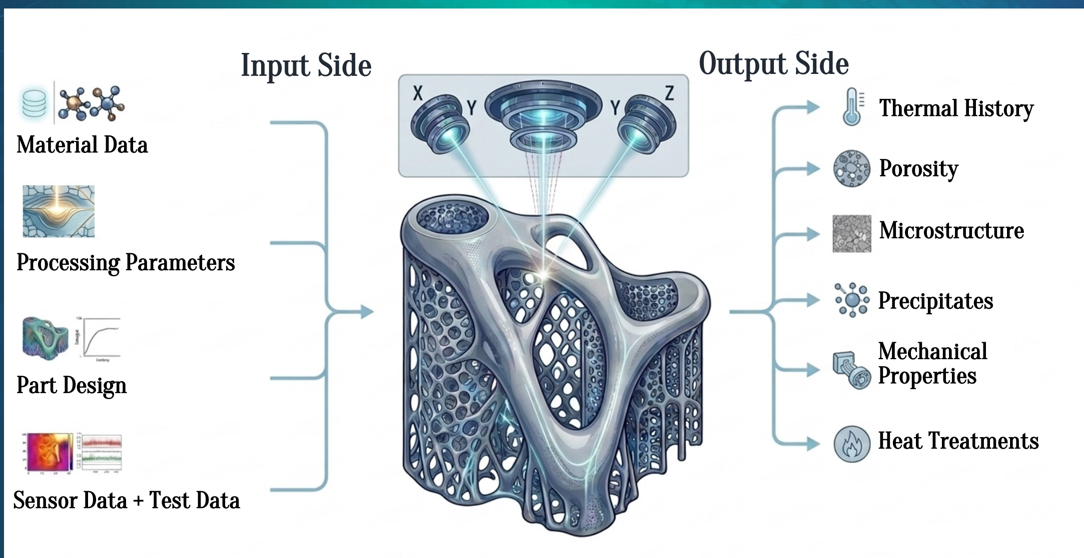
Whitepaper

Self-Evolution

From First Principles to Pre-qualification

SynaCore AM-DT Digital Twin



SynaCore
Drive physical manufacturing with virtual intelligence
www.synacore.net

Preface

Begin with the first principles

Self-Evolving Pre-Qualification Mechanism

Begin with the first principles

Recently, a colleague in the industry asked SynaCore's CTO, Dr. Guglielmo Vastola, "Why is it that the software architecture and algorithms of digital twin are static, yet it can be deeply adapted to different additive manufacturing equipment, giving each device its own unique 'brain'?"

Dr. Vastola's answer is simple:
The AM-DT digital twin is rooted in "first principles."

In digital twinning, "twin" means mirroring the real physical world, while "self-evoliving" inside of the "twin", hence twinning represents the vitality of self-evolution.

So, what exactly are these "first principles"? How do they operate from the most fundamental laws of physics to truly impact the manufacturing floor? How can they drive a leap in manufacturing paradigms and ultimately reshape our understanding of quality and certification?These are precisely the questions this whitepaper seeks to explore and answer. It is not just about technology—it is about rethinking manufacturing itself: moving from rigid processes and repeated human trial-and-error toward a continuously evolving and intelligent system. And this self-evolving capability of infinitely approaching physical manufacturing will ultimately bring about a paradigm shift in quality inspection.

Today, standing at a critical juncture in the development of the additive manufacturing industry, I deeply feel that we are at a historic turning point. The traditional manufacturing paradigm—based on trial-and-error experience, dependent on extensive destructive testing, and requiring certification cycles of years or even decades—is being replaced by an entirely new paradigm. At the core of this new paradigm lies Digital Twin technology, and its ultimate form will be the deep integration of Self-Evolution and Pre-Qualification.

Over the past two decades, the additive manufacturing industry has achieved remarkable technological advancements. However, we must confront a harsh reality: from laboratory innovation to industrial mass production, several formidable chasms still stand in the way. The first-principles insights into these chasms are elaborated in detail in the SynaCore whitepaper "Scaling Up." In this whitepaper, we focus on one of these chasms—Qualification—and provide a detailed analysis of its development trends.

To understand why qualification in additive manufacturing is so challenging, we must recognize that the root cause lies in our understanding of the manufacturing process being lagging, localized, and empirical. We manufacture a part, then verify through various inspection methods whether it meets requirements. If problems arise, we adjust parameters, manufacture again, inspect again—repeating this cycle until sufficient data is accumulated to "prove" the reliability of the process.

