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OPINIONS/PERSPECTIVE/POINT OF VIEW

Trust By Design: Enabling Responsible Precision Health Through Blockchain-Powered Digital Twins And Trusted AI

Ingrid Vasiliu-Feltes[1,2,3]; Christina Yan Zhang[4]; Stephen Dennis[2]; Elliot Siegel[2,5,6] and Daniel Uribe[7]

[1]Institute SEI, USA; [2]Softhread, USA; [3]The Center for Excellence for Digital Twins in Healthcare, Partners in Digital Health Institute, USA; [4]The Metaverse Institute, UK; [5]University of Maryland, USA; [6]United Theranostics, USA; [7]Genobank.io, USA.

Corresponding author: Ingrid Vasiliu-Feltes, Email: ivfeltes@miami.edu

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Abstract

The Executive Session, Trust by Design: Enabling Responsible Precision Health through Blockchain-Powered Digital Twins and Trusted AI, explores how the convergence of blockchain, artificial intelligence, genomics, 6G wireless technology, and other advanced technologies can be leveraged to power precision health digital twins. The dialogue focused on governance, interoperability, cybersecurity, and the impact of blockchain and trusted AI-powered digital twins on advancing precision healthcare and personalized medicine. Use cases—for genomics, radiology, theranostics, and end-of-life care—illustrated both opportunities and barriers. Throughout the discussion, speakers emphasized the centrality of trust, patient sovereignty, and resilient infrastructures for the next generation of healthcare.

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Precision health is reshaping medicine by moving away from reactive models toward preventative, continuous, and patient-centered care. This evolution depends heavily on integrating advanced technologies, particularly blockchain, artificial intelligence (AI), genomics, 6G wireless technology, and the Internet of Things (IoT) to power healthcare digital twins.

These tools promise secure, interoperable, and transparent infrastructures capable of delivering hyper-personalized, precision healthcare. At the same time, they raise pressing questions about governance, compliance, standards, and cyber-ethics, given the current lagging or divergent global frameworks. Our experts examined these tensions while highlighting opportunities to create healthcare ecosystems grounded in trust by design.

Literature Review

Scholarly research publications underscore the use of digital twins in healthcare, often in conjunction with blockchain, AI, and federated learning. Singh et al. consider digital twins in the broader metaverse, noting how blockchain strengthens accountability and patient trust.[1] El-Din and Amged provide a technical exploration of architectures that combine blockchain with federated learning to improve security and resilience.[2] A meta-review by Etindele Sosso et al. consolidates findings across multiple applications, drawing attention to persistent issues such as data integration, cost, and ethical compliance.[3]

Researchers have also examined system-level implications. Oulefki et al. highlight the capacity of digital

twins and AI to enable more robust, data-driven decision-making.[4] Wu et al. demonstrate how federated digital twins optimized with AI can improve scalability and efficiency across distributed health systems.[5] Roopa and Venugopal underscore the requirements for resilient cyber-physical architectures capable of supporting complex healthcare operations.[6]

Frameworks that synthesize existing work are increasingly important. Pellegrino et al. present a systematic meta-review pointing to the need for harmonized governance and global standards.[7] De Oliveira El-Warrak and Miceli de Farias emphasize the potential societal and public health impact of digital twins, while Jain et al. provide a taxonomy of architectures, applications, and organizational challenges.[8,9]

Recent contributions also focus on blockchain-enabled digital twins. Repetto et al. propose predictive models leveraging federated learning to improve accuracy and privacy.[10] Vallée stresses the role of epidemiological data and advanced modeling in ensuring reliable outcomes for personalized medicine.[11] Together, these studies underscore three recurring themes: (1) the promise of hyper-personalized and preventative care, (2) the need for secure and interoperable systems, and (3) the persistent challenges of scale, governance, and ethics.

