Digital Twin/Digital Thread Solution Definition for Aerospace and Defense: Phase 3

Business Architecture Frameworks/Methodologies

Release 1.0

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Abstract

The Aerospace & Defense PLM Action Group (AD PAG) collectively sponsored a team of industry experts from AD PAG member companies to define objectives, requirements, and roadmaps for digital twin/thread solutions.

In Phase 1, the team conducted research that identified a plethora of digital twin/thread concepts and definitions. A method of describing this phenomenon was prepared to organize and understand the definitions. In support of preparing the A&D industry's digital twin/thread definitions, the team prepared constructs to describe the intended functionality and utility of the digital twin/thread. These resulting A&D industry definitions are the collaborative work of representatives from several leading A&D companies.

In Phase 2, the team published the *Digital Twin/Digital Thread Solution Definition for Aerospace and Defense* position paper for the A&D industry. The purpose of this document was to facilitate an industry baseline definition and understanding of the current capabilities of the digital twin/thread in the A&D industry.

In this Phase 3, the team reviewed popular business architecture frameworks and associated methodologies to determine the utility related to digital twin/thread as defined in Phase 2.

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Table of Contents

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Revision Record

Release	Date	Description
1.0	**January 2023**	Initial release of the *Digital Twin/Digital Thread Business Architecture Frameworks/Methodologies* paper. This paper is the Phase 3 deliverable of the AD PAG Digital Twin/Digital Thread project.

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Digital Twin/Digital Thread Business Architecture Frameworks/ Methodologies

Executive Summary

The Aerospace and Defense Product Lifecycle Management (PLM) Action Group (AD PAG) is an association of aerospace Original Equipment Manufacturers (OEMs) and aircraft engine manufacturers within CIMdata's globally recognized PLM Community Program, which functions as a PLM advocacy group. The AD PAG has sponsored a project team of industry experts (also known as SMEs, *subject matter experts)* from the member companies to define objectives, requirements, and roadmaps for digital twin/thread solutions for creating and managing the digital representation of a product through the various stages of the product lifecycle. As is the custom of the AD PAG, a primary objective is to present a unified voice to the software solution provider community regarding unmet needs or pain points common across the A&D industry.

This project is designed to be executed in multiple phases. Seven phases were proposed and approved, each with a specific objective and associated deliverable. Each phase builds upon the knowledge and deliverable(s) of the prior phase(s). The deliverable of Phase 1 was a literature search of documentation intended for internal use by the project team in support of the Phase 2 work. The principal deliverables of Phases 2 through 7 are publicly released position papers.

- Phase 1 – Research – Examination of existing industry digital twin/digital thread technical literature
- Phase 2 – Digital Twin/Digital Thread Solution Definition for Aerospace and Defense
- Phase 3 – Digital Twin/Digital Thread Business Architecture Frameworks/Methodologies
- Phase 4 – Digital Twin/Digital Thread Comparative Analysis of Industry Standards
- Phase 5 – Digital Twin/Digital Thread Value Proposition
- Phase 6 – Forward-Looking Digital Twin/Digital Thread Strategy and Roadmap
- Phase 7 – Digital Twin/Digital Thread Project Consolidation

Multiple business architecture frameworks and methodologies exist. From a historical perspective, these frameworks and methodologies have evolved incrementally. With the introduction of the digital twin/thread, the following question arises: Which framework and methodology aligns with or has the adaptability and extensibility to address digital twin/thread constructs?

The team's primary objectives of Phase 3 were to do the following:

1. Identify and define unique digital twin/thread business, systems, and technological architecture and methodology constructs.
2. Review existing business architecture frameworks and their associated methodologies in terms of the framework and methodology adaptability to digital twin/thread requirements.

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3. Conduct a detailed review of at least one business architecture framework and methodology to determine how well the requirements of digital twin/thread could be adapted into that framework and methodology.

Introduction

In March 2021, executives from the AD PAG member companies – Airbus, Boeing, Embraer, Gulfstream, Pratt & Whitney Canada (P&WC), Rolls-Royce, and SAFRAN – met to review and approve a proposed special project. They agreed to sponsor a project team of industry experts from the AD PAG member companies to define objectives, requirements, and roadmaps for digital twin/thread solutions for creating and managing a product's digital representation through the various stages of the product lifecycle.

