# Literature Review

## Digital Twins

### Origin of Digital Twins.

The concept of the "Digital Twin," which has emerged as a pivotal framework in the realm of engineering and industrial applications, finds its origins in the early 2000s. Dr. Michael Grieves, a scholar at the University of Michigan, is credited with applying and pioneering the foundational ideas behind it. (Sjarov et al., 2020) Initially referred to as the "Mirrored Spaces Model," later renamed by NASA’s John Vickers as “digital twin”, the Digital Twin comprises three fundamental components that collectively constitute its essence. These components, seen in the figure below, consist of the "Real Space," representing the tangible, physical counterpart; the "Virtual Space," serving as the digital replica or simulation of the real-world entity; and the intricate web of connections that interlink data and information, bridging the gap between the virtual and real products. (D’Amico et al., 2019) This innovative framework has since evolved into a versatile and indispensable tool, offering profound insights into various domains, including crane fleet monitoring, where it enables the creation of highly accurate virtual representations of physical assets and facilitates the real-time tracking and analysis of their performance.

A diagram of a space shuttle

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*Figure 1 – Components of a Digital Twin.*

### How do Digital Twins Work?

Real-world machines are equipped with an assortment of sensors that record critical performance data. These sensors capture information on various aspects of the crane's operations, including parameters such as load capacity, movement, environmental conditions, and more. (IBM, n.d.) In the realm of digital twinning for fleet monitoring, the convergence of physical and virtual elements assumes paramount significance. This integration is prominently illustrated through the acquisition of multifaceted physical measurements, derived from the Programmable Logic Controller (PLC) of cranes, which encompass variables such as spatial position and speed of the crane's spreader. These tangible data inputs form the foundation for the construction of a comprehensive digital twin. Furthermore, on the virtual side, the research underpins a substantial augmentation in the depth and breadth of available information. This augmentation is primarily achieved through the incorporation of an extensive array of behavioural characteristics. These attributes, inclusive of various performance parameters, not only facilitate the visual representation of the crane but also empower rigorous testing of its capabilities, ensuring a holistic understanding of its operational dynamics. Although the present investigation emphasizes the capacity for virtual testing, it is pertinent to note that for certain applications, the focus may primarily be on generating lightweight virtual models to mirror physical counterparts, with the foremost aim being real-time visualization of intricate systems, even in cases where comprehensive performance testing may not be feasible or necessary.

### Digital Twin: Use Case Models.

The application of Digital Twin technology in crane monitoring and fleet management unveils a realm of profound utility, effectively harnessing the capabilities of conceptualization, comparison, and collaboration as outlined by Michael Grieves. (Grieves, 2014) Conceptualization, in the context of crane operations, enables a transformative approach to understanding the status and performance of these heavy machinery assets. Unlike conventional data processing, Digital Twins offer the unique advantage of real-time, visual representation, eliminating the need for manual translation of visual information into symbolic data. Through the Digital Twin, operators can simultaneously visualize both the physical crane's condition and its virtual counterpart, allowing for a seamless comprehension of crucial data.

Moreover, the concept of comparison becomes an indispensable analytical tool in the context of crane and fleet monitoring. The Digital Twin allows for the immediate evaluation of desired operational outcomes against actual results, eliminating the inefficiencies associated with manual data cross-referencing. By overlaying the ideal characteristics and tolerance corridors, the Digital Twin empowers users to swiftly assess whether the cranes and fleet are performing within acceptable parameters, with deviations colour-coded for instant recognition. These comparisons extend to various measurements, including tensile strength, torque readings, and other critical performance metrics, enhancing real-time decision-making.

Collaboration in crane and fleet management takes on a new dimension with the Digital Twin. Traditionally, operational assessments and troubleshooting were confined to a local context. However, the Digital Twin enables a shared conceptualization that can be accessed and visualized by teams worldwide, transcending geographical boundaries. This global perspective allows stakeholders from various locations to not only monitor their fleets but also compare their performance with fleets across the globe. In the event of an issue in one fleet, the solution can be promptly identified and shared with other fleets, fostering collaborative innovation on a global scale.

