universität Witten/Herdecke

ATLAS
DIGITAL HEALTH ECONOMY

Digital Twins:

The Next Frontier of Intelligent Healthcare

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Content

Preface ..... **i**

Executive Summary ..... **ii**

1. Background and Context **1**

Digital Twins in Healthcare 1

Toward Personalized, Proactive Care through Digital Twins 3

2. Application Scenarios of Digital Twins in Healthcare **4**

Organ-Level Twins – “Virtual Organ Twins” 4

Patient-Level Digital Twins – “Virtual Human Twins” 7

Process-Level Digital Twins – “Virtual Health Gatekeeper Twins” 11

3. Challenges and Roadmap **14**

4. Outlook **16**

Key Takeaways **17**

References **18**

Preface

Germany's healthcare system stands at a critical crossroads, facing dual pressures: on one hand, growing demand for high-quality, personalized medical services; on the other, limited resources and a shortage of healthcare personnel. In this context, digital transformation is not merely an option but a strategic necessity. As a cutting-edge force in this revolution, digital twin technology has evolved from an engineering theory into a paradigm that delivers practical value in clinical practice and healthcare delivery operations.

This white paper aims to dispel myths surrounding digital twin technology, move beyond conceptual description, and provide clear, practical use cases. We will explore how these dynamic virtual designs are reshaping healthcare across three dimensions: organs, patients, and processes. It demonstrates the potential of digital twins to enhance precision diagnostics and treatments for organs, enable proactive personalized care for the whole person, and optimize complex workflows across entire healthcare institutions. By presenting specific application scenarios, real-world case studies from Germany, Europe, and the United States, and analyzing implementation challenges, it offers practical recommendations for implementing digital twins across different types of healthcare providers. Our goal is to empower readers not only to understand the potential and application scenarios of digital twins but also to confidently plan their implementation pathways.

We want to take this opportunity to thank our partners in business and academia for the valuable collaboration, and the state of North Rhine-Westphalia, especially the NRW Ministry of Economic Affairs, for financial grants to the ATLAS project.

ATLAS Team

Witten, October 2025

Executive Summary

- **Digital twins are entering mainstream healthcare with significant economic benefits:** transitioning from engineering to medicine, digital twins have demonstrated value in organ simulation, patient management, and hospital operations. Market forecasts consistently indicate exponential growth in the healthcare digital twin sector by 2030. Additionally, digital twins can reduce patient hospital stays, lower equipment maintenance costs, and improve hospital bed turnover rates.

- **Organ-level twins advance precision medicine:** Organ-level twins are highly refined models of specific organs. They simulate the state of individual organs or physiological systems with high fidelity. As dynamic simulators continuously optimized by real-time data, organ digital twins enable intervention simulations in zero-risk environments. They empower clinicians to conduct precise research and treat single-organ pathologies.

- **Patient-Level Twins Drive Personalized Treatment:** Patient-level digital twins are comprehensive virtual replicas of an individual's health status, integrating cross-organ, cross-system, and cross-temporal data. These twins incorporate interconnected simulations of multiple bodily systems and conditions, enabling physicians to explore complex interactions. “Virtual patients” provide clinicians with powerful tools to simulate treatment plans and monitor health trajectories, facilitating more precise personalized medical decisions for patients.

- **Process-Level Digital Twin Optimizes Healthcare Delivery Operations:** Process-level digital twins utilize computer simulation technology to model entire medical workflows, operational processes, and even complete clinical environments and behaviors. Essentially serving as decision support systems for healthcare operations, they enhance service efficiency, flexibility, and data-driven capabilities. For healthcare providers, these twins improve operational efficiency, reduce costs, and optimize staffing. For patients, they elevate service quality and strengthen confidence in medical care and medication safety.

- **Stepping beyond proof-of-concept into early application phases:** Organ-level digital twins (e.g., the MINIMAKI heart project) minimize surgical risks through preoperative simulations. Patient-level digital twins (e.g., the MED²ICIN project) deliver personalized treatment plans for chronic disease management. Process-level digital twins (e.g.,

SmartHospital.NRW) are building ecosystems that optimize hospital-wide operational efficiency, significantly reducing operational and maintenance costs.

- **A clear and stepwise plan of implementation and transformation:** It begins with awareness and organizational readiness, as hospitals recognize digital twins as strategic tools rather than experimental technologies. Through capability building, institutions gain hands-on experience, strengthen digital literacy, and foster technology trust. The next stage focuses on evaluation, where operation is assessed through measurable performance. Finally, digital twin systems evolve across departments and networks. Together, these stages form roadmap that transforms digital twin concepts into improvements in care quality, efficiency, and sustainability.

- **Future broader application scenarios of healthcare twins:** Digital twins are paving the way for predictive public health, lifelong health twins and virtual clinical research, that could enhance more precise, efficient, and personalized care.

1. Background and Context

Digital Twins in Healthcare

Germany's healthcare system faces a fundamental dilemma: the continuous growth in societal demand for high-quality, personalized medical services against limited resources and an increasingly pressurized healthcare workforce. Digital transformation holds the key to breaking this impasse, with Digital Twins at the forefront of this evolution. Originating in engineering, Digital Twins are no longer a distant concept for stakeholders in healthcare but a technological paradigm already creating value in clinical and medical operations.

Digital twins are virtual replicas of physical entities or processes that continuously exchange data with their real-world counterparts. In healthcare, they range from cellular and organ-level models to process-scale simulations. As defined by Kamel Boulos et al., a digital twin has “dynamic, bi-directional links between the physical entity and its corresponding twin in the digital domain”, enabling learning, hypothesis testing and “highly personalised treatments and interventions” (1).

The urgency of applying digital twins in the healthcare sector is most vividly reflected in its market projections and economic evaluations. While specific figures vary across different market analysis institutions, all reports consistently point to an exponential growth trend. Some prior projection indicates the market of digital twins in healthcare will reach $3.55 billion by 2030 with a compound annual growth rate (CAGR) of 25.9%, while more optimistic forecasts suggest it could hit $59.94 billion in 2030 with a CAGR as high as 68.0% (2, 3). Furthermore, data indicates digital twins can enhance collaboration that lead to a reduction of construction cost by 30% and decrease the failure of equipments with over 25% saving of repair and operational costs for hospitals (4). Thus, digital twins show their significant economic potential in healthcare.

