are using. Even though the use of Common Data Environments (CDE) has enhanced the information exchange process, there are still technical and organizational inefficiencies associated with data exchange and governance.

On the other hand, Digital Twin leverages a system of systems or digital thread as a mechanism for data synchronization. Instead of relying on numerous platforms and standards to share information, the digital thread offers a continuous and unified flow of data throughout the entire life cycle of an asset. This interconnected data stream powers different Digital Twin uses, allowing for access to reliable and up-to-date data, fostering efficiency, and reducing the potential for data silos or discrepancies. The digital thread adopts a lean approach to data interoperability and the necessary information and communication technology (ICT) infrastructure. It achieves this by synchronizing data from heterogeneous sources at pre-determined frequencies and based on intended Digital Twin uses.

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VI. Conclusion

6. Conclusion

For this Position Paper, the Digital Twin Integration Subcommittee set out to explore and understand the relationship between BIM and Digital Twin approaches to asset management in the built environment. Early in the effort to form clarity for the AECO industry, the team could see that the relationship was integrative in nature, but needed a discerning and comprehensive review to confirm this insight. Through months of research and discussion, this insight ultimately turned out to be true, and so this has been reflected in the Subcommittee's Top-Level Position on integrating the approaches of BIM and Digital Twin.

The listed positions in this paper form a collection of insights that go beyond just supporting the top-level position, they also address it by prompting and guiding further action. In this regard, they can be viewed as a checklist to be incorporated into future efforts. By diligently ensuring that these concepts are considered and leveraged in due fashion, AECO industry stewards (such as the NIBS Digital Technology Council and the DTC AECO Working Group) can begin their efforts with a comprehensive collection of innovative and collaboratively formed insights. Through this paper, members of this Subcommittee can stand with these stewards as they shepherd practitioners and the public through a gauntlet of institutionalized competing interests, rapid technological change, and basic human tendencies.

6.1 Call to Action

The following calls to action are aligned with the position statements. They are crafted to galvanize industry leaders, technologists, and practitioners into decisive steps that will capitalize on the strengths of BIM and Digital Twin.

Now is the time to harness this strength for creating value and driving efficiency, precision, and sustainability in projects and processes.

6.1.1. Engage the NIBS Digital Twin Integration Subcommittee

- Seek clarification and/or further discussion on the positions listed in this paper.
- Incorporate Subcommittee members in industry stewardship and alignment initiatives.
- Advocate for further tools from the NIBS Digital Technology Council and the DTC AECO Working Group.

6.1.2. Address Public Perception of BIM and Digital Twin

- Within your own groups and organizations, survey internal opinions and openly address the driving perception issues impacting your BIM and/or Digital Twin transformation efforts (ie. the use of key definitions, obstacles to implementation, or adoption behaviors).
- Form, support, and promote efforts that deliberately seek to engage, understand, and address the public.

- Identify and publicly support/recognize exceptional individuals, groups, and organizations dedicated to *inclusive and collaborative stewardship* of AECO digital transformation.
- Establish "public perception" as a formal topic in BIM and Digital Twin policy-shaping efforts to address how the general public's perception both impacts and is impacted by these efforts; assess/compare the general public's perception against industry concepts.
- Foster and/or formalize relationships with cross-industry Digital Twin organizations such as NIBS, the National Academies of Sciences, Engineering, and Mathematics (NAS), and the Digital Twin Consortium (DTC).
- Develop, influence, and deploy national adoption strategies for state and federal agencies, particularly in promoting contract policy and definitions that are calibrated against the public's understanding; minimize confusion, delay, and poor performance.

6.1.3. Implement and Standardize BIM and Digital Twin

- Actively adopt interoperability standards for BIM and Digital Twin.
- Directly align data structures and advocate for continuous use, development, implementation, and improvement of the digital thread.

6.1.4. Optimize Data Management for BIM and Digital Twin

- Conduct thorough data flow analysis and tailor data management strategies.
- Prioritize data flexibility and accessibility in system design and implementation.

6.1.5. Refine BIM and Digital Twin Use Cases

- Clearly identify and document specific use cases and roles.
- Engage in gap analysis to improve BIM and Digital Twin integration.

