Table Of Contents

[1. Abstract 2](#_Toc149163157)

[2. Introduction 2](#_Toc149163158)

[2.1. Background and Significance of the Study 2](#_Toc149163161)

[2.2. Research Objectives 2](#_Toc149163162)

[3. Literature Review 2](#_Toc149163163)

[3.1. Digital Twins 2](#_Toc149163167)

[3.1.1. Origin of Digital Twins. 2](#_Toc149163172)

[3.1.2. How do Digital Twins Work? 3](#_Toc149163173)

[3.1.3. Digital Twin: Use Case Models 3](#_Toc149163174)

[3.1.4. Choosing Unity 3D for Visualisation of Digital Twins 4](#_Toc149163175)

[3.2. Case Study 6](#_Toc149163176)

[3.2.1. Importance of Case Studies 6](#_Toc149163182)

[3.2.2. DIAMND: An Overview 6](#_Toc149163183)

[3.2.2.1. Addressing The Challenges 6](#_Toc149163191)

[3.2.2.2. Proposed Solutions 8](#_Toc149163192)

[3.2.3. Lessons from Previous Implementations 8](#_Toc149163193)

[3.3. Internet of Things (IoT) 8](#_Toc149163194)

[3.3.1. Fundamentals of IoT 8](#_Toc149163201)

[3.3.2. IoT Devices and Sensors 8](#_Toc149163202)

[3.3.3. IoT Integration with Digital Twin Systems 8](#_Toc149163203)

[3.3.4. IoT in Industrial and Smart Environments 8](#_Toc149163204)

[3.4. Big Data and Visualization 8](#_Toc149163205)

[3.4.1. Big Data Collection and Analysis 8](#_Toc149163213)

[3.4.2. Data Visualization Techniques 8](#_Toc149163214)

[3.4.3. Visualizing Big Data 8](#_Toc149163215)

[3.4.4. Impact of Visualization on Decision-Making 8](#_Toc149163216)

[3.5. Risk Analysis and Platform Issues 8](#_Toc149163217)

[3.5.1. Identifying Risks in Digital Twin Projects 8](#_Toc149163226)

[3.5.2. Evaluating Digital Twin Platforms 8](#_Toc149163227)

[3.5.3. Mitigation Strategies for Risks 8](#_Toc149163228)

[3.5.4. Case Studies of Platform-Related Failures 8](#_Toc149163229)

[4. Methodology 9](#_Toc149163230)

[4.1. Research Approach 9](#_Toc149163235)

[4.2. Data Collection Methods 9](#_Toc149163236)

[4.3. Data Analysis Techniques 9](#_Toc149163237)

[5. Implementation 9](#_Toc149163238)

[5.1. Real-World Application of Digital Twinning 9](#_Toc149163244)

[5.2. IoT Integration and Case Studies 9](#_Toc149163245)

[5.3. Big Data and Visualization Implementations 9](#_Toc149163246)

[6. Results 9](#_Toc149163247)

[6.1. Key Findings from the Implementation 9](#_Toc149163254)

[6.2. Data Analysis Results 9](#_Toc149163255)

[6.3. Successes and Challenges Encountered 9](#_Toc149163256)

[7. Discussion 9](#_Toc149163257)

[7.1. Interpretation of Results 9](#_Toc149163265)

[7.2. Comparing Findings with the Literature 9](#_Toc149163266)

[7.3. Insights Gained from the Study 9](#_Toc149163267)

[8. Conclusion 9](#_Toc149163268)

[8.1. Recap of Key Points 9](#_Toc149163277)

[8.2. Implications for Industry and Research 9](#_Toc149163278)

[8.3. Future Directions 9](#_Toc149163279)

[9. References 9](#_Toc149163280)

# Abstract

# Introduction



## Background and Significance of the Study

## Research Objectives

# 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 Figure 1, 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 interlinks 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

Description automatically generated

*Figure 1 – Components of a Digital Twin (D’Amico et al., 2019).*

### How do Digital Twins Work?

1. On the physical side, we now collect more
2. and more information about the
3. characteristics of the physical product. We
4. can collect all types of physical
5. measurements from automated quality
6. control stations, such as Coordinate
7. Measuring Machines (CMMs). We can
8. collect the data from the machines that
9. perform operations on the physical part to
10. understand exactly what operations, at
11. what speeds and forces, were applied. For
12. For example, we can collect the torque
13. readings of every bolt that attaches a fuel
14. pump to an engine to ensure that
15. each engine/fuel pump attachment is
16. successfully performed.

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 emphasises 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 visualisation 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 conceptualisation, comparison, and collaboration as outlined by Michael Grieves (Grieves, 2014). Conceptualisation, 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 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 fleet 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 conceptualisation, 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). It 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 the digital twin application is grounded in a solid foundation of reasons. Spatial rendering, especially for spatial-oriented data, presents a complex challenge that has long been the focus of the game industry. This challenge has led to the development of specialized software, often called game engines, which offer comprehensive toolsets and reusable components finely tuned for 3D rendering. In this landscape of options, Unity emerged as the optimal choice for the project, bolstered by familiarity with the platform, rooted in a background as a game development student (Leskovsky et al., 2020).