This model may work in traditional subtractive manufacturing because those processes have undergone decades of optimization and standardization. But for additive manufacturing—a complex process involving multi-physics coupling, cross-scale phenomena, and highly nonlinear behavior—the traditional qualification model has hit the ceiling of efficiency.

First Principles: Returning to the Origin of Physics

At SynaCore, we believe the key to solving this dilemma lies in returning to first principles.
What are first principles? They are not empirical formulas, not fitted curves, but modeling methods that derive system behavior directly from the most fundamental laws of physics. Newtonian mechanics tells us how the melt pool flows. Maxwell's equations describe how lasers interact with materials. Boltzmann's equation reveals how heat transfers at the atomic scale and influences the evolution of microstructures. Thermodynamic laws constrain the boundaries of phase transformation and solidification.

Process development that originally took months can now be completed in days; performance data that required destructive testing can now be obtained through digital twin simulation predictions.

With the foundation of digital twin, SynaCore is driving the paradigm of Physics-Informed Machine Learning, which combines Digital Twins with AI, is fundamentally changing how we develop processes, predict performance, and validate quality. We no longer need thousands of tests to "cover" all possible parameter combinations—physical models tell us which combinations are physically impossible, while AI efficiently come up with optimal solutions within the physically feasible domain.

Begin with the first principles

Self-Evolution: From "Human-Driven" to "Intelligence-Driven"

If first principles provide us with the "telescope" to understand manufacturing processes, then the self-evolution mechanism equips us with the "engine" for continuous improvement.

Traditional digital twins are static—they are digital mappings of physical entities at a specific moment in time. Self-evolving digital twins, however, are dynamic, learning, and evolving. Through continuous sensor data feedback, they constantly calibrate and update their model parameters. Through physics-based reasoning, they quantify prediction uncertainty and identify "knowledge boundaries." Through active learning, they intelligently select the most valuable experiments to fill knowledge gaps.

Digital twins will become valuable assets for manufacturing enterprises. SynaCore's digital twin system becomes more accurate with use. Every manufactured part contributes data to the system, and the wisdom elevated through digital twins and AI will empower manufacturing enterprises to improve part quality and manufacturing efficiency. Every comparison between prediction and reality enhances model accuracy. This is a "model-data symbiosis" evolution mechanism—the core characteristic that distinguishes SynaCore AM-DT Digital Twin as a digital asset from traditional simulation software.

Furthermore, self-evolution occurs not only at the individual part level but also across the entire manufacturing system. From parameter optimization of individual lasers to coordinated control of multi-laser systems; from process development of single machines to intelligent scheduling of entire workshops—self-evolving digital twins are building an adaptive, self-optimizing intelligent manufacturing system.

Pre-Qualification: From "Post-Hoc Verification" to "A Priori Assurance"

The ultimate value of self-evolution lies in achieving Pre-Qualification—before a part is physically manufactured, high-fidelity digital twin simulations predict its performance, verify its reliability, and generate its "digital birth certificate."

This represents a fundamental paradigm shift: from a linear "manufacture-inspect-qualify" process to a closed-loop "simulate-optimize-verify-manufacture" process. We no longer rely on extensive post-hoc destructive testing to "prove" parts are qualified; instead, we "guarantee" parts are qualified through physically rigorous digital twin simulation predictions.

The significance of this transformation for the industry is profound. More importantly, pre-qualification lays the foundation for distributed manufacturing and digital supply chains. When a part's "digital birth certificate" can be verified anywhere in the world, manufacturing is no longer constrained by geographical location but can be completed closest to where it is needed—this will fundamentally reshape the landscape of global manufacturing.

Progressive Pre-Qualification: Physics-Based Evidence Accumulation

Following each build, retrospectively validated correlations between thermal paths and microstructures are archived as traceable quality records. This physics-based accumulation of evidence transforms traditional static qualification into an incremental quality assurance process: the digital twin's physical interpretability of material-process-performance relationships establishes its accumulated data and predictions as the reliability evidence required for pre-certification.

Begin with the first principles

In the near future, product-level digital twins will significantly extend the service life of high-value components through full-lifecycle performance tracking and predictive maintenance, reducing replacement frequency and resource consumption.

At SynaCore, we firmly believe that the ultimate value of technology lies not in the technology itself, but in how it serves the sustainable development of human society. Digital twins are not meant to replace humans with machines, but to liberate people from repetitive trial-and-error to focus on more creative work. They are not meant to manufacture more products, but to manufacture better products—lighter, stronger, more durable, and more environmentally friendly products.