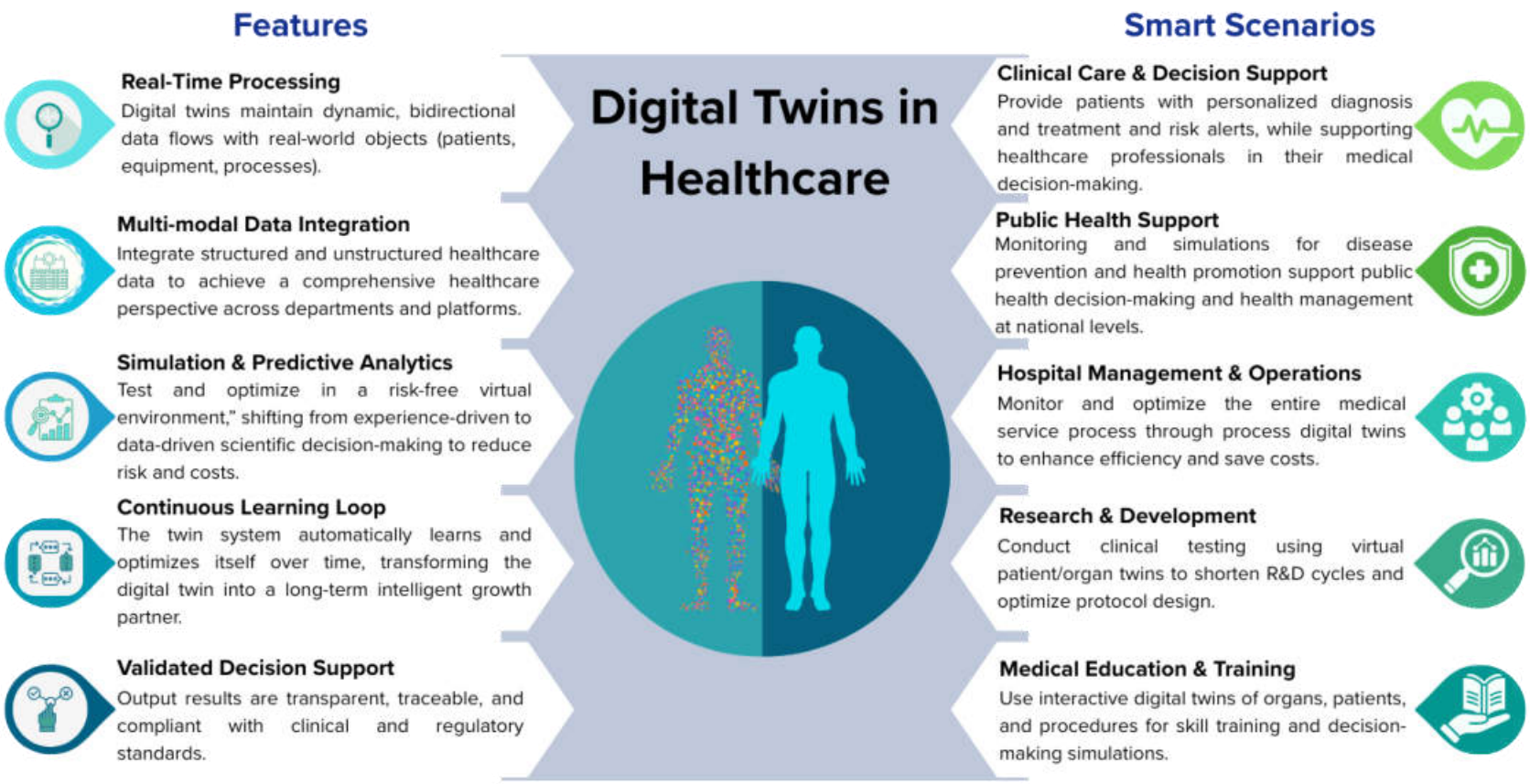


Figure 1. Digital Twins in Healthcare

Toward Personalized, Proactive Care through Digital Twins

Originally pioneered in engineering and aerospace, healthcare is one of the fastest-growing segments for digital twin technology applications (2, 5, 6). The digital twin is continuously fed with real-time data from the patient's health records, wearable sensors, medical imaging, genetic profiles and more, to update its status in parallel with the person's actual health or the progress in health services (5, 7). In other words, it's a living digital mirror of the real world. What makes this concept so powerful is the ability to simulate and predict outcomes in a risk-free virtual environment. Doctors can potentially use a patient's digital twin to run "what-if" scenarios. For example, predicting how that patient might respond to a certain medication or identifying early signs of deterioration before they occur clinically. The twin can integrate data and complex physiology in ways no human mind can: it can continuously compare an individual's metrics against vast datasets of others, disease models, and clinical guidelines to flag subtle patterns (5, 6, 8-11). This could enable truly personalized medicine. For instance, a digital twin might help in preventive care by forecasting an oncoming health crisis like a cardiac arrest or an epileptic seizure hours or days in advance, prompting preemptive action. It could also assist in treatment planning, surgeons might practice a difficult operation on the patient's virtual twin before entering the operating room, optimizing their approach to reduce risk (12). In chronic disease management, a twin could model disease progression under different lifestyle or therapy interventions, helping clinicians and patients choose the best path. Furthermore, at the system level, digital twins of hospitals or healthcare processes can identify inefficiencies and test improvements in silico without disrupting real-world operations.

In summary, digital twins could lead to a gradual shifting in healthcare sector from a one-size-fits-all, reactive model toward a data-driven, proactive, and patient-specific model.

2. Application Scenarios of Digital Twins in Healthcare

European and German initiatives are now coordinating efforts to support the development of digital twins in healthcare. For example, the EU's European Virtual Human Twins Initiative defines VHTs as digital representations of human anatomy at cellular through organ levels (13). Similarly, the EU-funded EDITH program is building a "shared digital twin ecosystem" by mapping stakeholders, use cases (e.g. cancer, cardiovascular) and drafting a European digital twins roadmap (14). In North Rhine-Westphalia, projects like SmartHospital.NRW (led by Universitätsmedizin Essen with Fraunhofer IAIS/MEVIS and RWTH Aachen) are advancing AI-based smart hospital models for personalized diagnostics and operations (15).

Seven key application areas of health digital twins are summarized by recent studies: hospital management and care coordination, device design, biomarker/drug discovery, bio-manufacturing, surgical planning, clinical trials, personalized medicine, and wellness (5). These areas span the four categories of digital twins we discuss here: Organ-level, Patient-level, Hospital/Process-level. Each section below begins with a vignette set in Germany (often NRW), followed by technical analysis, case studies, and strategic value, supported by current research and pilots.

