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Joana Filipa Correia Alves Antunes

Architecture and Prototype for Dry Port Digital Twin

Dissertation in the context of the Masters in Informatics Engineering, specialization in Information Systems, advised by Professor João Barata, Professor Paulo Rupino da Cunha, and Professor Jacinto Estima, and presented to the Department of Informatics Engineering of the Faculty of Sciences and Technology of the University of Coimbra.

July 2024

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DEPARTAMENTO DE
ENGENHARIA INFORMÁTICA
FACULDADE DE
CIÊNCIAS E TECNOLOGIA
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PRR Plano de Recuperação e Resiliência

REPÚBLICA PORTUGUESA

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Resumo

Os portos secos são infraestruturas críticas na cadeia logística, contribuindo para a otimização das operações portuárias marítimas através da disponibilização de serviços aduaneiros e de espaço para o armazenamento de contentores em terra. Atualmente, são significativos os investimentos na digitalização das suas operações e na redução do seu impacto ambiental. Contudo, a dependência na documentação em papel e a necessidade de fornecer informação de confiança às autoridades governamentais e às indústrias de transporte de mercadorias justificaram a consideração de indicadores das operações nos portos secos, capazes de fornecer informação útil para a tomada de decisões, em tempo real.

Os *Digital Twins* têm vindo a surgir como uma das soluções mais promissoras para a monitorização de dados em tempo real. Definidos como réplicas de objetos ou de sistemas físicos, têm vindo a ser adotados em contextos mais complexos, como fábricas e cidades. No entanto, a escassez de protótipos de *Digital Twins* de portos secos tem dificultado a exploração das capacidades desta tecnologia na melhoria e otimização das suas operações. Para representar adequadamente um porto seco, é crítico identificar toda a informação, processos, actores envolvidos, e outros elementos que compõem as suas operações, o que pode ser conseguido através de abordagens de arquitetura de empresas.

Esta dissertação aborda algumas das principais prioridades da Agenda NEXUS, um consórcio composto por universidades, empresas de tecnologia, e múltiplos portos nacionais, visando a transformação digital e a descarbonização das cadeias logísticas em Portugal. Os principais objectivos são (1) a modelação da arquitetura do *Digital Twin* do porto seco do Entroncamento, (2) a instanciação do protótipo correspondente, e (3) a proposta de princípios de *design* para modelar a arquitetura de *Digital Twins* em portos secos.

Os resultados foram obtidos através de um projeto de *Design Science Research* (DSR), realizado no porto seco do Entroncamento, e em colaboração com parceiros da Agenda NEXUS, a Fordesi e a Medway. A arquitetura e o protótipo criados foram incluídos na documentação da Agenda NEXUS, e avaliados por alguns dos seus parceiros, para facilitar a identificação e integração de oportunidades futuras relativas a *Digital Twins*. Enquanto contributo teórico, os resultados desta dissertação incluem princípios de *design* para orientar a modelação da arquitetura de *Digital Twins* em portos secos.

Palavras-Chave

Digital Twin, Arquitetura de Empresas, Arquitetura de *Digital Twin*, Porto Seco, *Digital* Twin em Portos

Abstract

Dry Ports are critical infrastructures in the logistics chain, contributing to optimizing seaport operations by providing customs services and container storage on land. Significant investments are ongoing to digitalize their operations and reduce their environmental impact. However, the current reliance on paper-based documentation and the need to provide reliable information to both government authorities and rail freight industries have justified the consideration of real-time indicators of Dry Ports, which are capable of providing valuable insights to support decision-making, in real-time.

Digital Twins have recently emerged as one of the most promising solutions for real-time data monitoring. Defined as replicas of physical objects or systems, they are being adopted in more complex contexts such as factories and cities. Nevertheless, the scarcity of Dry Port Digital Twin prototypes has complicated the exploration of this technology's capabilities to improve and optimize this infrastructure's operations. To accurately represent a Dry Port, it is critical to identify all information, processes, actors involved, and other elements of logistics operations, which can be achieved through enterprise architecture approaches.

This dissertation addresses some of the key priorities of the NEXUS Agenda, a consortium composed of universities, technology providers, and multiple national ports, aiming at digital transformation and decarbonization of the Portuguese logistics chains. The principal goals are (1) the modeling of Entroncamento's Dry Port Digital Twin architecture, (2) the instantiation of the corresponding prototype, and (3) the proposal of design principles to model Dry Port Digital Twins.

The results were obtained through a Design Science Research (DSR) project, conducted in Entroncamento's Dry Port and in collaboration with Fordesi and Medway, partners of the NEXUS Agenda. Both the architecture and the prototype were included on the NEXUS Agenda deliverables, and evaluated by some project partners, to support the identification and integration of future opportunities regarding Digital Twins. From a theoretical perspective, this dissertation's results include design principles to guide the architecture of any Dry Port Digital Twin.

Keywords

Digital Twin, Enterprise Architecture, Digital Twin Architecture, Dry Port, Digital Twin in Ports

Contents

Acronyms

API Application Programming Interface

CAI Container Artificial Intelligence

DSR Design Science Research

DT Digital Twin

EA Enterprise Architecture

FEDS Framework for Evaluation in Design Science

IoT Internet of Things

IS Information Systems

IT Information Technology

JUL Single Window Logistics *(Janela Única Logística)*

JUP Single Window Ports (*Janela Única Portuária*)

LPR License Plate Recognition

MedTOS Medway Terminal Operations System

MVC Model-View-Controller

OCR Optical Character Recognition

SRH Smart Rail Handling

TOGAF The Open Group Architecture Framework

TOS Terminal Operations System

ToS Threshold of Succes

TRL Technology Readiness Level

TDI Trustable Data Infrastructure

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Chapter 1
Introduction

This chapter describes the work conducted throughout the dissertation curricular unit of the master's degree in Informatics Engineering (MEI), with a specialization in Information Systems (IS), in the Department of Informatics Engineering (DEI) of the Faculty of Science and Technology of the University of Coimbra (FCTUC). This work was supervised by Professor João Barata, Professor Paulo Rupino da Cunha, and Professor Jacinto Estima.

Section 1.1 identifies the project's involved entities, followed by the context and motivation in Section 1.2. Section 1.3 explains the dissertation's goals, and Section 1.4 lists the main contributions of this dissertation. The chapter ends with a description of this document's structure, in Section 1.5.

1.1 Involved Entities

This dissertation is associated with the NEXUS Agenda[1], whose stakeholders include the Port of Sines and the Portuguese Government, aiming to digitalize and decarbonize the national ports and value chains through technological solutions. The work described in this dissertation is part of Work Package 3 (WP3) – *Smart Gates and Smart Terminals* – whose main goal is to produce digital solutions that combine value prepositions of Dry Ports and Seaports and facilitate the creation of innovative services at different nodes of the logistics network, for road and rail processes.

Two companies, Fordesi and Medway are leading WP3. Fordesi[2] is an Information Technology (IT) company with a large portfolio of technological solutions adopted within the logistics field, while Medway[3] is responsible for managing Entroncamento's Dry Port operations.

1.2 Context and Motivation

Seaports are crucial nodes in the global supply chains. However, various locations that produce and consume goods have difficulties accessing advantageous coastal areas or limited storage capacity, challenges that justified the creation of Dry Ports, extending

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[1] https://nexuslab.pt/ [Online] [Accessed on 4th of July 2024]
[2] https://www.fordesi.pt/en/ [Online] [Accessed on 4th of July 2024]
[3] https://www.medway-iberia.com/pt/services/entroncamento [Online] [Accessed on 4th of July 2024]

seaports' operations by managing higher flows of containers and expanding the storage capacity [1].

Dry Ports' digital transformation is a priority due to their challenges [2], including excessive dependence on regulations and physical documentation, traffic congestion, high environmental impact, and the need to provide reliable information to stakeholders (e.g., government, railroad and truck operators, and insurance companies). Therefore, data is critical for Dry Ports' operations (e.g., logistics planning, containers' characteristics, and tracking), justifying the major investments occurring in the sector. The definition of real-time indicators that provide insights and support decision-making has been recognized as a possible answer to optimize Dry Port's operations, requiring new technological solutions to represent and extract value from data.

Digital Twins are virtual replicas of physical systems that support the bidirectional communication between both spaces [3]. The data, captured by Internet of Things (IoT) devices or from various sources in real-time, can be used for multiple purposes, ranging from fault prevention and prediction to behavior simulation. Recently, with the recognition of this technology's capabilities, its application scope has shifted from the representation of smaller devices to more complex contexts, such as Smart Cities [4] and factories. To explore the capabilities and potential of implementing Digital Twins in Dry Ports, prototypes are a quicker and cheaper alternative, facilitating the creation of a product most likely to answer the needs of end-users [5].

However, WP3 of the NEXUS Agenda identified the lack of Digital Twin architectures and prototypes to guide Dry Port's digital transformation.

Modeling a system architecture is crucial to comprehend the elements that describe it and facilitate its adaptation to future changes [6]. In the case of Dry Ports, the complex relations between business and technological elements have to be accurately described, facilitating the integration of new solutions, especially when different technology providers are collaborating. Their information must be identified and managed from various sources and with different access permissions. ArchiMate is an Enterprise Architecture (EA) modeling language capable of addressing specific design concerns related to large IS projects and aligning business and technological elements within an enterprise [24]; therefore, it is an interesting choice to model a Dry Port Digital Twin.

1.3 Objectives

This dissertation has three main objectives: (1) the modeling of Entroncamento's Dry Port Digital Twin architecture, (2) the proposal of design principles to model any Dry Port Digital Twin, and (3) the instantiation of a prototype. The deliverables of the NEXUS Agenda are:

- Entroncamento's Dry Port Digital Twin architecture, modeled using ArchiMate;

- Entroncamento's Dry Port Digital Twin prototype, with a Technology Readiness Level 4 (TRL4). The TRL was proposed by NASA[4] as a measurement system that assesses the maturity of technology. With nine levels, the fourth level describes a technology that has undergone a first laboratory validation phase, conducted by specialists and possible stakeholders.

1.4 Work Contributions

The main contributions resulting from this dissertation are as follows:

- AS-IS architecture of Entroncamento's Dry Port and Entroncamento's Dry Port Digital Twin architecture, modeled with ArchiMate. The architectural artifacts are part of the NEXUS Agenda deliverable "*Customs Digitalization in Dry Ports – Software Analysis and Design*";
- Entroncamento's Dry Port Digital Twin prototype, implemented using the Azure Digital Twins platform;
- A scientific publication presented at the 18th Research Challenges in Information Science (RCIS 2024): J. Antunes, J. Barata, P. R. da Cunha, J. Estima, and J. Tavares, "A Reference Architecture for Dry Port Digital Twins: Preliminary Assessment Using ArchiMate," in Research Challenges in Information Science, J. Araújo, J. L. de la Vara, M. Y. Santos, and S. Assar, Eds., Cham: Springer Nature Switzerland, 2024, pp. 131–145. doi: 10.1007/978-3-031-59465-6_9.

1.5 Structure

This document has nine chapters. Chapters 1 to 5 were written during the first semester and continuously improved, focusing on the research of concepts and the methodology and presenting preliminary modeling of Entroncamento's Dry Port AS-IS architecture. Chapters 6 to 9 were written in the second semester, focusing on the requirements identification, the description of both the architecture and the prototype, and finishing with a reflection on the work done. The document structure is as follows:

- **Chapter 1 –** *Introduction*, provides the dissertation's context and motivation, its main objectives, and the entities involved.
- **Chapter 2 –** *Methodology*, describes the steps followed during the realization of the dissertation, the work plan for both semesters, and a risk analysis.
- **Chapter 3 –** *Background*, explains the main concepts of this dissertation, such as Dry Ports, Digital Twins, Enterprise Architecture, and Blockchain - one of the key technologies required to integrate the Digital Twin in Entroncamento's Dry Port.

[4] https://www.nasa.gov/directorates/somd/space-communications-navigation-program/technology-readiness-levels [Online] [Accessed on 5th of July 2024]

- **Chapter 4 –** *State of Art*, explores research about the key concepts explained in Chapter 3, focusing on examples of Digital Twins implemented in logistics, Digital Twin architectures, and platforms for Digital Twin development.
- **Chapter 5 –** *Entroncamento's Dry Port AS-IS Architecture*, lists the existing technological solutions that compose this infrastructure, identifies the limitations of its existing representation, and proposes an AS-IS architecture, modeled using ArchiMate.
- **Chapter 6 –** *Entroncamento's Dry Port Digital Twin Architecture*, explains the architecture of this infrastructure. It starts with the presentation of their new technological advances, followed by the explaining and presenting each of the views. It ends with the proposal of design principles to guide the modeling of any Dry Port Digital Twin.
- **Chapter 7 –** *Prototype Implementation and Demonstration*, starts by listing the prototype's functional requirements, then the implementation's explanation, and finishes with a demonstration of the implemented solution.
- **Chapter 8 –** *Evaluation*, explores the insights of each of the evaluation episodes with Fordesi and the NEXUS Agenda consortium.
- **Chapter 9 –** *Conclusion*, summarizes the work done during the two semesters, identifies its limitations, and suggests opportunities for future work.