In the future, self-evolving digital twins will connect additive manufacturing equipment worldwide, forming an intelligent, adaptive manufacturing network. Materials scientists, process engineers, designers, and regulators—all can achieve leaps in their creative, manufacturing, and regulatory capabilities through digital twins and artificial intelligence.

Roots and Evolution: From Research Foundations to Shared Future

SynaCore's origins are rooted in years of fundamental research from the Agency for Science, Technology and Research (A*STAR) Institute of High Performance Computing (IHPC) and the support of its brother institute, the Institute of Materials Research and Engineering (IMRE). Its development is indebted to the strategic backing of the National Additive Manufacturing Innovation Cluster (NAMIC), the expertise and support in advanced manufacturing technologies from the Singapore Institute of Manufacturing Technology (SIMTech), the National University of Singapore (NUS), Nanyang Technological University (NTU), and the Singapore University of Technology and Design (SUTD), as well as the strong support from the extensive A*STAR Additive Innovation Centre (AIC) ecosystem—spanning materials to manufacturers across diverse fields—throughout the R&D of the AM-DT additive manufacturing digital twin software.

SynaCore Vision

"Driving Physical Manufacturing with Virtual Intelligence"

It is also thanks to the trust and feedback from our early users. Benefiting from close interaction and deep collaboration with the application end, AM-DT has been continuously validated, refined, and perfected during its development, ultimately honed into a mature and reliable software proven in practice. It provides a solid foundation for the application and innovation of additive manufacturing technology. Here, on behalf of the SynaCore team, I extend sincere gratitude to everyone who has contributed love and support to this journey.

No two leaves are alike， Just as a leaf follows the immutable laws of photosynthesis and vascular structure while responding to its own unique interplay of light and wind, so do the machines of different OEMs vary, as do the parts produced by different manufacturers. Digital twins evolve alongside their physical counterparts, adapting to specific thermal histories, material batches, and geometric contexts. No two prints are identical, just as no two leaves are identical; yet all belong to the same living system, governed by universal physical truths.

SynaCore iterates rapidly to stay aligned with market realities. We believe digital twins should be appreciating assets—compounding in value through use, not depreciating like consumables.

Request trial access at www.synacore.net. This is a partnership: your operational insights directly improve our platform, while you develop proprietary digital assets unique to your processes. Quality emerges from authentic collaboration, if you encounter an issue or have a suggestion, we would love to hear it from you.

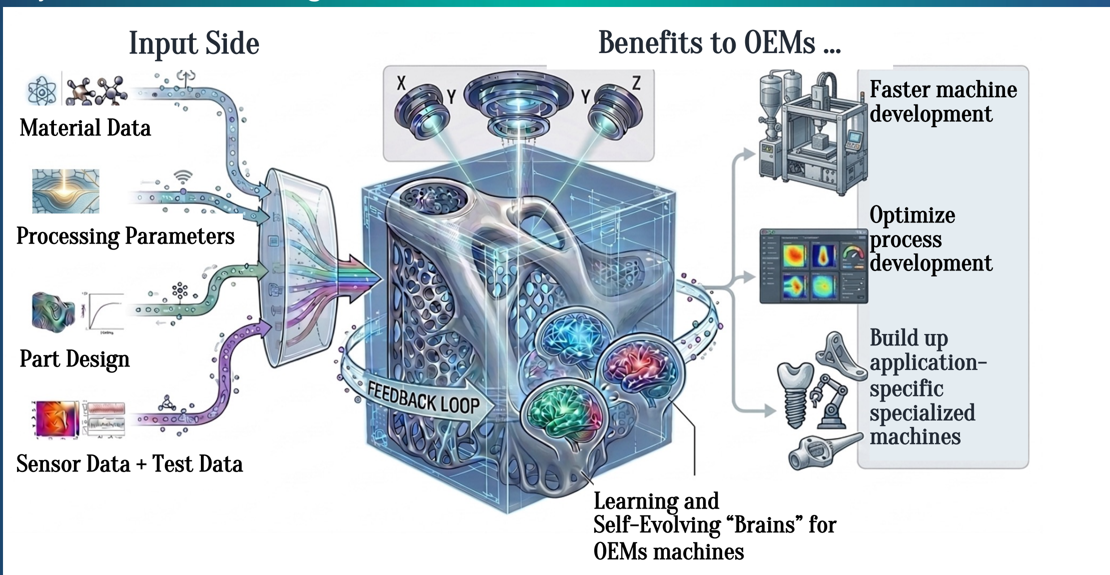
Let's advance additive manufacturing together——drive physical manufacturing with virtual intelligence.