The AD PAG Digital Twin/Digital Thread team's first workshop was held at the beginning of Q3 2021. The project team's charter defines seven phases to define and produce a series of sub-projects and associated deliverables to be executed over the course of two years.

Phase Three

The AD PAG Digital Twin/Digital Thread team's Phase 3 goal was to evaluate existing architecture frameworks and their associated methodologies to determine which, if any, is extensible to the necessary degree that would accommodate digital twin/thread requirements.

The team conducted an initial search of existing business architecture frameworks based both on popular uses within the A&D industry and on the familiarity and knowledge of the team. Research was also conducted to determine if there are any existing or emergent business architecture frameworks and associated methodologies specific to digital twins/threads.

The challenge of looking at business architecture frameworks for standardizing the definition and methods for the digital twin/thread is that there is no systematic methodology available for the business ecosystem analysis and architecture design to simulate/model a business ecosystem (Ma et al, 2021). Of course, this presumes the need for digital twins/threads within the business ecosystem—a concept that appears to have broadly accepted desirability, if not understanding. Current enterprise architecture frameworks and methodologies are a starting point in determining a recommended approach for establishing an ecosystem architecture framework that enables digital twins/threads.

Problem Statement

Business architecture framework communities promote an evolution of frameworks and methodologies that align with best practices preceding digital transformation and digital twin/thread constructs within the A&D industry. Any definition of the digital twin/thread introduces the need to verify that specific architectural constructs will in fact support the digital twin composition, decomposition and system, and subsystem interactions. In addition, architectural constructs defining the digital thread-enabled interactions between the digital twin, the associated environment, and other digital twin systems are required. This facilitates improved architectural consistency of the system design and technical capability of the implemented system.

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Specific areas of emphasis include the following:

1. Concurrency of digital/thread design, implementation, and utilization
2. Granular/atomic – fundamental artifact definition
3. Product lifecycle approach – toolbox approach/diagram, assess extensibility for value stream definition
4. Definition and alignment of data architecture, knowledge graphs and similar to the digital thread, and complex digital thread constructs (fabric)
5. Digital thread security throughout product lifecycle management
6. Enterprise data alignment with the ecosystem, such that the data is accurate, current, and secure
7. Alignment of the digital thread to the digital twin
8. Definition and modeling of monitoring, including analytics to represent organizational utility of the digital twin and the digital thread
9. Use of digital threads in the definition, construction, and analysis of digital twins (digital thread analytics).
10. Capability of incorporating analytics with the design of the digital twins and digital threads
11. Methodology of modeling digital twin analytical aggregation across the product lifecycle
12. Modeling of digital thread interoperability
13. Modeling of digital thread utilization across the product lifecycle—how this is this done today, and how will this be done tomorrow with digital threads
14. Modeling of digital thread data retention and long-term data preservation
15. Modeling of contextual digital twin parameters to enable consistency in representing digital twin responsiveness

Purpose and Objective

The purpose of this *Digital Twin/Digital Thread Business Architecture Frameworks/ Methodologies* paper is to provide an understanding of the current state of architecture frameworks and the architecture methods relative to the digital twin/thread and to identify the specific architecture constructs needed to support the digital twin/thread constructs. The objective is to provide a list of observations and suggestions for A&D organizations to consider when evolving their respective business architecture frameworks in support of the digital twin/thread.

Business Architecture Framework

This section includes several definitions (perspectives) of the business architecture framework and also introduces the concept of a digital twin/thread business architecture framework. Alternative viewpoints of business architecture framework exist and are also outlined.

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Definitions

According to CIO Wiki, the business architecture framework defines how an organization is structured and how elements of the organization fit together (*Business Architecture - CIO Wiki*, 2022).

Another definition, or perspective, is that a business architecture framework provides a blueprint of the enterprise that is used to align strategic objectives and respond to tactical demands. With the introduction of the digital twin/thread, new inter- and intra-organizational dynamics affect existing architecture elements, as well as create the need to address new enterprise and ecosystem architecture elements. Figure 1 provides a notional perspective of an aerospace ecosystem. A viable business digital twin/thread solution would be needed to address the complex interaction across the ecosystem.