The next chapter explains the methodology adopted in this dissertation, the work plan for both semesters, and a risk analysis.

Chapter 2
Methodology

This chapter describes the methodology and work plan. Section 2.1 explains the methodology selected for this dissertation and the work plan for both semesters, in Section 2.2. The chapter concludes with the risk analysis, in Section 2.3.

2.1 Research Methodology

The literature review was an essential step for developing this dissertation, as it provided insights into the studies on Digital Twins, their adoption in Dry Ports, and the correspondent architecture from an EA perspective. The sources ranged from scientific articles to conference proceedings, found mainly on Google Scholar. It was noticed that the Digital Twins adoption in logistics nodes, in particular seaports, has been gathering attention. However, their architecture modeling using ArchiMate is still an unexplored subject.

Therefore, the lack of guidelines to model a Dry Port's Digital Twin architecture justified the need to propose an adequate architecture modeled using ArchiMate and a list of design principles to guide the representation of other Dry Ports' Digital Twins. Design Science Research (DSR) [9] was the methodology selected to create such architecture, prototype, and design principles.

DSR has been adopted in multiple projects related to Digital Twin solutions in complex scenarios. An example is Agriculture 4.0 [7], where a scalable Digital Twin for vertical farming prototype was evaluated, and a reference model was provided. Design principles to follow when implementing a Digital Twin in sustainable regional development have been suggested [8], as well as a Smart City generic model [4]. These examples enhance the advantages of adopting this methodology within the context of this dissertation, as it led to the creation of design principles and reference models of Digital Twins, in various complex contexts, like that of a Dry Port.

Figure 1 depicts the six iterative steps, which can be realized non-consecutively, of the DSR approach, which aims to solve problems through artifacts in real-world settings.

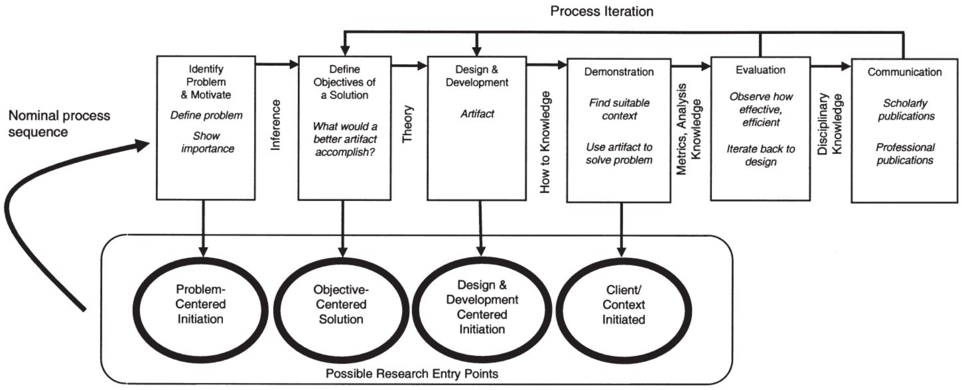

Figure 1. Design Science Research Methodology (source: [9])

The *Problem and Motivation Identification* (1) phase includes the identification of the research problem and its importance in finding a solution. *Objectives Definition* (2) implies the listing of the solution's goals. The *Design and Development* (3) phase describes the creation of artifacts, which can either be a model, instantiation, or a digital solution. *Demonstration* (4) applies the artifact developed in real-world contexts as a case study, simulation, or proof of concept. The *Evaluation* (5) phase measures how adequately the proposed solution answers the identified problem. Based on that result, the process can iterate through phase 3, to tailor the artifact. Lastly, *Communication* (6) describes the discussion of the problem and the proposed solution to stakeholders, researchers in the field, and other interested entities. Table 1 relates each of the steps to this dissertation.

Table 1. DSR, according to the DSR Grid (adapted from [9])

Problem	Objectives	Design and Development
Lack of existing architectures of Dry Port's Digital Twins, using ArchiMate, and absence of Dry Port's Digital Twins prototypes.	• Model a Dry Port Digital Twin architecture, using ArchiMate. • Implement a TRL4 prototype of a Dry Port Digital Twin. • Present generic Design principles to model Dry Ports' architecture.	Design a Dry Port's Digital Twin architecture, using ArchiMate, and implement a Dry Port Digital Twin prototype, adapting an implementation platform.
Demonstration	**Evaluation**	**Communication**
Adapt the developed artifacts to Entroncamento's Dry Port.	Gather insights and evaluations from the NEXUS Agenda Consortium and Fordesi, a major IT company, in the logistics field.	Contribute solutions for the identified problems, through scientific papers and reports.

This dissertation started with an analysis of port digitalization examples, Digital Twin architectures, Digital Twin implementation platforms, and the existing High-Level blueprint of Entroncamento's Dry Port. Afterward, a comparison between the existing representation of the Dry Port and its AS-IS architecture, modeled with ArchiMate, was realized. Then, Entroncamento's Dry Port Digital Twin architecture was modeled, and the corresponding prototype was instantiated using an implementation platform. Both of the artifacts were evaluated by Fordesi and the NEXUS Agenda Consortium.

2.2 Work Plan

This section provides an overview of the initial work plan and a comparison with the sequence of tasks completed during two semesters. Based on the dissertation proposal, the tasks defined for the first semester were:

- Research Dry Ports and their digitalization with critical data;
- State of Art regarding Digital Twins and digital transformation in Dry Ports;
- Modeling of an initial Dry Port Digital Twin architecture;
- Writing of intermediate report.

The results of the first semester were a literature review of the topics relevant to this dissertation, Entroncamento's Dry Port architecture modeled utilizing ArchiMate, a preliminary list of requirements for Entroncamento's Dry Port Digital Twin prototype, and the intermediate report. The first phase was the literature review, during which the concepts of Dry Ports, Digital Twins, ports' digitalization, Digital Twin architectures, and Digital Twin implementation platforms were studied. The second phase focused on the analysis of Dry Ports' challenges, leading to the definition of the prototype's requirements. Lastly, an initial version of Entroncamento's Dry Port architecture was modeled using ArchiMate and compared with the existing High-Level blueprint of this infrastructure.

Appendix A – First Semester's Work Plan shows the planned and executed Gantt diagrams of the first semester, relating each task with their execution time periods, split into weeks. By comparing the planned and actual Gantt diagrams, the main difference relates to a week's delay in searching about Digital Twins and their implementation platforms. The requirements identification took one more week than expected, but the objectives were all achieved by the 8th of January. Both delays, even though not accounted for initially, did not compromise the conclusion of the intermediate report, defended on the 24th of January. Based on the dissertation proposal, the tasks established for the second semester were:

- Implementation of a Dry Port Digital Twin prototype;
- Evaluation of the adequacy of the solution with project partners (e.g., Fordesi);
- Writing of Dissertation.

The results of the second semester are the dissertation, with Entroncamento's Dry Port architecture and prototype, their evaluation by Fordesi and by the NEXUS Agenda Consortium, and design principles to guide the modeling of Dry Port Digital Twin's architectures, adopting ArchiMate. During this period, the first task was the modeling of Entroncamento's Dry Port Digital Twin architecture, followed by a second task, which was the implementation of a TRL4 prototype of Entroncamento's Dry Port Digital Twin using the Azure Digital Twins platform. Changes to the initial report were realized based on the insights provided during its defense, and the evaluation of both the architecture and the prototype were guaranteed through meetings with Fordesi and the NEXUS Agenda Consortium.

Appendix B – Second Semester's Work Plan presents the planned and executed Gantt diagrams for the second semester, with some discrepancies: the identification of the needed elements to model the prototype was late, and the subsequent prototype's implementation was delayed by a month. Even though it was a reasonable setback, the development required less time than initially planned, managing to be finished on time to be evaluated. Modeling each architectural view was guaranteed within the period initially set. Despite these minor delays, the main goals were achieved according to the NEXUS timeline and the project deliverables requirements, with the work finished by the 8th of July, as expected.

2.3 Risk Analysis

When conducting any research, assessing risks and developing mitigation plans is critical. Risk management is essential, as risks not previously accounted for may affect a project's development and lead to significant delays in its conclusion[5]. Risk identification consists of assessing risks, determining their impact and probability, and creating mitigation plans to remove or minimize their impact.

Defining the Threshold of Success (ToS) is fundamental for risk analysis, and it is meant to represent the minimal requirements needed to be met to classify the work done as successful. For this research, the success factors established were:

1. Modeling Entroncamento's Dry Port Digital Twin architecture, describing this infrastructure's processes, applications, data, Blockchain storage, IoT devices, and relationships between those elements. This will be part of the NEXUS Agenda deliverables, to be evaluated by both Fordesi and the NEXUS Agenda Consortium;
2. Implementing Entroncamento's Dry Port Digital Twin prototype, giving insights into its capabilities to improve operations management and increase awareness among project partners. Fordesi and the NEXUS Agenda Consortium will validate this solution.

[5] https://www.simplilearn.com/risk-assessment-project-management-article [Online] [Accessed on 21st of December 2023]

The probability of each risk's occurrence can be classified as high (five points), medium (three points), or low (one point), while its impact can be *catastrophic* (five points), *critical* (three points), or *low* (one point). The latter defines the amount of effort needed to reach the ToS.

Risk analysis was an ongoing endeavor throughout this project. Table 2, Table **3**, and Table **4**, explain and classify the most relevant risks.

Table 2. Risk 1 – Selection of Limited Digital Twin Platform

ID	R1
Fact	The Digital Twin platform chosen to implement Entroncamento's Dry Port Digital Twin prototype has limited capabilities, restricting the implementation of all requirements and functionalities.
Probability	Low
Impact	Critical
Mitigation Plan	Testing in the early stages, and throughout the prototype development. In case of clear limitations, consider another platform out of the previously explored during the research stage.
Consequence	Impossibility of guaranteeing that all requirements are answered.

Table 3. Risk 2 – Limited Time for Researching Topics

ID	R2
Fact	The time assigned for each research task is shorter than the actual needed. Due to inexperience in task duration estimations, some research topics will require more time than initially planned.
Probability	Medium
Impact	Critical
Mitigation Plan	Analyze, at an early stage, the topics to research, and identify the ones that are not known or seem more complex. Assign longer periods to understand them, and reserve periods of lower availability for activities that will imply less time to realize.
Consequence	Delay in the execution of each research task, and subsequent impact on the conclusion date.

Table 4. Risk 3 - Delay in Communication with Fordesi

ID	R3
Fact	The unavailability of project partners to provide information fundamental for the creation of both the architecture and the prototype.
Probability	Low
Impact	Catastrophic

Mitigation Plan	Compile questions about the architecture and prototype every two weeks, to be answered and discussed with Fordesi at every meeting. Send emails when the lack of information is critical and directly affects the project's progress.
Consequence	Delay in the conclusion of the project and results with low quality.

For this project, each risk was classified based on its probability of occurrence and predicted impact, describing the effort needed to ensure that the ToS would be achieved. The relation between each of those classifiers with the identified risks is depicted in the risk matrix, in Table 5.

Table 5. Risk Matrix

		Scale of Impact		
Scale of Probability		Low	Critical	Catastrophic
	Low		R1	R3
	Medium		R2	
	High			

On the vertical axis, the probability scale can be *low*, *medium,* and *high*, while on the horizontal axis, the impact ranges between *low*, *critical*, and *catastrophic*. In this dissertation, only one risk could catastrophically impact its realization, and it occurred, however, not with such a level of impact. To gather insights regarding the adequacy of the proposed Entroncamento's Dry Port Digital Twin prototype from Fordesi, a meeting was held with a demonstration. Afterward, a questionnaire was sent, but the assembly of its answers took longer than expected, leading to a delay that was reduced with a shift in the evaluation steps. Instead of focusing solely on the answers provided, an analysis of the insights provided during the meeting and a comparison with the requirements were conducted. The first risk was avoided, with the selected platform answering most of the needs, and the second risk, even with the mentioned delays in various tasks, managed to have a lower impact, as the dissertation was finished by the 8th of July, as planned.