Executive Session Summary

Moderated by Prof. Dr. Ingrid Vasiliu-Feltes, the participants emphasized that digital trust is the center of precision health innovation and personalized care. Each speaker's contributions revolved around governance, standards, interoperability, cyber-ethics, and use cases. The broad impact on wellness, disease prevention, chronic disease management, oncology, and end-of-life care was highlighted.

Across the session, speakers agreed on the urgent need to leverage the advanced capabilities offered by blockchain, privacy-preserving AI tools, and digital twinning to deliver secure, precise, and personalized care.

Session Highlights

Dr. Christina Yan Zhang

- Focus: The convergence of advanced technologies, global standards, and interoperability.
- Insight: The integration of blockchain, AI, and 6G for digital twins will profoundly reshape global precision health ecosystems.

Prof. Dr. Stephen Dennis

- Focus: The role of cybersecure digital twins in precision health and personalized medicine.
- Insight: Blockchain and privacy-preserving AI-powered digital twins offer tamper-resistant structures that strengthen cybersecurity, though deployment challenges persist.

Prof. Dr. Elliot Siegel

- Focus: Leveraging blockchain and trusted AI in digital twins for radiology, theranostics, and end-of-life care.
- Insight: Emphasis on interoperability and patient data ownership.

Mr. Daniel Uribe

- Focus: Role of genomics and leveraging Biosample NFTs to improve personalized medicine.
- Insight: BioNFTs represent a promising approach to patient data sovereignty, giving cryptographic proof of identity and ownership at the start of the digital twin lifecycle.

Discussion Summary

Precision health and personalized medicine can succeed only when trust is embedded by design. The session explored how permissioned blockchain and trusted, AI-powered digital twins can offer that trust foundation—delivering secure, transparent, and patient-centric care.

As health systems pivot toward precision models, the convergence of blockchain, trusted AI, digital twins, genomics, and adjacent technologies (edge/IoT, 6G) offers a transformative path to resilient and ethical care.

The experts emphasized governance, global standards, interoperability, and cybersecurity as non-negotiable enablers. Cybersecurity scrutiny must intensify as multiparty ecosystems scale. Industry leaders showcased blockchain innovations for clinical trials, medical IoT, and privacy-preserving data architectures. In particular, permissioned ledgers with fine-grained access control and dynamic consent can streamline trial participation, automate reporting, and give patients and institutions accountable control over data flows.

They agreed that advances in blockchain and trusted AI-powered digital twins will reshape wellness, prevention, diagnosis, treatment, and chronic care—provided secure data handling, provenance verification, and robust communication protocols are in place.

While digital twins expand collaboration, they also widen attack surfaces; integrating permissioned blockchain with publish-subscribe patterns allows authenticated patients, providers, regulators, and manufacturers to exchange data securely, creating security-by-design, verifiable audit trails, and regulated access.

A major focus was imaging and radiology: moving from static snapshots to dynamic, predictive, and preventive models. Continuously updated twins can empower patients, improve interoperability, and

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support sovereign data control—helping rebuild trust between patients and clinicians. Looking ahead, 6G-class real-time flows and edge intelligence are expected to enable hyper-personalized care, where virtual patient replicas let teams simulate therapies (theranostics) before deployment. Speakers noted rapid market growth through 2030, driven by demand for personalization and prevention; AI across millions of twins can accelerate early detection, reduce costs, and improve outcomes.

The benefits of blockchain-powered digital twins are extensive and facilitate secure, interoperable, and auditable precision healthcare—although this discussion highlighted only a subset in depth:

- Compliance automation: immutable logs and real-time attestations streamlining HIPAA/GDPR/EU AI Act audits for trials, algorithm updates, and prior authorization.
- Privacy-preserving computation: orchestrated ZKPs—Zero-Knowledge Proofs, MPC—Secure Multiparty Computation, FHE—Fully Homomorphic Encryption, and TEEs—Trusted Execution Environments
- Immutable provenance and lineage, supporting reproducibility audits, explainability, and defensible clinical reporting.
- Fault-tolerant resilience
- Deterministic release governance
- Verifiable data integrity
- Cross-domain interoperability