XiaoYan (Kitty) Wang / CEO of SynaCore

First Principles

Grounded in First Principles Physics, SynaCore AM-DT transforms algorithms into living intelligence, enabling different OEM's additive manufacturing machine to evolve its own unique brain. Empowered by these machine brains, manufacturers can not only illuminate the "black box" of manufacturing processes to accelerate equipment iteration and enhance parameter optimization, but also develop application-specific specialized machines tailored to diverse industrial needs.

SynaCore AM-DT Digital Twin for OEMs



Based on First Principles

Rooted in First Principles, SynaCore AM-DT's physics foundation models serve as the meta-language that empowers diverse machine manufacturers to cultivate distinct intelligent "Brains" for their equipment—each self-evolving within the universal framework of physical laws

First Principles Characteristics

01 Rooted in universal physical laws

02 Physics-based solver integration

03 High-fidelity simulation capacity

04 Domain-specific uniqueness

Physical Consistency

Strictly adhere to energy, momentum, and mass conservation laws

Cross-Scale Scalability

First principles models can naturally transition from atomic scales to macroscopic scales. This multi-scale consistency enables SynaCore digital twin's physics foundation models to simultaneously predict microstructures (grain size, phase composition) and macroscopic properties (mechanical properties, residual stress).

Extrapolation Capability

Because they are based on universal physical laws, first principles models have far superior extrapolation capabilities to pure data-driven models when dealing with new materials and new process parameters.

Question:
How does a static-architecture digital twin empower every additive manufacturing machine with its own unique "brain" and self-evolving capabilities?

Answer:
Through first principles, SynaCore "translates" the additive manufacturing process into mathematical descriptions of physical processes (meta-language), unifying hardware differences within the framework of physical laws. Upon this foundation, equipment from different brands cultivates individualized decision-making hubs ("Brain")—device-specific intelligence capable of continuous learning and continuous optimization—based on their unique operational data, material responses, and environmental disturbances.

SynaCore AM-DT Physics Foundation Models simulate:

- Newtonian mechanics
- Maxwell's equations
- Boltzmann's equation
- Thermodynamic laws ...

The Physics Foundation Models of SynaCore AM-DT developed by Singapore's A*STAR Institute of High Performance Computing (IHPC) represent the underlying architectural innovation of additive manufacturing digital twin technology.

These models can simulate fundamental physical laws such as Newtonian mechanics, Maxwell's equations for electromagnetism, and Boltzmann's equation, using surrogate data generated by physics-based solvers to construct high-fidelity simulation frameworks.
To explore the uniqueness of SynaCore AM-DT, please read further information about SynaCore AM-DT for simulation, SynaCore Advanced Mesher, SynaCore AI Alloy and SynaCore Adaptive Tool Path in the following pages.

Based on First Principles

Digital DNA: The Uniqueness Factor

Unlike generic AI models, **first principles models are rooted in fundamental physical laws**, creating distinct "Digital DNA" for each implementation based on their specific physical contexts, materials, and process parameters.

Tailored Intelligence

This foundational approach ensures that device "brains" from different equipment OEMs remain inherently unique, poised to self-adapt to their specific manufacturing ecosystems in the near future while continuously evolving through accumulated additive manufacturing insights.

Competitive Advantage

First principles-based device brains provide **unmatched reliability and precision**, creating sustainable competitive advantages through physics-grounded intelligence that adapts to real-world conditions.

Key Characteristics

Physical Mirror

Each manufacturing environment has unique physical conditions

Material Properties

Different materials exhibit distinct physical behaviors

Process Parameters

Unique operational settings define system behavior

Question:
What makes SynaCore's physics-based approach uniquely powerful for unlocking the value in additive manufacturing for both equipment makers and the end part manufacturers?

Answer:
SynaCore embeds "Digital DNA" rooted in first principles—capturing the unique physics of different AM machine brands, different material, and different process to deliver precision that constantly adapts to real-world conditions, creating sustainable competitive advantages for both equipment makers and part manufacturers.

For equipment manufacturers

SynaCore's first-principles-based digital twins create unique "Digital DNA" for different brands of OEMs' machine, enabling precise performance prediction and optimization rooted in physical laws. This physics-grounded approach allows OEMs to differentiate their machines with proprietary digital capabilities that capture the specific behaviors of their hardware, materials, and process parameters.