This chapter described the methodology adopted for this research, from the study of the fundamental topics (e.g., Dry Ports, Digital Twins, Digital Twin platforms), to the modeling of Entroncamento's Dry Port Digital Twin architecture and corresponding prototype implementation. Then, the planning for the first and second semesters was proposed and compared with the actual tasks' duration, finishing with the risk analysis.

The next chapter introduces the main concepts of this dissertation, focusing on Dry Ports, Digital Twins, Enterprise Architecture, and Blockchain. Each will then be related in Chapter 4, the State of Art, the last stage of the DSR's first step regarding the problem's identification.

Chapter 3
Background

Dry Ports are critical within the logistics chains, improving product distribution flows and expanding the storage capacity of seaports. With the increasing necessity for operations awareness, indicators updated in real-time can provide critical information about this infrastructure's operations' state and help reduce some of its challenges and consequences. Digital Twins are a possible solution to those needs, replicating complex physical systems and providing information that helps decision-making based on data captured in real-time [10]. However, the increasing use of information and applications to support logistics and the various stakeholders involved has led to the focus on guaranteeing information reliability and security. Therefore, critical information has to be stored and exchanged securely, with Blockchain being one of the solutions [11].

This chapter introduces four main concepts discussed throughout this dissertation. Section 3.1 defines Dry Ports, focusing on their challenges and how they can potentially be reduced by implementing Digital Twins. Digital Twins are explained in Section 3.2, followed by the definition of Enterprise Architecture in Section 3.3. Lastly, Section 3.4 discusses the concept of Blockchain, and relates how it can improve the security and reliability of critical data in Dry Ports.

3.1 Dry Port

Historically, seaports have always been strategic to the economy, capable of facilitating the exchange of products and resources between various places. However, many locations that produce or consume goods lack access to advantageous coastal areas or have limited storage capacity for increasingly larger ships [1]. While seaports contribute to regional growth and provide multiple employment opportunities, their environmental impact, challenging accessibility, and traffic congestions are some of the downsides that led to the creation of Dry Ports [12], especially when considering that the "*...efficient handling and distribution of cargo to and from hinterland is crucial for the overall performance of seaports and the whole supply chain.*" [1].

A Dry Port can be described as "*...an essential node to coastal and landlocked countries that ensures the flawless transport of cargoes along the supply chain while safeguarding the integrity of the goods flow*" [12]. Also known as inland terminals, inland ports, inland hubs, or inland logistics centers [6], these address some of the main seaports' challenges, managing larger container flows [4], and decreasing transactional operations costs [13].

Figure 2. Entroncamento's Dry Port – General View and Location (source: [14])

Entroncamento's Dry Port, shown in Figure 2, is located in the center of Portugal. It facilitates communication through roads and train rails with other national Ports and European countries, particularly Spain [14]. With a total area of 220.000 square meters [14], this Dry Port optimizes the storage of containers, loading and unloading operations of trains and trucks, and other logistic operations managed by Medway.

Dry Ports offer numerous advantages but still face many challenges. Some of the most significant are limited connections between ports, strict procedures for crossing regional boundaries, non-automatized and optimized handling of containers, and limited visual awareness regarding this infrastructure [5]. Seaports have already been adopting technologies that provide them with real-time indicators about their operations [2], and in some cases predicting and recommending actions. Most of those examples describe Digital Twins, making them a worthy solution to explore in the context of Dry Ports.

3.2 Digital Twin

A Digital Twin is a virtual model of a physical object [3] that utilizes real-time data the physical twin collects to predict behaviors and dynamically prevent faults. This is achieved with the bidirectional transfer and information sharing between the physical and the digital counterparts [15], resulting in resource savings.

The concept of a Digital Twin was introduced during the Apollo Mission led by the National Aeronautics and Space Administration (NASA) in 1960. Out of two identical spaceships crafted, one was released into space while the other replicated its behavior on Earth. Data from the released spaceship was exchanged with the one remaining in real-time, allowing the mimic of its state, fault prediction, and safer problem-solving solutions [15]. In 2002, Digital Twins were introduced in product life cycle management [3] by Michael Grieves, and since then, the research about this technology has been increasing, especially from 2019 and onwards [15].

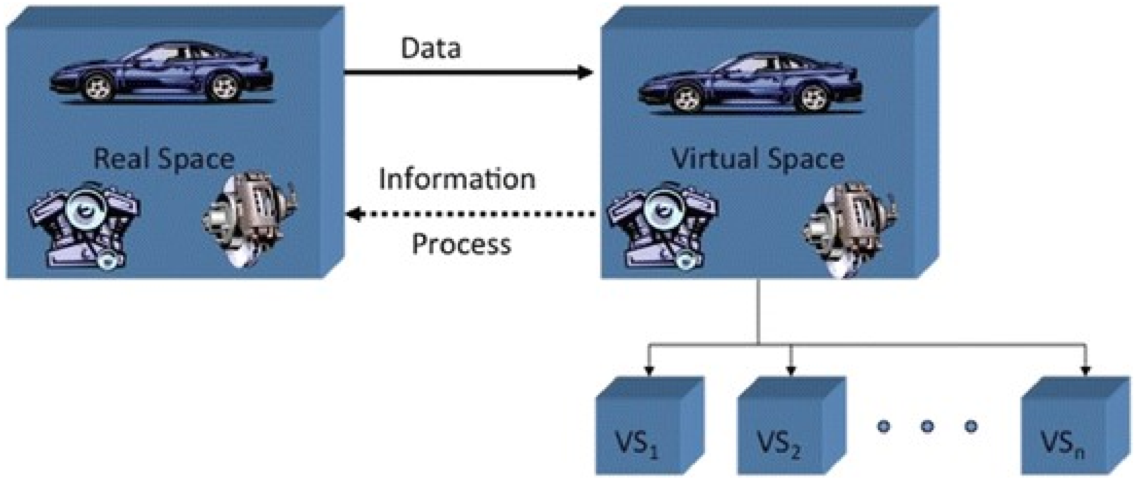

Figure 3. Digital Twin Components Representation (source: [3])

The main components of a Digital Twin, as presented in Figure 3, are the *link* between the physical and virtual spaces, allowing bidirectional data flow, the *physical object*, and its *virtual replica*. From a hierarchal perspective, it is possible to split the types of Digital Twins into three groups [15][28]: (1) a single part of the system, (2) an amalgamation of parts that represent a bigger object, and (3) the entire system.

A fundamental capability of a Digital Twin is the possibility of exchanging data with the physical object in real-time, allowing a predictive analysis [9], fault diagnosis and prognosis, and maintenance improvement [15]. Another crucial characteristic of this technology is resource-saving, speeding up the prototyping process [15] and removing the need to look for a fault's origin in the real object, possibly damaging it or leading to dangerous situations [15].

Recently, Digital Twins have been shifting their application scope from small devices to complex contexts like Smart Factories [16], Smart Buildings [17], and Smart Cities [18]. For example, the work of Gary White, Anna Zink, Lara Codecá, and Siobhán Clarke [18] shows their advantages in improving the quality of life in cities [18]. The authors use a green space simulation based on data gathered by IoT devices installed throughout the city (e.g., levels of air and noise pollution, amount of direct sunlight, and pedestrian traffic flow) to recommend the best location for green places in the city.

This technological solution, however, has some obstacles that are important to consider. The first is the cost, linked to creating a high-fidelity copy of a real system and implementing sensors to capture data in real-time [15]. The second is related to the difficulty in simulating all of the system's possible behaviors without high computing capability [3]. Lastly, significant data from various sources must be managed efficiently and safely, avoiding leaks and forbidden accesses during exchange [15].

When considering the implementation of Digital Twins in smart contexts such as Smart Factories [16] and Smart Cities [18], the focus on modeling the corresponding architecture from a service perspective, prioritizing indicators that answer the end-user needs, has increased. This need to accurately model the alignment between the business and technological elements has led to more research on adopting EA modeling languages, such as ArchiMate, an example being the framework suggested by Petterson [19].

3.3 Enterprise Architecture

The term architecture describes the design of the elements that make a product, device, system, or enterprise [20], including its properties, interfaces, and relationships. An adequate architecture facilitates the early analysis of potential trade-offs related to certain decisions, enables its update and control over time [6], and provides insights into the needs and priorities of the enterprise, focusing on business and technological perspectives.

EA addresses the design concerns related to large IT systems and the companies dependent upon them, documenting complex human interactions with the technology used to conduct business operations [20]. A well-defined architecture helps identify opportunities for change and adapt to the enterprises' growth in an innovative and controlled way [21]. Several frameworks for Enterprise Architecture [20] define the tasks and final artifacts of the architectural process and which views answer stakeholders' needs, easing their discussion [21]. Some examples of prominent frameworks include:

- The Zachman Framework [20], [22] was created in the 1980s. It is a two-dimensional table with thirty cells, considered by many to be the fundamental structure for EA. Although it is easy to create without much prior theoretical knowledge [22], it is challenging to read and does not allow a strategic analysis of new technological solutions to add value to the enterprise.
- The Federal Enterprise Architecture Framework (FEAF) was defined for the U.S. Federal Government in the 1990s to guide the integration of technology, business, and strategic processes across all U.S. Federal Agencies. Heavily influenced by the Zachman Framework, it shares its disadvantages and is challenging to adopt within the context of enterprises that do not consider the U.S Federal Agencies' standards [22].
- The Open Group Architecture Framework (TOGAF) was created in the 1990s and is one of the most widely used frameworks nowadays. It provides the steps required to model an Enterprise Architecture [22], identifying the business and IT goals and their alignment with the enterprise [23]. This framework intends to define a shared language understood by everyone involved. It is possible to align TOGAF with popular EA languages like ArchiMate [24]. This modeling language allows the creation of multiple views and layers and strategic justifications for certain changes.

The capabilities of EA approaches and modeling languages to represent large IT projects justified their introduction in the NEXUS Agenda requirements and subsequent use to model the architecture of a Dry Port Digital Twin. Several project partners are documenting their developments in ArchiMate, and crucial project deliverables related to the early stages of product specification have used this modeling language to improve the analysis of key building blocks related to the development (e.g., logistic processes and supporting applications, storage, and communication infrastructure).

One of the many advantages of Digital Twins is the increased awareness through data updated in real-time, supporting decision-making. Therefore, the information has to be reliable and exchanged/stored immutably, which can be guaranteed by the adoption of Blockchain.

3.4 Blockchain

Blockchain is a distributed system in which data is managed by multiple users without a central authority [25], justifying its unique features: immutability, transparency, and anonymity [26]. However, immutability requires considerable resource consumption, and transparency and anonymity can be challenging to achieve, as no confidentiality is needed to ensure access to all information [26].

This technology's name alludes to a sequence of blocks, each with information regarding the previous, current, and prospective blocks [25]. The general sequence of events that make up a transaction in a Blockchain system includes the announcement of a transaction issued by a user, followed by a correctness check performed by validator nodes. Based on the result of the consensus protocol, if the transaction is approved, it is grouped with others and forms a new block of transactions registered and appended to the Blockchain [26]. Those operations ensure that all details about every transaction are kept, contributing to the transparency of information, access by any anonymous users, and the establishment of distributed consensus protocols [26].

Blockchain has been adopted in multiple contexts, from healthcare [25] to logistics and, most notoriously, Bitcoin [27], a proposal to allow online payments between entities without an intermediary financial institute. Implementing this technology alongside Digital Twins, which exchange data between a physical and a virtual system and use that information to facilitate decision-making, can increase the guarantee that the information being considered is reliable.

This chapter introduced key concepts addressed in this dissertation: Dry Port's significance and challenges, Digital Twins' capabilities, Enterprise Architecture's frameworks, and an introduction of Blockchain, a possible solution to guaranteeing the reliability and security of the information shown and used by Digital Twins. The State of Art is presented in the next chapter, where most of these concepts will be related to guide the remaining steps of this dissertation.

Chapter 4
State of Art

After introducing the baseline concepts of this dissertation, this chapter studies the literature related to Digital Twins in ports, Digital Twin architectures, and Digital Twins implementation platforms.

Section 4.1 discusses examples of port digitalization, focusing on the adoption of Digital Twins to optimize and manage operations. Section 4.2 explores Digital Twin architectures and discusses some of their issues, followed by a more detailed analysis of Digital Twins, with Blockchain, architectures, and those modeled using the ArchiMate modeling language. Section 4.3 explores some of the characteristics of Digital Twin implementation platforms, followed by a brief comparative analysis of their features. This chapter finishes with a summary of the topics discussed in Section 4.4.

4.1 Port Digitalization

The scale and complexity of the ports' operations have been increasing, requiring sophisticated applications to guarantee their efficiency, reduce environmental impact, and increase the situational awareness of the overall infrastructure [28]. Therefore, ports are striving to adopt technological solutions capable of handling the increasing growth in demand for cargo transport, higher business complexity [29], and preoccupation with the environmental footprint [30] [28].

