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# Beyond Simulation: Integrating Dual-Use Artificial Intelligence, Digital Twins and 5G to enhance existing NATO Modelling & Simulation Architectures


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# Beyond Simulation: Integrating Dual-Use Artificial Intelligence, Digital Twins and 5G to enhance existing NATO Modelling & Simulation Architectures

- NATO is facing an operational environment where speed, complexity and hybrid threats challenge traditional planning and training models. As highlighted in the paper, “simulation is no longer a support tool but a strategic enabler” .
- This study proposes a research-driven, service-oriented approach to integrating **dual-use technologies**—Artificial Intelligence, Digital Twins, 5G fast-response networks and advanced Modelling & Simulation platforms—into a **flexible ecosystem** that can support multi-domain readiness without claiming to define a new NATO architecture




**Digital twin supporting pre-mission simulation and AR-enabled scenario exercises**


NATO OPERATIONAL READINESS
TACTICAL SIMULATIONS
LOGISTICS
GOAL: NATO READINESS
OPERATIONAL READINESS
METRIES
SATELLITE DOWNLINK DATA
SATELLITE DOWNLINK DATA
AI PREDICTIVE ENEMY PATHS
STEALTH MULTI-ROLE FIGHTERS
5G CONNECTED INFRASTRUCTURE
SO NETWORK NODE
PREDICTIVE AI FEED
STEALTH NGTTLE TANKS
5G NETRBFAI FEED
NIGH-VISIBILITY DRONE SQUADRON
AEGIS-GLASS DESTKOYER
MAIN BATTLE TANXS

# NATO Simulation Ecosystem for Multi-Operation Readiness



# AI-native, resilient, distributed and cognitive infrastructures.

- NATO and the EU are converging toward a common model: **AI-native, resilient, distributed and cognitive infrastructures**.
- Traditional defense simulation architectures often suffer from high latency, rigid scenario scripting, and siloing from live operational networks. Integrating emerging commercial technologies bridges the gap between simulated training environments and live Command and Control (C2/C4ISR) systems

# AI models, Digital Twin engines, and network orchestration as plug-and-play microservices

- AI models, Digital Twin engines, and network orchestration as plug-and-play microservices via standard APIs (e.g., High-Level Architecture / HLA, Distributed Interactive Simulation / DIS).
- Strategic contest: the security landscape requires NATO Allied Command Transformation (ACT) and NATO Communications and Information Agency (NCIA) to accelerate the transition towards fully integrated Multi-Domain Operations (MDO). Dual-Use Commercial Innovation: Rapid developments in commercial AI, telecommunications (5G/6G), and quantum computing offer state-of-the-art capabilities that outpace traditional defense procurement cycles

# Core Dual-Use Technology Pillars

| Dual-Use Technology | Tactical & Operational Role | M&S Platform Integration |
|---|---|---|
| **Artificial Intelligence (AI)** | Dynamic threat generation, predictive COA (Course of Action) analysis, and automated pattern recognition. | Generates non-scripted, adaptive Synthetic Forces (OPFOR) that react dynamically to trainee decisions. |
| **Digital Twins** | Continuous physical-to-digital state synchronization of assets, terrain, and infrastructure. | Feeds real-time operational status (logistics, battlefield readiness, structural degradation) into live simulations. |
| **5G URLLC & Edge Computing** | Ultra-Reliable Low-Latency Communication (URLLC) for high-bandwidth, real-time data streaming at the tactical edge. | Enables low-latency, multi-node distributed simulation in bandwidth-constrained or deployed environments. |
| **XR / Immersive VR Interfaces** | Spatial visual representation of multi-domain battlefields for intuitive mission rehearsal. | Connects distributed tactical operators directly into a shared synthetic training environment. |

# Why NATO is using BOTH SOA and Cloud without disrupting existing M&S architectures

- NATO is currently adopting both a Service-Oriented Architecture (SOA) and a Cloud-based model. These two approaches are not replacing existing Modelling & Simulation (M&S) standards such as HLA or DIS.
- **Instead, they provide an integration layer that allows AI, Digital Twins and 5G networks to be used as plug-and-play services.**
- This is the key message: **SOA + Cloud extend M&S — they do not replace it.**