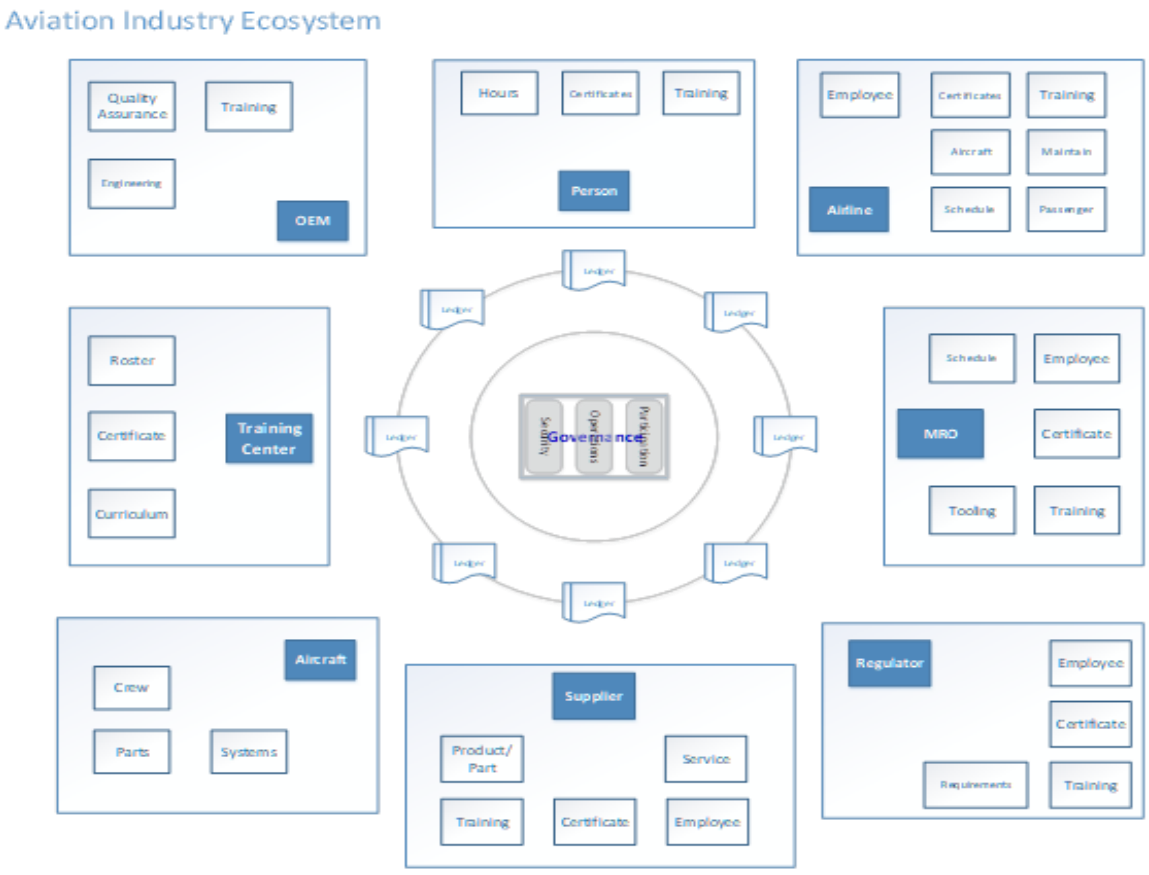

Figure 1 - Aerospace Ecosystem

Still another perspective of a business architecture framework introduces a more holistic, multidimensional business view of capabilities, end-to-end value delivery, information, and organizational structure (Nicholas, 2022). A unique construct of the digital twin/thread is the definition and utility across the product lifecycle. The dynamic of applying the digital twin/thread across the product lifecycle introduces an *ecosystem product lifecycle* perspective of the digital twin/thread. Constraining the definition and use of a digital twin/thread to within a specific

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organization and/or product lifecycle phase reduces the utility and contributed value of the enterprise and ecosystem.

Business architecture frameworks, such as Integrated Architecture Framework (IAF), Open Group's Architecture Framework (TOGAF®), and other frameworks, help organizations align their information technology (IT) with their business. These frameworks recommend steps to address organizational strategy and architecture governance and assume a central management entity is responsible for decisions about business–IT alignment within the organization. Now, in relation to the product lifecycle and the digital twin/thread persisting across multiple organizations within a company, this establishes the need for an architecture methodology that supports digital twin/thread ecosystem business, system, and technical models.