In summary, the application of Digital Twins in crane monitoring and fleet management aligns seamlessly with the conceptualization, comparison, and collaboration framework proposed by Michael Grieves. This technological advancement not only streamlines crane operations but also empowers global teams to collaborate in real time, driving innovation and efficiency across the fleet management landscape.

### Choosing Unity 3D for Visualisation of Digital Twins.

Unity3D serves as the linchpin in the landscape of digital twin development, offering an array of potent features and capabilities meticulously tuned to cater to the specific demands of digital twin applications. At its core, Unity3D excels in data ingestion and optimization. This powerful technology seamlessly imports data from diverse formats, including BIM (Building Information Modelling) and CAD (Computer-Aided Design), and integrates data from various systems such as PLM (Product Lifecycle Management), ERP (Enterprise Resource Planning), and IoT (Internet of Things). Unity's data preparation tools are nothing short of impressive, facilitating the import and optimization of over 70 formats. This results in the creation of a unified, real-time representation of physical assets that forms the bedrock of digital twins.

When it comes to flexible and efficient creation tools for digital twins, Unity3D stands out as a global leader. Renowned as the foremost real-time 3D platform worldwide, Unity is further enhanced by a suite of complementary products that expedite the creation, editing, and real-time iteration of interactive 3D content. This accelerates the development process, enabling rapid deployment of digital twins.

Unity3D also shines in the domain of dynamic visualization, supporting an extensive range of devices and platforms. With compatibility for over 20 platforms, including HoloLens, Quest, Windows, Mac, iOS, Android, and more, Unity3D emerges as a versatile choice for digital twin applications. It's not just versatility; Unity is a leading platform for crafting content for AR and VR applications, underpinning a substantial portion of head-worn AR experiences.

To streamline digital twin development, Unity3D provides advanced simulation services. These services encompass sensor and robotics emulation, performance-optimized simulation testing, and training, among others. Collectively, these features expedite decision-making processes. Unity3D's hallmark features, including versatility, real-time capabilities, and extensive support for diverse devices and platforms, establish it as an indispensable platform for the visualization and deployment of digital twins. (Unity, n.d.)

The decision to adopt Unity as the foundational platform for our digital twin application is grounded in a robust foundation of reasons. Spatial rendering, particularly for spatial-oriented data, poses a complex challenge that has long been the focal point of the game industry. This challenge has prompted the development of specialized software, often termed game engines, which offer comprehensive toolsets and reusable components fine-tuned for 3D rendering. In this landscape of options, Unity emerged as the optimal choice for our project, bolstered by firsthand familiarity with the platform, rooted in my background as a games development student. (Leskovsky et al., 2020)

Unity earns our favour for several compelling reasons. It provides extensive support for all essential aspects of our planned development, both directly and indirectly. Unity's user-friendliness ensures ease of learning, and its cost-effective pricing conditions are noteworthy. Moreover, Unity boasts comprehensive documentation and is distinguished for its rapid growth, continuously introducing new functionalities.

By choosing Unity, we unlock the potential of this versatile 3D engine. It empowers us to craft three-dimensional objects within a virtual space, offering dynamic manipulation, movement, and rotation. It also allows us to seamlessly integrate data from IoT devices. In the case of our crane, which is equipped with a multitude of IoT sensors, Unity's prowess in gathering and processing data from these sensors is invaluable. In the context of our digital twin development, we relied on the schematic diagram below illustrating the integration of Digital Twins within Unity3D (Gao et al., 2023) This diagram served as a valuable reference for our project. These capabilities lay the foundation for the immersive environment that our digital twin requires.

A diagram of a cloud server

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*Figure 2 – A schematic diagram of using Digital Twins in Unity3D.*

The camera, a pivotal component in 3D applications, plays a central role in shaping the user's viewpoint and impacting application control and display. Our application offers a spectrum of camera view modes, catering to diverse user needs, from PC desktop viewing to immersive VR experiences with headsets like Oculus. Unity's cross-platform compatibility is a standout advantage, allowing us to develop a unified application seamlessly running across platforms, spanning PCs, mobile phones, and the web. Unity further equips us with robust VR and AR tools that intuitively adapt the camera and interface to accommodate users and their equipment, whether involving a joystick, headsets, or other devices.

This combined section emphasizes Unity3D's pivotal role in digital twin development and offers a comprehensive perspective on the reasons for choosing Unity as the foundational platform for our digital twin application.

