

Full Length Research Article

Digital Twin Technologies In Transition: A PRISMA-Guided Analysis Of Architectures, Applications

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Abstract: Digital twin technology refers to the use of synchronised digital replication for the modelling, management, and enhancement of large-scale cyber-physical systems. As such, digital twin systems have been simplified (in terms of integration) using artificial intelligence (AI), cloud computing, and data-driven analytics. Unfortunately, rapid technological progress has led to many unresolved issues regarding the technology, methods, and structures of digital twins. A systematic literature review of the relevant digital twin literature (2023-2026), conducted using the PRISMA methodology, served as the basis for understanding advances through analytical overviews of the findings. After a thorough review of all relevant peer-reviewed research, including quality assessments and a comparison of articles by their main goals, we found that digital twin systems, which were previously considered fixed, are now being replaced by AI-driven analytics and cloud-edge computing systems. These new systems are modular, layered, and/or distributed. Such systems, which currently exist in the healthcare, energy, digital infrastructure and industrial sectors, each have their own rules for manufacture and operation. Research into AI-augmented digital twins is underway to determine the extent to which they can explain, verify, synchronise, or enable cross-platform interoperability and the management of large datasets. While the results of these studies are like those of earlier research, it's important for researchers to also consider standard design frameworks, useful analytics, and strict measurement methods. Moreover, the development of a modern, technically sound synthesis has greatly improved the creation, testing, and use of advanced digital twins.

Keywords: System Architectures of Digital Twin, Artificial Intelligence Integration, DT, Digital Twin, Human Twin

1. Introduction

Digital Twin Technologies enable us to observe, control, and improve large physical systems through digital replicas. A digital twin is a replica of an item, process, or system that moves. It always ensures that the real world and the online world are in sync. In the past several years, smart infrastructure, healthcare, energy systems, industry, and hyperphysical environments have all adopted digital twins. People are increasingly interested in IoT, cloud computing, edge computing, AI, and data analytics as these technologies advance. When you combine these technologies, digital twins become clever, adaptable, and capable of acting on their own. It could be challenging to develop and operate digital copy systems, but the technology is evolving swiftly. People don't use it as often because of its design, openness, size, real-time data integration, and fidelity to its model. Because technology is advancing rapidly, these challenges make it even more vital to provide a comprehensive, up-to-date evaluation of current digital twin research. Recent research focuses on comprehensive, data-driven, AI-enhanced digital twin systems that can function in real-world settings. This version makes several important changes. First, the architecture of buildings has shifted from massive, centralised to

smaller, more flexible ones that can develop and adapt. Second, digital twins may now make predictions, provide advice, and change on their own thanks to machine learning and cognitive analytics. Third, standardisation and sharing are becoming increasingly important to enable digital twins to be used across more systems and in more places. The findings indicate that research on digital twin technology is almost complete and no longer necessary. This progress, however, has shown that academics have faced problems in tackling substantial technological and scientific issues. Over the last several years, there has been extensive research and surveying on digital twin technologies, yet many of the findings have been inaccurate. Most recent judgments are based on research conducted after 2022. These studies do not demonstrate the evolution of AI integration, real-time frameworks, and large-scale system deployment over time. These findings may not fully reflect the current state of digital twin research. Several surveys use a descriptive approach, listing application areas or supporting technologies without discussing design trade-offs, research requirements, or construction trends. These methods generally lack scientific rigour and do not adhere to recognised review standards.