In addition, the discussion underscored the advantages of privacy-preserving technologies:

- Differential privacy that can safeguard patient identity in cohort analytics and population twins by adding calibrated noise, enabling useful statistics without re-identification.
- Homomorphic encryption for enabling encrypted risk scoring and therapy simulations on twin data across institutions or clouds without exposing raw-omics, imaging, or PHI.
- Secure multiparty computation that permits various healthcare stakeholders to jointly train twin models or compute biomarkers without sharing raw data, preserving confidentiality while combining insights.
- Federated learning and secure aggregation that allow training twin models from EHRs and other medical devices.
- Trusted execution environments that can run twin training or inference inside attested enclaves, protecting code and inputs from cloud admins, co-tenants, and malware.
- Zero-knowledge proofs that can verify compliance, provenance, or eligibility (e.g. trial matching) using twin evidence without revealing sensitive attributes or raw records.
- Private information retrieval, allowing clinicians to query longitudinal twin repositories without exposing query terms, reducing metadata leakage, and sensitive-interest profiling.
- Searchable encryption, supporting keyword or semantic search over encrypted twin archives—imaging, notes, and -omics—maintaining confidentiality during discovery.
- Attribute-based encryption that enforces fine-grained, purpose-bound access to twin layers (genomics, imaging, device telemetry) aligned with dynamic, revocable patient consent.
- Differentially private synthetic data that can enable sharing of realistic twin datasets for research and regulatory sandboxes while protecting individuals against re-identification.

Consensus

The consensus among the participants was related to the overall benefits of digital twins in precision health and personalized medicine. Each speaker underlined different portions of this continuum, and how they interlock to advance value.

Beginning with wellness, continuously updated personal twins fuse wearables, labs, and lifestyle signals. Permissioned ledgers capture consent and lineage, while trusted AI personalizes coaching and verifies that recommendations trace back to authenticated data and models. These same foundations drive disease prevention: federated risk models operate across institutions without moving protected health information, and smart contracts close care gaps with documented adherence and outcomes on immutable audit trails.

At population scale, digital twins support disease eradication. Cohort-level simulations test intervention strategies before deployment; zero-knowledge proofs validate coverage and compliance metrics without exposing identities; tamper-evident surveillance improves outbreak detection and response. Early diagnosis benefits from privacy-preserving analytics—secure multiparty computation, fully homomorphic encryption, and trusted execution environments—so multiomics and imaging patterns can be analyzed pre-symptomatically while preserving confidentiality and proving pipeline integrity through cryptographic provenance.

More precise diagnosis follows through multimodal fusion. Twins can integrate (Digital Imaging and Communications in Medicine (DICOM) imaging, -omics, Health Level Seven (HL7), and device telemetry; blockchain anchors end-to-end integrity, while explainable, attested models can produce traceable differentials

and variant interpretations. Personalized therapeutics and theranostics then leverage in-silico simulations to optimize dosing, device parameters, and combinations before bedside deployment. Smart contracts encode indications, contraindications, and dynamic consent—supporting adaptive trials and real-world learning with verifiable auditability.

In chronic disease management, signed, sequenced telemetry from wearables, implantables, and bedside devices prevents spoofed vitals and preserves continuity of care. Policy-as-code automates pathway transitions, refills, and payer reporting, tying adjustments to measurable, verifiable outcomes. Oncology care is accelerated by tumor-centric twins that track clonal evolution and therapy response; federated learning refines predictors across centers, while cryptographic audit trails reinforce protocol adherence and compassionate-use governance. For terminal illness and end-of-life care, advance directives, guardianship, and Provider Orders for Life-Sustaining Treatment (POLST) reside on permissioned chains with time-scoped, revocable access; symptom control and care coordination align with documented patient wishes across settings.

