



# Definition for Digital Twin

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# Progress

1. Paper Submitted to 6G-PDN2 [link](#)

2. Digital Twins in Networks: A Systematic Survey [link](#)

3. Future Network Services with Next-Generation Network Digital Twins: Architectural Framework & Tool Evaluation [link](#)

4. Extensive Survey paper [Working in Progress]

## An Architectural Framework for 6G Network Digital Twin

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**Abstract**  
In the context of 6G, Digital Twin technology has potential to play a crucial role by offering a sophisticated, dynamic model that mirrors the physical world in real-time. Integrating digital twins into 6G enables precise orchestration and optimization of network resources, meeting the diverse and stringent demands of next-generation applications. Furthermore, digital twins provide a platform for continuous learning and AI-driven insights. Research on the architecture of Network Digital Twins (NDTs) for 6G/6G is still limited, often focusing on partial implementations rather than comprehensive, full-stack approaches. This paper proposes a high-level architectural framework for 6G NDTs, structured across three layers: the Physical Twin Layer, Digital Twin Layer, and Application and Service Layer. We discuss the challenges of deploying these systems and the importance of selecting appropriate tools, presenting an experimental case study that demonstrates the impact of different tool choices on system performance. Our findings underscore the need for flexible, scalable solutions to fully realize the benefits of NDTs in 6G networks.

**CCS Concepts**  
• Networks → Network architectures; Network components; Network management.

**Keywords**  
6G, Mobile Network, Network Digital Twin, AI-driven Network

**1 Introduction**  
The concept of Digital Twins (DTs) has seen significant growth in recent years, evolving from its initial introduction at a product lifecycle management conference to becoming a critical technology across various industries, particularly in manufacturing and aerospace. Despite its widespread adoption in these areas, the application and evaluation of DTs within network systems remain relatively underdeveloped. As the telecommunications industry gears up for 6G networks—offering unprecedented improvements in speed, capacity, and latency—the relevance of Network Digital Twin (NDT) comes into focus [2].  
NDTs serve as sophisticated virtual replicas of network setups and operational strategies, pivotal in enhancing real-time monitoring, predictive analytics, and pre-implementation simulations of network changes. Research on DTs in the network has just begun, and its application is still in the infancy stage [15], particularly in the context of 6G networks. Most of the cases and studies that claim to introduce NDTs in networks, such as 5G, are partial NDTs, for example, focusing on the RF part or the network management part

[7]. Therefore, there is a lack of full-stack NDTs and overall architecture, especially for the next-generation 6G network. To address these gaps, we propose a high-level architectural framework for 6G Network Digital Twins system, consisting of three key layers: the Physical Twin Layer, Digital Twin Layer, and Application and Service Layer. We also explore potential strategies for deploying 6G NDTs and emphasize the importance of selecting appropriate tools for their implementation.  
The remainder of the paper is organized as follows. Section 2 reviews existing literature, highlighting the fragmented nature of current NDT studies. Section 3 introduces the proposed architecture for a 6G NDT. Section 4 benchmarks existing software tools that can be used for building NDTs, looking into aspects of scalability, performance, and extensibility, and then provides recommendations for future tool selection and architecture refinement, while Section 5 concludes the paper.

**2 Related Work**  
It is hard to have a unified and standard structure for an NDT system[8]. Currently, the three-layer or four-layer architecture is relatively common in the academic [1, 12–14], but there is less consensus on the details and structure of each layer.  
In [3], the basic idea of NDTs was retained. Ericsson implemented a 5G NDT, providing a secure virtual environment for testing and optimizing parameters like radiated power, with visualization through Nvidia Omniverse. They enhanced network performance and power efficiency using reinforcement learning. The design effectively embodies NDTs' idea and structure, utilizing AI as a tool. HEAVY.AI has developed an NDT application with a three-layer framework called HeavyRF [7], which integrates the SQL backend of Omniverse and HeavyDB, and is able to run real-time RF simulations on extremely high-resolution terrain data. Additionally, the study by Demir et al. [5] integrated vision from the outset, optimizing beam selection by extracting the spatial distribution of scatterers affecting wireless propagation from user-side camera images. These studies focus primarily on network parameter optimization. A more comprehensive approach can be seen in CAVAR-related research [1], which introduced an all-in-loop co-simulation that includes 3D space and vision, incorporating the essential components of a digital twin system, which can be considered a simplified prototype. However, most of these studies primarily focus on a part, like radio, with relatively little attention given to the digital twinning of other parts of the network, in other words, full stack 6G. Therefore, our work focuses on the full stack 6G. We explore a modular approach to the architecture, discussing the functional divisions and components, and based on this structure, we investigate the principles and strategies for implementing a more comprehensive full-stack 6G network digital twin system.