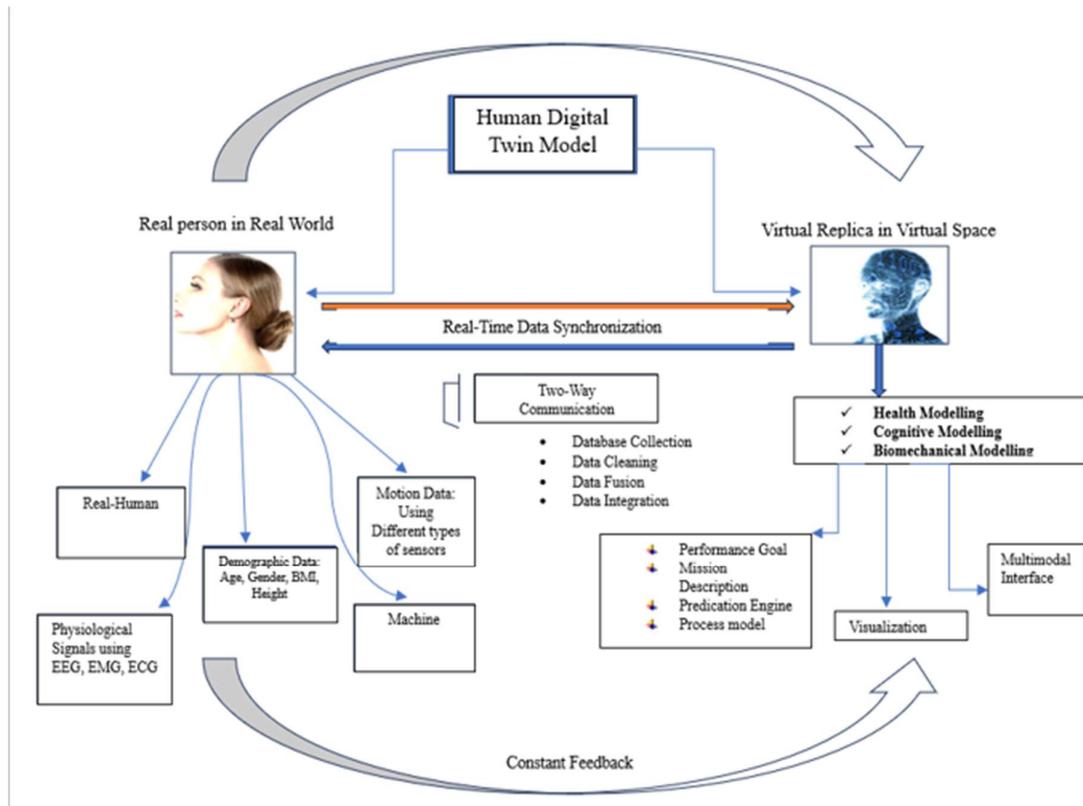


Fig. 1. Process of Digital Twin Technology: The Real-Life Object

This makes it hard for them to check their data or repeat it. Third, not many exams explicitly employ PRISMA-led screening procedures or specify the rules for entry and exit. Non-open papers provide less accurate outcomes. Most previous reviews do not sufficiently synthesise data from other disciplines to identify critical obstacles and prospective research directions. These constraints highlight the need for a comprehensive, methodologically sound, and current literature assessment of digital twin research, including both a general overview and an analytical synthesis. This research examines all newly introduced digital twin technologies between 2023 and 2026. We will discuss system ideas, examples of their use, and questions that still need to be addressed. This is achievable through an analytical synthesis and a PRISMA-based literature evaluation. This project delivers the field three vital things. We begin by taking a careful look at modern digital twin systems, starting with the most common design patterns and the tools that accompany them. Next, we gathered concepts from other sectors that may be useful in real life. We focused on what is the same and what is different. Third, we see significant gaps in the

study and problems that still need to be addressed, which will affect future research on digital twins. This study questions the following research questions:

RQ1: What sorts of buildings and technology do the best digital twin systems use? What changes have there been in the designs and architectures of digital twin systems during the last several years?

RQ2: What major research deficiencies, constraints, and outstanding challenges have arisen in recent investigations concerning digital twins? How do these gaps change the way research is done in different areas in the future?

2. Foundations of Digital Twin Technologies

Digital Twin Technologies make a copy of an object, process, or event that doesn't change. The digital and real worlds are linked, so data can be sent and received in real time or very close to it. That's what makes digital babies different. There are three parts to a digital twin: the original machine, its digital twin, and the data links that let them talk to each other. The information, study, or both can be used to build computer models. The most up-to-date system tool info is always stored in the computer model.