Multiple solutions have been studied for the port's digitalization, from reducing paper documentation to optimizing the movements when handling containers inside the depot parking areas. Implementing Digital Twins in ports is a revolutionary opportunity among multiple technological possibilities [2]. Increasing awareness and transparency, simulating reactions to future conditions [29], predicting risks [2], increasing safety, and optimizing asset use [1][19] are some of the main advantages of adopting this solution in Ports.

4.1.1 Digital Twin in Ports

There are various functional areas in ports where adopting Digital Twins can lead to improvements (e.g., process automatization, sustainability, safety, regulatory compliance, and stakeholder engagement [37]). The three core priorities for this infrastructure that can be guaranteed by Digital Twins are increased situational awareness, smarter decision-making, and facilitated collaboration [30].

Situational awareness relates to the presentation of updated information regarding the Dry Port, its operations, and the elements' state. This facilitates, for instance, a better flow of operations with instant knowledge about weather conditions and road congestion levels [37]. *Smarter decisions* describe the consideration of real-time information and its history to justify more adequate decisions. For example, the most efficient sequence to handle containers can reduce time wasted, unnecessary movements of reach stackers, and avoid congestion, while the selection of the most adequate terminal operator and reach stacker can optimize operations. Finally, Digital Twins can facilitate *collaboration* between different stakeholders, allowing them to witness the Dry Port's state in real-time and suggest certain actions [30].

Many ports put Digital Twins at the top of their digital transformation priorities. For example, a study conducted for the Qingdao Port [29] proposed a Digital Twin that integrated data from different sources and enhanced its visualization, allowing the early warning of risks and optimizing business processes. Valencia's Port [2] uses data captured by IoT devices to optimize cargo handling and, in Singapore's Port [2] (where the biggest value drivers are cost and risk reduction [37]), their software allows the modeling of the Port and, through real-time traffic tracking, the awareness of the procedures by the time a truck arrives, reducing traffic congestion. In China, Mawan's Port [2] accurately represents the structure operation, facilitating access to information from various sources and formats and creating simulations based on real data. In the case of Livorno's [2] Port in Italy, data from sensors and cameras is used to simulate the best placement for the cargo and the most efficient order for task realization. In Finland, Oulu's Port [2] uses Digital Twins to monitor real-time information and, based on it, formulate better environmental plans.

These examples indicate a rising interest in adopting Digital Twins in ports due to their advantages, which range from the capacity to model the Port and its components to data collection in real-time from multiple sources, which can then be used to simulate potential future issues and prevent risks.

4.1.2 Challenges

Despite the benefits of adopting Digital Twins in ports, some challenges [19] related to modeling, data acquisition, complexity, and adaptability to changes [23] are crucial to consider when contemplating their adoption in Dry Ports.

It is still challenging to adapt *modeling* tools to the context of Digital Twins due to the lack of solutions that integrate data from the physical system and data models [2]. Additionally, because each Port is unique, their logistical systems have limited interfaces, making deploying and integrating real-time data with the Digital Twin more challenging [20][21]. Because of the large volume of data produced by Port operations [30] and their natural unpredictability, *complexity* increases, and, subsequently, the need for better-predicting algorithms does too, when anticipating issues and adapting to *change*. Lastly, the lack of successfully implemented Digital Twins examples, tools, and standardization [28] contributes to a lower willingness and motivation to invest in their adoption.

While all challenges should be considered, the predominant ones are data-related [37]. Some of those include managing and integrating external data efficiently, ensuring the trustworthiness of the information, and protecting it from loss and attacks during transmission [32]. For example, privacy concerns and regulatory compliance can't be ignored when using drones [33] or other devices in Ports to capture data because it is crucial to ensure its trustworthiness. Along with these, protecting and managing cargo documentation has increased the interest in adopting Blockchain [2] to minimize the likelihood of data tampering.

4.2 Digital Twin Architecture

A Digital Twin is a combination of software and hardware, requiring accurate ways to describe the elements involved, data flows, capabilities, and interactions with the user [34]. Digital Twins are key components in an IoT ecosystem, "*...bringing many vendors and technologies together*" [35] and allowing a flexible way to integrate and configure other applications and devices. From virtually representing a unit to an entire system, the increased complexity and flexibility [20] of Digital Twins have complicated their maintenance, justifying the need for methods to describe each component more comprehensibly.

Modeling an adequate architecture is challenging and can lead to long-lasting impacts on the product and the organization that will consider it [20]. An architecture must describe the system's structure and communication between elements, supporting future analysis of its properties and implementation of required services [20]. One recommended way to classify an architecture is based on how well it fits the stated purpose. In [6], a list of recommendations for architecture evaluation is presented, including readability and capacity to change the relationship between elements and the data flow. These will be considered for a detailed evaluation of the adequacy of the existing AS-IS architecture of Entroncamento's Dry Port.

The architecture presented in [17] identifies three layers to model a Digital Twin of a building. However, it does not consider major elements like the communication protocols between the sensors in the physical layer, the software platform, and the data storage servers. A recent research [34] exploring the capabilities of this technology to ensure safety in buildings does not present an architecture. Still, it depicts a detailed view of the IoT devices used and how each interacts with the service and application layers. In [2], a five-layered Smart Port's Digital Twin architecture is analyzed, where the layers are physical, data, model, service, and application. Its readability is challenging, with an unclear delimitation between layers and a non-existent description of the arrows and their directions. Another example of a Digital Twin architecture of a Port is shown in [33], which considers three layers and identifies the data flow between each, as well as the direction, but does not identify, for example, the sensors installed or how the data captured is stored or accessed.

In the early stages of this research, the terms considered in Google Scholar were “Digital Twin Architecture” and “Dry Port”, which came up with only one result. When searching for the terms combining “Digital Twin Architecture” and “Smart Port”, eight results were found, which depicts the lack of papers exploring the architecture of this technology when implemented in Ports. Most Digital Twin architectures used layers, allowing better readability, but no design principles or guidelines were identified.

4.2.1 Digital Twin and Blockchain Architecture

The adoption of IoT devices is expected to grow considerably [35], driven by the need to deploy and integrate large amounts of intelligent devices and the data produced. However, communication between the devices faces multiple challenges, specifically regarding reliable data management, security, and privacy [35]. Understandably, Blockchain has started to be explored as possibly beneficial in enhancing data security and traceability of the real-time information captured by those devices [9] [27], which ultimately positively increases the trust provided by Digital Twins. This connection between Digital Twins and Blockchain has already started to be explored in the supply chain context to mitigate some of its risks, from the asymmetry of data exchanged between different parties involved to the lack of transparency, traceability, and control [11].

An example was explored in [36], where non-fungible tokens were considered to uniquely identify each product and allow tampering detection. Even without a detailed architecture, three layers were depicted to explain the integration between both technologies: the *physical* layer, representative of processes and production equipment, the *connection* layer, which includes both the Digital Twin and the token representative of each product, and the *Blockchain* layer, which comprises the blocks of data where the tokens are stored. In [37], architecture shows the interactions between a healthcare infrastructure and multiple Digital Twins through an application capable of accessing data stored in the Blockchain. This representation did not consider any layers, making its comprehension more challenging. For instance, it was unclear which elements were part of the Digital Twin or whether the representation was between hospitals with the technology and others without it. In [38], a possible architecture of a secure Digital Twin defines five layers: *physical*, *communication*, *virtual*, *applications,* and *security*. However, visually, even with the multiple views presented, it is difficult to understand how each layer communicates and how, specifically, security is ensured in each one.

Recognizing the advantages of integrating both Digital Twins and Blockchain implies identifying some challenges [9]. Defining data standards for its format, especially considering different sources, and integrating it with existing systems can be challenging, as can scalability, because some Blockchain systems might not handle large amounts of data [16]. However, the association of Blockchain and Digital Twins can answer a relevant number of challenges [16].

4.2.2 Digital Twin Architecture with ArchiMate

This research intends to model the architecture of a Dry Port Digital Twin using ArchiMate, and the next step was to confirm if there were any examples of analysis in that regard. Only four results were obtained through Google Scholar when searching for the topics "Digital Twin Architecture" and "ArchiMate," and when considering "Smart Port," "Digital Twin," and "Enterprise Architecture," only one out of eight papers was relevant to our work, named "Digital Twin in Rail Freight - The Foundations of Future Innovation" [39].

The Open Group Architecture Framework (TOGAF) supports four architectural domains [24] to model an enterprise: the *business*, *data, application,* and *technological* elements, and the most often used modeling language is ArchiMate. Those modeling languages intend to facilitate the stakeholders' comprehension, especially from different backgrounds, and trigger thoughtful analysis of the changes' impact.

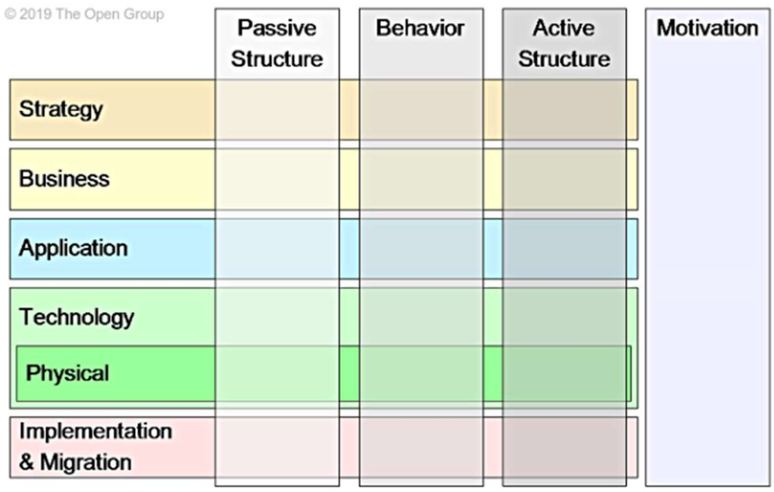

Figure 4. ArchiMate Modeling Language Framework (source: [24])

As shown in Figure 4, ArchiMate elements are divided into the *active structure* (structural concepts that have behaviors, such as the business actors or the application components), *behavior* (structural elements' actions, ranging from services to functions and processes), and *passive structure* (the elements recipients of behavior, for instance, data, information, and physical objects). In ArchiMate, the "…*higher layers utilize services provided by the lower layers*…" [40]. Each represents the connection between the users and stakeholders identified in the business layer with the physical infrastructure described in the technological layer. The layers regarding strategy and implementation/migration are used to identify and justify the addition or removal of technological solutions more clearly.

Digital Twins have three main features: modeling, connectivity, and data analysis, which can be represented through some of ArchiMate's layers. For example, in [41], it was suggested that its features could be modeled through the business layer, the data's flow and acquisition via IoT devices could be modeled with the technology layer, and the key capabilities (data analysis, connection, and modeling) could be described using the application layer's elements.

A case closer to the one explored in this dissertation is the analysis conducted to evaluate the adoption of a Digital Twin within rail freight in the Netherlands [39]. Firstly, all operations were explained, from the actors to the applications, as well as the interfaces between both. Then, the main problems were identified (i.e., the lack of transparency, data accuracy, and liability). Adopting a Digital Twin was considered, modeled using ArchiMate, and created in a prototype form to answer these challenges. The high-level architecture is shown, with six layers chosen based on modularity and scalability, and considering the architectural pattern called Model-View-Controller (MVC), recommended in [35] and which splits a system into three [42] main logical components: *model*, *view,* and *controller*. The *model* depicts all the data-related actions, functioning as the intermediate between the controller's data requests and the database accesses. The *controller* facilitates the connection between the model and the view (sending requests to the model and rendering the final output through the view). Lastly, the *view* is dynamically rendered and generates the user interface, which is to be accessed by the user.

In [39], the models to be used by the Digital Twin are stored in the database, included in layer 5, while the views to be interacted with by the user are described in layer 6. Lastly, layer 4 represents the controller. This modular structure allows for the straightforward incorporation of additional models and views into the Digital Twin, depending on future alterations. REST APIs are employed to integrate data from disparate sources to connect the existing technology. At the same time, an event hub ensures the asynchronous data acquisition from various sensors installed, facilitating the integration of new event-triggered solutions. Regarding the remaining layers, layer 3 represents the data server, where all data gathered by the IoT devices will be stored and shared with the event hub, layer 2 encompasses all the device controllers, and layer 1 represents the devices themselves.

The architecture presented in [39] is less specific and, therefore, easily adaptable to other rail freights or different industries, while the architecture presented in [41] does not prioritize modularity or adaptability. However, both proposals enhance ArchiMate's advantages in modeling Digital Twins architecture.