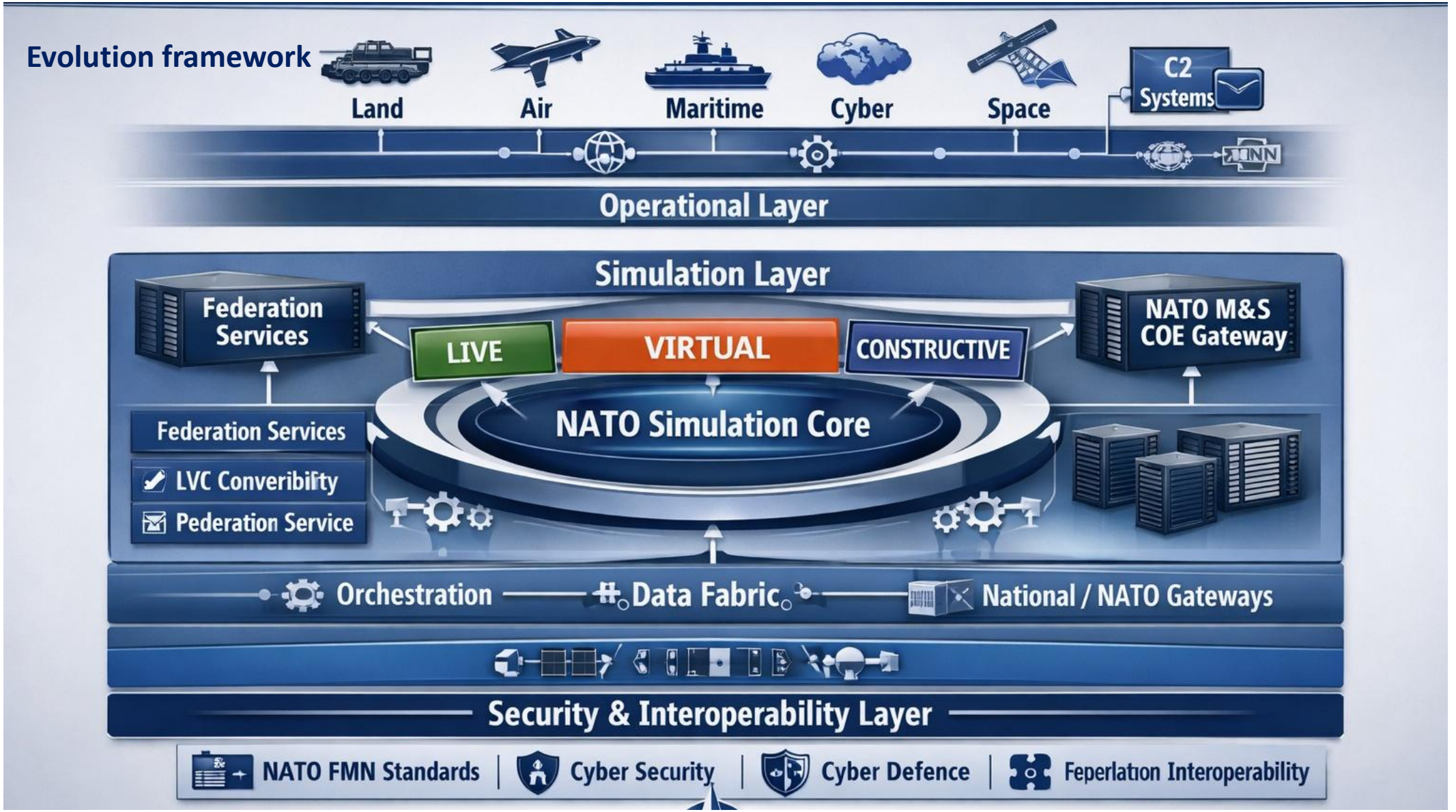
# Integrated Architecture for a NATO Simulation Ecosystem

- The proposed architecture is designed to be federated, modular and secure, ensuring interoperability across NATO nations while allowing each nation to maintain sovereignty over its systems. At the foundation lies the connectivity layer, where 5G and edge computing provide the low-latency communication required for distributed simulation. Above this, the data and intelligence layer aggregates multi-domain data and applies AI-driven analytics to generate insights, scenarios and predictions.
- The simulation layer hosts Digital Twins and integrates live, virtual and constructive elements into a coherent environment. The immersive layer provides VR-based interfaces that allow personnel to interact with simulation data in intuitive and collaborative ways. Finally, the interoperability layer ensures seamless integration with C2 and C4ISR systems through standardized data models, APIs and compliance with NATO Federated Mission Networking principles. This layered architecture ensures that simulation is not isolated but directly supports operational workflows.

# Operational Drivers for a NATO Simulation Ecosystem

- The need for such an ecosystem arises from several converging operational drivers. First, multi-domain operations require synchronized action across domains that traditionally operated in parallel rather than in full integration. Second, adversaries are increasingly leveraging hybrid tactics, cyberattacks and rapid maneuver strategies that evolve faster than conventional planning cycles. Third, NATO must maintain high levels of readiness despite resource constraints and the need to coordinate across diverse national systems and legacy platforms. Finally, the Alliance requires predictive capabilities that allow commanders to anticipate adversary behavior rather than merely react to it.
- **Proposed service-oriented integration architecture**. To avoid creating rigid architectural constraints or replacing existing NATO standards, this proposal outlines a layered Service-Oriented Architecture (SOA). This framework seamlessly bridges live operational C4ISR networks with synthetic training federations using NATO Federated Mission Networking (FMN) protocols.
- AI models dynamically adapt based on coalition tactics during exercises. The AI continuously probes all vulnerabilities, delivering realistic training scenarios that reflect modern asymmetric and hybrid warfare threats.  Cyber-Physical Resilience & Crisis Response :The integration of critical infrastructure Digital Twins allows NATO commanders to simulate hybrid attacks combining cyber operations, kinetic strikes, and information warfare simultaneously. This capability provides civil-military emergency response teams with actionable insights to strengthen resilience.

