# Next Generation 3D Simulation Standards - A Tipping Point

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**ABSTRACT:** *The simulation community is facing a question, are we at a tipping point where traditional simulation standards will be overtaken by those emerging from other sectors? This paper explores this central question by examining the emergence of 3D simulation standards originating from domains like film, gaming, and engineering. It focuses on open standards such as Open Universal Scene Description (OpenUSD), 3D Tiles, and glTF, and compares them with established simulation community standards, for example the Open Geospatial Consortium Common Database (OGC CDB).*

*OpenUSD supports collaborative 3D content creation, 3D Tiles enables the visualisation and streaming of large-scale geospatial datasets, and glTF provides an efficient format for transmitting 3D content. These standards contrast with the structured and domain-specific approach of OGC CDB, which is a long standard for simulation data management.*

*In order to achieve true interoperability between various simulation systems a similar view on the surrounding world must be established. Many standardization attempts have been made over the years but without any of the alternatives being widely adopted. Are appropriate standards still missing or are we missing coordination and communication in the simulation domain? Should the simulation domain simply just adopt what is being developed in other sectors?*

*By addressing challenges such as standards adoption and integration strategies, this paper proposes a strategy for the simulation community to evaluate and adapt to these evolving standards. Ultimately, it advocates for a strategic response to this potential tipping point, ensuring the community remains innovative and relevant in a rapidly changing standards landscape.*

# 1. Introduction

Since the early 1980s, the incorporation of 3D data in simulation has posed significant challenges. Developing and maintaining these environments can be expensive and complex, often necessitating future updates and modifications. In modern military flight simulators for instance, interaction with the environment extends beyond visual representation, utilizing various sensors, which complicates the integration of data from these different modalities and can lead to interoperability issues.

Recent advances in military training, which involve multiple diverse training devices operating together alongside live equipment, highlight the importance of a unified perspective on the surrounding environment for all participants. Despite numerous efforts within the defense Modeling and Simulation (M&S) community to lower costs, enhance reusability, and improve interoperability through the establishment of standards, widespread adoption has been limited in both military and commercial contexts.

On the commercial front, 3D technology has seen extensive application and has reached a broad audience. Over time, some standards have gained traction and have started to influence the defense M&S sector. This paper aims to identify key standards that have achieved substantial acceptance and to assess the existence and relevance of current guidelines. It will evaluate whether these guidelines are updated to reflect recent advancements in the commercial sector or if alternative solutions are needed.

Additionally, this paper will explore the roles of current organizations, such as NATO's Modelling and Simulation Group (MSG) and the Simulation Interoperability Standards Organization (SISO), in shaping future standards. The goal is to ensure these standards effectively support defense M&S acquisition efforts, enhancing interoperability, reusability, and cost-efficiency.

## 1.1. The Problem

The review of current guidelines and standards have been from the standpoint that they should enable a “Training Simulation System Procurement Officer” in any government to effectively carry out procurement activities. Key considerations include:

- The ability to quickly and cost-effectively reuse and update 3D data.
- Interoperability with other systems for sharing, reuse, and facilitating "fair fight training."
- Capability to leverage new and emerging 3D data services.
- Provision for fair competition in the marketplace.
- Prevention of vendor lock-in solutions.

## 1.2. What is 3D Data

3D Data refers to the information needed by a simulation system to accurately depict the surrounding environment and objects, enabling the execution of functions or activities to meet the system's objectives. It is often referred to as environment data, and for the purposes of this paper, these terms will be used interchangeably. According to reference [1] (SISO RIEDP 2018), environment data is defined as: *“Data about objects, geography, features, places, or phenomena, as well as their respective characteristics, which are used in representing, modeling, or simulating all or part of an environment, whether natural or man-made. The content, format, attribution, and quality may be changed during the manipulation and transformation processes of that data.”*.

A fourth dimension, time, can also be of great importance as factors such time of day, weather and season can influence the outcome of the simulation.

