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The metaverse-industrial complex

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ABSTRACT

This paper explores the role that Nvidia is playing in shaping the Metaverse for industrial applications in simulation and automation. As the world's largest manufacturer of Graphics Processing Units for computationally intensive tasks and one of the largest corporations by market capitalization, Nvidia has remained relatively overlooked within critical discussions of 'Big Tech', the Metaverse, and Artificial Intelligence. This paper draws on news media reports and publicly accessible Nvidia publications such as developer documentation and press releases to understand the role of Nvidia in shaping the Metaverse for industrial enterprises. It conceptualises the 'Metaverse-Industrial Complex' to theorise the processes of market capture, territorialization, and platform expansionism occurring within the convergence of the Metaverse and Artificial Intelligence that is reconfiguring the governance of public and private assets and infrastructure. Through an examination of Nvidia's 'Omniverse' platform and network of industrial partnerships, the paper examines the Metaverse-Industrial Complex as an assemblage of developer tools, platforms, data standards, and industry partnerships that converge machine learning and 3D graphics into photo-realistic 'digital twin' simulations of physical objects and environments.

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Introduction

Obituaries proclaiming the death of the Metaverse tell how – in just two years and some $36 billion invested by Meta alone – Mark Zuckerberg's vision of building an immersive virtual world had largely fell flat as a tone-deaf misunderstanding of 'what normal people actually want' (Manavis, 2023; Naughton, 2023). Instead, the industry pivoted to emerging applications in Artificial Intelligence (AI), such as ChatGPT and other Generative AI platforms, leaving the impression that the Metaverse was a fleeting object of curiosity of tech elites. However, despite the ephemeral hype for new technologies, there are good reasons to explore how the Metaverse persists in relation to developments in AI markets. In particular, the 'Industrial Metaverse' has emerged as a key area of Metaverse development by converging AI and 3D environments to create simulations of machines,

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systems, factories, urban environments and infrastructure (Bohné et al., 2023; McKinsey, 2022).

The Industrial Metaverse hinges on the intensification of datafication by quantifying all aspects of industrial infrastructure and advances in 'parallel processing' computing afforded by specialised chipsets such as Graphics Processing Units (GPUs) (Rella, 2024; Sharma, 2023). The vast majority of GPU chipsets are developed by Nvidia, a company now valued in the trillions due to surging demand for parallel processing chipsets (Megaw & Acton, 2024). Meta, for example, plans to create Metaverse environments using an AI 'supercomputer' powered by 350,000 Nvidia GPUs performing 'quintillions of operations' per second (Hern, 2024). Such developments place Nvidia in a unique market position and suggest a need to understand how new processes of accumulation, territorialization, and platform infrastructuralization are occurring within the convergence of AI and the Metaverse.

This paper develops the concept of the 'Metaverse-Industrial Complex' (MIC) for understanding the Industrial Metaverse as socially and materially shaped by ecosystems of platforms, data, corporate partnerships, lobbying, and financial arrangements that profit from the application of parallel processing to create simulation and prediction products of industrial systems (Rella, 2024; van der Vlist et al., 2024). While the MIC encompasses heterogenous corporations and sectors, companies such as Nvidia become powerful actors due to their dominant position in parallel processing research and innovation. In turn, the MIC highlights the increasing tendencies towards monopoly capitalism as financial processes of assetization and rentiership continue to shape how contemporary technoscientific capitalism seeks out new revenue streams by creating 3D simulations of industrial systems (Birch, 2019).

The MIC builds on existing theoretical and methodological approaches of Science and Technology Studies that unpack the historiographies, sociotechnical arrangements, and ecologies of digital platforms (Egliston & Carter, 2022b, 2022a; Helmond & Vlist, 2019; Sadowski, 2020a; Srnicek, 2017). The paper specifically unpacks Nvidia's efforts in shaping the marketplace for Industrial Metaverse products by analysing its 'Omniverse' ecosystem of platforms, tools, cloud computing infrastructure and data partnerships. Through a thematic analysis of publicly accessible Nvidia materials including Omniverse developer documentation, press releases, and news reports covering Nvidia's rapid ascension into a trillion-dollar company, this paper examines the MIC within a discussion of Nvidia's platform ecologies. This includes analysing the structural arrangements between Nvidia and other industrial sectors in developing the market for the Industrial Metaverse, and how it has sought to address broader issues of governance, monopolization, and geopolitical tensions in AI and semiconductor markets.