6.1.6. Advance Development and Scaling of BIM and Digital Twin

- Utilize BIM as a foundation for building comprehensive Digital Twin applications.
- Develop scalable Digital Twin models and extend their application to larger portfolios.
- Foster innovative practices in asset life cycle management to integrate BIM and Digital Twin.

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VIII. Appendices

Appendix A: Definitions

Table 1 Definition of Terms Used in this Document

Term	Definition	Reference
Agile	*An agile organization is characterized as a technology-enabled network of teams that have a people-centered culture and operate in quick learning and decision cycles.*	[10]
Agility	*Agility combines speed and adaptability with stability, providing a competitive edge in uncertain conditions*	[10]
Artificial Intelligence (AI)	*The theory and development of computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages.*	[11]
Asset	*Item, thing, or entity that has potential or actual value to an organization. This can include physical assets, such as computer hardware, software, and information. It can also include intangible assets, such as intellectual property, reputation, and customer relationships.*	[12]
Building Information Management (BIM)	*Functions of controlling the acquisition, analysis, retention, retrieval, and distribution of built environment asset information all within an information processing system. (Note: within the term, 'building' refers to the process of building a built environment asset, not a specific type of facility. BIM is a function that can be implemented across all types of built environment assets, including buildings, bridges, highways, tunnels, process plants, landscape, and other infrastructure and facility types.)*	[1]
Building Information Model (BIM Model)	*A shared digital representation of physical and functional characteristics of a built environment asset.*	Adapted from [1] – added the word "BIM" to the acronym
Building Information Modeling (BIM Modeling)	*Generating and using a shared digital representation of a built asset to facilitate design, construction, and operation processes to form a reliable basis for decisions.*	Adapted from [1] – added the word "BIM" to the acronym
Capability	*Capability is the ability to perform certain actions or achieve certain outcomes. The ability to drill a hole is a simple example of a capability. There are multiple use cases that require holes and each of them will have unique requirements in terms of the size, the depth or the substance that is drilled. This may be one of many capabilities required to complete a project where the hole is part of a successful solution.*	[13]
Common Data Environment (CDE)	*An agreed source of information for any given product or asset, for collecting, managing, and disseminating each information container through a managed process*	[14]
Component	*The individual instances of the products and equipment defined in the Type data table [within the COBie data schema]*	[1]

Composable Digital Twins	*Composable Digital Twins (CDT) is an application development approach for Digital Twins that is based on the composable enterprise architectural pattern. Composable applications, such as CDT, focus on faster time to value, service-based orchestration and reusing packaged business capabilities to develop and adapt applications as business requirements evolve.*	[13]
Data Standard	*A data standard is a technical specification that describes how data should be stored or exchanged for the consistent collection and interoperability of that data across different systems, sources, and users.*	[15]
Decoupled Data	*An information-centric approach decouples information from its presentation. It means beginning with the data or content, describing that information clearly, and then exposing it to other computers in a machine-readable format—commonly known as providing web APIs.*	[16]
Democratization of Data	*Providing everyone with access to data without gatekeepers who create bottlenecks. This approach necessitates that the access to data is accompanied by appropriate measures to ensure it's used effectively*	[17]
Digital Thread	*A digital thread is a mechanism for correlating information across multiple dimensions of the virtual representation, where the dimensions include (but are not limited to) time or life cycle stage (including design intent), kind of model, and configuration history.*	[18]
Digital Twin	*A Digital Twin of an asset is 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*	[2]
Digital Twin System	*A Digital Twin system is a system of systems that implements a Digital Twin.*	[18]
Digital Twin Cyber-Physical System (CPS)	*A Cyber-Physical System (CPS) is a virtual representation of an asset with bidirectional data flow between the digital and physical twins, often including an actuation layer.*	[2]
Digital Twin Prototype (DTP)	*A Digital Twin Prototype (DTP) is a virtual representation of a built asset designed to be connected to the physical asset in the future.*	[2]
Digital Shadow (DS)	*A Digital Shadow (DS) is a virtual representation of a built asset with data flow from the built asset to its Digital Twin.*	[2]
Digital Twin Use	*The purpose for applying Digital Twin*	Adapted from [1]
Digital Twin Use Case	*A specific application of a Digital Twin use to add value to a project(s) or party(s)*	Adapted from [1]
Digital Ecosystem	*Software systems that exploit the properties of biological ecosystems, which are robust, scalable, and self-organizing*	[19]
Internet of Things (IoT)	*The network of devices that contain the hardware, software, firmware, and actuators which allow the devices to connect, interact, and freely exchange data and information.*	[27]
Minimum Viable Product (MVP)	*An early, basic version of a product (typically a computer program or piece of technology) that meets the minimum necessary requirements for use but can be adapted and improved in the future, especially after customer feedback.*	[20]