4.3 Platforms for Digital Twin Development

The advantages of using Digital Twins' technology in various industries have led to an increased interest among IT companies in customizing this technology to fit their client's specific needs. This trend was confirmed in a report published in 2023 by Gartner [43], where three of the presented platforms were explored next. This research mostly focused on their case studies, tutorials available, and length of free trials, and the platforms chosen are Azure Digital Twins, AWS Digital Twins, and Oracle IoT Digital Twins,

4.3.1 Azure Digital Twins

Microsoft's Azure Digital Twins [44] was launched in 2018 and can present data provided by sensors and external devices in real-time, conduct predictive analysis to anticipate future events, and improve service quality [45]. It presents many capabilities, in-depth documentation [44], customization possibilities, and data protection (by using multiple security layers and identifying new threats in real-time [46]). This solution uses the Azure IoT platform, simplifying the connection between the Digital Twin models and Azure services and integrating physical systems and devices, allowing gateways' customization [46]. The models created use a language based on JSON, Digital Twins Definition Language, which describes all data types, states, properties, events, and relationships between the physical objects.

Microsoft's Azure Digital Twins are highly scalable and can be used in various contexts with multiple Digital Twins and different data sources. Regarding pricing, this solution allows a free trial period, with a credit of 183.71€ to be used within 30 days [46] or a paid period, during which the pricing is dependent on the number of resources used, from the messages to operations and query units [44]. Brands like Bentley, BMW, Volvo, and Volkswagen [44] have considered this platform to improve their operations and capabilities, showing notable relevance. The free trial and extensive documentation make this platform interesting for prototype development.

4.3.2 AWS Digital Twins

Amazon Web Services allows the creation of Digital Twins [47] through AWS IoT TwinMaker, a cloud-hosted platform [47]. This solution provides many capabilities, one of them being modeling the devices, spaces, and processes in a knowledge graph [47], containing metadata about the system and which can connect to information provided by Amazon Web Services or other data sources. The AWS IoT TwinMaker provides a scene composition tool that can be used to model 3D scenes, upload previously built 3D models, and overlay information to keep records and easily represent the updated state of the operations involved. This solution also provides a low-code experience that allows the creation of a dashboard application for end users, such as operators and maintenance engineers, to access the Digital Twin [47].

This solution provides a free trial period, with a credit of 50 million data access and API calls each month for a year [47] or a paid period, during which the pricing is dependent on the number of resources used [47]. Siemens [47] used this solution, which represented a gas turbine, to optimize its performance and reduce maintenance through the implementation of AWS Digital Twins.

4.3.3 Oracle IoT Digital Twins

Oracle enables the creation of a Digital Twin and/or a simulator of the IoT Digital Twin. The latter, a distinctive feature compared with the three previously mentioned solutions, allows the user to create non-real devices without having to configure them [48] and generate fake data, alerts, and events, simulating an entire scenario.

Implementing the Digital Twin platform considers three pillars: *virtual twin*, *predictive twin,* and *twin projections* [48]. The first relates to virtualizing a physical device or asset in the cloud, using models based on JSON to consider attributes (for instance, to virtualize a port's transportation, it is important to consider its location, weight, and altitude, among others). The *predictive twin* is considered a statistical prediction model, and the *projections* allow integration with other applications [48]. Oracle IoT Digital Twins does not allow a free trial period, with the pricing dependent on predicting the resources needed to implement the solution.

4.3.4 Comparative Analysis

One of the outcomes of this dissertation is a Dry Port Digital Twin prototype. To implement it, one of the referenced platforms will be selected and adapted to the case of Entroncamento's Dry Port.

Because of the focus on the possibility of configuring access to data stored in the Blockchain, this feature was classified as one of the preliminary selection criteria. Some IoT devices are already installed, and others will be added, making the platform's ability to adapt to exterior devices an important point to consider.

The three platforms identified can be adapted to use data captured by IoT devices or multiple other sources. When considering the possible interaction with critical data potentially stored in the Blockchain, a search in Google Scholar for "Azure Digital Twin" and "Blockchain Data" showed only two articles, one behind a paywall and another describing research conducted to configure Azure Digital Twins to access critical data [46]. When searching for "AWS IoT TwinMaker" and "Blockchain Data", followed by "Oracle IoT Digital Twin" and "Blockchain Data", there were no results shown, confirming the reduced investigation combining both of the platforms with data potentially stored in the Blockchain.

Because of this comparison, the overall advantages of Azure Digital Twins, with more tutorials available, case studies exploring its features, easier interface to configure, and visual capabilities, were deemed more advantageous when considering the objective of this dissertation and, therefore, it was the platform selected.

4.4 Summary

This chapter started by exploring real cases of Digital Twins being adopted in seaports, considering the notorious lack of examples of this technology applied in Dry Ports. Implementing Digital Twins in these logistics nodes can improve multiple operations, from the facilitated exchange of information between different entities to an optimized order of tasks when handling containers. Some of the identified challenges of adopting Digital Twins are exposed, focusing on the need to guarantee data reliability and security.

Digital Twin architectures were also studied, with a lack of examples and guidance, which justified the importance of this research. The modeling of such a complex context is still in its infancy, but some examples of seaport architecture were identified; however, none of them used ArchiMate. The search for enterprise architectures of Digital Twins led to even scarcer results, with only two examples found and only one related to logistics. Examples of modeling Digital Twins and Blockchain led to interesting results, confirming that the data's reliability and security are a priority when implementing Digital Twins.

Lastly, three implementation platforms were briefly explored and compared, the Azure Digital Twins platform being selected to implement a Dry Port's prototype.

Overall, this chapter provided insights regarding the lack of research on Dry Port Digital Twin architectures and confirmed the necessity of modeling complex systems from both business and technology perspectives. ArchiMate has been suggested as a possible modeling language to show alignment, and a few confirmations have been found in the literature. Blockchain has been adopted alongside Digital Twins, providing secure and reliable data. The next chapter explores the existing representation of Entroncamento's Dry Port and identifies some of its limitations, which are answered by modeling the architecture of this infrastructure using ArchiMate.

Chapter 5
Entroncamento's Dry Port AS-IS Architecture

This chapter explains the initial assessment of Entroncamento's Dry Port architecture. It was conducted during the first phases of the dissertation and aimed to comprehend the existing technologies and stakeholders' needs, ultimately leading to the addition of technological solutions to this infrastructure.

Section 5.1 presents Entroncamento's Dry Port blueprint at the beginning of the project, its main applications, some of the issues identified in the representation, and recommendations to improve it. Section 5.2 depicts and explains Entroncamento's Dry Port architecture, modeled with ArchiMate. All of the elements and relationships of this modeling language are described in Appendix C – ArchiMate's Relationships and Appendix D – ArchiMate's Elements.

5.1 Architecture AS-IS

Figure 5 presents Entroncamento's Dry Port's High-Level blueprint, modeled by Fordesi, and considered a starting point for the NEXUS Agenda developments.

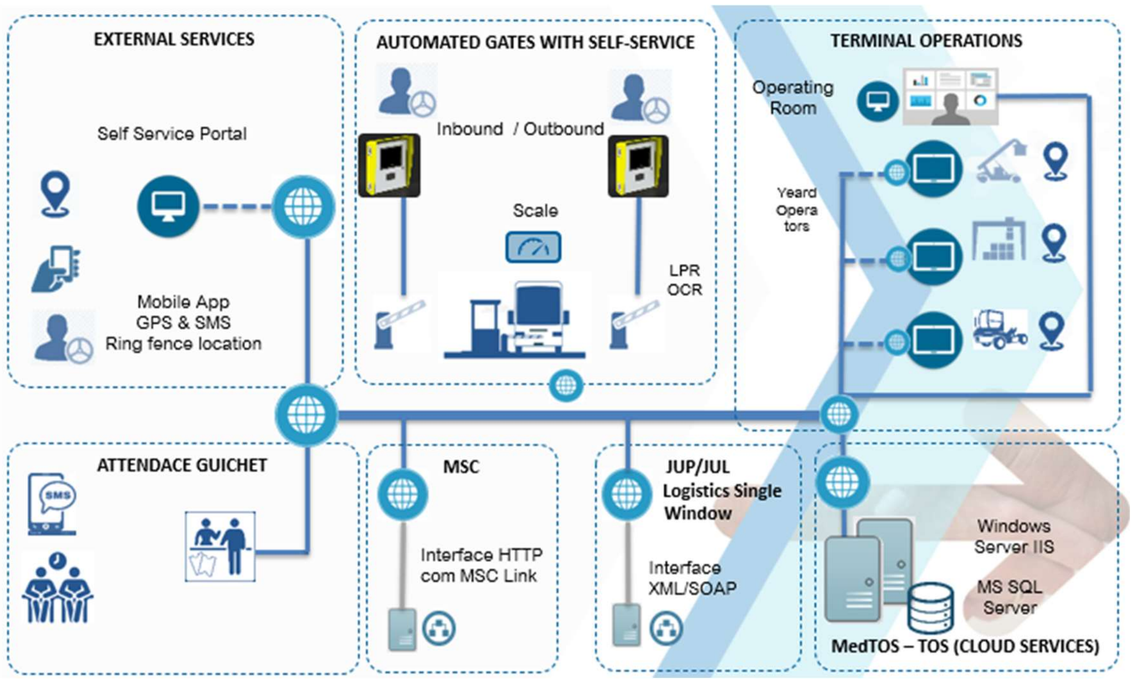

Figure 5. High-Level Blueprint of Entroncamento's Dry Port (source: NEXUS Agenda Proposal)

This representation divides Entroncamento's Dry Port elements into seven main groups. The external services group (on the top-left) represents the MedTOS self-service portal, which can be accessed by yard operators, clients, and the terminal manager. Right beside that group, the automated gates group identifies the technology used to control the arrival and departure of vehicles: License Plate Recognition (LPR) and Optical Character Recognition (OCR) cameras. The terminal operations group (on the top-right) identifies all processes and tasks at the Dry Port, controlled by the terminal manager. On the bottom-left, the attendance guichet group represents the service that involves direct contact with customers. The remaining three groups identify the Dry Port's technological elements: the Mediterranean Shipping Company[6] (MSC) is an Application Programming Interface (API) that optimizes the cargo's life cycle, *Janela Única Logística* (JUL) [49] allows the exchange of messages between various sources involved in the logistics chain (e.g., arrival and departure announcements, cargo loading and unloading permissions), and MedTOS [14] manages the port's operations.

Next, two relevant architectural elements are detailed: JUL, the national platform that integrates all of the data for logistic operations, and MedTOS, the central platform for operating Entroncamento's Dry Port operations.

5.1.1 JUL

JUL is an application implemented in 2019 by the Portuguese Ports Association (APP) to improve the information exchange between stakeholders and to centralize access to all information within the logistics chain [50] [49]. Installed on all Portuguese ports' administrations and with a strong connection with the Tax Authority, JUL considers both national seaports and hinterland Dry Ports. Acting as a hub facilitates message exchange, increases data flow efficiency, and amplifies the Dry Port's capabilities, reducing the need for physical documentation, administration costs, and waiting times. With multiple versions and updates [51], JUL has an ecosystem of applications that follow structural rules, facilitating their integration [50] [49].

5.1.2 MedTOS

MedTOS[7] is a Terminal Operating System that manages information regarding yard operations and shares real-time data with freighters and cargo agents through JUL, such as the gate in and gate out of trucks and trains. Figure 6 presents the High-Level architecture at the beginning of the NEXUS Agenda developments, describing the interaction between JUL and MedTOS.

