Journal of Intelligent Manufacturing (2023) 34:2511–2512
https://doi.org/10.1007/s10845-023-02145-w

Manufacturing metaverse

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Published online: 24 May 2023

The term metaverse is attributed to the science fiction book (Stephenson, 1992) published in 1992, just a year after the Internet was established. However, similar concepts under different names date back to 1980s. The term 'metaverse' combines two words 'meta' (implying beyond) and 'verse' (implying universe) and is defined in the literature as a universe beyond the physical world. Metaverse includes avatars (e.g., human, animals), portals (e.g., sensors, augmented reality), and the virtual world (parallel universe). It has not been embraced by the manufacturing research community for decades. One of the first mention of the metaverse in a virtual reality setting was presented in Huvila (2013). Attributed by some to the rebranding of Facebook as Meta in 2021 and announcement of Mesh by Microsoft, the interest in metaverse has spiked across different domains, including manufacturing. Thus far, the greatest beneficiary of metaverse appears to be the gaming industry. The 3D immersive experience enhanced with the interaction and collaboration features make metaverse attractive to manufacturing. The concepts originated in data such as digitization, digital twin, and cyber-physical systems as well as technologies ranging from virtual reality and blockchain to Web3 and artificial intelligence connect manufacturing to the metaverse. Metaverse is a technology to support the well-established frameworks and initiatives such as Industry 4.0 and 5.0, as well as Society 5.0, marked by a path from digital to universal manufacturing (Kusiak, 2022).

The concept of a manufacturing metaverse is illustrated in Fig. 1. It involves three spaces: physical, cyber (digital) and social space (biological). The exchange of data, information, knowledge, and models takes place between these three spaces.

The complexity and scale of each space in Fig. 1 varies across applications. For example, a model of manufacturing equipment (e.g., machine tool, robot) is usually less complex than that of the entire factory. Note that metaverse is human focused, while digital twin is technology oriented. The social space includes individuals or groups of individuals.

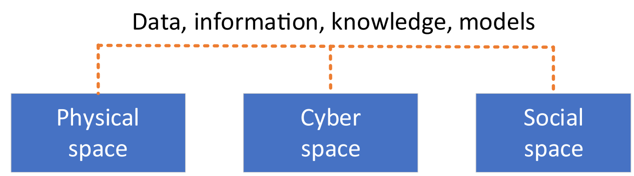

Fig. 1 Illustrative example of a manufacturing metaverse

The developments leading to the manufacturing metaverse are demonstrated in Fig. 2. The progression path is reflected in the simulation and visualization/implementation perspective.

The metaverse journey in manufacturing can be traced back to analog simulation, followed by the numerical 1D (D = dimension), and then 2D and 3D digital simulation. The 3D digital simulation has led to extended reality (augmented, virtual, and mixed). The extended reality in an enabling technology of the metaverse including avatars, places, and objects. Other types of virtual reality have been considered in the literature. A seven-layer metaverse architecture with the corresponding supporting technologies and companies involved in their development was presented in Wang et al. (2022). These layers include (from the bottom to the top): infrastructure, human interface, decentralization, spatial computing, creator economy, discovery, and experience.

Manufacturing metaverse vs digital twin

Metaverse offers capability of interest to Industry 4.0 and beyond as well as parallel concepts and initiatives. In particular, the concept of a digital twin and a manufacturing metaverse share some commonality as both are models (most likely derived from data), however, each serves its own purpose (see Table 1). The manufacturing metaverse offers

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Fig. 2 The developments in simulation leading of a manufacturing metaverse

Table 1 Basic characteristics of a manufacturing metaverse and a digital twin

Feature	Metaverse	Digital twin
Model	Yes	Yes
Purpose	Simulation	Operations
Model fidelity	Low	High
Decision making	What-if	Autonomous
Predictive capability	Desirable	Essential
Innovation support	Likely	Not likely

simulation capability, while the digital twin is intended to support operations and control of processes.

Due to its purpose, the fidelity of the model behind a digital twin is usually higher than that of a metaverse. The fact that a digital twin is expected to generate decisions or control a physical system, the demand for its autonomy is high. The simulation capability of a metaverse, makes it suitable for 'what-if' analysis. While the predictive capability might be useful in a metaverse, it is essential in a digital twin. The fact that different operational and decision-making scenarios can be assessed in a manufacturing metaverse, it offers opportunities for innovation.

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