For end-part manufacturers

SynaCore AM-DT digital twin provide reliable, physics-based predictions that constantly improve the consistency of part quality, reduce trial-and-error, and accelerate certification by demonstrating fundamental understanding of the manufacturing process. Ultimately, this first-principles foundation creates lasting competitive advantage for both equipment makers and part producers through scientifically validated digital assets that improve with each implementation.

SynaCore AM-DT
Digital Twin Core Competence

Current core competence matrix of SynaCore AM-DT Digital Twin

The future of manufacturing is digital, intelligent, and sustainable—and we are co-creating it together. SynaCore AM-DT puts this vision into practice. By organically integrating physics-based models, AI, and process data, SynaCore AM-DT digital twin gradually transitions quality assurance from post-process inspection toward pre-process prediction, parameter optimization, and adaptive tool path adjustment—steadily driving the evolution toward "self-evolving" intelligent production.

SynaCore AM-DT: Core Technical Capability Matrix

Multi-Scale Modeling

CORE

Adaptive kernel integrating machine, material, and workflow with process-structure-property correlation models

Value: End-to-end prediction of metal 3D printing results

AI Alloys

AI-POWERED

Digital twin with built-in machine learning capabilities

Value: Dramatically shorten alloy development cycle (titanium alloy, nickel based high temp alloy development, Fe based alloy...), reduce waste

Adaptive Toolpath

Self Evolve

Layer-by-layer prediction of printing process based on digital twin

Value: Adaptively adjust parameters to reduce defect formation

Multi-Modal Data Fusion

SENSOR

Integration of optical, thermal, and acoustic sensor data

Enables correlation analysis between melt pool dynamics and internal defects. Currently implemented through offline sensor data learning; online analysis capabilities will be implemented in the near future.

Pre-Qualification

Traditional Additive Manufacturing qualification remains bogged down in cycles of destructive sampling, lengthy statistical inference, and prohibitive costs—often taking years while remaining blind to the complexities of internal geometries.

Question:
If validating a single qualified part requires mass-producing and destroying dozens of specimens, then waiting years for statistical confirmation—doesn't this "quality assurance" model, which wastes both time and material, represent a collective paradox for modern manufacturing?

Answer:
SynaCore AM-DT resolves this collective paradox by embedding first-principles physics to predict microstructure, mechanical integrity and heat treatment, minimizing dependence on lengthy destructive testing campaigns—a paradigm shift that aligns with the urgent mandates of international standards and certification bodies actively seeking alternatives to avoid wasteful qualification cycles.

Challenges of Traditional Inspection & Qualification

Traditional inspection and qualification for additive manufacturing are slow, costly, and often destructive. From geometry to material properties, each step faces limitations in measurement, coverage, and efficiency—hindering scalability and innovation.

Critical Challenge: Traditional qualification methods require thousands of tests , taking years or even up to 15 years in some cases, reflecting the complexity arising from the high sensitivity of part performance to process parameters.

⚠ Most methods are destructive or have significant limitations

Inspection Category	Limitations of Traditional Methods
Geometric Inspection	Complex internal cavities, micro-truss dimensions difficult to measure by contact methods
Surface Inspection	Rough surface finishes interfere with inspection results
Internal Defect Inspection	Complex geometries make defect orientation detection difficult
Density Inspection	DESTRUCTIVE Cannot be used on final parts
Material Characterization	DESTRUCTIVE Requires sampling, cannot achieve full coverage
Composition Analysis	DESTRUCTIVE Limited sampling points make it difficult to capture the chemical homogeneity across different locations in complex structures (such as gradient materials, multi-material interfaces, or enclosed internal cavities).
Mechanical Properties	DESTRUCTIVE Requires large numbers of specimens, high cost
Functional Verification	Cannot predict long-term use performance

Transforming AM Inspection & Qualification Paradigm

Three-Layer Architecture

System-Level DT
Process chain management

Offline-Level DT
Parameter optimization simulation

Product-Level DT
Full lifecycle traceability

Question:
What if the microstructure, mechanical properties, etc. of a metal part could be predicted and suitable heat treatment processes recommended at the moment you define its design and process parameters?

Answer:
SynaCore AM-DT digital twin makes this foresight actionable: grounded in first-principles physics, it calculates porosity, surface roughness, and microstructure based on multi-layer laser trajectories, thereby deducing microstructure evolution and mechanical performance, while simultaneously deploying SynaCore Adaptive Toolpath to achieve layer-by-layer self-adaptive optimization of scanning strategies.