You can use what you learn on the internet to make things better, direct other people, or decide what to do. Digital twins check and change how things work, collect data from different times, and cover the whole life cycle of a system. You can make, use, change, and get rid of digital copies of things. But the old models were only used for testing or making improvements. Better models and training are what digital twin technologies are built on. At first, digital copies were used as offline computer models to test systems. The functions of these models didn't match real life because they were hard and had to be changed by hand. Digital twins are one of the few cyber-physical devices that can do both at the same time. Systems can change to what's happening now and guess what will happen in the future. People are moving away from technologies that only find problems and toward smart system models that can see problems coming and fix them before they happen. In many digital twin systems, each layer or part does a different job. Real-life events and situations make up the base layer. Sensors and other devices send useful info to this layer. It's time for system code. It is in the layer for models and simulation. Machine learning, statistical models, physics-based models, and other types of models can be used at this stage. The digital model is used in analytics and intelligence to make decisions, predict results, improve processes, and find outliers. Lastly, the application and show layer makes it easier for the business and outsiders to talk to each other. You can use this layer to talk to your PC version. You can see it, talk to it, and change it. With this skill, you can think ahead and make smart choices. Because we think in layers, we can compare and understand digital twin patterns. It's hard to study the terms "digital model," "digital shadow," and "digital twin" because they mean so many different things. It is possible to save computer models of real systems. It doesn't get new information from the internet right

away and is mostly used for offline research or making models while preparing. Form changes have to be done by hand. Thoughts that happen between the digital form and the real system are called digital ghosts. The real world gives computers knowledge, not the other way around. The digital ghost can only use data to report how the real system is working right now. It is voiceless and can't help you. A digital twin, on the other hand, closes the gap between the real and digital worlds by letting data move both ways. Digital copies can change real systems because they can work both ways. This gives people the power and freedom to chooses.

3. Research Methodology: PRISMA-Guided Framework

This study employs a comprehensive literature review and a PRISMA-based analysis report to examine recent advancements in digital twin technology. When people look back at old stories, they often use studies that aren't fair, and they don't always explain how they chose the studies they used. A PRISMA-based system, on the other hand, stays scientific because it makes the rules for adding and removing things, the search methods, and the screening processes very clear. This method is good for the topics we talked about because it involves carefully sorting, comparing, and breaking down subjects. It also helps the study reach its goals. Many good academic sources in computer science and engineering were checked to find all the important, high-quality, peer-reviewed materials. People mostly use Scopus and other databases to find books and papers from meetings that they want to read. The goal of that search method was to find new studies that were mostly about digital twin technologies and not studies that were only a little bit about those technologies. We were able to pair words that were both broad and narrow thanks to Boolean operators.

Table 1. Databases and Search Strings

Database	Search String
Scopus	("digital twin" OR "digital twins") AND (architecture OR framework OR system OR application)
IEEE Xplore	("digital twin") AND (cyber-physical OR IoT OR AI OR architecture)
Web of Science	("digital twin technology") AND (design OR implementation OR analysis)
SpringerLink	("digital twin") AND (model OR platform OR system)

ScienceDirect	("digital twin") AND (application OR architecture OR framework)
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Table 2. Inclusion and Exclusion Criteria

Criterion Type	Description
Inclusion	Peer-reviewed journal or conference papers
Inclusion	Published between 2023 and 2026
Inclusion	Explicit focus on digital twin systems or architectures
Inclusion	Clear methodological or technical contribution
Exclusion	Studies published before 2023
Exclusion	Editorials, short abstracts, tutorials, or opinion pieces
Exclusion	Studies using "digital twin" terminology without technical implementation
Exclusion	Non-English publications

The four standard PRISMA steps of discovery, screening, selection, and admission were used to choose the studies. The first set was created during the recognition step by combining information from all the chosen sources. We went through all the records by hand to make sure there were no

duplicates. During the screening process, we looked at the titles and descriptions of the papers to get rid of the ones that were clearly not relevant. A complete full-text review was done on the other papers to make sure they were good enough, following strict rules about what to include and what to le

Table 3. PRISMA Screening Summary ave out.

PRISMA Phase	Description	Number of Studies (Indicative)
Identification	Records identified through database searches	N ₁
Screening	Records after duplicate removal	N ₂
Eligibility	Full-text articles assessed	N ₃
Included	Studies included in the final analysis	N ₄

A universal quality rating system was used to evaluate each study, which made sure that the analysis was accurate. The quality of the studies was judged by how clear the goals were, how well the methods were used, how detailed the architecture was, and how well the studies answered the research

questions. First, a detailed summary was made to find patterns in the types of studies, the areas of application, and the types of publishing. Second, an analysis summary was used to find common design patterns, compare building patterns, and find study holes that cross different areas. The subsequent

design analysis, application-focused discourse, and gap identification are all grounded in this dual synthesis methodology.