### 1.3. Why is 3D data important

In a simulation, both people and machines must interact with environmental elements that accurately mimic their normal interactions with the surroundings. As systems grow increasingly complex and more attuned to their environments through sensors, reproducing essential aspects of the environment becomes increasingly challenging. When various systems and individuals are engaged in distinct tasks, the simulation must incorporate even more environmental facets. Without the necessary data, the simulation would lack the ability to replicate any characteristics of the surrounding environment. Below is a quote from the latest version of the NATO M&S standards profile, highlighting the significance of the environment and 3D data.

*"The development, archiving and reuse of environmental data representing in M&S the natural and human-made features of the real world, are very important parts and a* ***significant cost driver*** *of M&S systems. Database development is a complex process and the* ***interoperability of environmental databases is also a key issue****"*(NATO AMSP-01, 2021, reference [14]).

### 1.4. 3D database and formats

The development of a 3D or environmental database typically involves the following key steps:

1. **Acquire Source Data**

   This involves gathering satellite or aerial imagery, elevation data, terrain type information, building and material descriptions, light points, and 3D object models. Existing environment databases may sometimes be reused, provided they are in an agreed format, and the content and fidelity meet the requirements for content and fidelity without overwhelming the system's processing capacity.

2. **Refine and Organize Data**

   Data must be prepared and refined to ensure it is usable in the simulation. This stage often involves optimizing the format for the specific system, which requires an export function to facilitate data reuse by other systems. An agreed export format is essential.

3. **Distribute Data**

   Data copying or streaming occurs in real-time to various systems. The extent of processing before and after distribution can vary based on factors such as the processing power of the target system and the bandwidth of the distribution method.

4. **Process and Utilize Data**

   Finally, the data is processed within the target system and either used directly or presented in the intended manner.

## 2. Use Cases

A relevant use case illustrating the significance of 3D and map data in a weapon system can be found with most modern fighter systems. Typically, a fighter mission starts after the pilot has been briefed on the mission objectives and mission planning activities starts. In its simplest form breakpoints are placed on a map depending on certain criteria and the required fuel quantity can be calculated by the mission planning system based on the aircraft configuration. Mission rehearsal activities can take place in either a mission simulator or in the planning system where important parts of the mission can be trained in order to maximize the mission success probability.

Breakpoints can sometimes placed near an easily recognizable terrain feature and might indicate the entry into an important mission phase. The importance of having these terrain features present in the same location in all mission support equipment, mission simulators and aircraft moving map display and accurately correlated with the real world is crucial.

In the fighter example a common 3D data generation can be used that ensures that correlated data can be distributed to all the relevant parts of the complete weapon system which ensures that all electronic parts of the system share a common view of important aspects of the environment. New or updated data can be processed with the common 3D data generation system when needed and distributed to all parts of the weapon system so that missions can be executed with an updated view on the mission area.

Difficulties arise when several different systems, that might have been produced by different vendors in different countries, have to cooperate on the same mission or if several different mission simulators are interconnected to allow for these crews to train or rehearse mission jointly and cannot share the same solution for 3D data generation.

# 3. Challenges with the Acquisition of Synthetic Training Devices

## 3.1. Current Guidelines

The dominating guideline that inspired many national defense procurement organizations is the NATO Modelling and Simulation Standards Profile (NATO AMSP-01, 2021, reference [14]). The Guideline aims to promote interoperability between training solutions from different NATO countries to ensure that they can be used to train NATO countries to operate together cohesively, reducing misunderstandings and increasing coordination in joint missions. It serves as a valuable educational resource for military personnel at all levels, particularly during training programs designed to enhance understanding of NATO principles and operational procedures. References to SISO RIEDP (SISO RIEDP, 2018, reference [1]) can be found in the document as one of the more recent references in the category “Synthetic Physical Model”.

The guideline also refers to other frameworks and data formats and the following section aims to briefly describe some of the more common ones used to produce or exchange 3D data.