Machine Learning (ML)	*Computer's ability to learn something without being explicitly programmed*	[21]
Ontology	*A formal and explicit description of the concepts in a domain of discourse, properties of each concept describing various features and attributes of the concept, and restrictions on the slot*	[22]
Proprietary Software	*Proprietary software is owned by an organization or an individual, as opposed to "public-domain software," which is freely distributed. The explosion in the use of the Internet has expanded the reach of public-domain software since it is now much easier to transmit these programs. While many commercial software developers have developed software that has become the de facto standard (e.g., Microsoft's Windows programs), proprietary software that is based on proprietary protocols, or standards, can create obstacles for application development and usage.*	[24]
Synchronization	*A form of embedded middleware that allows applications to update data across two systems so that the datasets are identical. These services, which can operate over various transports, typically require some understanding of the data's context to be synchronized.*	[25]
System of Systems (SoS)	*A system of systems is an assemblage of components which individually may be regarded as systems and which possesses two additional properties: (1) operational independence of the components: if the system of systems is disassembled into its component systems the component systems must be able to usefully operate independently. That is, the components fulfill customer-operator purposes on their own, (2) managerial independence of the components: the component systems not only can operate independently, they do operate independently. the component systems are separately acquired and integrated but maintain a continuing operational existence independent of the system of systems.*	[26]

Appendix B: Literature Review

The discussion on the relationship between BIM and Digital Twin is gaining traction in the AECO industry. However, there are few peer-reviewed references that discuss the correlation between them. The general view either sees BIM as a component of Digital Twin or a separate concept that can be leveraged to create a digital twin. Here, the most relevant literature on this topic is presented.

There are a few peer-reviewed publications that explore the relationship between BIM and Digital Twin. One study conducted by Deng et al. described Digital Twin as a progression for BIM Modeling. The authors defined five classes, namely, BIM, BIM+simulation, BIM+sensors, BIM+AI, and digital twins [3]. Another paper stated that using BIM is the most optimal approach to make a precise high-value Digital Twin. They pointed out that the integration of BIM and Digital Twin has the potential to greatly enhance building design, construction, and performance. They viewed BIM as an advanced 3D modeling technology [not from a building information management perspective]. They compared the characteristics of BIM and Digital Twin. Some of the similar characteristics identified in their paper include 3D model visualization, API interoperability, and data standardization. It is worth mentioning that their list of characteristics includes capabilities, use cases, and benefits [4]. Another group of researchers proposed a framework that leverages the BIM maturity process to enable the implementation of Digital Twin for Facilities Management (FM). The maturity model entails five levels, including level 0: Digital Twin Strategy, level 1: Unified BIM Model, level 2: Dynamic BIM Model, level 3: Analytical Digital Twin, and level 4: Dynamic Digital Twin [5].

Another category of papers mentions BIM and Digital Twin but does not discuss their relationship and mainly considers BIM as a component of Digital Twin: In a study, a BIM-based modular platform architecture was proposed to collect, integrate, manage, and use airport asset data. Their platform acts as a meta-framework for a Digital Twin [6]. In another study, a Digital Twin architecture was proposed for smart buildings that integrated BIM and IoT data [7]. Similarly, a framework was proposed in another study to merge BIM, GIS, and IoT to create a Digital Twin at the city level [8]. Another group of researchers incorporated the utilities' BIM Model and a 3D model of excavators as the basis for a dynamic virtual model to create a Digital Twin. The main purpose of their Digital Twin was to monitor urban excavation to enhance safety [9].

There are also a significant number of Blog posts that present individuals' opinions on this matter. Some of these opinion pieces are published on software vendors' websites or online magazines. While these sources were not peer-reviewed or technically reviewed, they indicate an increasing interest in the topic.