4. Descriptive Analysis of Selected Literature

The existing literature indicates a sustained and increasing interest in digital twin technologies among researchers. Digital twins are evolving from experimental models to practical systems capable of addressing real-world challenges, as evidenced by the consistent growth in published research. Unlike earlier investigations that primarily emphasized system design and proof-of-concept applications, contemporary studies are increasingly focused on scalability, data sharing, lifecycle integration, and real-time intelligence. This temporal shift reflects an evolving research agenda. Frequently, these studies address the complexities of real-time data management and integration. They also show that the methods are too hard to understand and don't work well together. In recent years, there has been a significant increase in writing about the use of biology and healthcare. The primary focus of this discussion encompasses patient-specific models, the monitoring of medical devices, and the operational management of healthcare facilities. A significant portion of the research is dedicated to enhancing performance, extending operational lifespans, and improving durability. Often, these books go over more ground. They're excellent for understanding the theoretical underpinnings of concepts, as well as their real-world applications. Even though ideas have become clearer over the last few years, different types of research show that we still need to study digital twin systems on a big scale and for a long time in the real world. There are digital twin studies going on all over the world, which makes them very interesting to people. Universities, business partners, and government agencies are working together on research more and more often, especially when the study is useful in real life. These agreements show that companies are becoming more interested in digital twin technologies. They also help to put the new study to use in the real world. But the study also shows that the area isn't round. Developing places aren't making a big difference yet. The detailed analysis highlights three main points. First, the research on digital twins showed consistent improvement.

Second, smart cities, healthcare, and energy systems are no longer just used in business. They are now used in other areas as well. This third point says that there are many thoughts and tests, but not many complete studies or set rules. The next part of the study will go into more depth about building, so this knowledge is very important. Digital twin technologies are currently being used in various ways. This allows for a comparison of building

trends, design choices, and technical trade-offs across different research projects.

5. Architectural Analysis of Digital Twin Systems

A recent investigation indicates that digital twin systems are evolving beyond the paradigm of standalone, monolithic products. Consequently, a discernible trend is emerging towards structured design methodologies that prioritize adaptability, scalability, and interoperability. The examined study posits that the architectural style of a digital twin is a critical determinant of its operational efficacy. Specifically, the selected design influences data processing velocity, model accuracy, system scalability, and the capacity for sophisticated analytical operations. Design is shifting away from its traditional role in planning, increasingly focusing on assembly. From this perspective, a central computational instrument, typically cloud-based, receives data from physical systems. However, the research also raises concerns regarding controlled methodologies. Distributed digital twin approaches leverage edge and fog computing to mitigate the limitations inherent in centralized systems. This emerging field of research is significant. These systems contain many interconnected components that work together to run models and manage data. The existing research suggests that breaking down computing tasks improves system stability and scalability. A recent investigation into digital twins indicates that the most prevalent design patterns currently employed are those characterized by stacked and flexible architectures. This architectural model divides digital twin systems into distinct functional layers. Each layer is responsible for specific tasks, including data collection, model creation, analytical processing, and user interface design. As a result, recent work increasingly advocates balanced modularity, in which architectural decompositions are guided by application requirements rather than rigid templates. A shift from purely physics-based models toward hybrid architectures that combine mechanistic models with machine learning techniques. AI-enabled digital twin architectures support predictive, prescriptive, and adaptive functionalities. Some studies further explore self-learning digital twins that update their internal models based on operational feedback. However, the integration of AI introduces architectural challenges related to model explainability, data quality, and computational cost. Several studies emphasise the need for architectural mechanisms that support transparent decision-making and continuous model validation to maintain trust in AI-driven digital twins. Recent architectural proposals increasingly emphasise the use of open standards, standardised data models, and service-oriented designs.