This paper argues that the Industrial Metaverse is in part shaped by hardware manufacturers such as Nvidia that organise heterogenous actants around GPUs for high-performance parallel computing. This occurs across numerous technological modalities, sociotechnical discourses, partnerships, and industrial sectors. This strategy differs from the approaches taken by Meta that concentrate Metaverse development into a specific corporate division (Reality Labs) and build the Metaverse around consumer hardware such as their Oculus VR headset for social media and entertainment applications (Egliston & Carter, 2022b). Central to such questions then is the changing composition of 'Big Tech' and the underlying ecosystems of platforms and data that have profoundly reshaped contemporary capitalism (Birch & Bronson, 2022). This paper therefore provides an invitation for future research into Nvidia and the sociotechnical shaping of AI markets.

The Metaverse and Platform Infrastructure

Tech billionaires routinely proclaim bold visions of the future through capital investment programmes such as the Metaverse (Craib, 2022; Rushkoff, 2022; Smith & Burrows, 2021; Tutton, 2021). Such programmes are underpinned by important questions concerning the power of tech elites to enact radial political ideologies and futurist imaginaries borrowed from science fiction, including Neil Stephenson's *Snow Crash* where the term 'Metaverse' originates (Stephenson, 2008). The Metaverse is generally understood as a successor to the mobile internet that incorporates spatial computing technologies and haptics such as 3D virtual worlds, avatars, and Virtual Reality devices to allow users to inhabit the internet (Ball, 2021; Egliston & Carter, 2022b). Despite variegated definitions, Metaverse developers envision digital futures through spatial and embodied epistemes that converge physical and virtual environments, objects, and bodies into a seamless and immersive experience (Figueiredo, 2022). Metaverse stakeholders and evangelists such as Mark Zuckerberg and Matthew Ball believe the Metaverse will 'revolutionize' how people socialize, work, and play (Ball, 2022; Gorichanaz, 2022).

Underlying these predictions are important questions about the expanding power of digital platforms. Despite the often lofty ambitions of creating an open Metaverse, scholars have drawn attention to an emergent sense of 'Silicon Valley dystopianism' of platform control based on the intensification of surveillance, predictive analytics, market consolidation, and extractivist financialization (Karppi & Nieborg, 2021; Sadowski, 2020b; Zuboff, 2019). Growing concerns that a handful of technology companies now form the 'infrastructural core of a new socio-technical system anchored in digital technologies' are exercising unprecedented control over information systems with countless social, political, and economic implications (Hendrikse et al., 2022, p. 60). In this context, the Metaverse poses key questions concerning the power of platforms to organise market and social relations (van Dijck et al., 2019).

Critical Metaverse studies have therefore sought to examine the social and material processes of platform expansionism, datafication, and capital accumulation to reflect on the changing political economies of platform capitalism (Alvarez León & Rosen, 2024; Egliston & Carter, 2022b; Jungherr & Schlarb, 2022). This body of research builds on existing critical research into platform materialities and historiographies that situate platforms as intrinsically complex organizations with scalable 'platform logics' of information control, vertical integration, and cross-sectorization (Andersson Schwarz, 2017; Srnicek, 2017; Van Dijck, 2021). This occurs when, for example, platforms establish specific kinds of data standards and Application Programming Interfaces (APIs) to extend the organizational logics of platforms across the internet (Helmond, 2015). As Plantin et al. (2018) argue, academic discussions of platform and infrastructure studies are mutually complimentary. This suggests a need to rethink platforms as complex assemblages of market arrangements, technical devices, standards, users, and social practices that shape platform relations (Birch & Bronson, 2022; Kenney & Zysman, 2016; Lehdonvirta, 2022; Sadowski, 2020a).

Platform infrastructures capitalise on decentralised and interdependent services distributed across economy and society (Blanke & Pybus, 2021). An important contribution within these programmes of research highlights the business-to-business arrangements between platforms and the broader ecosystem of actors, customers, and 'peripheral players' to understand the economic logics and interdependencies of digital infrastructure (Dieter et al., 2019; Grabher & van Tuijl, 2020; Narayan, 2023; Smith, 2019; van der Vlist & Helmond, 2021). For Helmond et al. (2019), social media platforms such as Facebook have become entrenched in the ecosystems of connective media that 'derives power from its ability to create institutional dependencies among its vast network of partners' (p. 124). As a result, a core concern throughout platform scholarship is the 'black boxing' of power relations through technical configurations of programmable objects, data standards, and esoteric user agreements that constitute the modalities of 'platform governance' (Gorwa, 2019).