Organ-Level Twins – "Virtual Organ Twins"

Organ-Level Twins are highly detailed models of specific organs or physiological systems. They model an individual organ or physiological system (e.g. heart, lungs, liver) with high fidelity, capturing their anatomy, physiology, and even pathology in silico under various conditions. It is a "virtual organ" that can be probed, tested, and manipulated digitally as a stand-in for the real organ. Organ twins rely on medical imaging (CT/MRI/X-ray, ultrasound) for anatomy, physiological sensors (ECG, blood flow, pressures) for dynamics, and biophysical simulation engines (finite-element mechanics, fluid dynamics, electrophysiology). They integrate AI/ML models to capture tissue behavior (e.g. neural network learned valve movement) and can use real-time data from monitors or wearables during procedures. A

bidirectional link updates the twin from the real organ (e.g. intraoperative echo), while the twin can feed back predictions (e.g. forecast tissue deformation). Modern organ digital twin architectures are typically layered: a physical layer (the actual organ + sensors), a data layer (medical records, live streams), a simulation/model layer (the twin model and analytics engine), and a services layer (apps for visualization, AR, analytics). Organ twins function as dynamic simulators – they are continuously refined with new data and can simulate interventions in a risk-free environment. They help clinicians study and treat conditions in a single organ with extraordinary precision.

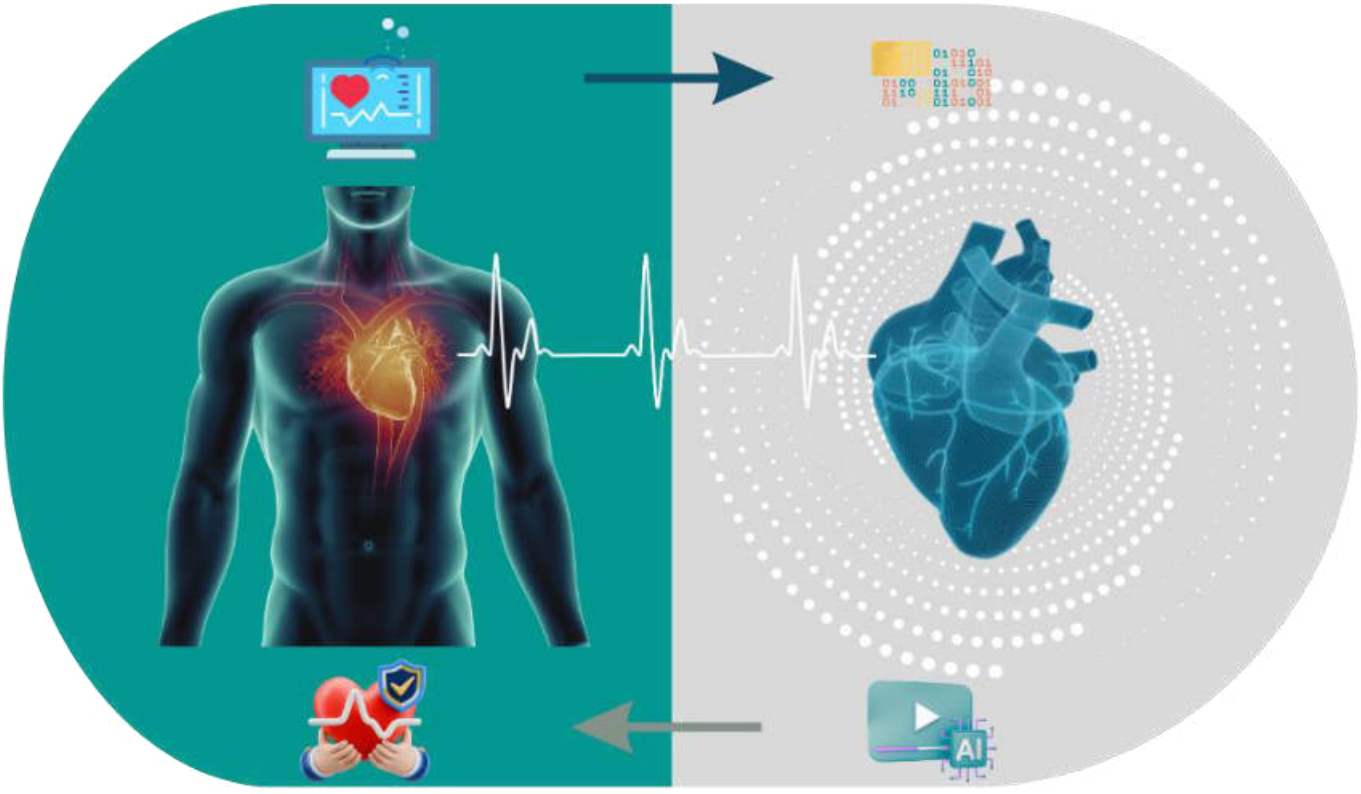


Figure 2. Virtual Digital Organ Twins

Table 1. Real-World Examples (EU focus): This table highlights some real-world organ-level twin projects, including European initiatives, and their use cases

Organ System	Use-case / Description	Project	Lead Institutions	City/ Country
Brain Twins	This is a virtual twin model of the brain for treatment-resistant epilepsy. The model helps to understand the mechanism of signal transmission in the patient's brain and locate the areas that trigger seizures, thereby minimising the need for surgical intervention. (16)	Epinov	Dassault Systèmes & Hôpitaux de Marseille	Marseille, France
Orthopedic Twins	Two specialised 3D printers – a large-volume SLS (selective laser sintering) printer and a DLP (digital light processing) printer – can be used to manufacture patient-specific implants, models and instruments. By creating a customised 3D model of the affected area, surgeons can plan and successfully perform complex operations, thereby avoiding amputation. (17, 18)	REACT	3D Centre at Münster University Hospital	Münster, Germany
Pulmonary/ Lung Twin	Using computed tomography (CT) scans and artificial intelligence, the technology constructs a highly detailed, patient-specific virtual model of the lungs. This model allows for the precise analysis of mechanical stress and strain across different regions of the lung, enabling clinicians to tailor ventilation strategies to the individual needs of each patient. (19)	EXIST	Ebenbuild and Technical University of Munich (TUM)	Munich, Germany
Cardiovascular/Heart Twin	It is an AI-supported digital twin of the heart to improve planning and execution of complex heart valve surgeries. Using moving CT or MRI images, the system captures the anatomy and valve dynamics of a patient's beating heart, creating a detailed and dynamic virtual model. This digital heart twin allows surgeons to simulate various surgical strategies—such as placing virtual sutures or implanting valve rings—and observe in real time how these actions would affect valve function. The model can be used during preliminary consultations to plan the optimal surgical approach and is viewable in 3D via AR/VR glasses or on standard monitors, enabling immersive interaction and remote collaboration. In the operating room, the virtual model can be displayed alongside the patient's real heart, providing visual guidance throughout the procedure. This technology aims to enhance surgical precision, reduce risks, and improve patient outcomes. (20)	MINIMAKI	Fraunhofer MEVIS, Siemens Healthineers & German Heart Center Berlin and Charité	Berlin, Germany