# Conceptual work-in-progress based on ongoing NATO and EU digital transformation trends.



# NATO's M&S Architecture: What Changes and What Stays

- **NATO is adopting a Service-Oriented Architecture (SOA) and a Cloud backbone to integrate AI, Digital Twins and 5G into Modelling & Simulation (M&S).**
- **This does *not* replace HLA, DIS or LVC. It simply adds an integration layer that connects simulation with C2/C4ISR systems through FMN standards.**

•LVC – Live, Virtual, Constructive simulation
•HLA – High-Level Architecture (simulation standard)
•DIS – Distributed Interactive Simulation (real-time protocol)
•SOA – Service-Oriented Architecture (microservices + APIs)
•FMN – Federated Mission Networking (interoperability framework)
•C2/C4ISR – Command & Control / Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
•TWC – Transatlantic Warfighting Cloud (NATO cloud backbone

# NATO is not replacing its existing Modelling & Simulation architectures

- **“NATO is not replacing its existing Modelling & Simulation architectures. HLA, DIS and the LVC federations remain the backbone of the simulation ecosystem. What NATO is doing is adding a new integration layer based on SOA and Cloud technologies.”**
- **“Through a Service-Oriented Architecture, AI models, Digital Twin engines and network-orchestration tools can be exposed as modular microservices. These services connect to existing simulations through standard APIs, without modifying or rewriting legacy systems.”**
- **“At the same time, the Transatlantic Warfighting Cloud provides a federated backbone where these services can run at scale — enabling distributed AI, predictive analytics, and multi-domain data fusion across 32 nations.”**
- **“FMN protocols ensure that this SOA-Cloud layer integrates seamlessly with operational C2 and C4ISR systems, creating a bridge between live operations and synthetic training environments.”**
- **“In short: SOA and Cloud do not disrupt NATO’s M&S architecture. They enhance it. They allow us to bring AI, Digital Twins and 5G into the simulation ecosystem in a modular, secure and interoperable way.”**

# NATO's Cloud Transition
# Public Evidence from ACT

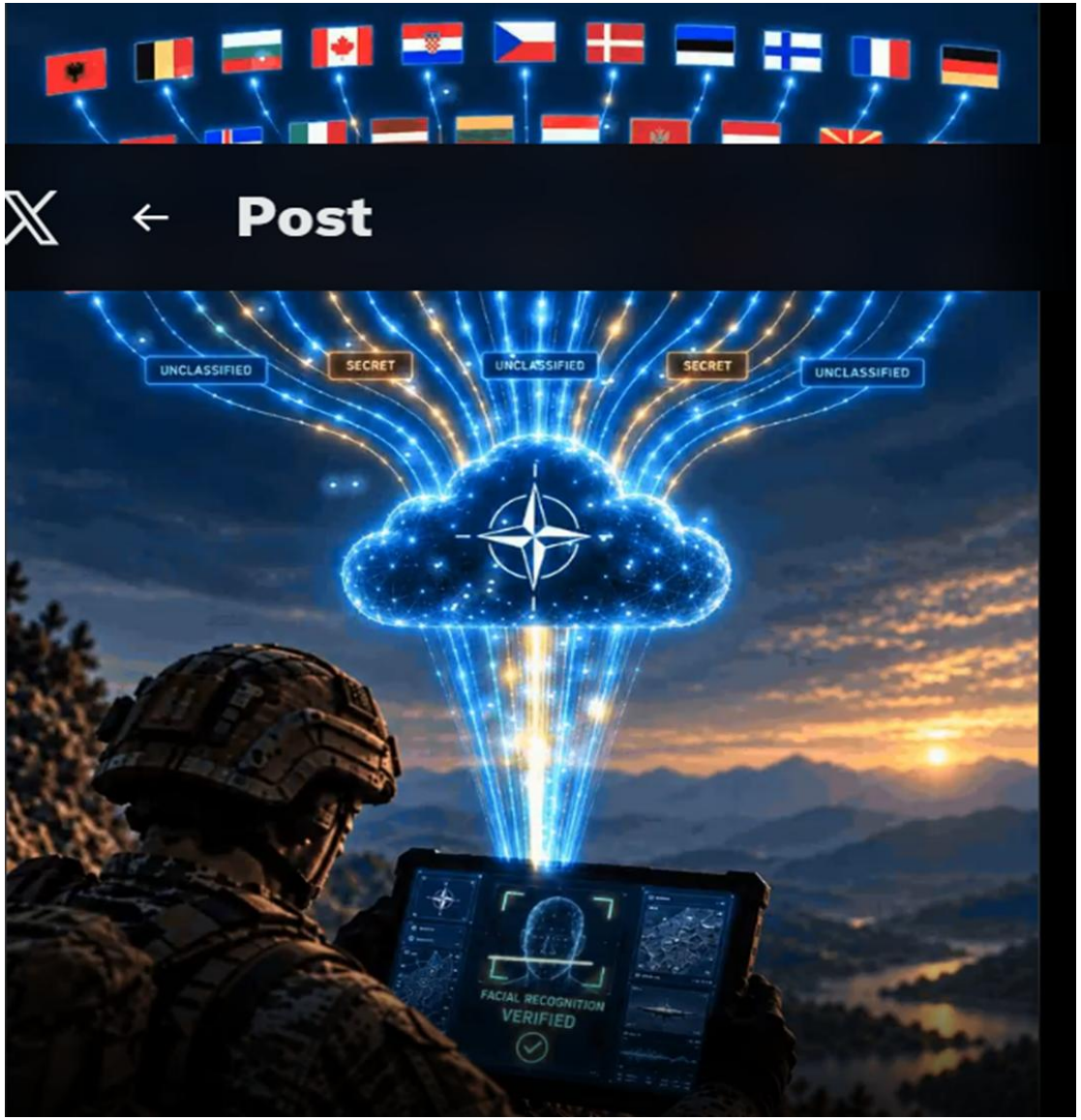
**To close, these are not conceptual ideas.**