These arguments emphasize a need for understanding the material transitions of platforms and the economic value of data in order to theorise the nature of platform power, influence, and governance through financialised market structures and cumulative network effects (Barns, 2019; Langley & Leyshon, 2017). This includes the concentration of ownership of platforms into oligopolistic market structures (Birch & Bronson, 2022; Srnicek, 2017), the intensification of datafication through surveillance (Sadowski, 2019; Zuboff, 2019); and the rise of digital 'rentiership' that reinforce social inequalities through financialization and extractivism (Birch, 2019; Birch & Cochrane, 2022; Sadowski, 2020a, 2020b). These material processes highlight the changing economic geographies of value creation and capture where platforms perform numerous inter-related roles in shaping markets as intermediaries while also acting as 'data hubs' that aggregate data for AI (Kenney & Zysman, 2020).

In this context, platform studies have taken particular interest in the intensification of 'Big Data' and 'hyper-scalable computing' through cloud computing infrastructures and studies in AI to theorise platform expansionism (Narayan, 2022; van der Vlist et al., 2024). Game engine companies such as Unity and Epic Games have recently begun to attract scholarly attention for their extended reach beyond their role in the gaming sector into creating 'extended reality' environments (Jungherr & Schlarb, 2022). Graphics Processing hardware has likewise been examined for its 'multiplying capacity' towards other applications that require intensive parallel processing, such as crypto-mining, to further comprehend the materialities and semantic qualities of computation (Rella, 2024). Finally, discussions of 'web3' technologies such as blockchain, crypto, and the Metaverse argue that platforms seek to extend their connective reach, expand specific economic and cultural logics of production, and extract value across the production process through financialised mechanics (Alvarez León & Rosen, 2024; Sadowski & Beegle, 2023).

Platforms are therefore embedded across a range of objects, contexts, and geographies. This is important for understanding predictions that the Metaverse signifies the next iteration of the internet characterised by spatially immersive content (Ball, 2022). Such predictions espoused by Silicon Valley elites and stakeholders of social media platforms claim that we are entering a new threshold of digital media immersion (Clegg, 2022). We will soon 'inhabit' virtual environments, like a second home, that will offer limitless kinds of creative freedom for our digital avatars (Gorichanaz, 2022). Mark Zuckerberg's infamous and rather awkward 2021 announcement proclaimed the Metaverse would become 'the successor of the mobile internet' (Milmo, 2021; Paul, 2021). Such views neatly encapsulate how the Metaverse is socially constructed within a historical narrative of platform evolution that gestures to a digital future where platforms expand to new modalities, haptics, and devices such as VR headsets (Egliston & Carter, 2022a; Harley, 2022). Metaverse companies have likewise invested in virtual 'landmaking' technologies and platforms for mediating virtual real-estate markets in an effort to territorialise the Metaverse for capitalist accumulation (Alvarez León & Rosen, 2024). In this respect, the creation of Metaverse assets such as real estate is also deeply intertwined with enacting systems of governance, such as when platform create specific kinds of rules for facilitating market exchanges, protecting private property rights, and upholding the value of digital assets.

However, while discussions of the Metaverse have understandably focused on user-facing devices such as VR headsets, there is a need to examine how the Metaverse is constituted by infrastructures of hardware, platforms, and cloud computing solutions that are essential for building and rendering 3D objects and environments. As the Metaverse aims to provide immersive 3D experiences for users, there is a need to understand how the materialities of computer graphics processing intersect with processes of capital accumulation and industry consolidation (Gaboury, 2021; Rella, 2024). Furthermore, research into business-to-business interactions is crucial for understanding ongoing developments in platform ecosystems (Grabher & van Tuijl, 2020; Narayan, 2023). Such gaps highlight the need to consider how studies of 'Big Tech' can include hardware developers such as Nvidia to create and organise the marketplace for the Metaverse by assembling actors into financial and discursive arrangements that collectively comprise an industrial complex for Metaverse infrastructure.

Nvidia and the Omniverse Ecosystem

As of this writing, Nvidia is among the world's most valuable corporations by market capitalisation (having surpassed both Apple and Google in 2024) and is considered an 'AI superpower' due to its specialisation in high-performance computation hardware, software, and cloud services (Corbyn & Morris, 2023; Enderle, 2022; Goldman, 2023; Megaw & Acton, 2024). Nvidia is best known for producing GPUs that use multi-core systems and 'Compute Unified Device Architecture' (CUDA) parallel processing computer architecture. Parallel processing performs multiple computations concurrently and is well suited for complex calculative operations such as 3D graphics rendering, machine learning and AI, computational lithography, and crypto-mining (Rella, 2024). ChatGPT, the popular AI chatbot, for example, uses a parallel processing infrastructure of some 10,000 interconnected Nvidia GPUs (Hamblen, 2023).