## 3.2. Existing Frameworks and Data Formats

**SEDRIS**

Initiated in 1994, SEDRIS (Synthetic Environment Data Representation and Interchange Specification) was established to address the longstanding challenge of effectively representing environmental data. This program, led by the U.S. government with active participation from industry, was primarily sponsored by the U.S. Department of Defense's Distributed Environmental Modeling and Simulation Office (previously known as MSCO and DMSO). SEDRIS provides a standardized framework for representing and exchanging environmental data, facilitating the interoperability of synthetic environment databases that are crucial for simulation, modeling, and visualization applications. Central to this framework is the Data Representation Model (DRM), which defines the structure and semantics for accurately representing environmental data, thus ensuring consistency and interoperability across various platforms. Complementing the DRM is the Transmittal Format (STF), a platform-independent file format that enables efficient storage and exchange of SEDRIS data between different systems and applications. Additionally, SEDRIS offers standardized Application Programming Interfaces (APIs) that allow developers to access and manipulate SEDRIS data, empowering them to create applications capable of reading and writing SEDRIS transmittals. The system's extensibility further enhances its efficacy, as it supports the addition of new data types

**OGC CDB – Common Database**

The OGC CDB (Open Geospatial Consortium Common Database) is a standardized framework created to facilitate the creation, management, and sharing of geospatial data specifically for modeling and simulation environments. Originally funded by the United States Special Operations Command (US SOCOM) and developed by CAE in 2004, the CDB framework provides a comprehensive architecture consisting of specifications, data models, and best practices that support the integration of geospatial information across various applications and systems. It was submitted to the OGC as a standard in 2016 and has since been released in versions 1.0 to 1.2. The CDB serves both as a run-time format and a simulation database interchange format, utilizing the WGS84 geographic coordinate system. Its modular structure includes distinct layers for terrain, imagery, features, and other data types. By adhering to international standards and best practices, the CDB promotes seamless interoperability among different geospatial data sources and simulation platforms.

### RIEDP

The initiative that began in 2009 through SISO is closely related to SEDRIS, with a narrowed scope focused on existing commercial off-the-shelf (COTS) formats. Known as RIEDP (Reuse and Interoperation of Environmental Data and Processes), this framework is designed to standardize the sharing and reuse of environmental data and processes, particularly within the realms of simulation and modeling. RIEDP establishes standardized rules, methods, and semantics for the exchange of data across various stages of simulation database generation. It aims to enhance interoperability by ensuring that data from diverse sources can be integrated and utilized seamlessly. Additionally, RIEDP leverages widely recognized GIS and simulation data formats, such as GeoTIFF and Shapefile, to facilitate effective data exchange. To support the creation and sharing of simulation databases, it includes a Reference Process Model (RPM) and a Reference Abstract Data Model (RADM). This initiative is especially beneficial in settings where consistent and interoperable data are critical, such as in the defense, aerospace, and training industries that rely heavily on simulation.

### OpenFlight

The 3D geometry model file format, originally developed by Software Systems (later known as Presagis) Inc. in 1988, was initially called "Flight." This format was created as a non-proprietary solution specifically for real-time 3D visual simulation image generators. Over the years, it has become the de facto standard for modeling 3D terrain features and moving models, particularly with its adoption in MultiGen Creator for real-time 3D modeling. In 2019, it was issued to the Open Geospatial Consortium (OGC) for consideration, further solidifying its relevance and use within the industry.

### Shapefile

Shapefile is a widely used geospatial vector data format developed by ESRI, primarily designed for geographic information system (GIS) software to store geometric location and associated attribute information. Shapefiles effectively store geometric shapes, such as points, lines, and polygons, representing various features like water bodies, roads, and lakes. Each geometric shape can have associated attributes, which are stored in a separate dBase IV format file with the .dbf extension. A shapefile consists of at least three mandatory files: the .shp file contains the feature geometry, the .shx file serves as an index for the geometry, and the .dbf file stores the attribute data. Additionally, a .prj file may be included to georeference the data. However, it is important to note that shapefiles do not store topological information, meaning they lack an inherent understanding of the spatial relationships between the features they represent.