Concept of the Digital Twin/Thread Business Architecture Framework

Incorporating digital twin/thread discussion into the Business Architecture Framework community facilitates the alignment of business value with the digital twin/thread. As indicated above, the business architecture framework facilitates alignment of the business value strategy with the respective PLM organization's strategy and its information systems strategy. An integrated view of how the business will realize value through digital twins/threads use is paramount to gaining leadership understanding and support for effective implementation of a concept that by its very nature will disrupt an organization’s daily operations. As such, the business architecture framework should be able to represent the required digital twin/thread architectural artifacts, models, and methods (Wieringa et al., 2021).

To address the dichotomy of organizational interests, the following must be considered:

- Use of a business ecosystem perspective to convey participant collaboration
- Definition of a model of how participants will interact, cooperate, and compete
- Recognition that organizations will participate with the objective of supporting their self-interests

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Digital Twin/Thread Definition Framework

In Phase 2, the digital twin/thread definition framework shown in Figure 2 was defined as a rational way of describing diversity in digital twin/thread definitions. The framework consists of three rows and eight columns. The rows represent views from a business, system, and technical perspective. Each column represents a phase of the product lifecycle. The Supplier column represents an Original Equipment Manufacturer (OEM) perspective relative to the part or component produced by a supplier and integrated into the manufactured product. The inclusion of this Supplier column elevates the importance of the supplier and the supply chain's digital twin/thread contribution to the OEM and to the customer/user/owner/operator within the A&D ecosystem. Each cell represents a unique business perspective.

Digital Twin/Thread Definition Framework

		Supplier	OEM				Customer/User/Owner/Operator		
		Part/ Component/ Material	Requirements	Design	Engineer	Manufacture	Operation	Maintenance	Disposition
Business	Artifacts								
System	Models and Data								
Technical	Tools and Methods								

Figure 2 - Digital Twin/Thread Definition Framework

Alternative Viewpoints/Perspectives

From an organizational perspective, each organization is going to have a unique architecture viewpoint. For example, Sales and Marketing may view the use of the business architecture framework to model the functional relationship and data use between the customer and the OEM. The viewpoint from the Finance or Engineering organization is expected to be different. While a functional relationship between the customer and the OEM may exist, the Finance organization will have a different perspective. Yet, it is important to note there will be functional and data viewpoint intersections. The same holds true with the system and technical perspectives.

Business Perspective

The ecosystem of suppliers, including co-competitors (competitors who also cooperate), software developers, start-ups, and other innovators can consistently and reliably achieve desired outcomes for customers. To enable all partners to collaborate on the outcome, a comprehensive business ecosystem architecture framework is required. This framework would enable an integrated, connected, and aligned solution for all partners.

The business ecosystem architecture framework and methodology is a useful tool for bridging the engineering PLM perspective with the functionality of the enterprise. The ecosystem perspective of the product lifecycle includes a broad, multidirectional spectrum of industry functions and

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associated data. This includes sales/marketing, financial, regulatory compliance, operations, and supply chain (Melgarejo, 2022).

Figure 3 illustrates how use cases and members may engage in an ecosystem-enabled environment throughout the course of the A&D product lifecycle.