Nvidia controls around 88% of the global GPU market, some 80% of the total market share for AI semiconductor technology, and 98% of the market for data-centre GPU shipments (Allan, 2024; Oi, 2024).[1] Interestingly, Nvidia is a 'Fabless' (fabrication less) manufacturer that outsources the material fabrication of chipsets to specialised semiconductor foundries such as Taiwan Semiconductor Manufacturing Company Limited (TSMC) (Toews, 2023). Nvidia therefore depends on complex global supply and distribution networks for manufacturing GPUs. Increasingly, these networks are impacted by geopolitical tensions and regulatory demands between China and the United States, raising concerns of an emergent global 'chip war' or 'arms race' for semiconductor dominance in AI markets (Geist, 2016; Miller, 2023). Nvidia is currently barred from selling its most advanced GPUs to China and instead ships inferior products due to national security concerns raised by the United States (Baptista et al., 2024).

In addition to geopolitical issues, Nvidia has also been subject to concerns over industry monopolization, such as its now abandoned efforts to acquire UK semiconductor manufacturer Arm Limited from Softbank Group for $40 billion USD due to 'insurmountable' regulatory issues that would give Nvidia 'too much market power' (Sweney, 2022). In September 2024, the US Department of Justice's antitrust division announced an investigation into Nvidia and a handful of other big tech companies for potentially abusing their monopolistic dominance of AI technology markets (Fitch, 2024; Naughton, 2024). In effect, Nvidia has become entangled in a unique position where it must address multiple and complex regulatory concerns over its crucial role in semiconductor research and development for maintaining US competitive advantage in a global AI arms race, while also addressing concerns of monopoly power over its influence in domestic markets.

Not surprisingly, Nvidia has recently stepped up its lobbying efforts as part of a 'delicate dance' of maintaining relationships with state and business stakeholders (Nieva, 2024). Nvidia's efforts to shape semiconductor policy include recruiting corporate lobbyists who have previously held roles in the U.S. Treasury, State Department, and Homeland Security. Nvidia recently hired a new director of technology policy and engagement, Eric Breckenfeld, whose previous work experience includes positions in key U.S. military institutions such as the Defense Advanced Research Projects Agency (DARPA) and Naval Sea Systems Command. Breckenfeld also served as Director of Technology Policy for the Semiconductor Industry Association, a policy fellow for the White House's National Nanotechnology Initiative, and as a lead scientist for defence contractor Booz Allen Hamilton. For Breckenfeld, the securitization of AI is crucial for maintaining American competitiveness. As he sees it, AI and the emerging 'bioeconomy' are

> inseparably linked to our societal values in a way that the disruptive technologies of previous decades were not. It is therefore imperative for not only economic competitiveness, but also national security that the United States continues to set the pace of innovation for both the foundational technologies of these domains (Nieva, 2024)

In addition to being a key hardware vendor to government agencies such as the US Navy, Nvidia has also been a major recipient of Department of Defense contracts including DARPA to develop high-performance GPU computing using parallel processing for building 'exascale' supercomputers (Nvidia, 2010).

In this context, Nvidia has arguably become an 'obligatory point of passage' when discussing the political economy of high-performance computing applications such as 3D graphics rendering and AI markets (Callon, 1984). However, its role in building the Metaverse has received less attention but nonetheless reveals how Nvidia has sought to become a central player by exploiting its structural position in parallel processing technology to create photo-realistic 3D environments and simulations for Metaverse experiences. Nvidia's efforts in building the Metaverse are most evident in their release of

'Omniverse', a 'design collaboration tool' used for creating Metaverse content at an industrial scale (Cherney, 2021). Announced in 2019, Nvidia describes Omniverse in its corporate timeline as playing a 'foundational role in the building of the Metaverse, the next stage of the internet.'[2]

Omniverse is a platform ecosystem of data, tools, and high-performance cloud computing infrastructures used by professional designers and engineers for collaborative production in sectors such as entertainment, transportation, and industrial fabrication. The ecosystem includes modular components, Application Programming Interfaces (APIs), Software Development Kits (SDKs), AI content generators, and cloud computing services. Collectively, these components are employed for 'industrial digitalization' and 'generative physical AI' applications that depend on state-of-the-art parallel processing hardware.[3] Omniverse is licensed to enterprises on a 'per-GPU' basis.