### GeoPackage

GeoPackage (GPKG) is an open, non-proprietary, platform-independent, and standards-based data format designed for geographic information systems (GIS) by the Open Geospatial Consortium (OGC). This format serves as a lightweight and efficient container for geospatial information, utilizing a single SQLite database file to store vector features, tile matrix sets of imagery, raster maps, and non-spatial attributes. Its design is compact and optimized for mobile applications, making it particularly suitable for environments with limited connectivity, including those that may experience disconnected or degraded network conditions. Furthermore, GeoPackage allows for extensibility, enabling it to evolve and meet future operational needs while ensuring interoperability across various computing environments, including desktop, server, and mobile platforms.

## 3.3. On-the-fly Terrain Data Generation

On-the-fly terrain data generation refers to the real-time creation and modification of terrain data in response to specific needs during simulation or visualization processes. This technique enables systems to generate terrain information dynamically rather than relying solely on precomputed or static datasets. The need for a specific data format for intermediate storage is also, to some degree, omitted.

The system can create and modify terrain data in real-time, allowing for immediate adaptation to user input or changes in the environment. This is particularly useful in simulation environments, video games, and virtual reality applications where user interactions might require instantaneous updates. This often employs procedural generation techniques, which use algorithms and mathematical functions to create terrain features such as mountains, valleys, rivers, and textures. This approach can produce highly detailed and varied landscapes without the need for extensive manual design. On-the-fly generation can leverage various data sources, including heightmaps, satellite imagery, and other geospatial data. The generated terrain can blend with existing datasets, creating a seamless experience for the user. By generating terrain data on-the-fly, systems can minimize storage requirements since they do not need to store extensive precomputed datasets. However, this can result in competition over compute resources with the rendering process. This can enhance performance and reduce lag in applications that require quick access to updated terrain information.

A drawback if using different solutions from different vendors might be that terrain isn't generated in a correlating manner and thus creates interoperability and "fair fight" issues.

### 3.4. Insights from Current Guidelines

From the AMSP-01 (NATO AMSP-01, 2021, reference [14]) the following recommendation can be found:

*"Standardization efforts targeted to representation and visualization of simulated natural and human-made environment are even more critical realizing that "de facto" standards, commercial products and SEDRIS are competing; there is a lack of coordinated effort and of a general policy in this domain and the idea of a collective reflection should be promoted and better specified."*

The limited adoption of 3D Data Standards highlighted in the AMSP-01 beyond the defense M&S domain suggests that affordable commercial solutions may not be readily applicable. The presence of competing standards could lead to confusion in procurement projects and hinder effective reuse and interoperability.

## 4. Developments outside the Defense M&S Arena

The field of 3D graphics has witnessed rapid advancements, driven largely outside traditional defense M&S by sectors such as entertainment and engineering. These developments have significant implications for real-time rendering, collaborative design, and geospatial visualization, enabling more efficient and scalable virtual environments. Although highly competitive, technology companies have come together create and maintain open standards for 3D data largely as it helps to advance their industries and support a sustainable knowledge base. Among the most prominent innovations in open standards are OpenUSD (Universal Scene Description), 3D Tiles, and glTF (GL Transmission Format), each of which plays a distinct role in the 3D content pipeline.

OpenUSD, developed by Pixar and now managed by the Alliance for OpenUSD, provides a robust framework for structuring and managing complex 3D scenes. It facilitates interoperability across different software tools and teams, making it particularly useful for industries requiring high-fidelity simulations, such as digital twin environments and virtual production (Pixar, 2023, reference [12]). Conceptually, OpenUSD can be likened to the architectural planning of a virtual city, where it ensures that all components are well-organized and accessible for modification and visualization.

Complementing OpenUSD, the 3D Tiles specification, originally introduced by Cesium, enables efficient streaming of large-scale 3D datasets. By dividing expansive environments into smaller, hierarchical tiles, 3D Tiles allow for real-time rendering of massive geographic datasets without overwhelming computational resources (Hagedorn et al., 2022, Reference [4]). This mechanism ensures that only the necessary sections of a virtual city load as a user navigates through the space, akin to level-of-detail (LOD) optimizations used in gaming and GIS applications.