## A Systematic Survey

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es into sharper focus [16]. These NDTs are sophisticated virtual replicas of network setups and operational strategies, pivotal in enhancing real-time monitoring, predictive analytics, and pre-implementation simulations of network changes. The enhancement of these capabilities is crucial for meeting the demands of modern communications, as shown by studies from [18] and [3]. Research on DTs in the network has just begun, and its application is in the infancy stage[16]. At present, however, the next generation DTs are likely to be truly applied and fully realize their functions in the 6G network. Wireless communications can be the next scenario where DTs can be applied to fully realize their functions. A new paradigm, 6G holds significant research and application value when combined with DTs[7].

Keyword	Arxiv	IEEE	ACM DL	ScienceDirect
manufacturing	79	485	1,000	1,041
—	27	179	136	46
—	57	200	50	19
—	91	244	2,069	64
—	51	275	1,271	116
Industry	214	969	3,465	990
—	39	136	—	147
—	99	438	—	579
—	25	79	—	81
—	65	449	—	200
—	42	176	593	83

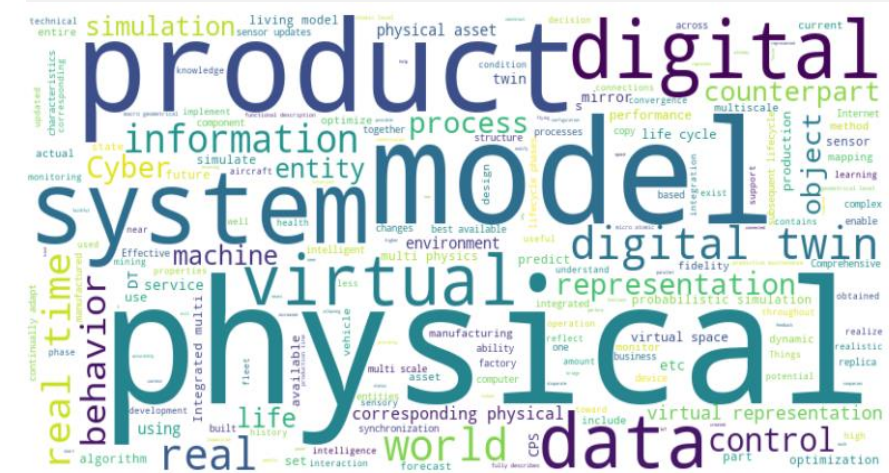
Table 1: Total Number of Papers Abstract Related to "Digital Twin" with Different Keywords By 4Q-2024

Building on the current foundation of existing adoption and utility of DTs across multiple sectors, our research specifically aims at exploring the role of NDTs within the context of 6G telecommunications technologies networks, represented by 6G networks.

### Main Contributions

Digital Twins have achieved relative maturity in manufacturing areas, such as production line management. However, their adoption and evaluation in networks are not as widely discussed and remain somewhat underdeveloped. Table 1 shows the statistics of number of papers with different keywords from different databases as of 2024. As shown in Table 1, where reflects that current research on DTs is more on Manufacturing and Industry, and there is relatively less research on 6G/6G networks. Additionally, there is a big gap in people's understanding of NDTs, concepts involved are often more ambiguous and there are often conflicts in the use of terms. Our research advances the field of Network Digital Twins (NDTs) through several integrated contributions:

## Thus:



**Fig 1: Wordcloud for all definitions we found**

# Existing Digital Twin Definitions

1. We investigated around 100 definitions of Digital Twin;
2. We manually selected the most common aspects and areas of emphasis;
3. We conducted NLP techniques to identify and match the key aspects across different definitions (with random manual sampling inspection), shown in Fig 2;
4. Then, we categorized them into the following bigger aspects / focuses in Fig 3.