Omniverse consists of five interconnected modules for creating, rendering, and simulating 3D objects and environments. *Nucleus*, the central database and collaborative engine that stores project files on an Nvidia cloud server. *Connect* provides the content libraries and connection protocols for working with other software such as Unreal Engine, Unity, Maya, and Sketchup. *Kit*, the Omniverse SDK provides modular tools to build apps and services. *RTX Renderer*, a cloud-based multi-GPU graphics renderer that makes digital objects appear more 'natural' and 'photo realistic'. Finally, *Simulation* is an aggregation of machine learning tools for manipulating object properties in 3D simulations. Collectively, these components create a software 'stack' (Bratton, 2015) that scales the industrial production of Metaverse content across individual workstations and cloud services in real-time.

Omniverse employs 'cloud rendering' through its 'Graphics Delivery Network' where the necessary computational resources for creating 3D objects are performed remotely and then streamed to a workstation. Omniverse also capitalises on Nvidia's proprietary 'RTX' technology for 'ray tracing' (a complex technique of parallel processing used in Nvidia GPUs that can realistically simulate the lighting of a scene and its objects by rendering physically accurate reflections, refractions, shadows, and indirect lighting). Collectively, these processes allow designers to create photo-realistic scenes that could be stored and rendered remotely using Nvidia's suite of cloud computing solutions.

Not surprisingly, such endeavours intensify the scope of datafication and the need for data standardization across the ecosystem. Omniverse uses the 'Open Universal Scene Description' (OpenUSD) framework for standardizing 3D data created by Pixar Animation Studios to help digital artists transfer 3D content across different platforms for film production. OpenUSD is widely used in media industries for real-time collaboration whose standards are maintained by the Alliance for OpenUSD[4], a consortium of Pixar, Adobe, Apple, Autodesk, Nvidia, and the Linux Foundation to drive content interoperability. According to Nvidia Vice President of Omniverse Platform Development Richard Kerris, OpenUSD will eventually be adopted as a global standard for 3D content, much like what HTML did to standardise web development (Cherney, 2021). While such predictions echo the lofty ambitions of Metaverse developers of revolutionizing the internet, there are nevertheless important distinctions in directing capital investment to create Metaverse products intended for industrial enterprise.

Envisioning the Industrial Metaverse

Nvidia's Omniverse is designed for 'Industrial Metaverse' applications that exploit parallel processing architectures to create 3D simulations of objects and environments within industrial modes of design and fabrication. The Industrial Metaverse is, therefore, a unique departure from the conventional meanings of the Metaverse as a shared 3D immersive world for socialising, consumption, and gaming. Instead, the Industrial Metaverse aims to reconfigure industrial modes of production by assembling complex socio-technical networks of corporations, data, and platforms sustained through parallel processing infrastructure. This financial and discursive process collectively shapes a Metaverse 'industrial complex' wherein corporations such as Nvidia assemble to envision new possibilities for mediating industrial modes of design and fabrication using 3D virtual environments.

According to the World Economic Forum, the Industrial Metaverse is a 'persistent 3D platform that serves as a digital reflection of an entire organization in its operational environment by integrating processes, materials, machines and people in a bidirectional flow between real and virtual worlds' (Bohné et al., 2023). A key example of how the Industrial Metaverse assembles physical and virtual objects and environments together is by creating 'digital twins' (Grieves, 2019). Digital twins are virtual representations of physical objects, environments, and systems (Siemens, 2024). Digital twins are created using a data stream that connects a physical ('real-world') system and its digital replica to model and predict system behaviour in real-time (Kreuzer et al., 2024). Nvidia CEO Jensen Huang has even called the Metaverse 'a virtual world that is a digital twin of ours' further underscoring the relationship between the Industrial Metaverse and digital twins (E. Shapiro, 2021).

As Tuegel et al. (2011, p. 2) argue, digital twins are 'ultrarealistic' in geometric and material detail that will enable the 'reengineering of structural life prediction process'. A factory could attach digital sensors across an assembly line, and feed that data into a digital platform (such as through Omniverse) to derive probabilistic models of object interactions for assembly line optimization (Wagg et al., 2024). Digital twins are not necessarily new, however, advancements in machine learning, AI, and the Metaverse have resulted in a resurgence of scholarly and applied interest in using digital twins for automating industrial fabrication, predictive maintenance of complex artefacts such as aircrafts, and the management of everyday infrastructures such as 'smart cities' (Barachini & Stary, 2022; Cooke, 2021; Goodchild et al., 2024). Digital twins in this respect, could dramatically extend the flexibilization of 'post-Fordist' production to new plateaus of organizational control through data extraction and simulation where every variable is datafied and tested to a desired performance threshold (Deleuze, 1992).