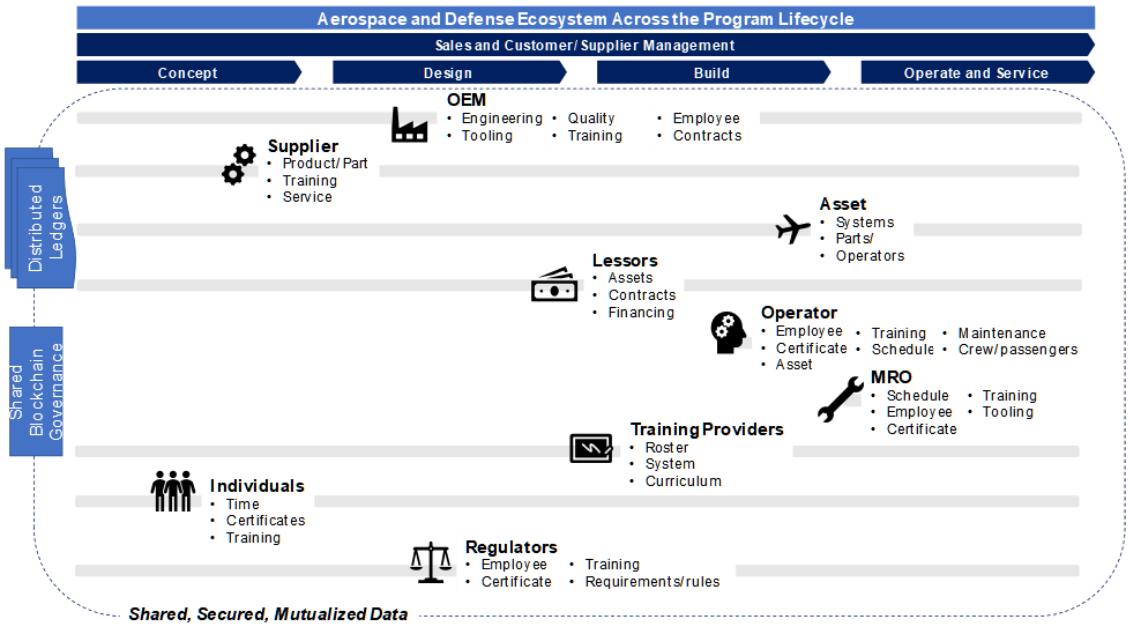

Figure 3 - Ecosystem Perspective Across the Product Lifecycle

This collaborative ecosystem solution involves collecting and analyzing data from all participants, including customers. It ensures that the customers' anticipated outcome is measurable, and the users' expectations are met. Participants contribute with the intent to collaborate, compete, and differentiate product and service offerings within the ecosystem. The collaborative ecosystem solution provides a critical view into the probability that an outcome will be realized, determines the cost and the risk to value, and recommends/implements actions to mitigate and/or minimize the risk to value.

System Perspective

A system represents a business' function as a whole. Product lifecycle phases represent the functional domains within the system. In an ecosystem, all elements are strongly interconnected. Every linkage in the ecosystem is a utilization of a thread of data that is planned to augment the functioning of the system (Anwar & Gill, 2019). The digital twin/thread ecosystem is the mixture of all related digital touchpoints that work on important business information, the people that interact with them, and the business processes and technology that support them.

To elaborate, the potential for realizing a digital twin/thread ecosystem lies necessarily in the known engineering design theoretical framework, as well as in the existing PLM conceptual frameworks. Crystalizing the product model in each domain area is required because that forms the backbone for structuring the domain-specific information, both for understanding the data/information for what it is and for people/processes to adequately interact with the ecosystem

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framework. Then, by appropriately connecting between the domain-specific product models, it is possible to obtain a multi-domain product modelling framework that can support an evolution from the current state to an improved state with the desired digital thread/twin enabled.

Figure 4 illustrates an example of a multi-domain, product modelling framework where the capture, representation, tracking, and cross-pollination of digital artifacts across the product lifecycle are possible from both virtual and physical perspectives.