[6] https://www.msc.com/en/solutions/inland-solutions [Online] [Accessed on 21st of December 2023]
[7] https://www.fordesi.pt/solucoes/gestao-para-terminais-multimodais-de-mercadorias/ [Online] [Accessed on 19th of January 2024]

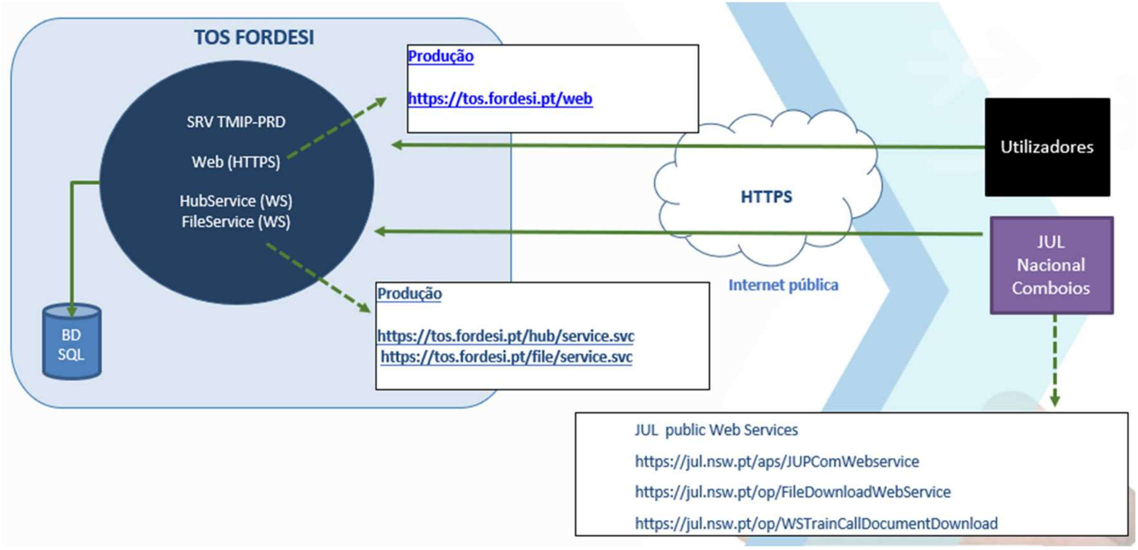

Figure 6. Architecture of TOS and JUL Interaction (source: NEXUS Agenda Proposal)

Figure 6 identifies the MedTOS application with a blue rectangle on the left and describes both the database used to store the information and the web addresses to access its services. MedTOS communicates with JUL and users (e.g., clients, yard operators, terminal manager) through https. Even though it is possible to comprehend the information exchange between both applications, some changes can improve the architectural representation, namely:

- The exchange of messages between JUL and MedTOS is bidirectional. Therefore, the arrow that connects both elements should have both directions, representing the data flow from and to MedTOS.
- The distinction between the reading and writing operations could be made using a distinct color or pattern in the arrow representing the data flow.
- The architecture should be presented in a clear background, without imagery or other elements that may confuse, and the information like web services addresses should be explained in text after the architecture.

It was concluded that the architectural representations available had problems and were insufficient to comprehensively and completely model Entroncamento's Dry Port. The next section discusses recommendations to answer the issues identified in the representations, followed by possible improvements.

5.1.3 Architecture Analysis

Table 6 summarizes the main issues in the High-Level blueprint shown in Figure 5. This analysis is based on the work proposed by Anthony J. Lattanze [11]. The first column presents quotes describing good practices for modeling any architecture, the second identifies issues in the existing representation, and the last column suggests some changes that could be applied and improve the overall representation.

Table 6. Dry Port's Architecture Analysis

Recommendation	Issue	Possible Improvement
An architecture "*should feature well-defined modules whose functional responsibilities are allocated on the principles of information hiding and separation of concerns… thus insulating the bulk of the software from change*" [20]	The defined groups are inadequate for future change, as the dependencies between elements are difficult to identify. Additionally, using imagery to describe each task can be challenging, especially if not presented consecutively.	1. Create groups in a way where dependencies among each are clearer. For example, MedTOS considers data from JUL and MSC. Still, that data is not accessed directly by any user or operator, and because of that, the information exchange relationship should be better presented. 2. Describe tasks using text instead of pictures.
"E*ach module should have a well-defined interface that incapsulates changeable aspects… from other software that uses its facilities"* [20]	The interfaces between each group are identified. The only issue is the lack of clarity when representing which element uses which facility.	1. Organize the applications and the data sources each uses separately and more straightforwardly. For example, JUL and MedTOS exchange messages, but the operator responsible for the port's operations management only interacts with MedTOS.
"Modules that produce data should be separated from modules that consume data" [20]	The data flow is not clear, as the direction of each arrow is not identified.	1. A direction for each arrow should be added to represent the data flow between groups and elements. 2. The reading and writing operations should be added using distinct colors or patterns in the arrows.
"*Every task or process should be written so that its assignment to a specific processor can be easily changed*" [20]	The architecture does not include a detailed description of each task of the processes. However, the imagery used allows the overall identification of a few of the operations, such as, for example, the yard	1. The addition of a more detailed description of each process, identifying the tasks, the information needed for each, and the applications used (it is fundamental to identify all applications and actors

Recommendation	Issue	Possible Improvement
	operations, including the loading and unloading of the cargo and the management of the vehicles within the port.	involved in each step of a process so that it is easier to identify the need for change and its consequences.
An architecture "*should lend itself to incremental implementation via the creation of a skeletal system in which the communication paths are exercised*" [20]	How the architecture is presented will easily be adapted by the original team modeled it. However, for example, expanding the cameras' capabilities can be more challenging to model, as the actual representation only identifies them but does not explain how they exchange the data with the remaining elements.	1. The identification of all elements and the way they each interact with each other allows the identification of all dependencies and needed information when considering changes to be implemented.

In the next section of this chapter, based on the suggested improvements, the ArchiMate architecture of Entroncamento's Dry Port is explained. This modeling language's capabilities offer a good alternative to modeling more complex settings like the ones addressed in this dissertation.

5.2 Modeling the AS-IS Architecture with ArchiMate

Figure 7 proposes a possible AS-IS architecture of Entroncamento's Dry Port, representing all of its services, actors, interfaces, applications, and IT infrastructure.

The framework presented in [19] inspired the model of the architecture, as it has been widely adopted within other Smart Contexts, establishing two perspectives and seven layers. The perspectives are those of the stakeholders and data. The layers, from top to bottom, include (1) context that describes the drive of each service, (2) services to meet the needs of the citizens, (3) business layer revealing the flow of the enterprise's procedures, (4) application layer describing the systems responsible for managing various data sources, (5) data relevant for information's storage, and both the (6) technological and (7) physical layers regard the devices that produce the real-time data and the infrastructure to run the applications.

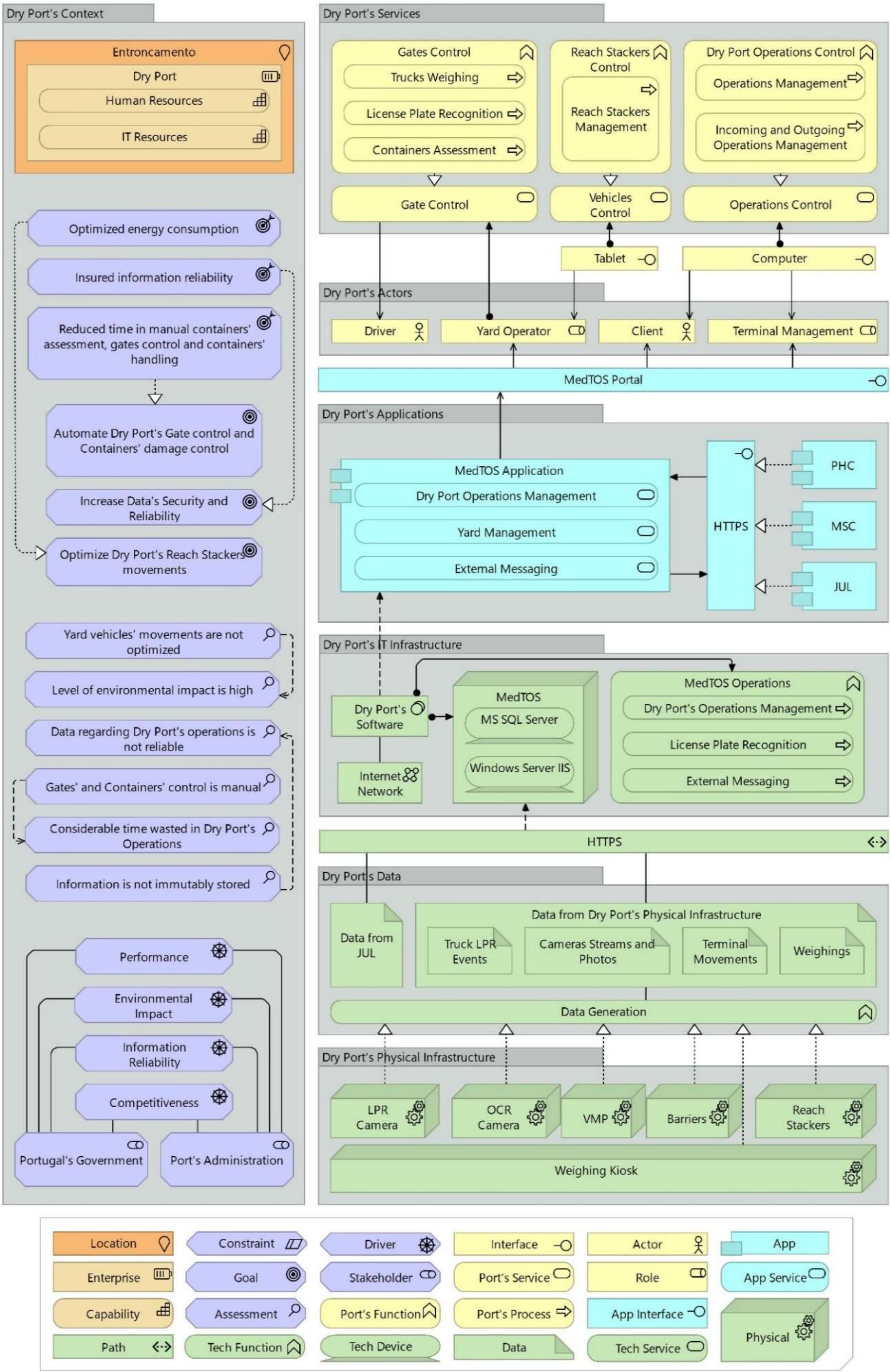

Figure 7. AS-IS Architecture of Entroncamento's Dry Port with ArchiMate

The *context* layer (on the left, in Figure 7) identifies the main stakeholders of the Dry Port (the port's administration and the national government), their drivers, and the assessments done. After identifying the main problems in Entroncamento's Dry Port, the *service* layer (top-right) presents the functions of this infrastructure, split into services. The interfaces are included between this layer and the *actors*' layer (yard operators, terminal managers, clients, and drivers). The *application* layer includes the main application responsible for managing Entroncamento's Dry Port's operations, MedTOS, and the Application Programming Interface (API) accessed, including JUL, MSC, and PHC (to handle information regarding taxes and other financial information).

The layer describing the *IT infrastructure* includes the servers, while the *data* layer identifies all the data needed for the operations. The *physical infrastructure* layer includes all devices that capture or need information, from cameras to yard vehicles, the weighing kiosk, and the barriers. The MedTOS application considers information from JUL, MSC, and PHC that is captured by the IoT devices, the latter stored in the TOS server and used to, for instance, control the entry of trucks in the Dry Port.

Several issues found in the initial architecture were solved using ArchiMate. An analysis of the improvements, following the recommendations proposed by Anthony J. Lattanze [20], is presented as follows:

- *The groups defined are not easily adaptable, and the description of tasks using images is challenging to understand* – in the new architecture version, the layers facilitate the distinction between elements and the identification of their dependencies.
- *The interfaces of each element are not clear* – through this new architecture, the interfaces between elements are much clearer as, between some layers, those are identified. For instance, it is now easier to understand that the yard operators are accessing information regarding the operations through a tablet.
- *The data flow between elements is not comprehensible* – when using ArchiMate, the interactions between elements are relationships. For instance, the application MedTOS" exchanges information with the remaining APIs using https.
- *Lack of detailed description of each process* – the view in Figure 7 is meant to be a High-Level representation of the elements that compose Entroncamento's Dry port. ArchiMate, however, allows the creation of multiple views, which will later be considered to represent each of this infrastructure's operations.
- *Lack of explanation about data exchange between applications and IoT devices* – in the new architecture, the IoT devices used to capture data are identified, as well as the information produced by those and how it is stored in the servers.

This chapter presented the technologies used in Entroncamento's Dry Port when the project started. Key problems of the initial artifacts used to represent the architecture were also presented, and solutions were proposed. The team confirmed that ArchiMate was a suitable language to represent Entroncamento's Dry Port.

Chapter 6
Entroncamento's Dry Port Digital Twin Architecture

To model Entroncamento's Dry Port Digital Twin architecture using ArchiMate requires a comprehensive understanding of all components that comprise its IT infrastructure, business processes, and how each interacts with actors and applications. As discussed in Chapter 5, the representation of Entroncamento's Dry Port cannot be easily modified to accommodate technological or business additions. However, by using ArchiMate to model multiple views of Entroncamento's Dry Port, it is possible to delineate layers, portray interactions between elements more effectively, and improve awareness of the elements that compose this infrastructure.

Section 6.1 lists and explains the new technological advances in Entroncamento's Dry Port, followed by the identification and explanation of each of this infrastructure's views in Section 6.2. Lastly, Section 6.3 proposes a list of Design principles to consider when modeling a Dry Port Digital Twin's architecture.