**NATO ACT is publicly stating that the Alliance is moving toward the Transatlantic Warfighting Cloud.**

**This confirms that SOA and Cloud integration are active lines of development, not theoretical constructs.**

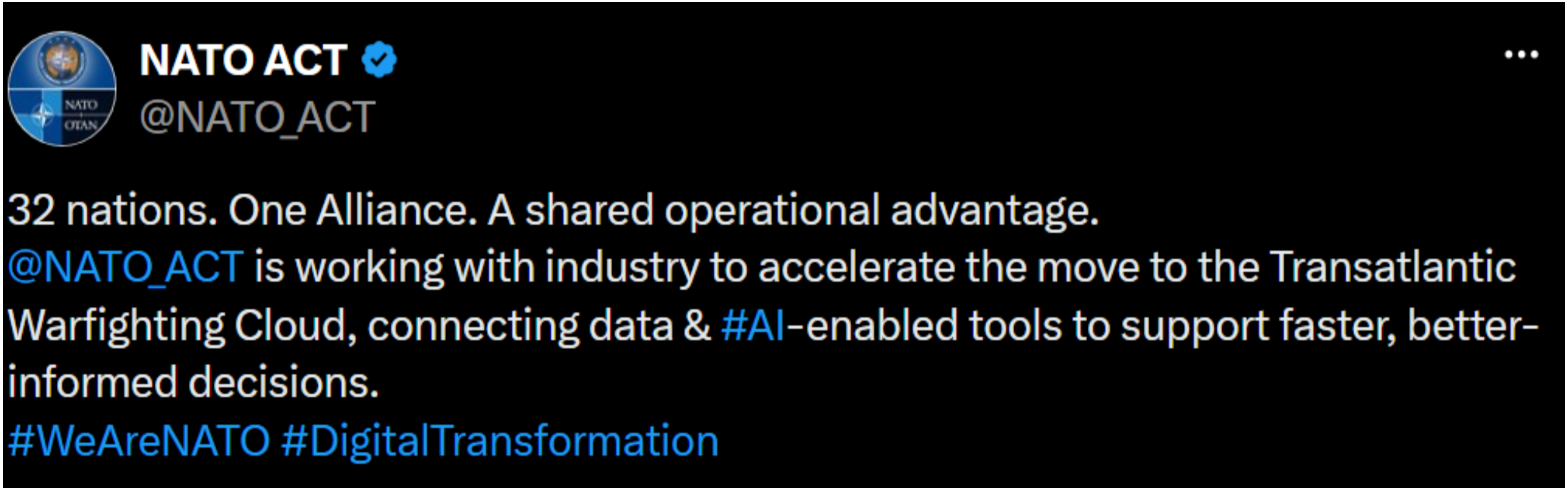
**This is the core message: NATO is not replacing M&S. It is extending it with SOA and Cloud, keeping HLA, DIS and LVC intact while enabling AI, Digital Twins and 5G."**

https://x.com/NATO_ACT/status/2102398842624700617



# NATO’s Cloud Transition
# Public Evidence from ACT

NATO ACT su X: "32 nations. One Alliance. A shared operational advantage. @NATO_ACT is working with industry to accelerate the move to the Transatlantic Warfighting Cloud, connecting data & #AI-enabled tools to support faster, better-informed decisions. #WeAreNATO #DigitalTransformation" / X




Rete Tattica 5G Avanzata
Satellite GG Quantum
- Link Satcom
Canale Satcom Criptato
Unità Mobile Terrestre
Nex! Gen Node
Ing Giovanni Gasbarrone
Velivolo stealth
Piattaforma aerea
Sciame di UAV Autonomi
Droni Intelligenti
UAV UCAV
Drone da Combattimento
5G Link
5G
Sciame di UAV Autonomi
Droni Intelligenti
AI
Sciame di UAV Autonomi
Droni Intelligenti
Nodo 5G
Backhaul di Rete



Conceptual AI-generated autonomous ground platform
(not representative of any specific vendor product).

# Technical Description of a proposal for Advanced 5G Tactical Network

- 5G forms the communications backbone of NATO's emerging digital battlespace. Under NCIA's Federated Mission Networking (FMN) standards, 5G URLLC provides deterministic latency, encrypted transport and mission-critical Quality of Service (QoS) required for distributed simulation, C2 telemetry and multi-domain coordination. In contested electromagnetic environments, 5G slicing and software-defined networking (SDN) ensure continuity of operations by isolating high-priority C2 and ISR traffic from non-essential flows.
- Deployable 5G tactical nodes—mounted on ruggedized vehicles or mobile shelters—extend cloud capabilities to the forward edge, enabling MEC (Multi-Access Edge Computing) for AI inference, Digital Twin updates and sensor fusion. This architecture supports ACT's requirement for resilient, distributed command networks capable of operating in DDIL (Disconnected, Degraded, Intermittent, Low-Bandwidth) conditions. As NATO moves toward cognitive 6G architectures, 5G becomes the stepping stone for autonomous optimization, spectrum resilience and real-time operational synchronization. The diagram illustrates an advanced 5G-enabled tactical network designed to support distributed operations, autonomous systems coordination and real-time data fusion across multiple domains. The architecture integrates terrestrial, aerial and space-based assets through a service-oriented communication fabric aligned with NATO M&S and C2/C4ISR interoperability principles. At the core of the system is a **Next-Generation Terrestrial Mobile Node**, acting as a 5G tactical hub capable of hosting edge-computing functions, secure data processing and multi-domain connectivity. This node interfaces with a **5G backhaul network**, enabling high-bandwidth, low-latency communication with other tactical units and command elements.