Organ-level digital twins offer significant benefits in precision medicine. They enable personalized surgical planning and intervention – rather than relying solely on population-based guidelines, doctors can test a therapy on the patient's own digital organ. This improves procedure success rates and reduces complications. For instance, using a heart twin to plan a valve replacement can highlight if a certain valve size would obstruct blood flow, prompting selection of a better fitting device before surgery. These twins also serve as powerful educational and training tools, giving medical teams a realistic sandbox to practice complex procedures. In cardiology, digital hearts have been used to predict how specific heart conditions (like arrhythmias or heart failure) progress, allowing earlier and more targeted interventions. In research, organ twins provide ethically safe testbeds to study diseases (especially rare ones) and evaluate new treatments. Overall, organ twins can shorten R&D cycles for devices and therapies – "virtual crash-tests" identify failures or optimal designs early, so only the most promising solutions move to real patients. Economically, this may lower development costs and, by improving success rates, reduce the downstream costs of complications or ineffective treatments.

Patient-Level Digital Twins – "Virtual Human Twins"

A patient-level digital twin is a holistic virtual replica of an individual person's health state, integrating data across organs, systems, and time. It is essentially a "digital patient" – a comprehensive, dynamic model that can mirror a person's physiology, diseases, and responses to treatments (21–23). Unlike an organ twin which focuses on one body part, a patient twin spans multiple organs and data domains: it may include the cardiovascular system, metabolic profile, musculoskeletal structure, etc., all interconnected. This type of twin is a dynamic, virtual model of an individual that integrates diverse medical data sources—including electronic health records, imaging, genetic information, and data from personal health devices—to create a comprehensive baseline of their health. This baseline is structured using knowledge graphs or ontologies to ensure interoperability. The twin incorporates interconnected simulations of various bodily systems and conditions, such as heart disease or diabetes, enabling clinicians to explore complex interactions like how heart failure may affect kidney function. Artificial intelligence and machine learning personalize the model based on the patient's unique data, while predictive analytics allow clinicians to run future health scenarios and assess risks of complications. The digital twin

continuously evolves, updating its forecasts with every new data point. Ultimately, it functions as a “virtual patient,” offering clinicians a powerful tool to simulate treatments, monitor health trajectories, and make more informed, personalized medical decisions.

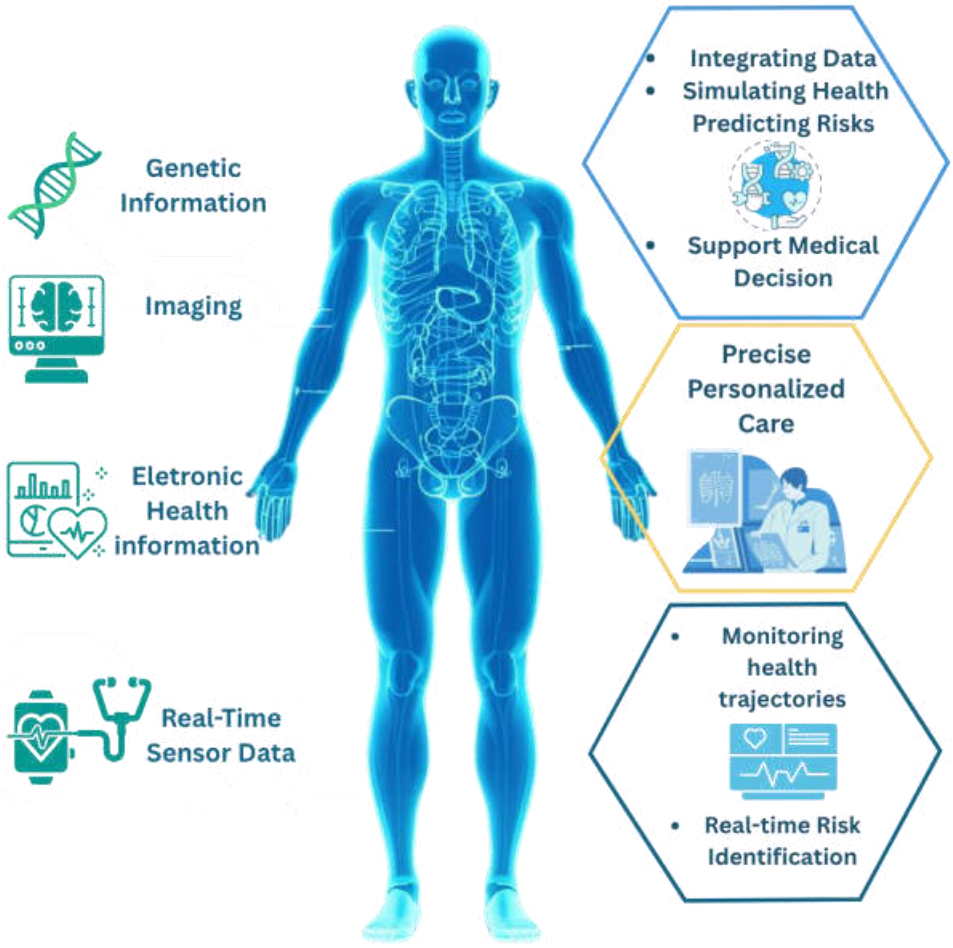


Figure 3. Virtual Digital Patient Twins

Table 2. Real-World Examples

This Table highlights initiatives in patient-level digital twins, particularly in Germany/EU, and their focus