6.1 Technological Advances in Entroncamento's Dry Port

Table 7 lists the technological advances proposed by NEXUS Agenda to Entroncamento's Dry Port, followed by their description and the expected improvements.

Table 7. Technology Advances for Entroncamento's Dry Port (source: NEXUS Agenda proposal)

Technology	Description	Improvement
License Plate Recognition (LPR) Cameras	Cameras that capture the truck's license plates and confirm if each is allowed to enter (or exit) Entroncamento's Dry Port.	Remove the need for manual traffic flow control.

Technology	Description	Improvement
Optical Character Recognition (OCR) Cameras	Cameras that capture images of all sides, from each container that enters (or exits) Entroncamento's Dry Port.	Add another layer of control of the cargo arriving and leaving Entroncamento's Dry Port.
Container Artificial Intelligence (CAI) OCR Application	Application responsible for Container License Plate and Label identification, using Computer Vision.	Remove the need for expensive licensing to do Container License Plate and Label identification with OCR cameras and automate containers' identification.
Trustable Data Infrastructure (TDI) Application	Application responsible for the immutable and reliable storage of information (e.g., messages exchanged through JUL, documents) in the Blockchain.	Add another layer of information security to the data exchanged through Entroncamento's Dry Port operations.
Smart Rail Handling (SRH) Application	Application responsible for generating an optimized sequence of containers and corresponding wagons. The list will be accessed by yard operators through a tablet.	Optimize energy consumption, increase human resources organization, and reduce delays.
Trucker Application	Application responsible for allowing remote check-in, when within an established ringfence. This functionality will be accessed by truck drivers through their phones.	Remove the need for manual traffic flow control, and reduce delays.
Digital Twin	Prototype to visualize data regarding Entroncamento's Dry Port in real-time, with color variations and warnings on a 3D scenario	Increase awareness and control over Entroncamento's Dry Port operations.

Each of these technologies is being implemented by different teams of people, part of not only the WP3 but other Work Packages that compose the NEXUS Agenda. The integration of the new technological solutions, particularly in Entroncamento's Dry Port, justifies the need for an architecture of this infrastructure, detailed and complete, useful not only from a process design perspective but also for the NEXUS Agenda's audit. In the next section, the views necessary to model Entroncamento's Dry Port architecture are presented and explained, followed by a detailed description. Later in this chapter, a list of Design principles is proposed to model the architecture of any Dry Port Digital Twin using the modeling language ArchiMate.

6.2 Architectural Views: Identification and Modeling

The literature on modeling Digital Twins has no guidelines about the fundamental viewpoints to accurately describe Dry Ports. Viewpoints are abstractions that facilitate addressing different stakeholders' needs and convey specific information they can easily understand [52]. The framework presented in [19] and the example viewpoints defined by the ArchiMate specification[8] were considered in establishing the needed views. Table 8 enumerates and justifies all of the viewpoints that accurately describe Entroncamento's Dry Port Digital Twin and depicts the stakeholders' comprehension regarding each of its elements.

Table 8. Entroncamento's Dry Port Digital Twin - Architecture Views

View	Justification	Stakeholders
High-Level	Considering both the proposed "*layered*" viewpoint of ArchiMate's specification and the "*context*" viewpoint presented in an Enterprise Architecture Framework for Cities [19], this view aims to provide an overview of Entroncamento's Dry Port Digital Twin architecture, identifying and relating its main components.	Port's Administration, Fordesi, NEXUS Agenda Consortium
Stakeholder	Based on ArchiMate's specification and an Enterprise Architecture Framework for Cities [19], this view aims to model stakeholders, their external and internal drivers, and the corresponding assessments of Entroncamento's Dry Port.	Port's Administration, NEXUS Agenda Consortium

[8] https://www.visual-paradigm.com/guide/archimate/full-archimate-viewpoints-guide/ [Online] [Accessed on 30th of March 2024]

View	Justification	Stakeholders
Goal Realization	Considering the viewpoint by the same name, listed in ArchiMate's specification, this view aims to relate the High-Level goals with particular objectives and the corresponding requirements and constraints.	
Requirements Realization	This viewpoint intends to demonstrate the realization of requirements by core elements of ArchiMate's three main layers: business, application, and technology, as listed in the specification.	Fordesi
Application Usage	As defined in ArchiMate's specification, this viewpoint illustrates the interaction between applications, their support of business processes, and user services. Essential to accurately describe Entroncamento's Dry Port Digital Twin architecture, this view demonstrates how the new technological additions directly impact the business processes and services.	Port's Administration, Fordesi, NEXUS Agenda Consortium
Technology	Based on ArchiMate's specification, this view shows how the technological elements support the application layer, focusing on identifying all physical devices, networks, and software systems.	Fordesi

View	Justification	Stakeholders
Technology Usage	Considering the viewpoint by the same name, listed in ArchiMate's specification, this view aims to show how the applications are supported by the software and hardware technology and how each relates to business elements. This view focuses mostly on the interaction between applications and the needed technological elements.	Fordesi
Information Structure and Access	This view illustrates the information structure used in Entroncamento's Dry Port Digital Twin. It considers both the proposed "*information structure*" viewpoint of ArchiMate's specification and the "*ownership and access*" view presented in the Enterprise Architecture Framework for Cities [19]. The modeling of data access types was deemed crucial due to information only meant to be accessed by authorized entities and other information only relevant to specific individuals who are part of the Dry Port.	Port's Administration, Fordesi

This catalog of viewpoints was defined through multiple meetings with the WP3 partners (e.g., Fordesi, NEXUS Agenda Consortium, and other researchers developing technological solutions to solve Entroncamento's Dry Port limitations). The modeled views were included in the official deliverables of the NEXUS Agenda.

6.2.1 High-Level View

The High-Level view aims to present a simplified description of all architecture's elements, smoothing the explanation to all project stakeholders.

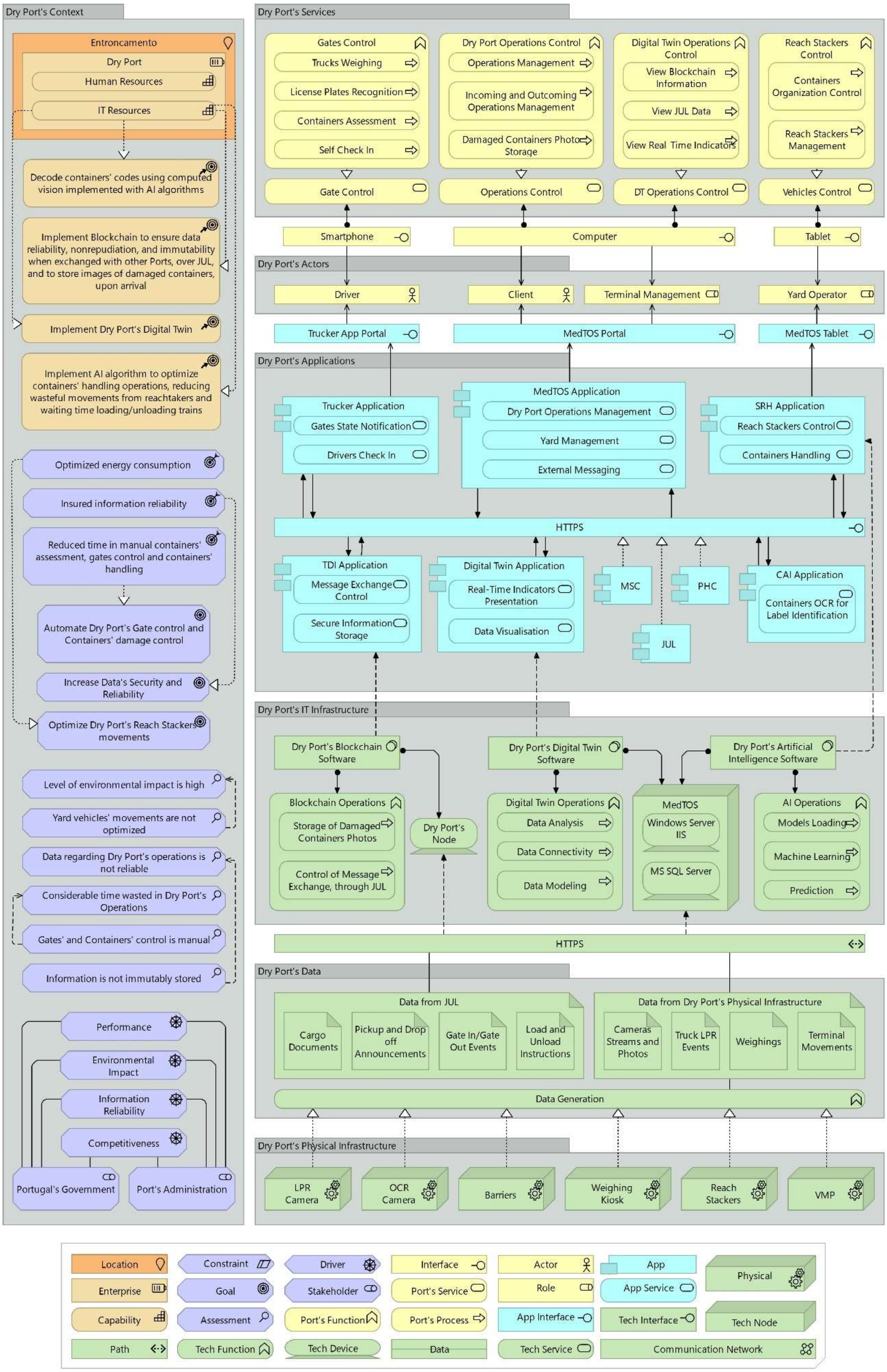

Figure 8. Entroncamento's Dry Port Digital Twin High-Level View

Figure 8 depicts Entroncamento's Dry Port Digital Twin High-Level viewpoint, consisting of seven horizontal and one vertical layer, based on the framework explored in [19]. To identify all of the components, documentation from the NEXUS Agenda was considered, as well as multiple interviews with the partner company, Fordesi, and Entroncamento's Dry Port manager, Medway.

- The *Context* layer, on the left, includes the justification of the drivers and goals established for the enterprise. In the context of Entroncamento's Dry Port, it was crucial to identify the main stakeholders (Port's Administration and Portugal's Government), and their drivers. Some of the assessments were then recognized and related (for instance, "information is not immutably stored" leads to "data regarding Dry Port's operations is not reliable"), followed by the outcomes that realize each of the goals. Then, the main capabilities of Entroncamento's Dry Port were identified, and the courses of action realized by those were described, representative of the new technological elements within the Dry Port.
- Both the *Services* and *Actors* layers, in yellow, depict the business elements of Entroncamento's Dry Port. The services available to the actors (drivers, terminal managers, clients, and yard operators) are split into four categories: gate control, reach stackers control, Dry Port operations control, and Digital Twin operations control. When comparing the *Services* layer with the equivalent one in the AS-IS architecture, there are new functions to improve the Dry Port's operations: the containers' state assessment is not manually done, and critical data is now stored in the Blockchain. Additionally, the direct interaction between actors and the business services was replaced with interfaces. For example, the driver's access to the Dry Port check-in is now done through a smartphone.
- The *Applications* layer (blue elements) includes five new applications: Trucker Application, SRH Application, TDI Application, CAI Application, and Digital Twin Application, each explained in detail in Table 7. For instance, the Digital Twin Application allows the visualization of data and real-time indicators, while the SHR Application is responsible for presenting the most optimized sequence to handle containers. The MedTOS Application also uses data from JUL, MSC, and PHC.
- The *IT Infrastructure* layer (green elements) depicts Entroncamento's Dry Port servers and the software responsible for Artificial Intelligence, Digital Twin, and Blockchain capabilities. Artificial Intelligence capabilities' main functions are model loading, machine learning, and prediction operations, while Digital Twin operations include data modeling, data connectivity, and data analysis. Lastly, the Blockchain component has functions related to storing pictures of damaged containers and controlling messages exchanged over JUL.
- The *Data* layer (green elements) identifies the data used by Entroncamento's Dry Port operations and communicates with the *IT Infrastructure* layer through https. The information can be divided into two categories: information from JUL and information realized by IoT devices.

- The *Physical Infrastructure* layer describes the devices that capture information in real-time, including cameras, reach stackers, weighing kiosks, barriers, and the Variable Message Panel (VMP).

This High-Level viewpoint allows an overall understanding of Entroncamento's Dry Port's main elements, facilitating the comprehension of how each relates to each other and how to integrate new technological solutions. For instance, if new IoT devices are integrated, the correspondent layer would be the *Physical Infrastructure*, while adding business services would lead to changes in the *Services* layer.