# Artificial Intelligence,5G and Immersive reality / digital twin



# The Political Context: Why the EU and NATO Accelerated on AI (2025–2026)



## A New Strategic Landscape

- Russian drone incursions
- Hybrid warfare tactics
- Attacks on critical infrastructure
- Dependence on non-EU platforms

## NATO's Acceleration

- Drone-enabled defence
- Counter-UAS protection
- Securing the Eastern Flank
- AI in C4ISR operations

## The EU's Coordinated Response

- Strategic investments
- Regulatory frameworks
- Interoperability standards
- Industrial cooperation




## Convergence Toward a Shared Model

AI-native, resilient, distributed, and **cognitive defence infrastructures.**

# Technology Pillars : Artificial Intelligence

- **Technology Pillars - Artificial Intelligence**
  - AI acts as the cognitive engine of the ecosystem. Its applications range from decision support—such as generating courses of action, predicting threat evolution and assessing operational risks—to automated scenario generation that adapts in real time to trainee performance or evolving mission parameters. AI also enhances C2 and C4ISR integration by fusing multi-sensor data, triaging intelligence inputs and prioritizing alerts. In logistics and sustainment, AI enables predictive maintenance and supply chain optimization, ensuring that readiness is maintained even under resource constraints. By reducing cognitive load and accelerating decision cycles, AI becomes a force multiplier for commanders.
- **Role of Artificial Intelligence  Network Cybersecurity**
  - Artificial Intelligence is becoming the cognitive engine of NATO's mission-critical networks, enabling Allied forces to detect, classify and counter cyber threats at a tempo consistent with modern multi-domain operations. Within contested environments—characterized by electronic warfare, hybrid attacks and persistent probing—AI provides the decision advantage required by ACT's operational transformation objectives. By processing millions of events per second across distributed C4ISR infrastructures, AI identifies hostile patterns, anomalous behaviors and early indicators of compromise before they degrade operational effectiveness. In this context, *AI does not merely support the network; AI becomes an integral defensive layer of the network itself.*
  - NATO's cyber-enabled architectures may rely on five interdependent pillars: the **Cloud**, hosting secure governance layers, protected data lakes and strategic AI models; the **Edge**, where inference engines operate close to sensors and tactical units; **5G and fiber networks**, delivering encrypted,

EUROPEAN DEFENCE AGENCY

Publication date: 09/05/2025




# Developing Responsible, Ethical, and Trustworthy AI Systems for European Defence

# ARTIFICIAL INTELLIGENCE STRATEGY
# **China**'s Military-Civil Fusion Strategy: Development, Procurement, and Secrecy

Key Takeaways

• China's AI strategy is built and layered atop decades of ideological and institutional planning. From Deng Xiaoping's reform era to Xi Jinping's digital governance, AI has been folded into evolving doctrines of modernization, centralization, and techno-political control, rather than developed as a discrete or standalone policy initiative.

• The CPC sees AI as a strategic asset to reinforce, not disrupt, Party dominance. AI is embedded in national governance as both an industrial tool and an ideological instrument, used for surveillance, censorship, and "social governance" purposes that align with core Party interests.

• This brief consolidates, in one place, the full scope of CPC policies guiding AI development. It offers an accessible mapping of national strategies, historical context, and institutional actors, providing a foundation for understanding how AI fits into China's broader goals of state control, global competitiveness, and innovative government

# Artificial Intelligence and Immersive Reality

AI and immersive reality are transforming military training. Virtual reality (VR) and augmented reality (AR) technologies offer highly realistic simulation environments where soldiers can train in complex scenarios without leaving their bases. These technologies replicate real combat situations, providing an intensive and immersive training experience that improves troops' tactical and decision-making skills.

VR is particularly useful for training dangerous or inaccessible missions. For example, soldiers can simulate operations in hostile environments, such as besieged cities or mountainous terrain, facing unpredictable variables in a safe environment. AR, on the other hand, enriches physical reality with digital information, allowing soldiers to view tactical data and maps directly in the field, improving situational awareness and unit coordination.