Nvidia has taken a particular interest in developing Omniverse for creating digital twins for Industrial Metaverse environments by exploiting the affordances of the platform and the OpenUSD standard for creating physics-based data libraries and APIs to perform simulations of object-interactions. This addition of object programmability expands the possibilities for control over the production process used in the design, optimisation, process control, virtual testing, predictive maintenance, and lifetime estimation of industrial production (Wright & Davidson, 2020). For example, an automotive company could employ Omniverse to build a new vehicle 'from concept to production to sales' (D. Shapiro, 2023). Design and production could be assembled into the Omniverse ecosystem, including automotive design, systems integration, product testing, and prototype demonstration of the vehicle within an AI-generated environment. Digital twins can simulate the relations between assembly line components to optimise production. Finally, such processes of industrial customisation and simulation can be scaled to retail customers, such as by allowing prospective car buyers to personalise their vehicle and virtually test drive the car in a photo-realistic Metaverse simulation rendered across numerous modalities such as a web interface, mobile app, or VR headset.

Stakeholders predict that digital twins will become ubiquitous across the production process. As Nvidia argues, eventually, 'everything manufactured will have digital twins' (Nvidia, 2024b). The global consulting company McKinsey (2022) believes that digital twins will be the 'engine' of Industrial Metaverse applications: 'every asset, process, or person within and related to an enterprise will be replicated virtually – and connected. As a result, nearly every aspect of work can take place solely digitally or, at the least, before it does so physically.' Such predictions in effect place significant pressure on extending processes of datafication whereby techniques for data extraction and generation become embedded throughout industrial infrastructures. For example, Nvidia has invested in creating 'SimReady' (Simulation Ready) assets as a new category of 3D content designed for simulating objects in Omniverse. SimReady is a data specification for creating 'physically-accurate 3D objects that encompass accurate physical properties, behaviour, and connected data streams to represent the real world in simulated digital worlds' that can be used to rapidly train AI models and assist in building digital twins.[5] Put simply, the SimReady specification allows designers working with 3D objects to conform these objects for machine learning research (operating in Omniverse like 'Lego bricks' according to Nvidia), making these objects 'purpose-built for simulation' or synthetic data generation (Nvidia, 2024c).

The Metaverse-Industrial Complex

So far, this paper has explored Nvidia's Omniverse as a key example of how the Industrial Metaverse reconfigures sociotechnical relations of production by intensifying the scope of datafication and simulation. However, Nvidia has also sought to build a marketplace for Omniverse and other high-performance computing solutions using Nvidia hardware by creating a network of clients across sectors such as industrial manufacturing, cloud computing, media, and the public sector. The Nvidia Partner Network (NPN)[6], for example, brings Nvidia products and solutions to market by providing enterprise customers access to a database of over 1100 vendors, equipment manufacturers, service providers, consultants, and product distributors partnerships that specialise in, and are loyal to, Nvidia. Partners possess various kinds of expertise in using Nvidia products and solutions across different sectors and areas of competency for high-performance computing. Partners are 'ranked' into three categories of distinction based on their relationship to Nvidia and commitment to the NPN. While it is unclear exactly what metrics and thresholds define each tier, partners are incentivized to participate in the network to gain unique rewards, such as partner pricing for Nvidia products, priority allocation of stock for backorders, and access to Nvidia expertise and technical support. In this respect, the NPN aims to create a marketplace for the circulation of Nvidia products, services, and expertise by recognizing and rewarding partners that invest in Nvidia products both financially, and by providing technical training for clients.

The NPN reveals how the political economy of the Industrial Metaverse depends on sustaining partnerships and sociotechnical relations between industrial sectors across various modalities, including at the infrastructural level of building modular technical components for platform interoperability, and by creating industry partnerships that orbit around Nvidia's market dominance. Such partnerships have become a crucial aspect for understanding how platform ecosystems govern marketplaces (van der Vlist & Helmond, 2021) while also highlighting the underlying political role that Nvidia is playing in governing the Industrial Metaverse and how various sectors may come to utilise and depend on Nvidia's platform ecosystem. For example, Nvidia is partnering with German technology conglomerate Siemens to connect Omniverse with Siemens' 'Xcelerator' portfolio of cloud-based industrial software for digital twins.[7] The objective is to transform industrial digitalisation through ultra-realistic digital twins of infrastructure where designers, planners, and engineers can integrate 3D applications into a unified virtual dataset, or what Nvidia calls a '*single source of truth*' for decision-making (Nvidia, 2024a).