6. Application-Oriented Analysis

Manufacturing is still the most advanced and researched field for digital twin technology. There has been a lot of new study on how digital twins may assist in planning outcomes, improving processes, checking quality, and predicting maintenance. Digital twins are usually. These enormous applications highlight how crucial it is to create systems that can operate with newer ones, structures that can be extended, and data that can be handled rapidly. Digital twins are being produced over time. More and more smart cities and infrastructure are using digital twin technology to keep track of and simulate complicated operations in the city. A new research looks at how digital twins may assist with planning infrastructure, case studies, and real-time monitoring for things like buildings, utilities, transit networks, and other sectors.

Several studies have also proven that it's still challenging to maintain data accurate and up to date in places that are continually evolving. Even with these problems, digital twins of smart cities might make communities stronger, help them make better choices, and help them take care of the environment. A new research focuses into personalized digital twins, monitoring medical equipment, and improving hospital systems. The purpose of these technologies is to improve the accuracy of testing, care plans, and the utilization of resources. A lot of the time, hybrid applications illustrate how adaptable digital twin concepts can be. But they also indicate where existing design and research methodologies don't work. The report indicates that it's challenging to shift digital twin solutions from one place to another since the data, actual restrictions, and performance objectives are all different. It seems that digital twin technology can be applied in a variety of different situations. How effectively they operate will depend on the aims and restrictions of each case. To build powerful and flexible digital twin designs, you need to know this.

7. Comparative Analysis and Thematic Synthesis

The chosen situations show that the design and application of digital twin systems can be very different in a number of different areas. Several design ideas keep coming up when you think about systems in terms of how applications can grow, how much data they use, and how fast they can run. To make the system more useful, it's easy to add more analysis tools. This way, the system can do more. Edge computing is being used by more and more people to quickly handle data close to where it comes from. It seems like this trend keeps showing up. Digital twins that work at the edge are often used in areas where things need to happen quickly, like

running plants and controlling energy. Researchers who looked into digital twin systems had to choose between fast systems, systems that could grow, and models that were accurate. A lot of the time, high-fidelity models need a lot of computer power. The study's findings suggest that the best trade-offs depend on the specific situation and must align with the program's goals.

Not much research has been done on how to choose the best trade-offs in a planned way. This shows that the methods used for designing buildings and judging their performance are different as compare to what existing literature review showed that there are four main areas of study that need more research: building design, advanced analytics, application-specific implementation, and system interaction. The study of architectural design examines how the system is put together and how its parts work together as the One type of study that focuses on analytics looks at how the system can change and make predictions. Research that only looks at a few uses of digital twins shows that they don't always work well in other situations. On the other hand, system integration studies look at the problems that arise when rules are in place, data needs to be shared, and different types of data need to be shared. It's important to keep in mind that not all studies look at design, data, apps, and integration at the same time and this spread shows that most digital twin research is done alone right now, with few chances for researchers from different fields to talk about their ideas. A lot of important things came out of the comparison and subject study. Digital twin systems are becoming more popular and can be changed easily to begin with. For kids to grow and learn, they need to be able to work at the same time. Which later on define how AI is an important part of digital twin systems today, and it also makes them harder to test and control. Third, people are aware of the trade-offs between efficiency and design, but they don't plan them well.

8. Future Research Directions

Researchers should be focusing on building digital twin designs in the future that make it easy for massive, complicated systems to flourish as this entails building distributed and structured systems which can manage a lot of data, make it simpler for systems to interface with one other in real time, and keep track of assets that are spread out in various areas and It's also vital to see how effectively things operate in real life. Long-term studies that examine how a system operates over time might teach us a lot about how far it can expand and how robust its design is.

There aren't enough studies like this one right now. There aren't any rules that everyone agrees on, which is a huge challenge that makes it tougher for more individuals to embrace digital twin technology.

Future research should make it simpler to create and evaluate standardized reference designs, data models, and ways to communicate. Businesses, colleges, and standards organizations need to work together extremely closely because if research that connects new technologies to old ones makes it simpler to connect, digital twins may be easier to employ in other areas. When safety is the most essential thing, it's extremely vital to design AI approaches that can be explained and are made only for digital twin systems. Digital twin technologies have great promise for achieving sustainability and resilience objectives. Researchers need to investigate the use of digital twins to optimize resource allocation, mitigate environmental impact, and enhance system resilience in the face of failures. There might be a lot of wonderful things that come from using energy systems, constructing with climate change in mind, and designing things that endure.