Finally, glTF, developed by the Khronos Group, serves as a lightweight and efficient format for transmitting 3D models over the web. Often referred to as the "JPEG of 3D," glTF optimizes asset storage and transmission, making it ideal for applications in augmented reality (AR), virtual reality (VR), and mobile-based rendering (Khronos Group, 2022, reference [6]). Within the virtual city analogy, glTF is responsible for individual assets, such as buildings, vehicles, or street furniture, ensuring they are portable and visually accurate across different platforms.

Together, these three standards - OpenUSD for creation, 3D Tiles for streaming, and glTF for asset sharing - form a comprehensive ecosystem for managing 3D content efficiently. Platforms such as NVIDIA Omniverse leverage OpenUSD to enable real-time collaborative workflows in digital twin applications, while Cesium extends 3D Tiles support to Unreal Engine and Unity, facilitating open and interoperable geospatial visualization (NVIDIA, 2023; Cesium, 2022, references [9] and [3]).

### 4.1. The Role of Standards Organizations in 3D Ecosystems

Several standards organizations play a critical role in maintaining and advancing these 3D technologies. The Khronos Group, a consortium that includes major industry players such as NVIDIA, Apple, Google, and Microsoft, develops and maintains widely adopted standards like glTF and OpenXR, which support immersive XR applications (Khronos Group, 2022, reference [6]). Meanwhile, the Alliance for OpenUSD, composed of contributors from Pixar, Adobe, Autodesk, and Apple, focuses on extending OpenUSD's capabilities to a broader range of industries (Alliance for OpenUSD, 2023, reference [2]).

Cesium, as the original developer of 3D Tiles, manages the standard through the Open Geospatial Consortium (OGC), ensuring that it aligns with best practices for geospatial data visualization and streaming (OGC, 2023, reference [11]). Additionally, the Metaverse Standards Forum brings together organizations such as Meta, Microsoft, NVIDIA, and Khronos to promote interoperability across virtual worlds, ensuring that 3D assets and environments can function seamlessly across different platforms (Metaverse Standards Forum, 2023, reference [7]).

These organizations, in conjunction with established technical bodies such as the IEEE, contribute to the evolving landscape of 3D graphics, ensuring that open standards remain viable for a wide range of applications, from military simulation to commercial gaming and industrial design.

### 4.2. Emerging Technologies and Future Implications

Looking forward, emerging technologies such as Gaussian Splatting are poised to revolutionize 3D rendering. This technique represents 3D scenes using layers of translucent "Gaussian blobs," offering significant advantages in rendering speed, visual realism, and adaptability for real-world scans and extended reality (XR) applications (Kerbl et al., 2023, reference [5]). Gaussian Splatting integrates well with existing standards like OpenUSD, 3D Tiles, and glTF, potentially improving rendering efficiency and asset fidelity.

Artificial Intelligence (AI) is also playing an increasing role in the 3D content pipeline. Techniques such as text-to-3D generation, image-to-3D conversion, and large-scale procedural modeling are reducing the time and expertise required to create detailed virtual environments (NVIDIA Research, 2023, reference [10]). By leveraging AI-driven automation, designers can generate realistic 3D assets from simple textual descriptions or photographic inputs, making high-quality 3D modeling more accessible across industries.

As these innovations continue to mature, the integration of AI and new rendering techniques will likely enhance the scalability, accessibility, and realism of 3D environments. This progression will not only benefit traditional M&S applications but also extend to sectors such as digital twins, urban planning, autonomous vehicle simulation, and immersive training environments.

The rapid advancements in 3D graphics, underpinned by open standards such as OpenUSD, 3D Tiles, and glTF, are reshaping how complex virtual environments are created, streamed, and shared. With major industry consortia ensuring standardization and interoperability, these technologies are increasingly applicable across defense, industrial, and entertainment domains. Emerging methods such as Gaussian Splatting and AI-driven 3D content generation further signal a future where high-fidelity, interactive simulations become more efficient and accessible. As these developments continue, the synergy between open standards and leading-edge computing techniques will likely drive the next generation of 3D visualization and simulation capabilities.