Unity earns favour for several compelling reasons. It provides extensive support for all essential aspects of the 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, the potential of this versatile 3D engine is unlocked. It empowers the crafting of three-dimensional objects within a virtual space, offering dynamic manipulation, movement, and rotation. It also allows for the seamless integration of data from IoT devices. In the case of the crane, equipped with a multitude of IoT sensors, Unity's prowess in gathering and processing data from these sensors is invaluable. In the context of digital twin development, reliance on Figure 2, a schematic diagram illustrating the integration of Digital Twins within Unity3D serves as a valuable reference for the project (Gao et al., 2023). These capabilities lay the foundation for the immersive environment that the digital twin requires.

A diagram of a cloud server

Description automatically generated

*Figure 2 – A schematic diagram of using Digital Twins in Unity3D (Gao et al., 2023).*

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, the goal is to address the limitations of the DIAMND system and propose a more effective solution. The existing DIAMND system, used for crane management, presents several challenges, especially in terms of its appearance and functionality. It relies on data collection 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 to populate job and load statistics tables in SQL.

Throughout this project, active engagement with members of the sales and engineering teams at Liebherr has been crucial in gathering insights and requirements for the improved system. These inputs have played a significant role in shaping the approach. This case study highlights the potential of modern technology and data-driven solutions in not only overcoming the limitations of legacy systems like DIAMND but also in improving the overall user experience and aesthetics of crane management operations.



#### Addressing The Challenges

In this section, the existing DIAMND system is examined, highlighting 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 PLC 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 Figure 3 and Figure 4 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

Description automatically generated*

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

A screenshot of a computer

Description automatically generated

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

#### Proposed Solutions

To address these formidable challenges, a comprehensive transformation of the DIAMND system is proposed to streamline data management and enhance the user experience. Firstly, the utilization of an Application Programming Interface (API) is recommended 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, the implementation of Power BI for data visualization is proposed. 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 provides valuable insights for future projects. By examining the challenges and successes of this transformation, lessons can be extracted 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.

## Internet of Things (IoT)



### Fundamentals of IoT

### IoT Devices and Sensors

### IoT Integration with Digital Twin Systems

### IoT in Industrial and Smart Environments

## Big Data and Visualization



### Big Data Collection and Analysis

### Data Visualization Techniques

### Visualizing Big Data

### Impact of Visualization on Decision-Making

## Risk Analysis and Platform Issues



### Identifying Risks in Digital Twin Projects

### Evaluating Digital Twin Platforms

### Mitigation Strategies for Risks

### Case Studies of Platform-Related Failures

# Methodology



## Research Approach

## Data Collection Methods

## Data Analysis Techniques

# Implementation



## Real-World Application of Digital Twinning

## IoT Integration and Case Studies

## Big Data and Visualization Implementations

# Results



## Key Findings from the Implementation

## Data Analysis Results

## Successes and Challenges Encountered

# Discussion



## Interpretation of Results

## Comparing Findings with the Literature

## Insights Gained from the Study

# Conclusion



## Recap of Key Points

## Implications for Industry and Research

## Future Directions

# References

D’Amico, D. *et al.* (2019) ‘Conceptual framework of a digital twin to evaluate the degradation status of complex engineering systems’, *Procedia CIRP*, 86, pp. 61–67. doi:10.1016/j.procir.2020.01.043. (Accessed: 18 October 2023).

Gao, P. *et al.* (2023) ‘Prediction system for overhead cranes based on Digital Twin Technology’, *Applied Sciences*, 13(8), p. 4696. doi:10.3390/app13084696. (Accessed: 20 October 2023).

Grieves, M., 2014. Digital twin: manufacturing excellence through virtual factory replication. White paper, 1(2014), pp.1-7. (Accessed: 18 October 2023).

IBM (no date) *What is a digital twin?*, *IBM*. Available at: https://www.ibm.com/topics/what-is-a-digital-twin (Accessed: 18 October 2023).

Leskovsky, R. *et al.* (2020) ‘Proposal of digital twin platform based on 3D rendering and IIoT principles using virtual / augmented reality’, *2020 Cybernetics &amp; Informatics (K&amp;I)* [Preprint]. doi:10.1109/ki48306.2020.9039804. Available at: https://library.ittralee.ie/ (Accessed 20 October 2023).

Sjarov, M. *et al.* (2020) ‘The digital twin concept in industry – a review and systematization’,*2020 25th IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)* [Preprint]. doi:10.1109/etfa46521.2020.9212089. Available at: https://library.ittralee.ie/ (Accessed 18 October 2023).

Unity (no date) *Digital Twins*, *Unity*. Available at: https://unity.com/solutions/digital-twins (Accessed: 20 October 2023).