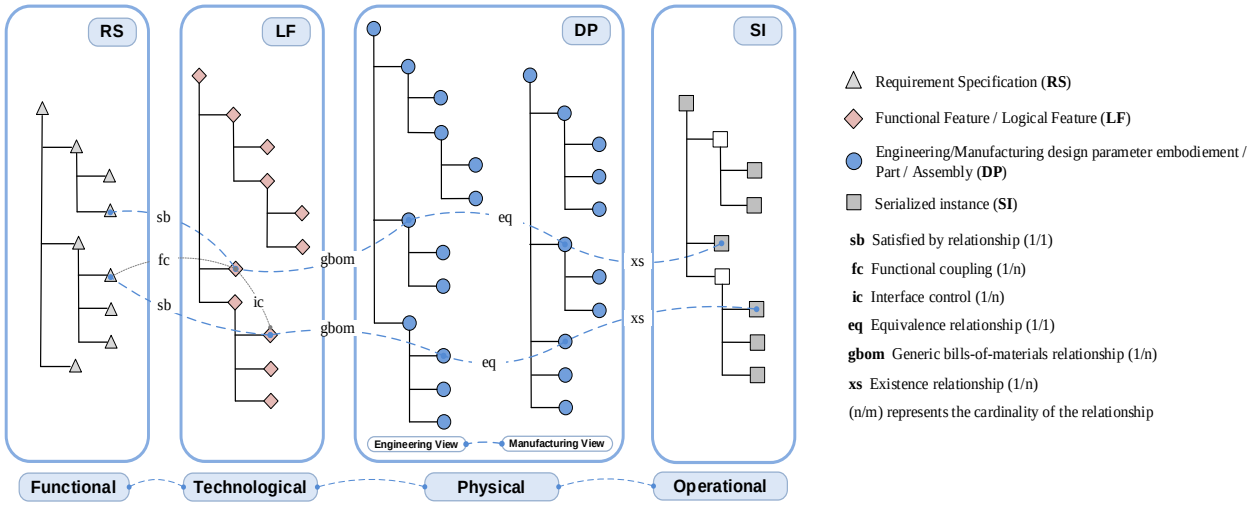

Figure 4 - A Multi-Domain Product Modelling Framework (No Process View, No Variability, No Experimental/In-Service Data Feed Represented), Ref. Theory of Domains in Engineering Design. Adapted from (Toche, 2017)

The challenge with using non-isomorphic hierarchies models for product structuring lies in enabling and maintaining the interconnectivity, communication, and consistency between the different models or structural views, especially in a concurrent engineering environment (Claesson, 2006; Van Den Hamer & Lepoeter, 1996). Construction of semantically-aware relationships/links between the models or views is believed to be an effective means to overcome the challenges that arise from multiple product models/views (Claesson, 2006; Erens & Verhulst, 1997; Männistö et al., 2001; Svensson & Malmqvist, 2001; Toche et al., 2017).

Technical Perspective

The digital twin/thread is approached from the information technology system engineering or model-based design perspective. Both functional and system requirements are used as a baseline to define the technical architecture. This technology-based digital twin/thread perspective requires the utilization of digital technologies, including Internet of Things (IoT) sensors, a nearly unlimited network bandwidth to communicate vast amounts of data (5G/Edge Computing), autonomous decisioning supported by artificial intelligence (AI), and advanced analytics to enable prognostic decisioning in support of customer experience optimization. Designing sensors into products and allowing data collection about products' usage, as well as monitoring real-time use via the IoT is only the first step. Combining this with advanced analytics to derive insight into the outcomes that the products provide is the second step. To succeed in the outcome-based economy and

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consistently provide desired outcomes for customers, technology companies need to take a third step—build an extended ecosystem of business partners and customers.

Review of Business Architecture Frameworks

This section outlines the business architecture frameworks reviewed by the team and provides a list of general observations noted in the process.

Frameworks Reviewed

The following business architecture frameworks were reviewed as part of this study:

- The Business Architecture Framework (BACOE)
- Business Architecture Framework (EaLearning)
- A Business Ecosystem Architecture Modeling Framework (IEEE)
- Business Ecosystem Architecture Development
- Model Based System Engineering SysML
- The Open Group Architecture Framework (TOGAF)
- Unified Architecture Framework (UAF)
- Zachman Architecture Framework

In addition, a paper titled *Seven Modelling Approaches for Digital Ecosystem Architecture* (published by IEEE) was most useful in adding to the team's understanding of the existing and future capabilities of these business architecture frameworks.

It is worth noting that the use of the terms *digital twin* and *digital thread* were **not** found during the team's review of these business architecture frameworks/methodologies. This is indicative of the newness of digital twin/thread terminology and illustrates that these terms have yet to be incorporated into the lexicon of business architecture.

Generalized Observations

Though there was an absence of the terms *digital twin* and *digital thread*, the team identified the following based on review of the frameworks listed above.

- The business architecture framework should support the following:
  - Ecosystem architecture design perspective, enabling digital twin/thread purpose and opportunity
  - Definition of architecture constructs in support of a networked, organizational, collaborative, and competitive operational model
  - Definition of a networked organization without a central regulator; the ecosystem is self-regulating; regulation would be by way of agreed-to industry standards and requirements imposed by government regulators that define what needs to be done, not specifically how it should be done
  - Definition of a value viewpoint and the alignment of the defined value viewpoint among ecosystem participants

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  - Definition of value modeling and value mapping where each member of the ecosystem has defined its own business goals and value interests
- The system and technical architecture should facilitate the definition, utilization, and integration of digital twin/thread.
- Emphasis should be on data with data commonality across the product lifecycle, and the data should be tracked with tools that enable data utilization.

Go Forward Plan

This Phase 3 *Digital Twin/Thread Business Architecture Frameworks/Methodologies* position paper has provided a review of business architecture and associated methodologies required to incorporate and utilize digital twin/thread concepts within the A&D industry. The paper involved review, identification, and presentation of generalized observations that could serve as recommendations by the team for consideration in the selection and use of a business architecture in association with digital twin/thread initiatives.