Longevity and healthy aging benefit from lifespan twins that forecast frailty and polypharmacy risks and orchestrate preventive interventions. Selective-disclosure credentials enable secure cross-border care, and longitudinal provenance supports equity-aware programs that integrate social determinants alongside clinical data.

Taken together, these perspectives converged on a single thesis: blockchain and trusted AI can elevate digital twins from promising pilots to a verifiable, privacy-preserving, scalable operating system for global precision health.

Our expert speakers elaborated on two illustrative pilots. One for how blockchain and trusted AI-powered digital twins can manage end-of-life directives and the other for the impact of genomic medicine for newborns. While speakers shared only a few potential applications during this executive roundtable, many other use cases are feasible across the precision health and personalized medicine continuum.

All guest speakers accentuated the ongoing challenges we must address:

- Global legal & regulatory fragmentation
- Standards misalignment
- Interoperability gaps
- Cyber-ethics silos
- Costs

All speakers were aligned on the future of precision health and personalized medicine. Blockchain and trusted AI-powered digital twins will be anchors for trusted, secure, responsible, and patient-centric care. Realizing that promise requires harmonized regulations and standards; privacy-preserving AI and permissioned blockchain with audit-by-design; interoperable identity and consent; secure, edge/6G-ready infrastructure; and embedded cyber-ethics and equity safeguards. With these foundations, health systems can scale from early exemplars to a comprehensive, trustworthy precision health ecosystem.

Future Directions

Blockchain and trusted AI-powered digital twins represent a powerful foundation for advancing precision health and personalized medicine. They hold the capacity to reorient healthcare toward preventative, equitable, and sovereign models of care. Realizing this vision requires harmonized global standards, interoperable architectures, embedded cyber-ethical safeguards, and scalable infrastructures. Building systems around trust by design ensures that the convergence of advanced technologies can deliver secure, transparent, and patient-centered healthcare.

As scientific breakthroughs and technology converge, digital twins will also benefit from nanotechnology and bioimplant-generated datasets and will likely expand the precision and granularity of physiological monitoring. Nanotech-based biosensors and implantable devices can continuously feed high-fidelity, real-time data into digital twin ecosystems, enabling earlier detection of disease onset and more accurate therapeutic interventions.

The rise of multi-agentic AI and physical AI will further enhance healthcare operations. Multi-agentic AI allows for decentralized, cooperative intelligence across patient care networks, while physical AI embodied in robotics enables real-time actuation of personalized treatment plans, surgical assistance, and rehabilitation support informed directly by digital twin simulations.

Multiomics integration—encompassing genomics, proteomics, metabolomics, and beyond—will enrich the knowledge base that underpins digital twins, ensuring that patient models are biologically comprehensive. This integration enables hyper-personalized medicine, where interventions are optimized not only for disease type but also for each individual's unique molecular profile.

In parallel, quantum computing and quantum simulation have the potential for radical acceleration of the computational power available for modeling complex biological systems within digital twins. Quantum-enhanced simulations of protein folding, drug–receptor interactions, or population-scale epidemiological models can refine personalized treatment recommendations and accelerate drug discovery. Quantum-driven optimization also strengthens predictive analytics, enabling more robust early warning systems for both individual patients and public health.

Brain–computer interfaces (BCIs) will likely augment blockchain and trusted AI-powered digital twins by

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directly integrating neural signals into patient models. This enhances real-time monitoring of cognitive and neurological health, enabling more precise diagnostics, adaptive neurotherapies, and hyper-personalized treatment plans while preserving sovereignty and data integrity through secure, ethical infrastructures.

Together, the convergence of blockchain and trusted AI-powered digital twins with other advanced technologies forms the blueprint for the next generation of precision health. This integrated ecosystem promises to advance predictive, preventative, and participatory medicine, where patients are empowered collaborators, healthcare is adaptive and anticipatory, and data are secured, transparent, and ethically governed on a global scale.

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Application of AI-Generated Text or Related Technology

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