Patient Twin Project	Scope & Focus	Lead Organisations	City/ Country
MED³ICIN	Holistic digital patient model combining an individual's clinical data with population statistics and clinical guidelines. Pilot implementation for chronic conditions (e.g. chronic inflammatory bowel disease (IBD)) demonstrated personalized treatment recommendations and integration of 170+ patient parameters into a cohesive dashboard, improving decisionmaking at University Hospital Frankfurt (DE). (29–31)	Fraunhofer Consortium & University Hospital Frankfurt	Frankfurt, Germany
"Patient Twins*"	R&D program exploring future patient twinning in domains like oncology and cardiology. For example, a concept project follows "Sophia", a fictitious cancer patient, to illustrate how in ~10 years a digital patient twin might seamlessly integrate AI, robotics, and data from all Siemens devices to optimize her lung cancer care at every step. This drives long-term innovation roadmaps (DE). (32)	Siemens Healthineers	Germany
ISPOT-K	The project aims to improve the understanding and treatment of chronic diseases by merging organoids taken from patients with digital twin technology. The project uses organoids, which are three-dimensional, miniaturized organs grown in vitro from patient cells. These organoids mimic the structure and function of the patient's own organs, providing a more accurate model for studying disease mechanisms and testing potential treatments. And digital twin involves creating a virtual replica of a physical object or system and is used to simulate the behavior of the patient's organoids, allowing researchers to predict how the patient will respond to different treatments. By combining organoids and digital twin technology, ISPOT-K aims to develop personalized treatments tailored to the individual patient's unique disease characteristics. (33, 34)	University Hospital Bonn & ESQlabs	Bonn, Germany
Digital Sepsis Twin	An AI-powered rapid overview of clinical parameters for assessing the course of illness in sepsis. Based on the former EFRE-funded SepsisDataNet.NRW, the Digital Sepsis Twin enables data-driven classification into different clusters (A, B, C)—quickly, visually, and individually. The aim of this research is to create a digital twin for personalized sepsis treatment. (35, 36)	Knappschaft Kliniken, University Hospital Bochum & Zentrum für Künstliche Intelligenz Medizininformatik und Datenwissenschaften	Bochum, Germany
EDITH – European Virtual Human Twin	European initiative to unify digital twin efforts across member states . Aims to develop a reference "European Virtual Human Twin" platform by coordinating research on organ and patient twins, addressing legal barriers and interoperability. Focused on enabling personalized medicine and health system planning through widely adopted patient-level twins in Europe. (30)	VPH Institute & EU Partners	Europe

Notes:

* This is a visionary scenario rather than a deployed product, reflecting industry commitment to patient twinning.

Patient-level twins unlock highly personalized healthcare. They are expanding across several key application fields, with patient-level models driving personalized and predictive medicine. At the clinical level, digital twins support individualized treatment planning by simulating a patient's response to various therapies based on their unique health profile, including genomics, physiological data, and disease progression (24). These simulations guide decisions in areas like oncology, cardiology, and diabetes care, optimizing therapy selection and dosing. Another major field is clinical decision support and predictive monitoring, where digital twins continuously assimilate real-time data from wearables or home devices to detect early signs of deterioration in chronic diseases (25). For example, subtle changes in heart failure or COPD patients can be flagged early, allowing timely interventions that prevent hospitalizations. These models enhance proactive care and streamline complex decisions, particularly in multi-morbidity cases. Beyond individual care, digital twins are transforming medical research by enabling the creation of virtual patient populations (23, 26, 27). These synthetic cohorts can be used to simulate clinical trials, especially useful in rare diseases where real-world recruitment is limited (26, 27). Researchers can ethically model thousands of virtual patients to test drug efficacy, optimize trial protocols, and study disease dynamics without putting real patients at risk (27). Initiatives like the European EDITH program are working toward a comprehensive digital twin ecosystem by uniting hospitals, industry, and academia to map existing efforts and build a roadmap for integrating virtual humans into both research and clinical practice (28). Overall, digital twins are reshaping healthcare delivery, diagnostics, and drug development through their ability to simulate, predict, and personalize care.

Patient twins enable precision medicine at its fullest. Patient-level digital twins mark a significant advance toward truly personalized medicine by enabling tailored therapies based on an individual's predicted response, which can improve treatment efficacy and reduce adverse drug reactions through optimized drug selection and dosing. These dynamic models continuously integrate patient data, allowing for proactive and preventive care by detecting early warning signs and prompting timely interventions, which helps prevent emergencies and hospitalizations while enhancing quality of life and reducing healthcare costs. Digital twins also serve as effective communication tools, visually demonstrating the impact of lifestyle choices and medical adherence, thereby motivating patients to engage more actively in their care. In complex cases, digital twins synthesize vast amounts of data into actionable insights, supporting clinicians with integrated analyses and evidence-based recommendations, which streamlines decision-making, ensures more consistent care, and reduces unnecessary procedures. Economically, this

approach can lower costs by minimizing failed treatments and complications, as demonstrated in studies on chronic disease management.

Process-Level Digital Twins – “Virtual Health Gatekeeper Twins”

Process-level digital twins model entire healthcare workflows, operational processes, or even full clinical environments (like a hospital ward or an emergency department) in silico. Unlike a device twin which focuses on a piece of equipment, a process twin focuses on how people, equipment, and activities interact over time. It is essentially a virtual replica of a healthcare service delivery process that learns and evolves with real-world data. Core components include an infrastructure model (hospital blueprint, medical devices), process logic (patient flow rules, scheduling), and data feeds (hospital information systems, IoT sensors) etc.

In Germany, several pilots are underway. The SmartHospital.NRW project (Essen UniMed, Fraunhofer IAIS/MEVIS, RWTH, TU Dortmund, and industry partners) attempt to creat process twins for NRW hospitals. Although focused broadly on AI readiness, several SmartHospital workstreams simulate patient pathways (37, 38). It aims at optimizing the existing clinical workflows and enhance productivity of hospitals, while also improving transparency and fostering better both internal and external collaboration.

Another scenario unfold in a digital twin command center of a large US. tertiary hospital - Johns Hopkins Hospital. A massive digital screen integrates real-time data from emergency departments, wards, and operating rooms—including admissions, surgery schedules, bed occupancy, and patient medical records. Advanced algorithms simulate and forecast hospital operations, predicting patient flows and resource needs for the coming hours. If an ICU bed shortage is anticipated in two hours, the system sends an alert to management and clinical teams, suggesting solutions such as rescheduling surgeries or accelerating discharges. This kind of digital twin-driven coordination improves resource allocation and enhances patient experiences. At Johns Hopkins Hospital, this system reduced emergency-to-ward patient transfers by one-third and surgical delays due to bed shortages by two-thirds within its first year of implementation. Hospital administrators commented that achieving this level of efficiency would be impossible without these intelligent tools.