System-Level DT

Focuses on management, planning, and decision-making across the entire process chain. SynaCore AM-DT constructs digital twins for instance-qualified components by integrating data from design, material selection, process planning, production, and post-processing stages, while building scalable networks of manufacturing equipment, data storage systems, and computing platforms.

Offline-Level DT

SynaCore AM-DT utilizes thermal simulation models to predict part-scale thermal history, combining sensor features as inputs to machine learning models to achieve predictions of porosity, precipitated phases, microstructure, mechanical properties, and heat treatment, and realizes adaptive optimization of processing paths through Adaptive ToolPath. In the near future, SynaCore will deploy online-level digital twins, extending the capabilities of predicting part manufacturing results and process optimization to self-evolving fully automated additive manufacturing units and self-evolving additive manufacturing workshops.

Product-Level DT

In the near future, through the integration of additive manufacturing digital twins with subtractive manufacturing digital twins and others, the focus will be on full lifecycle management of products, tracking their performance and status during service. By continuously updating virtual models with data collected from physical products, multi-scale, multi-physics models will be constructed to predict maintenance needs, optimize product performance, and extend product lifespan.

Three Technical Layers of SynaCore AM-DT digital twin

1. **Multiscale Simulation Based on First Principles**
2. **Adaptive Parameter Optimization**
3. **Closed-Loop Feedback and Self-Evolution**

Often, people mistake visualization software for digital twins — but a true digital twin goes far beyond dynamic pictures; it mirrors reality, learns from it, and evolves with it to drive intelligent decisions.

SynaCore AM-DT digital twin handle **dynamically evolving physical entities**—parts growing layer by layer, to predict the geometry, thermal state, microstructure, mechanical strength and heat treatments.

Toward the future
Standard-Embedded Product Pre-Qualification

Future Qualification Transformation

Manufacturers submit to regulators or customers **not merely limited physical test reports but high-confidence digital twin models** supporting part manufacturing and their historical prediction accuracy proofs.

By reviewing digital twin completeness and accuracy, combined with partial physical validation, **rapid and low-cost "pre-qualification" for** mass production as key references becomes possible.

Pre-Qualification vs. Physical Qualification: Dialectical Unity

Traditional Qualification

- Legal effectiveness confirmation
- Dependent on physical testing
- Sampling inspection
- Mandatory and final

Pre-Qualification

- Process performance prediction
- Based on models and data
- Full-population coverage
- Flexible and forward-looking

Together they form "prediction + confirmation" dual-track quality assurance. Pre-qualification shortens qualification cycles; qualification endows pre-qualification with social credibility.

Future Development Trends

Initial Phase

Pre-qualification as auxiliary tool for design optimization and risk screening

Mid Phase

Pre-qualification conclusions conditionally accepted by regulators in specific scenarios

Long-term

Formation of "simulation-first, test-validation" new processes

Core Mechanisms of Pre-Qualification

Design Phase Standard Compliance: Automatic verification against material specs, geometric tolerances, NDT criteria

A Priori Certification: Virtual testing before print jobs, verifying predicted performance meets requirements

Pre-Qualification-as-a-Service: Digital twins as "certifiable agents" with queryable confidence intervals

Digital Twin Pathway for Pre-Qualification

Question:
How does SynaCore's digital twin foresee its potential in terms of transforming manufacturing qualification into a more sustainable and accessible process for society?

Answer:
By progressively reducing reliance on destructive physical tests through virtual simulations and monitoring, SynaCore helps lower material waste, shorten qualification cycles, and make certified additive manufacturing more accessible—paving the way toward safer, more efficient production of critical components across industries.

Traditional Inspection	Digital Twin Assistance Solution
Dimensional Accuracy	Geometric digital twin + online contour measurement
Penetrant Inspection	Coaxial vision + thermal imager surface monitoring
Radiographic Inspection	Thermal history simulation + SynaCore AM-DT prediction model
Density Testing	In-situ acoustic monitoring + machine learning classification
Metallographic Examination	SynaCore AM-DT Multi-scale microstructure evolution simulation
Chemical Analysis	Spectral emission monitoring + element distribution prediction
Tensile/Hardness Tests	SynaCore AM-DT Mechanical Strength prediction
Functional Test	Multi-physics performance simulation + virtual verification

Evolution Timeline Expected & Key Milestones

Coming Now	2-3 Years	3+ Years
Auxiliary Pre-Qualification	**Parallel Qualification**	**Integrated Qualification**