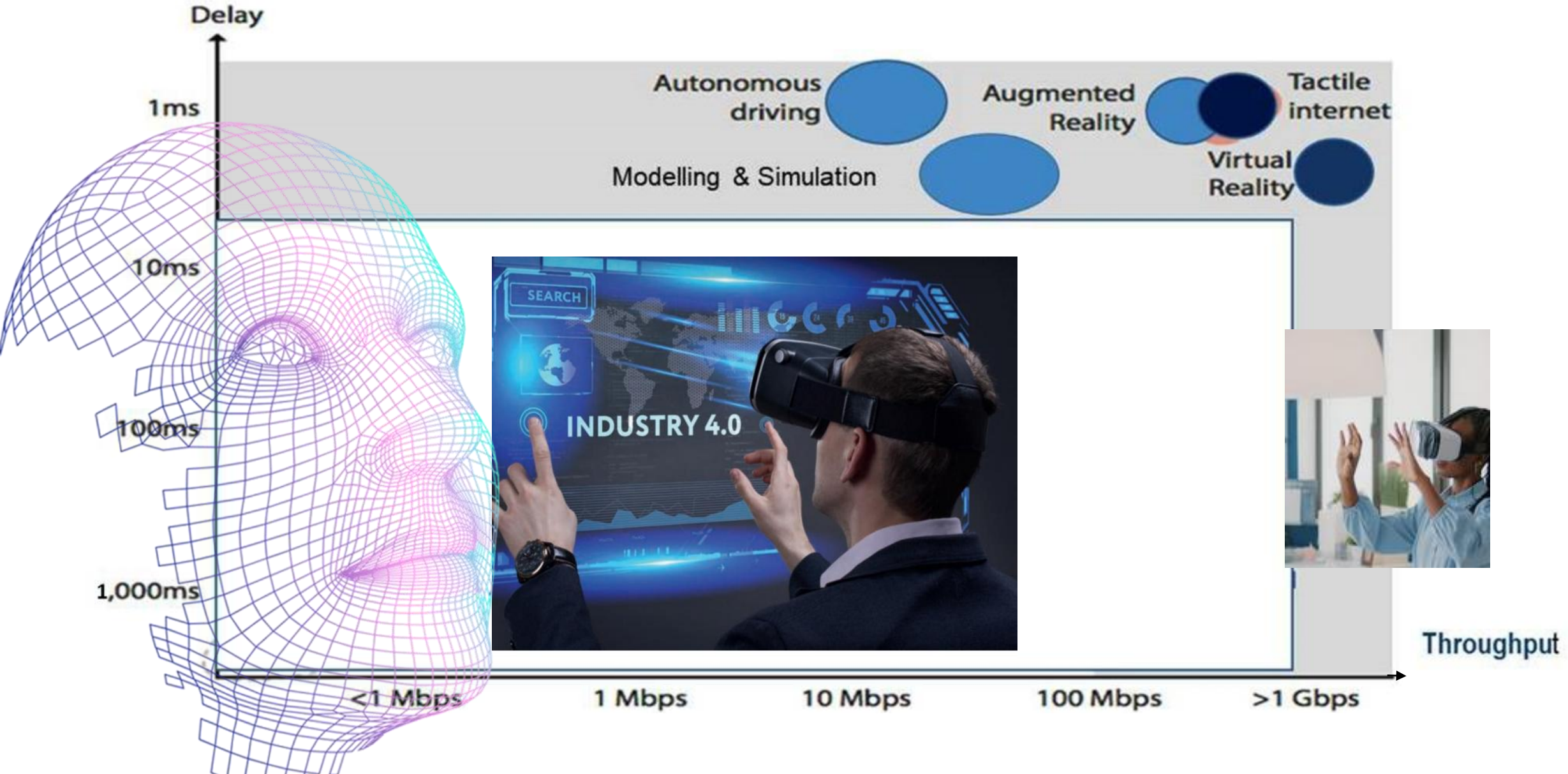
# 5G, the fast network for the battlefield simulation & modelling

It will be possible to make **holographic calls** on the **5G network** and thanks to the viewers available for **virtual and augmented reality** with 5G smartphones it will be possible to participate in 3D battlefield simulation and real time by sharing them from commad & control tablets. Augmented reality and virtual reality are the applications that will travel on the 5G network thanks to the increased bandwidth: **a real killer application.**