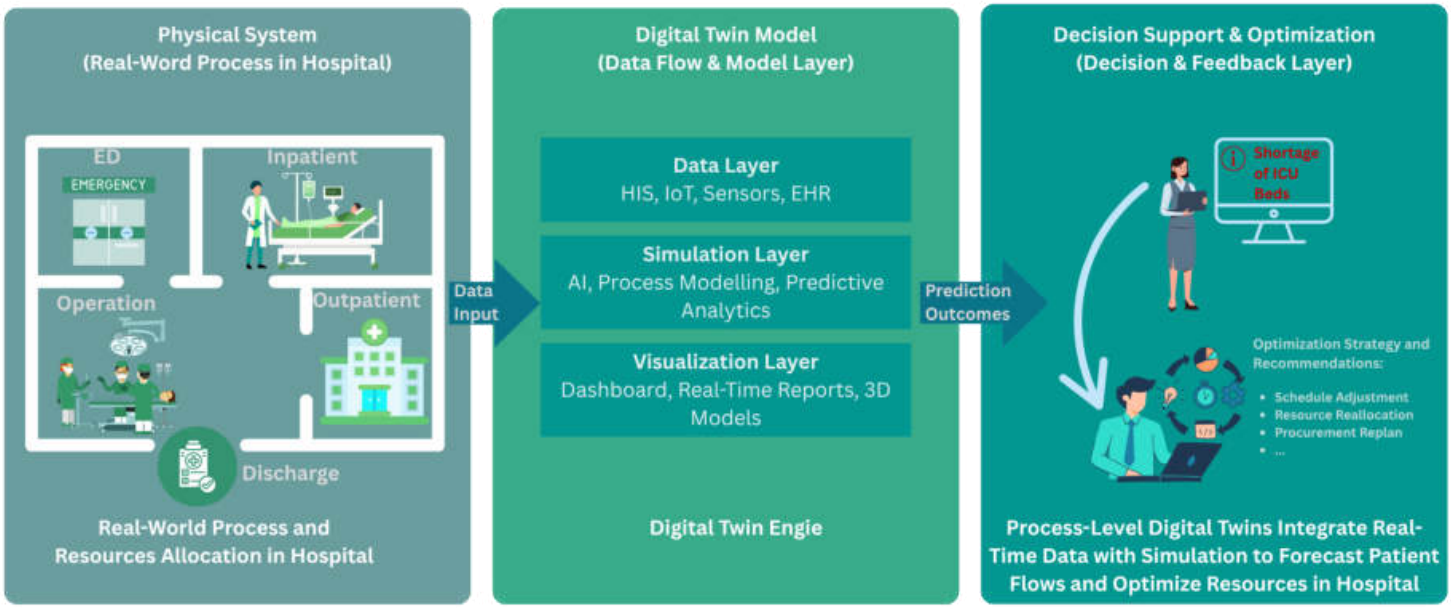


Figure 4. Digital Process Twins

However, the application of digital twins in pharmaceutical companies and medical technology enterprises differs significantly from hospital twins, focusing more on the value chain spanning from R&D, production, supply chain to Compliance. An example is the well-known German pharmaceutical company Merck KGaA, Darmstadt (39). Merck developed a M-Trust™ platform creates digital twins of physical products, effectively linking them with digital identities to enhance traceability and quality assurance throughout the supply chain. Simultaneously, the PharmaLedger Association (PLA) is working to establish a Digital Trust Ecosystem for Healthcare (DTE-H) aimed at uniting stakeholders in the healthcare sector to address complex challenges like supply chain traceability and counterfeit detection. By combining M-Trust™'s digital twin technology with PLA's blockchain framework, a robust and tamper-proof record of product information can be established. This ensures that data related to pharmaceuticals is secure, immutable, and easily accessible to authorized parties. Such transparency allows for real-time tracking of products from production to end-users, significantly reducing the risk of counterfeit drugs entering the market. For patients, this means access to genuine and safe medications, leading to better health outcomes and increased confidence in medical products.

The impact of process-level twins on healthcare systems is increasingly documented. Take economic impact: Operational efficiencies translate to cost

savings, optimized staffing reduces overtime and agency staff costs. On the patient side, improved processes mean better access and quality and certainly improve patient security about medical services and medication. A more smoothly run hospital also tends to have less stressed staff, potentially improving staff retention and well-being, which is a critical indirect benefit in times of healthcare workforce burnout.

In summary, process-level digital twins act as decision support systems for health operations, making healthcare delivery more efficient, adaptable, and data-driven. As the technology matures, we can expect to see them become commonplace in hospital command centers and health system planning departments worldwide.