SynaCore AM-DT Pre-Qualification Potential

Dimensional Accuracy — GEOMETRY

Physics Model: SynaCore AM-DT Thermal-mechanical coupled simulation

Method: Predict residual stress and deformation, optimize support structures

Density/Porosity — DEFECTS

Physics Model: SynaCore AM-DT Melt pool dynamics + solidification model

Method: Predict lack-of-fusion and keyhole porosity

Microstructure — MATERIAL

Physics Model: SynaCore AM-DT Phase field model + grain growth model

Method: Predict grain size, precipitate, and phase composition

Mechanical Properties — PERFORMANCE

Physics Model: SynaCore AM-DT Multi-scale mechanical models

Method: Predict macroscopic mechanical properties from microstructure

Residual Stress — STRESS

Physics Model: SynaCore AM-DT Thermal-elastoplastic simulation

Method: Predict residual stress distribution, optimize heat treatment

Toward the future: Transformation to Self-Evolving Manufacturing

From "Empirical Trial-and-Error"

Traditional: Extensive physical testing, iterative parameter adjustment

To "Predictive Optimization"

Digital twin: Virtual testing, adaptive tool path parameter optimization

Intelligent AI Alloy Development

SynaCore AM-DT integrated AI Alloy function enables AI-Driven Smart Alloys

Toward the future of "Born-Qualified" Parts

Closed-loop integration ensures every part's manufacturing process can be completely recorded, predicted and pre-qualified.

AM-DT

Drive physical manufacturing with virtual intelligence

Question:
How can manufacturers ensure their proprietary knowledge remains secure and independent when adopting digital twin technology?

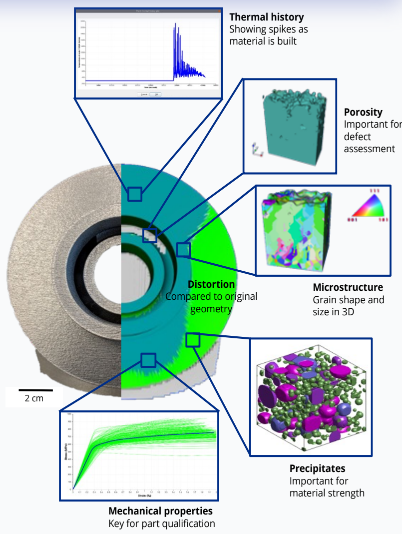
Answer:
Operating as a neutral infrastructure, SynaCore is grounded in universal first principles—physical laws that belong to no single entity—empowering manufacturers with complete ownership of their unique "digital DNA." Since every piece of brand-name equipment and every component is one-of-a-kind, the intelligence generated from the fusion of manufacturer data with the SynaCore digital twin infrastructure likewise possesses distinctiveness unique to the equipment brand owners and part manufacturers. This exclusivity constitutes proprietary asset value for the manufacturer, becoming a continuously appreciating digital asset that perpetually evolves and strengthens their competitive advantage in equipment and component manufacturing.

SynaCore AM-DT digital twin
Simulation

VIRTUAL WORLD
Digital twin creates virtual replicas enabling simulation, prediction & optimization before physical production

KEY INSIGHT
Digital twins enable **scalability** through virtual validation before physical production

PHYSICAL WORLD
Real-time production with sensor feedback enabling continuous optimization & quality assurance



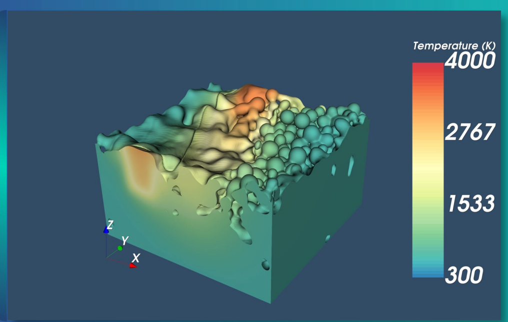
SynaCore AM-DT Digital Twin

SynaCore Digital Twin for Simulation
One-Stop Self-Evolving Advantage

SynaCore's Digital Twin transcends traditional simulation by integrating **continuous learning capabilities** that automatically refine predictions based on real-world manufacturing feedback, eliminating the iterative manual calibration cycles.