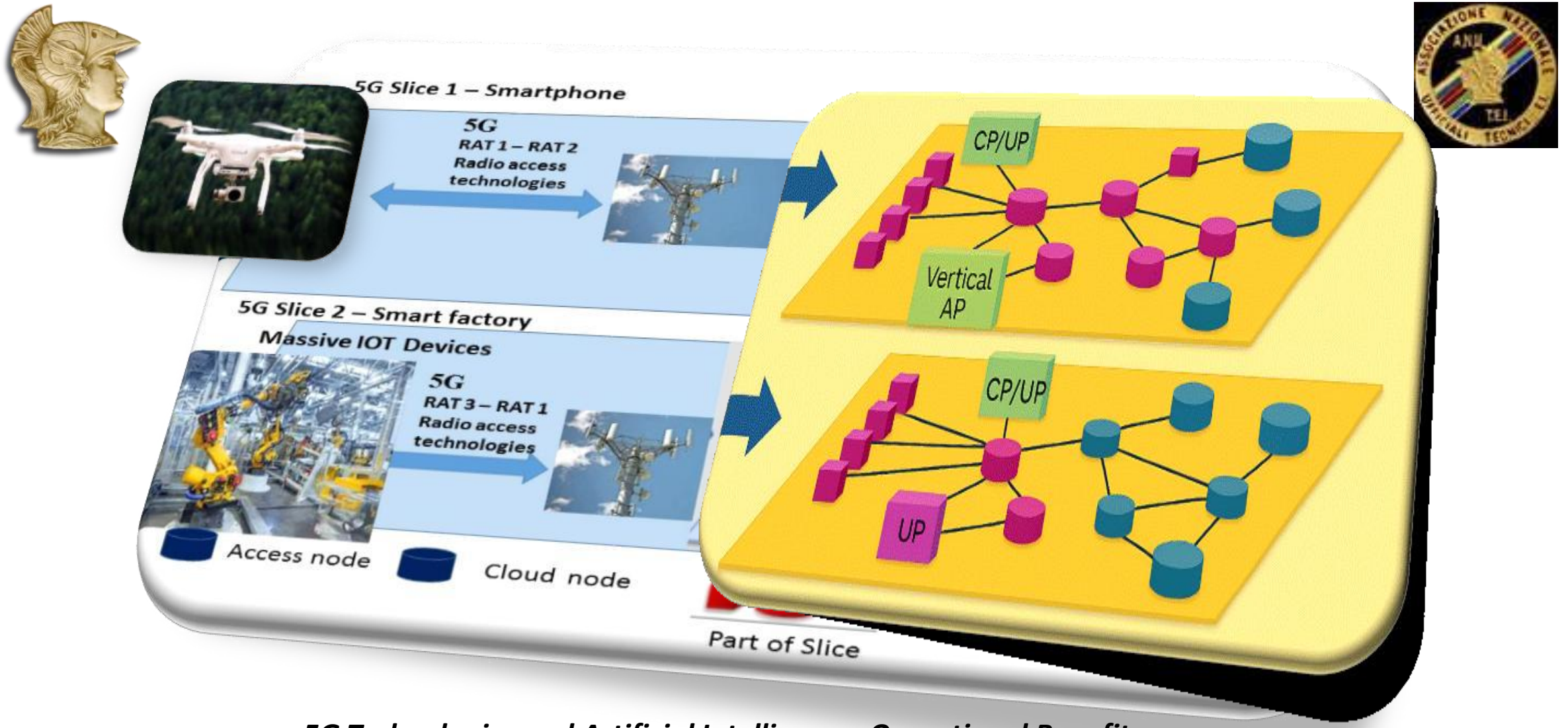

The next dual use cases, therefore, see **the interaction with holograms in the workplace in which the evolution of augmented reality takes place with 5G thanks to its low latency and very high bandwidth characteristics through the creation of a space for virtual battlefield**. in which the organizer's avatar interacts with those of colleagues who are in other locations, sharing multimedia content in the **3D work tables**.

# 5G Use Cases and Application requirements



# 5G Network Slicing

- Slicing is provides logically independent network on a single network infrastructure to meet diversified service requirements and provides DC-based cloud architecture to support various application scenarios.
- Slicing Uses Cloud-RAN to reconstruct radio access to provide massive connections of multiple standards and implement on-demand deployment of RAN functions required by 5G.
- Slicing Simplifies, we are implementing automatic network slicing service generation, maintenance, and termination for various services to reduce operating expenses through agile network O&M.

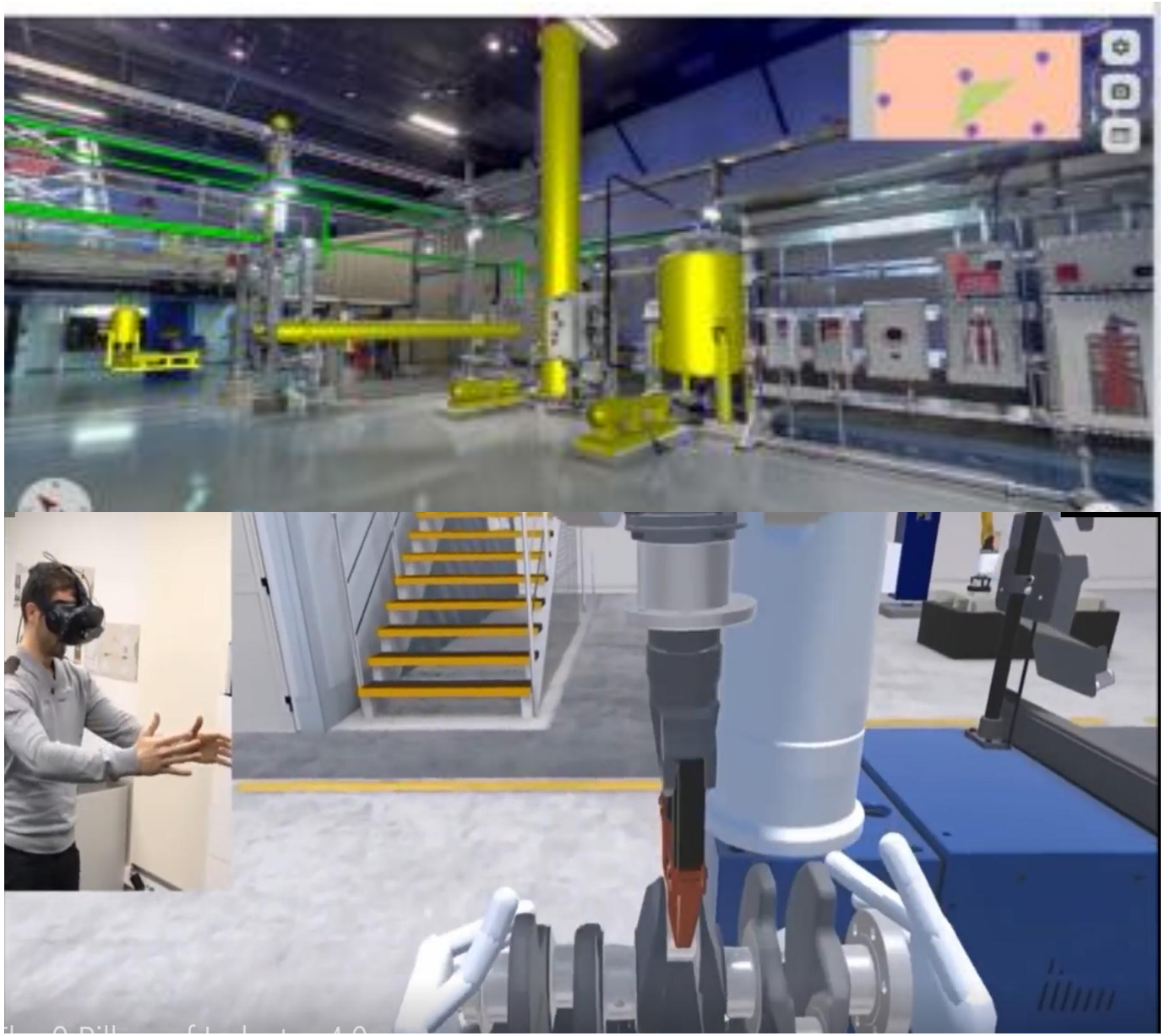



***5G Technologies and Artificial Intelligence: Operational Benefits***

- ❑ *5G Reduced Decision Latency Faster command execution and threat response.*
- ❑ *AI Enhanced Intelligence Real-time fusion of data from multiple sources.*
- ❑ *AI & 5G Resilience & Redundancy Slices can reroute or self-heal in case of node failure.*