3. Challenges and Roadmap

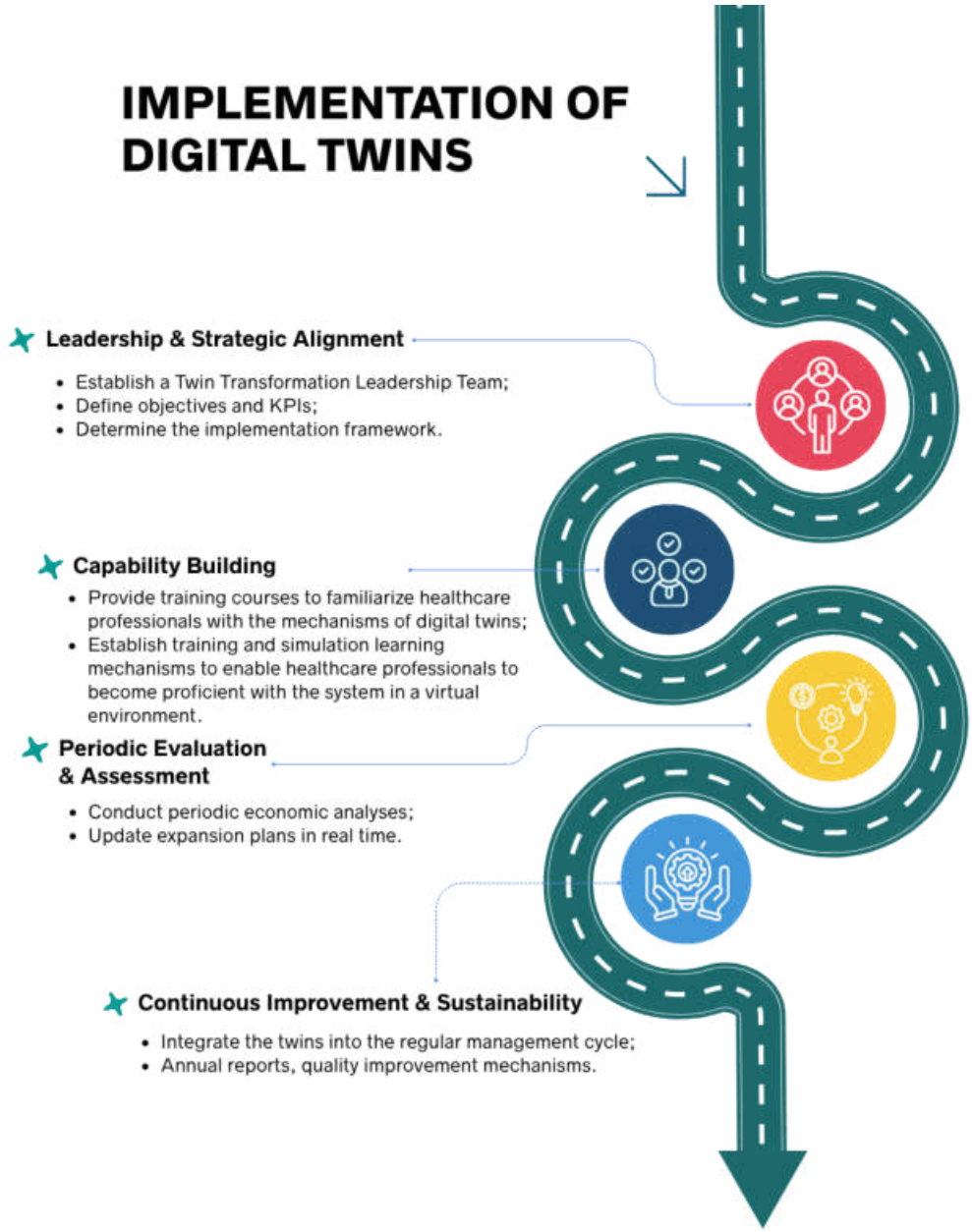
Today, digital twin technologies in healthcare remain predominantly in the research and pilot stages globally, far from being widely implemented in routine clinical care or hospital operations (5, 10). Although some notable examples have emerged, most applications are still in proof-of-concept or early implementation phases (10).

Several major barriers underlie this status quo. First is the issue of data integration. Healthcare data from different sources often lack unified standards and vary in quality, making real-time synchronization and integration a complex task. Ethical and regulatory hurdles further complicate the landscape. Digital twins rely on deep analysis and simulation of patient health data, raising privacy, data ownership, and algorithmic bias concerns. Currently, there are no clear regulatory guidelines covering patient consent, data protection, or the safe validation of digital twin models. From an economic standpoint, implementing high-precision digital twin technologies involves substantial investment in infrastructure, algorithm development, and ongoing maintenance. For resource-constrained healthcare institutions, unclear cost-benefit ratios deter adoption. Without innovative business models or cost-sharing mechanisms, digital twins could exacerbate the digital divide in healthcare.

Despite the challenges outlined above, the future of digital twins in healthcare remains inspiring. Achieving a large-scale application requires health institutions step-by-step acceptance and an individual action plan.

First, digital twins should be seen by healthcare frontline workers as familiar clinical tools. This transition will require learning and adaptation. Hospitals can offer training and simulations to improve trust and proficiency. Additionally, institutions of different scales will follow varied digital twin adoption paths. Large tertiary hospitals, with strong financial and talent bases, can lead the way by co-developing tailored digital twin systems or developing in-house

models for specific clinical needs. These institutions may first deploy twins in high-risk domains like cardiac surgery or ICU management before expanding them across the organization. In contrast, smaller hospitals and primary care centers, facing limited resources, may adopt modular, cloud-based solutions. These systems allow remote digital twin services via web or app, reducing technical and cost barriers. Open-source models also offer an accessible starting point for customization without developing from scratch. Through these flexible pathways, smaller institutions can also board the digital twin train, narrowing the technological gap.



4. Outlook

As a frontier technology in digital healthcare, digital twin technology will exceed hospital boundaries in the future, driving fundamental reforms in healthcare delivery. At the macro level, it holds promise for empowering predictive public health and urban health management. By constructing “health twins” for cities or regions, it can simulate infectious disease trajectories and the long-term health impacts of public policies, enabling precise resource allocation and source-based disease prevention. At the individual level, it may evolve from “patient twins” to “health twins” covering the entire life cycle. This creates a dynamic health model for each person, starting at birth and lasting throughout life, providing comprehensive health management from personalized check-ups and aging predictions to reverse rehabilitation guidance. Its core objective shifts from “treating existing illnesses” to “preventing illnesses before they occur.” At the enterprise level of medical innovation, it will fundamentally reshape R&D processes. By creating vast “virtual patient populations” for digital drug and device testing, this “virtual clinical trials” model will dramatically accelerate the introduction of new therapies, significantly reduce development costs, and offer novel solutions to long-standing challenges like rare disease treatment. Together, these three dimensions outline a future healthcare system that is more resilient, personalized, and fundamentally more efficient.

Key Takeaways

- Digital twins are emerging as a new paradigm for healthcare digitization, capable of both enhancing clinical outcomes and optimizing management in health branches.
- The technology delivers tangible value at three interconnected levels: precision medicine for the individual patient (organ- and patient-level twins) and operational efficiency for the healthcare facility (process-level twins).
- Practical examples from Germany, Europe and US demonstrate that this technology has transitioned from research to initial implementation and is now forming an ecosystem.
- While data quality, interoperability, and resource constraints remain major barriers, healthcare providers can adopt tailored digital twin strategies that match their size, resources, and readiness—ensuring that transformation remains inclusive rather than selective.

References

1. Kamel Boulos MN, Zhang P. Digital Twins: From Personalised Medicine to Precision Public Health. J Pers Med 2021; 11(8).

2. Grand View Research. Healthcare Digital Twins Market Size, Industry Report, 2030. Available from: URL.

3. Market and markets. Digital twins in healthcare market: growth, size, share, and trends; 2025. Available from: URL.

4. Smartspatial. Operational Digital Twins in Healthcare: Revolutionizing Hospital Infrastructure and Equipment Management; 2025. Available from: URL.