- Multi-Scale Ready
- Memory Optimized
- API Integration

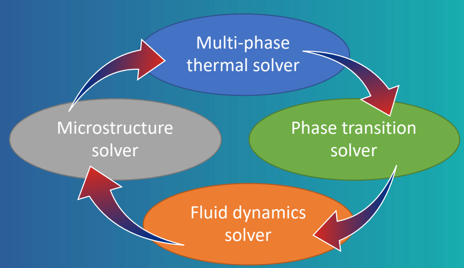
3× Faster Iteration



End-to-End Prediction Pipeline

Multi-layer individual laser tracks to compute porosity, surface roughness, and microstructure

1. **Macro Deformation Prediction**
   Warpage, shrinkage, and distortion analysis
2. **Microstructure Evolution**
   Grain growth, phase transformation, and solidification modeling
3. **Mechanical Property Forecasting**
   Tensile strength, hardness prediction...



Key Differentiators

- Part Scale, site specific
- Close loop
- Multi-scale integration
- Embedded heat treatment prediction and optimization
- Embedded functions including Mesher, AI alloy, and Adaptive ToolPath

SynaCore AM-DT digital twin
Advanced Mesher

Core Capabilities

Complex Geometry Handling

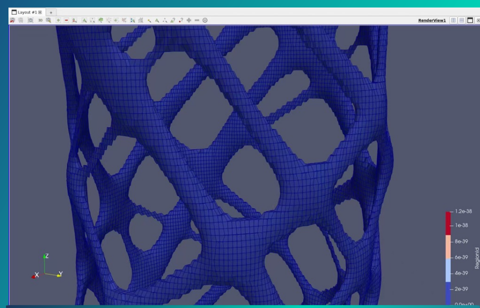
Automatic mesh generation for intricate CAD models with internal channels, lattice structures, and freeform surfaces

Adaptive Refinement

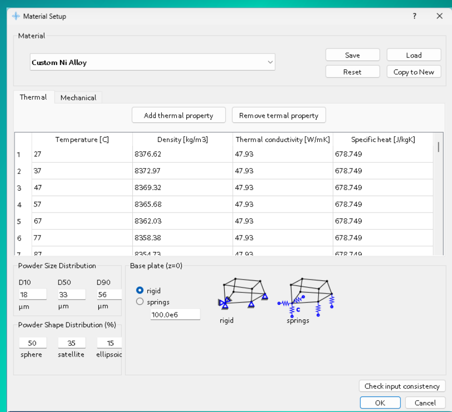
Dynamic mesh density adjustment based on stress concentration, thermal gradient, and geometric complexity

Computational Efficiency

Optimized mesh topology that balances accuracy with solver performance, reducing computation time



SynaCore Advanced Mesher



SynaCore AI Alloy

SynaCore AM-DT digital twin
AI Alloy

Disrupting Traditional Experience-Based Development

SynaCore's **AI Alloy** module fundamentally transforms alloy design by replacing decades of trial-and-error experimentation with **AI-driven computational materials science**. The system leverages artificial intelligent to predict composition-property relationships with unprecedented accuracy.

Traditional Approach

- years development cycle
- Expert-dependent decisions
- High experimental cost
- Limited exploration space

AI Alloy Approach

- Shortened development
- Data-driven optimization
- Significant cost reduction
- Full composition space

SynaCore AM-DT digital twin

Adaptive ToolPath

Question:
Why do traditional static toolpaths fall short while thermal-aware adaptive paths transform manufacturing outcomes?

Answer:
Static paths ignore heat dynamics, causing unpredictable defects—SynaCore's adaptive approach leverages digital twin thermal predictions to proactively adjust paths and minimize distortion, though perfection remains a journey; this closed-loop feedback marks the beginning of self-evolving manufacturing where each build makes the next smarter.

Thermal History-Driven Strategy

SynaCore's **Adaptive ToolPath** technology generates intelligent machining strategies by analyzing **thermal segments** during the manufacturing process. The system dynamically adjusts tool paths based on accumulated heat distribution, reducing cracking, preventing deformation, and avoiding other defects.

Thermal Monitoring

Continuous temperature field calculation and heat accumulation tracking

Dynamic Path Adjustment

Adaptive tool path modification based on thermal gradients

Thermal Damage Prevention

Automatic cooling pauses and speed adjustments to prevent overheating

Built-in Digital Twin Integration

Adaptive ToolPath seamlessly integrates with SynaCore's Digital Twin platform, enabling **close loop feedback** between predicted and actual performance.

SynaCore Built-in Adaptative Toolpath

1. **Composition Optimization**
   Multi-objective optimization balancing strength, ductility, and cost
2. **Property Prediction**
   Mechanical property forecasting
3. **Phase Diagram Prediction**
   Thermodynamic stability and phase transformation modeling
4. **Process Parameter Link**
   Integrated AM process window optimization

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