# DIGITAL TWINS

## Smart factory : new work places





# Thank you for your interest


***Ing. Giovanni Gasbarrone***

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# Acronym Definitions

- **SOA – Service-Oriented Architecture** An architectural model where capabilities (AI models, Digital Twins, orchestration engines) are exposed as modular services accessible through standard APIs.
- **Cloud / TWC – Transatlantic Warfighting Cloud** NATO's federated cloud backbone designed to host AI-enabled tools, shared data, and decision-support services across 32 nations.
- **M&S – Modelling & Simulation** The traditional NATO simulation ecosystem, including Live, Virtual and Constructive (LVC) federations.
- **HLA – High-Level Architecture** The main NATO/IEEE standard for distributed simulation, enabling multiple simulators ("federates") to interoperate in a federation.
- **DIS – Distributed Interactive Simulation** A real-time simulation protocol used for tactical training and platform-level interoperability.
- **FMN – Federated Mission Networking** NATO's framework for secure, interoperable data exchange across nations during operations and exercises.
- **C2 / C4ISR – Command and Control / Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance** The operational systems that M&S must increasingly integrate with.

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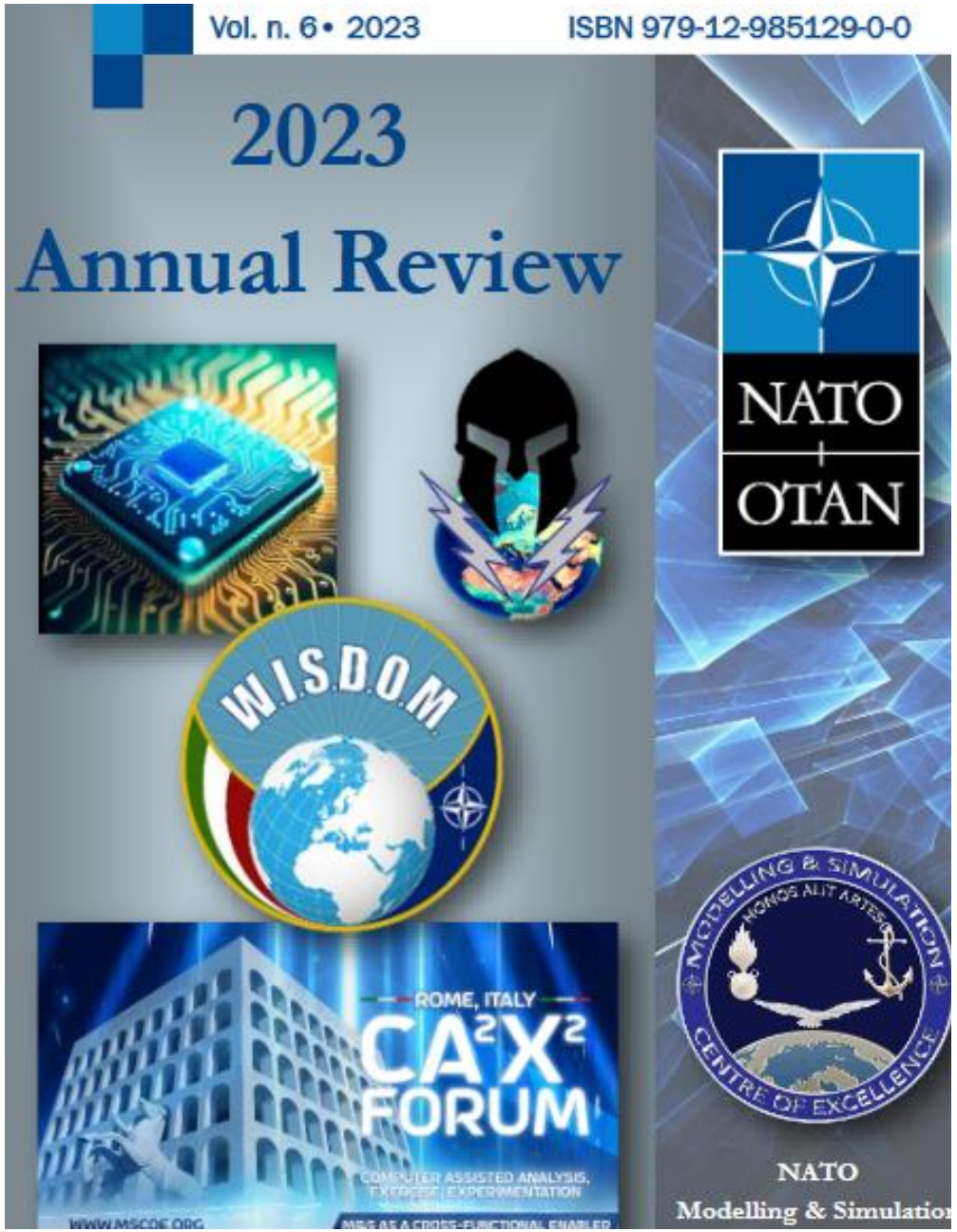

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