Due to space limitations, the definitions will not be listed in this slide

# Key Aspects and Composition of Digital Twin

We find the small key aspects across different definitions:

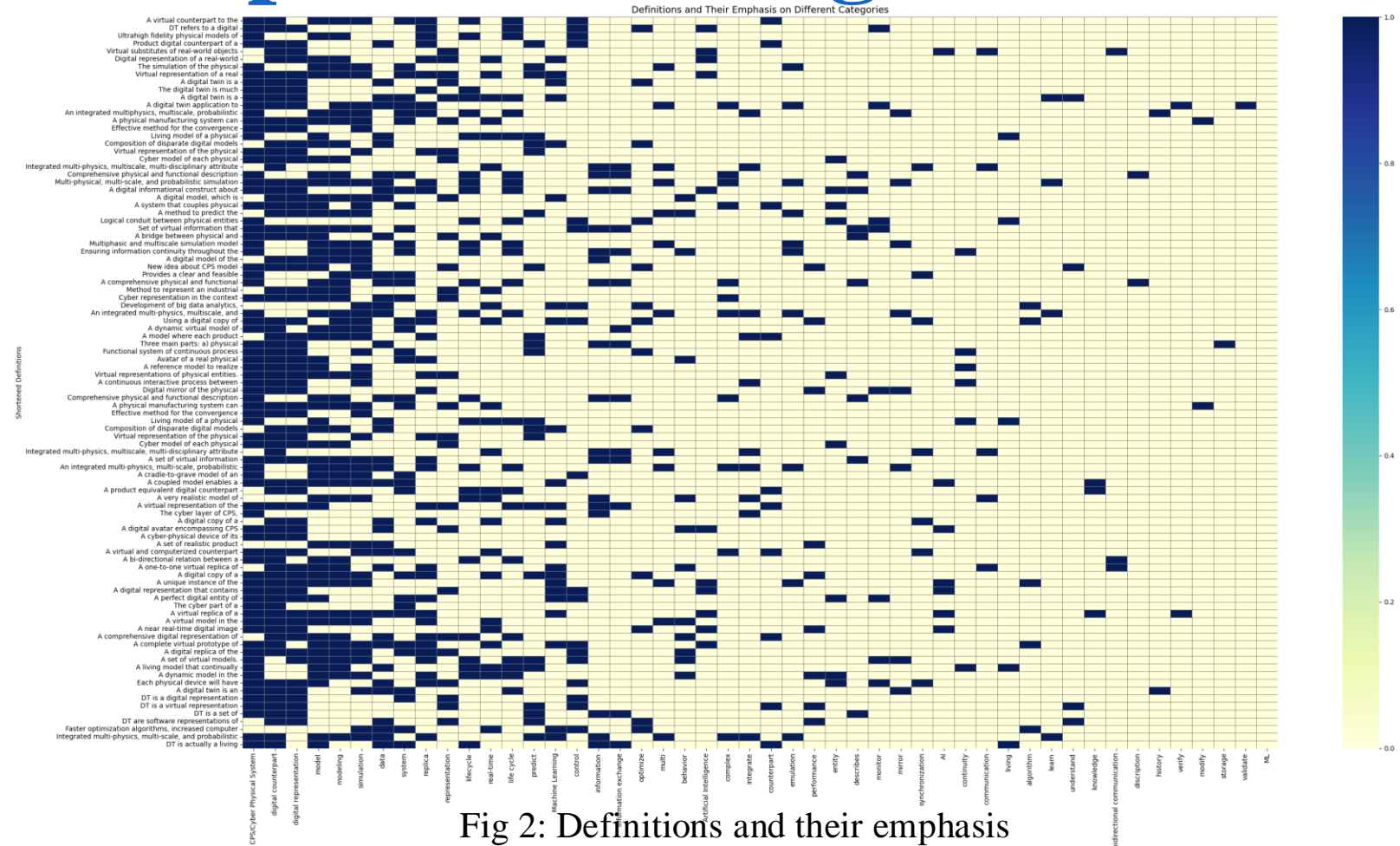


Fig 2: Definitions and their emphasis on different categories



# Key Aspects and Composition of Digital Twin

**We summarize and abstract the main focused topics:**

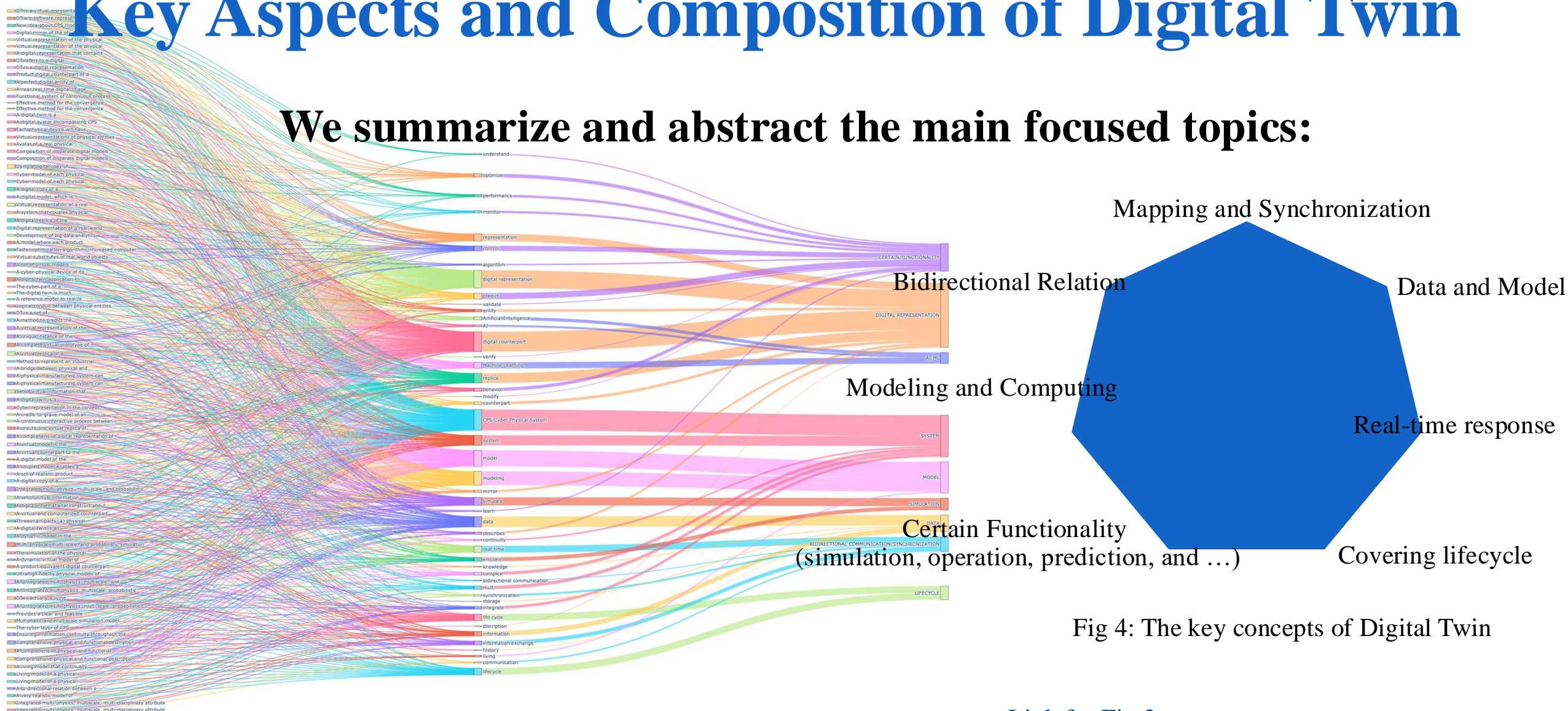


Fig 4: The key concepts of Digital Twin

[Link for Fig 3](#)

### Fig 3: Sankey Diagram Combining Definitions, Small Topics, and Large Categories

# What should our definition be?

**When we propose our definitions, there are some requirements, the definition should:**

- Focus on the big picture, not the details
- Be aligned with our proposed architecture and existing applications
- Be practical and capable of guiding real-world development
- Prioritize and align our efforts towards areas of our research (networks)

**Thus, we proposed our candidate definition for Digital Twin.**

# Digital Twin Definition

**Based on the literature review and investigation of existing definitions,  
We define *Digital Twin* as follows:**

*A **Digital Twin (DT)** is a virtual representation that maps a physical object, system, process, or an intricate combination of these elements at certain levels.*

*It enables bidirectional synchronization between the physical and digital realms, allowing for seamless information exchange and simulation of physical behaviors.*

*It is developed to achieve further objectives by utilizing its functionalities (such as simulation, prediction, optimization, control, etc.).*



# Ongoing work

- Taxonomy Based on the Definition
- Use case ZERO
- Reference Architecture
- Standards