Concepts to Consider

In summary, primary concepts to consider now and going forward include the following:

- The Why?
  - The concept and constructs of the digital twin/thread introduce change to the business process, system definition, and technology that will need to be identified and incorporated into business, system, and technical architectures
  - The concept of business value is defined within that digital twin/thread and brings awareness of interoperability within the A&D ecosystem, including the supply chain and development partners
- The What?
  - Revised definition and alignment of business architecture to include digital twin/ thread constructs
  - Interoperability of business processes and information systems in the A&D ecosystem
  - Digital Product Authoritative Source of Truth - An aggregation of truthful authoritative sources within the aviation and aerospace industry ecosystem
  - Business architecture and methodologies revised to model digital twin/thread functions with the enterprise and A&D ecosystem
  - Determination of which enterprise and ecosystem organizations and partners need to be involved
- The How?
  - Revision of business architecture and methods to incorporate digital twin/thread functional, system, and technical definitions
  - Definition of product lifecycle digital twin/thread business objects
  - Definition of the digital twin/thread business reference architecture
  - Definition of the required IoT and IT architecture and tools
  - Definition of the required product lifecycle management reference architecture

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  - Definition of the digital twin/thread development methodology and alignment with the product development and support lifecycle
- The definition and modeling value that digital twin/thread brings to the A&D ecosystem

Comparative Analysis of A&D Digital Twin/Thread Industry Standards (Phase 4)

The next phase of the Digital Twin/Digital Thread project is for the team to do the following:

- Conduct a comparative analysis of existing industry standards relative to digital twin/thread definition and proposed utilization.
- Conduct analysis to determine the applicability of existing standards for use and/or revision and identify new digital twin/thread standard requirements, if needed.
- Promote recommendations for new standards, revisions to existing standards, and elimination of standards that need to be retired.
- Define and recommend a standards taxonomy for digital twin/thread.
- Deliver a Phase 4 document that provides a summary of digital twin/thread standards recommendations, digital twin/thread taxonomy, and industry guidance by the estimated timeline of Q1-Q2 2023.

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About A&D PLM Action Group

The Aerospace & Defense PLM Action Group (www.ad-pag.com) is an association of aerospace and defense companies within CIMdata's globally recognized PLM Community Program, which functions as a ***PLM advocacy group*** to:

- Set the direction for the aerospace & defense industry on PLM-related topics that matter to members (*including promoting, not duplicating, the work of standards bodies*)
- Promote common industry PLM processes and practices
- Define requirements for common interest PLM-related capabilities
- Communicate with a unified voice to PLM solution providers
- Sponsor collaborative PLM research on prioritized industry and technology topics

CIMdata administers Group operations, coordinates research, and manages the progression of policy formulation.

Note: This project is one of two current projects sponsored by the Aerospace & Defense PLM Action Group (AD PAG) focused on the digital thread. Concurrent with the effort to broadly define a vendor neutral solution encompassing the digital twin/digital thread requirements, the AD PAG is conducting a survey in sponsorship with multiple software solution providers focused on the current state and anticipated future trends of digital thread implementation designed to maximize the benefits that can be received from any Product Lifecycle Management investments.

About CIMdata

CIMdata, a leading independent worldwide firm, provides strategic management consulting to maximize an enterprise's ability to design and deliver innovative products and services through the application of Product Lifecycle Management (PLM) solutions. Since its founding over thirty years ago, CIMdata has delivered world-class knowledge, expertise, and best-practice methods on PLM solutions. These solutions incorporate both business processes and a wide-ranging set of PLM-enabling technologies.

CIMdata works with both industrial organizations and providers of technologies and services seeking competitive advantage in the global economy. CIMdata helps industrial organizations establish effective PLM strategies, assists in the identification of requirements and selection of PLM technologies, helps organizations optimize their operational structure and processes to implement solutions, and assists in the deployment of these solutions. For PLM solution providers, CIMdata helps define business and market strategies, delivers worldwide market information and analyses, provides education and support for internal sales and marketing teams, as well as overall support at all stages of business and product programs to make them optimally effective in their markets.

In addition to consulting, CIMdata conducts research, provides PLM-focused subscription services, and produces several commercial publications. The company also provides industry education through PLM certification programs, seminars, and conferences worldwide. CIMdata serves clients around the world from offices in North America, Europe, and Asia-Pacific.

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