Digital twin design and assessment systems need to incorporate measurements of the environment and evidence of resilience for them to genuinely make a difference. This is because most digital twin solutions are built for certain sectors, thus they don't work as well in others. Researchers should concentrate on developing digital twin components that are adaptable, independent of particular domains, and easily modifiable to accommodate various contexts. If we look at modeling methodologies, flexible designs, and reusable model packages, it could be simpler to build software. This might also make more individuals want to utilize these technologies. Cross-domain case studies could also assist discover issues that arise in other areas and solutions that might be employed in other areas. Digital twin study has to improve in many areas than only technology. It also needs to find better methods to accomplish things. In the future, researchers should employ stricter methods to assess, such as utilizing the same criteria, undertaking studies that are comparable, and being explicit about what their work can and cannot achieve. It may also be simpler to link theoretical frameworks with practical application when systematic review methodologies and empirical evidence are used concurrently. Making these types of modifications to the way research is done would make studies of digital twins more accurate and helpful.

Conclusion

In the end this study used the PRISMA method to review digital twin technologies, focusing mainly on new research by combining existing and new studies, the research looked at how digital twin designs have changed, what their main uses are, and the most important areas that need more research where the results show a clear trend toward digital twin technologies becoming more widely used and

more intelligent. The temporal scope of this review, spanning the years 2023 to 2026, while enabling an assessment of contemporary and developing trends, might inadvertently exclude seminal research that continues to exert a significant influence within the domain of digital twin investigations.

The study has its limitations, such as only considering English-language publications from specific academic databases, which might have excluded valuable research in other languages or published elsewhere. Additionally, the qualitative approach used in the study provides insight into concepts and ideas, but doesn't fully explore the connections between citations and publications. As with any systematic review, the findings are dependent on the quality of the included studies. On the other hand, digital twin technologies hold a lot of promise, with established use cases in manufacturing and emerging applications in smart cities, energy systems, and healthcare. However, the adoption of digital twin technologies is still hindered by complexities in development, data management, and validation. This study highlights these challenges and provides guidance for future research. By addressing these limitations, policymakers, researchers, and developers can create digital twin systems that are resilient, reliable, and adaptable. One of the key benefits of digital twin technologies is their ability to create virtual models of complex systems, such as cities, energy systems, and patients. For instance, digital twins can be used to simulate urban planning and management, optimizing energy consumption and reducing waste. In healthcare, digital twins can be used to create personalized models of patients, aiding in diagnosis and treatment. However, these applications are still in their infancy, and further research is needed to fully realize their potential. Despite the challenges, digital twin technologies have the potential to make a significant impact on various aspects of life, from manufacturing and energy to healthcare and urban planning. The study's findings can be used by policymakers to inform regulations and standards, by researchers to identify areas for further study, and by developers to create more user-friendly and effective digital twin systems. For example, policymakers can use the findings to develop guidelines for the use of digital twin technologies in different industries, while researchers can use them to explore new applications and developments in the field. In conclusion, digital twin technologies are a promising area of research, with many potential applications and benefits. While there are still challenges to be overcome, the potential rewards are significant, and continued research and development in this field can lead to the creation of more efficient, effective, and sustainable systems. By addressing the limitations and challenges of digital twin technologies, we can unlock their full potential and

make a positive impact on various aspects of life. Some of the potential applications of digital twin technologies include: Creating virtual models of cities to aid in urban planning and management, Simulating energy systems to optimize energy consumption and reduce waste, Developing personalized models of patients to aid in diagnosis and treatment, Improving manufacturing processes and supply chain management, Enhancing the resilience and reliability of critical infrastructure Overall, digital twin technologies have the potential to transform various industries and aspects of life, and further research and development are needed to fully realize their potential. But there are still some hurdles to clear, like making sure these systems are developed and validated in a way that works. If we can tackle these challenges and keep pushing the boundaries of what's possible with digital twins, we can build systems that are smarter, more efficient, and better for the planet - and that can make a real difference in all sorts of areas.

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