5. Katsoulakis E, Wang Q, Wu H, Shahriyari L, Fletcher R, Liu J et al. Digital twins for health: a scoping review. NPJ Digit Med 2024; 7(1):77.

6. Elkefi S, Asan O. Digital Twins for Managing Health Care Systems: Rapid Literature Review. J Med Internet Res 2022; 24(8):e37641.

7. Es-haghi MS, Anitescu C, Rabczuk T. Methods for enabling real-time analysis in digital twins: A literature review. Computers & Structures 2024; 297:107342.

8. Chattopadhyay I, Sizemore N, Oliphant K, Martin C, Claud E. A Digital Twin of the Infant Microbiome to Predict Neurodevelopmental Deficits; 2023.

9. Banoub RG, Sanghvi H, Gill GS, Paredes AA, Bains HK, Patel A et al. Enhancing Ophthalmic Care: The Transformative Potential of Digital Twins in Healthcare. Cureus 2024; 16(12):e76209.

10. Ringeval M, Etindele Sosso FA, Cousineau M, Paré G. Advancing Health Care With Digital Twins: Meta-Review of Applications and Implementation Challenges. J Med Internet Res 2025; 27:e69544.

11. Aluvalu R, Mudrakola S, V UM, Kaladevi AC, Sandhya M, Bhat CR. The novel emergency hospital services for patients using digital twins. Microprocessors and Microsystems 2023; 98:104794.

12. Han Y, Li Y, Li Y, Yang B, Cao L. Digital twinning for smart hospital operations: Framework and proof of concept. Technology in Society 2023; 74:102317.

13. European Commission. European Virtual Human Twins Initiative; 2024. Available from: URL.

14. National Institute for Research in Digital Science and Technology, France. Health: a European ecosystem for digital twins; 2024. Available from: URL.

15. Fraunhofer-Institut für intelligente Analyse- und Informationssysteme IAIS. KI Anwendungsfälle. Available from: URL.

16. French Healthcare. Dassault Systèmes caused a surprise at CES with its digital twins of the human body; 2023. Available from: URL.

17. Gesundheit-Muensterland. 3D-Center: Implantate, Modelle und Instrumente nach Maß am „Point-of-Care“; 2024. Available from: URL.

18. Thum M. Innovatives 3D-Druck-Center an der Uniklinik Münster eröffnet; 2024. Available from: URL.

19. Bavarian BIOTECH Cluster Development. BIOTECH IN BAVARIA: INCUBATING

SCIENCE FOR HEALTH, Report 2023/24. Available from: URL.

20. Fraunhofer Institute for Digital Medicine MEVIS. Precise Planning for Heart Surgery. Available from: URL.

21. Fraunhofer-Gesellschaft. Digital Patient Twins for Improved Diagnosis and Treatment; 2025. Available from: URL.

22. Chandra S, Prakash PKS, Samanta S, Chilukuri S. ClinicalGAN: powering patient monitoring in clinical trials with patient digital twins. Sci Rep 2024; 14(1):12236.

23. Moingeon P, Chenel M, Rousseau C, Voisin E, Guedj M. Virtual patients, digital twins and causal disease models: Paving the ground for in silico clinical trials. Drug Discov Today 2023; 28(7):103605.

24. Domenico M de, Allegri L, Caldarelli G, d'Andrea V, Di Camillo B, Rocha LM et al. Challenges and opportunities for digital twins in precision medicine from a complex systems perspective. NPJ Digit Med 2025; 8(1):37.

25. Riahi V, Diouf I, Khanna S, Boyle J, Hassanzadeh H. Digital Twins for Clinical and Operational Decision-Making: Scoping Review. J Med Internet Res 2025; 27:e55015.

26. Wang H, Arulraj T, Ippolito A, Popel AS. From virtual patients to digital twins in immuno-oncology: lessons learned from mechanistic quantitative systems pharmacology modeling. NPJ Digit Med 2024; 7(1):189.

27. Zhao C, He H, Ma H. Editorial: Virtual patients and digital twins in the systems analysis of drug discovery and development. Front. Syst. Biol. 2023; 3.

28. European Virtual Human Twin. Building the European Virtual Human Twin. Available from: URL.

29. Fraunhofer-Gesellschaft. Forschung Kompakt: Fraunhofer-Institute stellen ersten Prototypen für digitalen Patienten-Zwilling vor; 2021. Available from: URL.

30. Institut national de recherche en science & technologies du numérique. Health: a European ecosystem for digital twins; 2024. Available from: URL.

31. Fraunhofer Institute for Computer Graphics Research IGD. Video: Der Digitale Zwilling im Gesundheitswesen; 2022 2022 Sep 22. Available from: URL.

32. Siemens Healthineers. Patient twin: Why Sophia is no longer afraid of cancer. Available from: URL.

33. Universität Bonn. Mit „Mini-Tumor“ und digitalem Zwilling zur personalisierten Krebstherapie; 2025. Available from: URL.

34. Deutsches Ärzteblatt. Bonn: Mini-Tumore und digitale Zwillinge sollen personalisierte Therapien bei Darmkrebs verbessern; 2025. Available from: URL.

35. Knappschaft Kliniken GmbH; 2025 2025 May 26. Available from: URL.

36. Knappschaft Kliniken Universitätsklinikum Bochum. Künstliche Intelligenz trifft Spitzenmedizin: Ein Blick ins Zukunftslabor der Knappschaft Kliniken Universitätsklinikum Bochum; 2025. Available from: URL.

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ATLAS ITG Project

The project “Innovation and Digital Transformation in Healthcare” (ATLAS-ITG), funded by the State of North Rhine-Westphalia through the Ministry of Economic Affairs, Industry, Climate Action and Energy, provides science-based solutions to practical challenges in the digital transformation of the healthcare sector.

ATLAS conducts socio-scientific analyses on the impact of digitalization in the healthcare economy, connects lighthouse projects across North Rhine-Westphalia, and supports theory-to-practice transfer by summarizing current research findings and contextualizing technological innovations through use cases for health professionals.

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Witten/Herdecke University

The ATLAS project is based at the Faculty of Management and Society and specifically at Chair of Management and Innovation in Healthcare at Witten/Herdecke University.
Our chair’s research team focuses on economic issues within and between organizations in the healthcare sector. As a member of the Interdisciplinary Center for Health Services Research (IZVF), the chair contributes to the description, explanation, testing, and evaluation of concepts aimed at ensuring high-quality healthcare delivery.

More about the Chair: http://www.uni-wh.de/MIG
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