There are many applications in both private and public sectors. Deutsche Bahn, for example, has been developing a digital twin of the entire railway network using Xcelerator and Omniverse (Geyer, 2022). The digital twin is a 3D realistic simulation of 5,700 railway stations and 33,000 kilometres of track that incorporates datasets and simulation tools developed by Siemens. Omniverse is used to connect and funnel a myriad of datasets into a 3D digital twin of the entire railway infrastructure, and ostensibly allows engineers to make continuous improvements in the network, optimizing the deployment of vehicles and railways. This simulation can also train AI systems that automate the rail network by synchronizing the digital twin and physical infrastructure of trains and railway switches. Should an anomaly arise, such as a train detecting an obstruction on a railway, the system can automatically update and adjust train schedules to minimize disruption.

Nvidia is also shaping the industrial production of media assets and consumer experiences using Generative AI tools. For example, Nvidia's partnership with the global marketing and communications company WPP aims to 'transform advertising production and branded 3D experiences by unifying content creation workflows.'[8] Formed in 2023, the Nvidia/WPP partnership is described by Nvidia as enabling marketers to produce the 'next era of branded online content' that will leverage digital twins, 3D experiences, and AI-generated content for marketing automation. The objective is to develop a 'content engine' to accelerate the marketing production process by building 'brand compliant' and 'product accurate' digital content that could be personalized to individual consumers, 'while preserving the quality, accuracy and fidelity of their company's brand identity, products and logos' (Nvidia, 2023). A graphics designer could respond to changing needs and demands of a client through GenAI semantic prompts to manipulate a digital twin of a consumer artefact, including environmental properties to create the 'right' scene, atmosphere, and 'brandscape' for a product (Ash, 2012; Murakami Wood & Ball, 2013).

Such partnerships illustrate how the MIC is structured through converging sociotechnical networks of industrial partners across multiple sectors investing in parallel processing technologies for industrial automation that can be applied in both public and private markets. Crucially, there is a discourse of governance that underlies MIC, particularly with respect to how emergent technologies engender questions concerning how platforms and infrastructures actualise material and discursive governance practices (Gillespie, 2010; Gorwa, 2019; Plantin & Punathambekar, 2018). Governance occurs across multiple layers and modalities, such as across its partner program, and in the governance of infrastructure through platform logics and AI systems. These modalities illustrate how Nvidia has become deeply enmeshed in managing the marketplace for parallel processing, and their crucial but overlooked role in creating the necessary ecosystem for influencing how private and public infrastructure is managed. In turn, the MIC demonstrates how platform ecosystems have become a defining feature of contemporary capitalism that centralizes and monopolizes data infrastructure to extract monetary and data rents in an effort to develop continuous revenue streams, such as by licensing Omniverse software (Andersson Schwarz, 2017; Grabher & van Tuijl, 2020; Nieborg & Poell, 2018; Rikap, 2022; Sadowski, 2020a; Srnicek, 2017).

The MIC illustrates the expanding influence of big tech and platform ecosystems, in this case through the production of 3D simulations to accelerate the automation of infrastructure and knowledge intensive labour such as public transportation management or creative content production. While Nvidia and others typically frame the Industrial Metaverse in technocratic dimensions of product optimization, flexibility and resilience, there is also an underlying consideration of the structural dependencies created due to the sunken costs of creating a digital twin to manage various aspects of industrial production and infrastructure. For that matter, the social consequences of automation, such as through algorithm bias and the impacts of AI on organizational decision-making have been a long-standing concern (boyd & Crawford, 2012; Crawford, 2021). Questions of how, if at all, large organizations such as Deutsche Bahn could withdraw from Omniverse without risking critical infrastructural failure are not easy to answer but suggest an embedding and potentially irreversible platform dependency. Such issues are critical given Nvidia's market capitalization and influence on AI development and will inevitably raise questions about how the MIC is reshaping structural relationships between private and public sectors, particularly as stakeholders predict that digital twins will eventually mediate everything.