## Case Study

### Importance of Case Studies.

In the realm of technological advancements and systems improvement, case studies play a pivotal role in showcasing the significance of innovation. The case of DIAMND (Diagnostics and Monitoring, Crane Management System) serves as a compelling example of how such studies shed light on the transformation of existing systems. It highlights the importance of critically examining and addressing the challenges posed by legacy technologies, especially when it comes to aesthetics and functionality. The importance of this case study lies in its potential to inspire others to explore new, more efficient solutions and improve the user experience, as well as to create visually appealing interfaces for data management systems.

### DIAMND: An Overview.

In this case study, we aim to address the shortcomings of the DIAMND system (Diagnostics and Monitoring, Crane Management System) and propose a more effective solution. The DIAMND system, as the existing approach to crane management, presents several challenges, particularly in terms of aesthetics and functionality. It has relied on data acquisition from diverse sources, including direct connections to a crane’s Programmable Logic Controllers (PLCs) through SignalR and OPC, hourly trace files containing around 35,000 signals, and feedback arrays within the PLCs used to populate job and load statistics tables in SQL.

Throughout this project, I have actively engaged with members of the sales and engineering teams at Liebherr, to gather insights and requirements for the improved system which have been integral in shaping our approach. This case study serves as a testament to the potential of modern technology and data-driven solutions in not only overcoming the limitations of legacy systems like DIAMND but also enhancing the overall user experience and aesthetics of crane management operations.

#### Addressing The Challenges.

In this section, we delve into the existing DIAMND system (Diagnostics and Monitoring, Crane Management System) and the imperative need for its transformation. DIAMND serves as the primary approach to crane management, but it presents a series of challenges, particularly in terms of aesthetics and functionality. These challenges stem from its reliance on data acquisition from various sources, including direct connections to a crane's Programmable Logic Controllers (PLCs) through SignalR and OPC, hourly trace files containing approximately 35,000 signals, and feedback arrays within the PLCs, which are used to populate job and load statistics tables in SQL.

One of the significant challenges is the complexity of data management. The DIAMND system grapples with the intricacies of data acquisition, storage, and presentation. Diverse data sources not only make data management convoluted but also introduce noise and irrelevant information into the system. This noise can obscure critical data, contributing to inefficiencies and suboptimal data aesthetics.

Another issue is the outdated user interface. As highlighted in the figures below, the user interface of the DIAMND system is visually unappealing and does not align with modern design principles. This not only impacts the user experience but also underscores the pressing need for a modern and visually pleasing solution. It's worth noting that the current interface appears thrown together, lacking proper labels, and missing the company's distinctive touch, including its logo.

*A screenshot of a computer

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*Figure 3 – A view of the main spreader information displayed in DIAMND.*

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*Figure 4 – A view of some spreader information displayed in DIAMND.*

#### Proposed Solutions.

To address these formidable challenges, we propose a comprehensive transformation of the DIAMND system to streamline data management and enhance the user experience. Firstly, we recommend the utilization of an Application Programming Interface (API) to seamlessly query data from an OPC Server, connected to PLC, for certain variables and send it to an Azure database. This streamlined approach simplifies data acquisition, ensuring that relevant information is obtained swiftly and accurately. Secondly, data will be securely stored in an Azure database, offering enhanced data management capabilities. The Azure platform provides scalability, reliability, and accessibility, facilitating efficient data storage and retrieval. Lastly, to improve data aesthetics and user-friendliness, we propose the implementation of Power BI for data visualization. This powerful tool enables the creation of clear and visually appealing data presentations, making it easier for users to derive insights from the information.

The proposed solutions promise to mitigate the challenges faced by the existing DIAMND system, offering a path toward more efficient, user-friendly, and visually appealing crane management, in alignment with contemporary standards and user expectations.

### Lessons from Previous Implementations.

Drawing on lessons from previous implementations, the DIAMND case study offers valuable insights for future projects. By examining the challenges and successes of this transformation, we can extract lessons that extend beyond crane management. The key takeaway is the importance of aligning technology with user expectations and needs. Learning from this case study can guide future implementations, ensuring they are more efficient, user-friendly, and aesthetically pleasing.

# References

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