## 5. Way Forward

As discussed, the evolution of 3D interoperability standards is increasingly shaped by a dynamic interplay between standards organizations, industry consortia, and private enterprises. While organizations such as the Khronos Group, the Alliance for OpenUSD (AOUSD), and the Metaverse Standards Forum play a central role in developing and refining these technologies, their strategic direction is often influenced by the commercial interests of their members, including major technology firms such as NVIDIA, Apple, Microsoft, and Meta (Khronos Group, 2022; AOUSD, 2023, references [6] and [2]). This intersection between open standards development and proprietary business models creates a complex landscape where innovation, market competition, and interoperability coexist.

Despite these competing influences, the governance of 3D standards remains distributed among multiple stakeholders, necessitating continuous engagement and negotiation. Open standards serve as a foundation for collaborative technological advancements, yet their long-term sustainability depends on industry-wide adoption, regulatory policies, and adaptation to emerging applications (Metaverse Standards Forum, 2023, reference [7]). The challenge, therefore, lies in maintaining a balance between commercial innovation and broad accessibility, ensuring that 3D interoperability frameworks remain adaptable to diverse sectors, including defense, industrial simulation, and geospatial visualization.

## 5.1. The Role of Defense Standards Organizations

While commercially driven 3D standards are developed to serve a broad range of industries, their applicability to military and defense modeling and simulation (M&S) requires careful evaluation and organizations such as SISO and the NMSG can play a role in integrating defense-specific requirements into the global standards development process.

SISO has historically served as a focal point for military M&S standards, ensuring that defense applications benefit from advancements in commercial simulation technologies while maintaining mission-critical security and interoperability (SISO, 2023, reference [13]). Given the rapid evolution of 3D rendering, simulation, and real-time data visualization, SISO could engage with standards bodies such as the Metaverse Standards Forum and the Khronos Group to advocate for defense requirements.

Key areas where SISO can contribute include:

- Assessing the applicability of commercial 3D standards, such as glTF, OpenUSD, and 3D Tiles, to military training, simulation, and operational planning.
- Developing extensions for defense-specific use cases, including classified data management, real-time multi-resolution rendering, and battlefield simulations.
- Providing procurement and acquisition guidance, ensuring that military organizations adopt commercially viable standards that align with long-term interoperability goals.

Through these initiatives, SISO can bridge the gap between military-specific requirements and broader commercial 3D standardization efforts, ensuring that defense applications benefit from technological advancements while maintaining security and scalability.

NATO MSG operates as a multinational collaborative forum that consolidates the M&S requirements of allied nations and translates them into actionable inputs for standardization efforts (NATO MSG, 2023, reference [8]). Unlike SISO, which focuses on technical expertise and advocacy, NATO MSG primarily engages in requirements gathering, validation, and large-scale testing of simulation technologies.

NATO MSG's role in 3D interoperability standardization is twofold:

- Harmonization of defense requirements – NATO MSG can aggregate multi-national military needs and present a unified set of interoperability objectives to commercial standards organizations. This ensures that global defense applications maintain compatibility across allied forces.
- Validation and testing – NATO MSG can conduct rigorous testing of commercial 3D interoperability standards within military simulation environments. This process is essential for ensuring that standards such as OpenUSD and 3D Tiles meet the operational demands of mission-critical scenarios.

By aligning its efforts with SISO, NATO MSG can strengthen the influence of the defense sector in shaping the future of 3D standards, ensuring that military applications are not merely adopters of commercial technology but active participants in its development.

## 5.2. Defense Engagement in 3D Standards

To ensure that defense requirements are effectively integrated into the future of 3D interoperability, SISO and NATO MSG could adopt a proactive and collaborative approach. The following strategies are recommended:

1. **Development of Defense-Specific Extensions**

   SISO should work with the Khronos Group and AOUSD to create extensions for glTF and OpenUSD that address classified data security, real-time geospatial rendering, and military training environments.

2. **Establishment of Joint Working Groups**

   NATO MSG and SISO should collaborate with industry consortia to address concerns such as multi-domain interoperability, AI-driven simulations, and cloud-based defense applications.

3. **Validation of Commercial 3D Standards in Military Environments**

   NATO MSG should conduct simulation exercises to test and validate the applicability of commercial 3D standards for coalition-based operations and joint military training.