Nvidia is of particular importance in shaping the Industrial Metaverse due to its market dominance in parallel processing and its capacity to organise market relations through partner networks. For Nvidia, the Metaverse signifies an opportunity for expanding market dominance in parallel processing capital by converging content production platforms such as Omniverse with GPU cloud processing centres. At the same time, it has sought to expand the Metaverse towards industrial applications, particularly by leveraging Nvidia's Omniverse and parallel processing infrastructure for creating digital twin simulations of state and corporate assets such as public transportation infrastructure. The MIC encapsulates key technological and economic convergences between platform ecosystems to shape the industrial production of Metaverse applications. These convergences highlight the role of Nvidia as a 'Big Tech' player that occupies a unique role in building both hardware components such as GPUs and data processing centres, and software such as Omniverse. Corporate partnerships and content license agreements with industry heavyweights such as Nvidia, Siemens, WPP, Adobe, and Getty Images illustrate the kinds of market structures for shaping the Metaverse. Infrastructural components and the Omniverse ecosystem of programmable objects and data standards, and the use of 3D graphics data-processing centres in the cloud all mutually shape the Metaverse-Industrial Complex as an ongoing process of assembling actors into various kinds of content license agreements, data sharing partnerships, and creating path dependencies between platform ecosystems that reorganize industrial production processes.

Conclusion

This article conceptualised the Metaverse-Industrial Complex to understand the structural relationships between big tech, state, and industrial enterprises that are mutually shaping the market for AI driven simulations in Metaverse environments. Extant scholarship has so far largely overlooked the Industrial Metaverse, and the role of Nvidia in shaping the marketplace for Metaverse applications. This paper sought to address this gap by examining the complex arrangement of platforms, cloud-infrastructures, programmable objects, content licensing, data standards, and industrial partners that converge in shaping the Industrial Metaverse. Nvidia has become a focal point of these developments given its market dominance in parallel processing technology and its investment in platform ecosystems for the Industrial Metaverse. This suggests a need to reflect on the changing modalities of the Metaverse as AI investment continues.

Such developments likewise highlight the increasing scope of datafication where industrial enterprises collaborate in data collection and predictive analytics for building digital twins. Such processes arguably reconfigure platform governance wherein decision-making becomes increasingly entrusted to virtual representations of industrial systems (Korenhof et al., 2023). In this sense, the delegation of power to digital twins to mediate the world is both a political decision and technocratic concern for optimisation that reflects ongoing institutional pressures of global market competition, and the need to demonstrate efficiency and resilience in public services such as transport networks. The MIC becomes increasingly important for understanding how industrial networks assemble digital twins across heterogeneous sectors, creating more pressure on firms to intensify the magnitude of datafication for constructing increasingly 'precise' simulations. Systems become increasingly dependent on Industrial Metaverse platforms to manage the complex data streams and blurring of physical and virtual objects.

While Metaverse evangelists claim that nobody will ever actually 'own' the Metaverse, corporate partnerships, alliances, and consortiums nevertheless reveal the processes of property ownership and capital accumulation occurring in the Metaverse (Alvarez León & Rosen, 2024). In this context, the MIC is structured by legal regimes of content and platform licensing arrangements and forms of rentiership that direct capital to powerful industrial entities such as Nvidia that provide the underlying platform infrastructures for creating Metaverse content AI simulations (Birch & Cochrane, 2022). At the same time, Nvidia's Omniverse intensifies the processes of platform infrastructuralization using cloud-based data processing capital necessary for designing, building, and rendering real-time Metaverse simulations. This suggests a need to continue to unpack the changing political economies of computational architecture driving new markets for parallel processing (Rella, 2024).

Further research is warranted to explore the political economies of the Industrial Metaverse, its structural arrangements between corporations and the public sector, and how these relations will transform markets for parallel processing. In any event, the ascension of Nvidia as a major powerhouse in building the necessary computational capital for 3D rendering and machine learning cannot be underscored and will likely figure into emergent discussions of AI and Big Tech. The analysis of Nvidia's infrastructure for AI, parallel processing, and Industrial Metaverse ecosystem will benefit from a closer examination of the commercial licensing and industrial partnerships shaping the MIC. The future scholarship will need to reflect on how Nvidia fits within the ecosystem of platform capitalism, the materialities of the Metaverse, and what impacts Nvidia will have on reshaping the institutional relations of 'Big Tech'.

Notes

1. Nvidia's main competitor is Advanced Micro Devices (AMD) whose CEO Lisa Su is also Nvidia CEO Jensen Huang's cousin.
2. https://www.nvidia.com/en-eu/about-nvidia/corporate-timeline/
3. https://www.nvidia.com/en-gb/omniverse/
4. https://aousd.org/
5. https://developer.nvidia.com/omniverse/simready-assets
6. https://www.nvidia.com/en-gb/about-nvidia/partners/
7. https://www.sw.siemens.com/en-US/digital-transformation/
8. https://www.nvidia.com/en-eu/industries/media-and-entertainment/wpp/

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