4. **Educational and Procurement Support**

   SISO should provide guidance documents and training resources for defense procurement teams, ensuring that acquisition decisions align with emerging 3D interoperability standards.

By implementing these strategies, the defense community can ensure that its unique requirements are embedded within global 3D interoperability frameworks, reinforcing the importance of open, scalable, and secure simulation technologies for military applications.

# 6. Conclusion

The evolution of 3D interoperability standards is at an important juncture, where the defense M&S community must navigate an increasingly complex landscape of commercial and open-source developments. While organizations such as the Khronos Group, the Alliance for OpenUSD, and the Metaverse Standards Forum drive progress in 3D technologies, their direction is heavily shaped by commercial interests, leaving military applications to adapt or advocate for their specific needs. This presents both challenges and opportunities: a fragmented and rapidly evolving ecosystem on one hand, and the potential for defense to leverage cutting-edge advancements in 3D visualization, real-time rendering, and geospatial data processing on the other.

The limitations of legacy standards such as SEDRIS, RIEDP, and OpenFlight, coupled with a lack of coordinated policy in environmental representation, have resulted in inconsistent adoption and interoperability issues across defense simulation systems (NATO AMSP-01, 2021, reference [14]). Additionally, the defense sector faces the ongoing dilemma of balancing open standards adoption with security, cost-effectiveness, and long-term sustainability. While newer commercial frameworks such as OpenUSD, 3D Tiles, and glTF offer compelling alternatives, their integration into military systems remains largely unstructured and requires deliberate standardization efforts.

The Simulation Interoperability Standards Organization (SISO) and the NMSG play crucial roles in shaping the defense community's engagement with these emerging standards. SISO's role in advocacy, technology assessments, and procurement guidance is vital for aligning military training and simulation systems with evolving commercial solutions (SISO, 2023, reference [13]). At the same time, the NMSG must continue to consolidate defense-specific 3D requirements, validate standards through rigorous testing, and ensure coalition interoperability across allied nations.

A path forward requires greater collaboration between defense stakeholders and commercial standards bodies to address key issues such as:

1. Developing defense-specific extensions for glTF and OpenUSD, ensuring secure, high-fidelity military simulations.

2. Establishing formal engagement mechanisms with organizations like Khronos, AOUSD, and OGC, ensuring defense priorities influence mainstream 3D standardization.

3. Validating commercial 3D streaming solutions (e.g., Cesium, NVIDIA Omniverse) within military training and simulation environments to ensure compatibility, scalability, and security.

4. Educating defense procurement officers on the long-term implications of adopting commercial 3D standards, ensuring cost-effective, future-proof acquisitions.

Ultimately, there is no single, universally accepted solution for 3D interoperability within defense M&S. However, through proactive engagement with industry, strategic adoption of open standards, and coordinated NATO-led efforts, defense organizations can achieve greater interoperability, reduce costs, and future-proof their training and simulation infrastructures. We suggest that the defense community should now take steps to bridge the gap between legacy standards and the new wave of open standards, ensuring that the next generation of 3D simulation standards supports both military readiness and sustainable technological innovation.

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**STEFAN SANDBERG** has more than 30 years of experience from working with software development in aerospace and automotive with primarily simulation, training and test applications. He is currently working as a COO for a company in the simulation and test industry after a few years with Vector and Qualcomm in the test and development of ADAS systems. Before joining Qualcomm he was the Managing Director of Pitch Technologies, a provider of innovative and standards based interoperability products and services for all types of simulation. He has a long experience from working with various types of flight simulators at Saab Aerosystems, where he was employed in a variety of roles from 1989 to 2009. At Saab he, among other things, established a program to provide Mission Flight Simulators to all operators of the Gripen fighter aircraft. He has also managed a Swedish government IPT with the aim to coordinate all simulation resources and software development tools used in the development process for the Gripen Aircraft. He has served on the RAeS Flight Simulation Group Committee (FSGC) for a number of years and is active within SISO in the Executive Committee and SISO inc. Board of Directors. Stefan Sandberg has studied industrial Engineering and Management at the Linköping Institute of Technology and is a holder of a PPL flight certificate.