6.2.2 Stakeholder View

Entroncamento's Dry Port Digital Twin aims to help reduce the consequences of various challenges noted by Dry Ports, providing information transparency, operations state updates in real-time, and warnings regarding situations that might negatively affect this infrastructure. So, before establishing the requirements, a thorough analysis of the drivers and goals of each involved stakeholder was conducted in cooperation with the project partners.

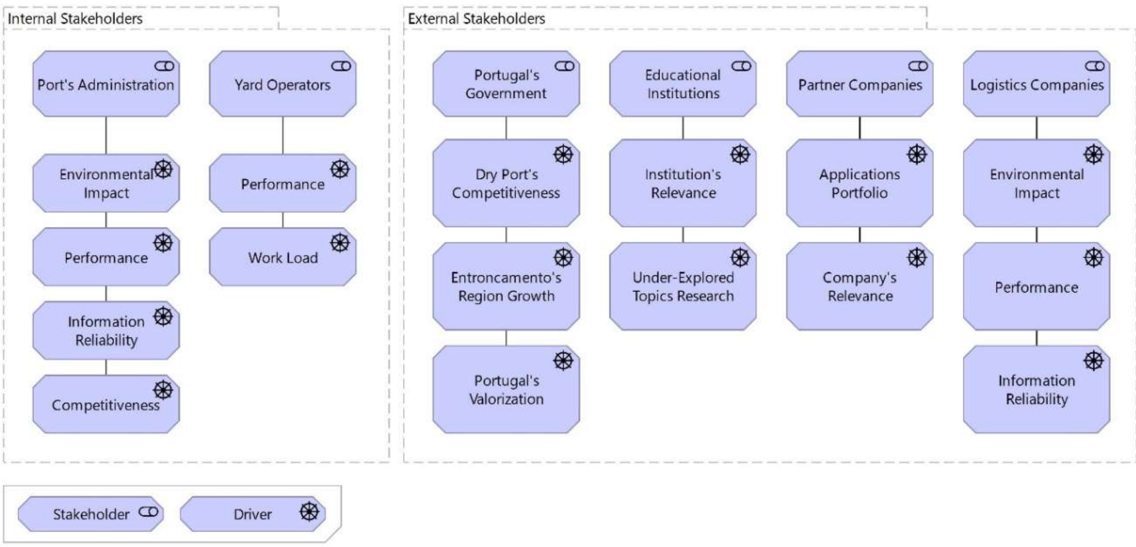

Figure 9. Entroncamento's Dry Port Digital Twin Stakeholders View

Figure 9 shows the stakeholders of Entroncamento's Dry Port split into two groups: internal stakeholders, part of the Dry Port and directly affected by changes (e.g., the Port's Administration and yard operators), and external stakeholders outside of the Dry Port but still dependent on its capabilities improvement. The concerns modeled as drivers lead to a clearer understanding of the stakeholders' main priorities. For instance, for the Port's Administration, environmental impact, performance, competitiveness, and information reliability, are the main factors that justify changes in Entroncamento's Dry Port, while for Portugal's Government, the increased competitiveness of Dry Ports, their region's growth, and the country's recognition as a reliable node within the logistics chain are of greater importance.

6.2.3 Goal Realization View

Each stakeholder's drivers led to an assessment of Entroncamento's Dry Port, in areas related to performance, optimization, and environmental impact. It was recognized that a substantial number of operations were done manually, like container assessment and gate control, reach stackers' movements were not optimized, and information was not stored carefully to ensure its immutability and reliability.

Requirements were divided into three categories for easier comprehension: *data*, *technology*, and *application*. *Data* requirements describe the information characteristics and how it is handled (e.g., storage of license plate photographs in the Dry Port's servers). The *technology* requirements describe the applications and IoT devices, as well as their capabilities (e.g., registry of reach stackers' location, capture of high-quality videos of both license plates and containers). The *application* requirements describe the specific Digital Twin implementation capabilities (e.g., visualization of information stored in the Blockchain, exchanged messages over JUL, indicators, and warnings about the Dry Port's operations). The principal constraint for the applications' implementation in Entroncamento's Dry Port is their need to be integrated with the existing applications' landscape and interact with various sources of information.

The outcomes are realized by fulfilling the established requirements, which include neutralizing carbon emissions by optimizing the reach stackers' movements handling the containers, reducing time spent manually assessing the containers' state, optimizing gate control, and storing critical data in the Blockchain (Figure 10).

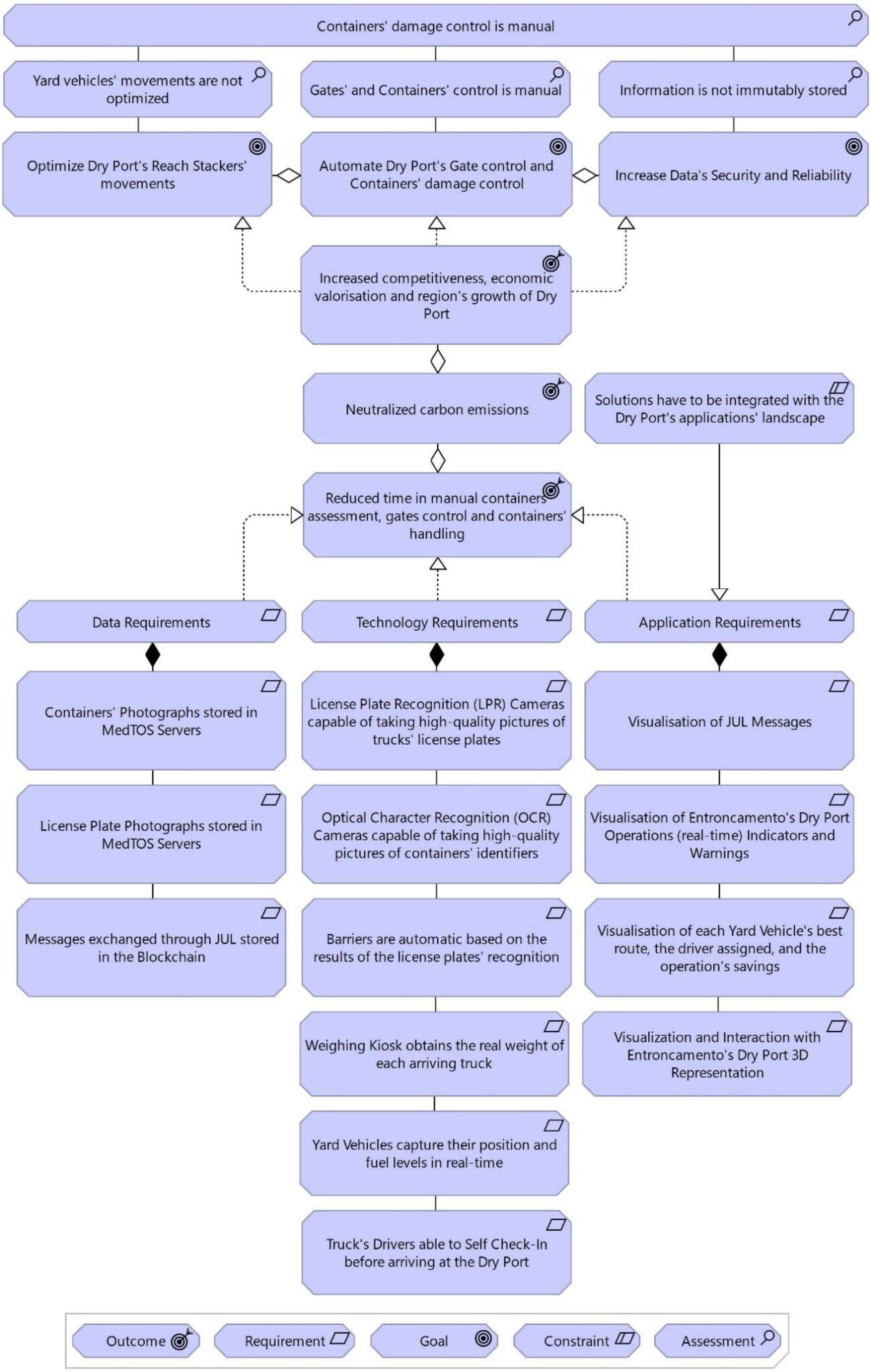

Figure 10. Entroncamento's Dry Port Digital Twin Goal Realization View

6.2.4 Requirements Realization View

Requirements directly influence the technological solutions adopted within the Dry Port, which justified the modeling of views relating to the application services, business elements impacted by them, and a High-Level description of the technological elements that guarantee them. Considering the three groups of requirements established in the Goal Realization View (Figure 10), the applications and technological elements responsible for realizing them are depicted in the next subsections. The Requirements Realization View is fundamental to confirm if all established prerequisites are realized by application services and if they can be easily adapted over time, with the addition or remotion of requirements, applications, technological elements, or business services.

6.2.4.1 Data Requirements Realization View

The data requirements describe how information must be stored within the Dry Port. Figure 11 describes the relationship between both the requirements and the applications. For instance, messages exchanged through JUL and damaged container pictures are stored in the Blockchain, while license plate photographs and container pictures are saved in the MedTOS servers.

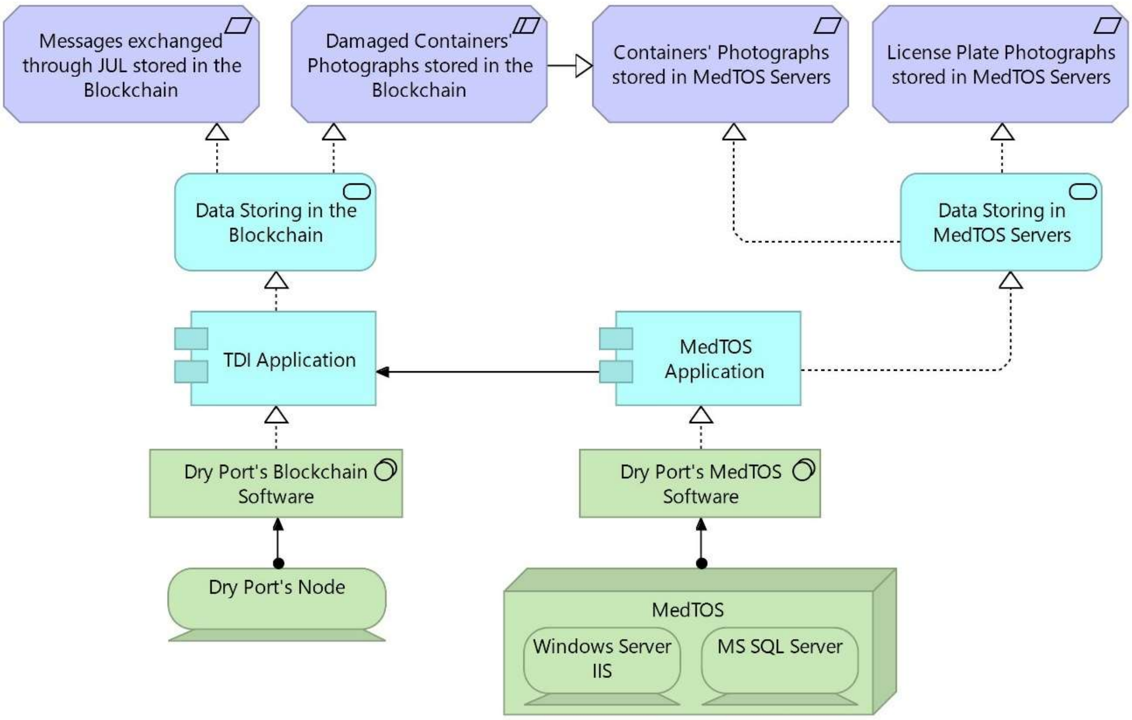

Figure 11. Entroncamento's Dry Port Data Requirements Realization View

6.2.4.2 Technology Requirements Realization View

The technology requirements describe new application services implemented and the technical characteristics of devices that gather data within Entroncamento's Dry Port. While the previously described data requirements relate to operations not seen by users and dependent on assessments (e.g., the storage of containers' pictures in the

Blockchain occurs if damage was identified, not if any entity wants that information to be stored), the technological requirements include interaction with business elements.

Figure 12 shows the relationships between the requirements and the application services that realize each business process. Both the SRH Application and the Trucker Application exchange data bidirectionally with MedTOS. For instance, the self-check-in done by the truck drivers through the Trucker Application is shared with MedTOS and, subsequently, with the SRH Application, to generate an optimized list to handle each of the containers, shown to yard operators through the MedTOS Tablet.

This view is crucial for Fordesi, allowing them to understand if the technological additions being developed answer the identified requirements and optimize some of the business processes.

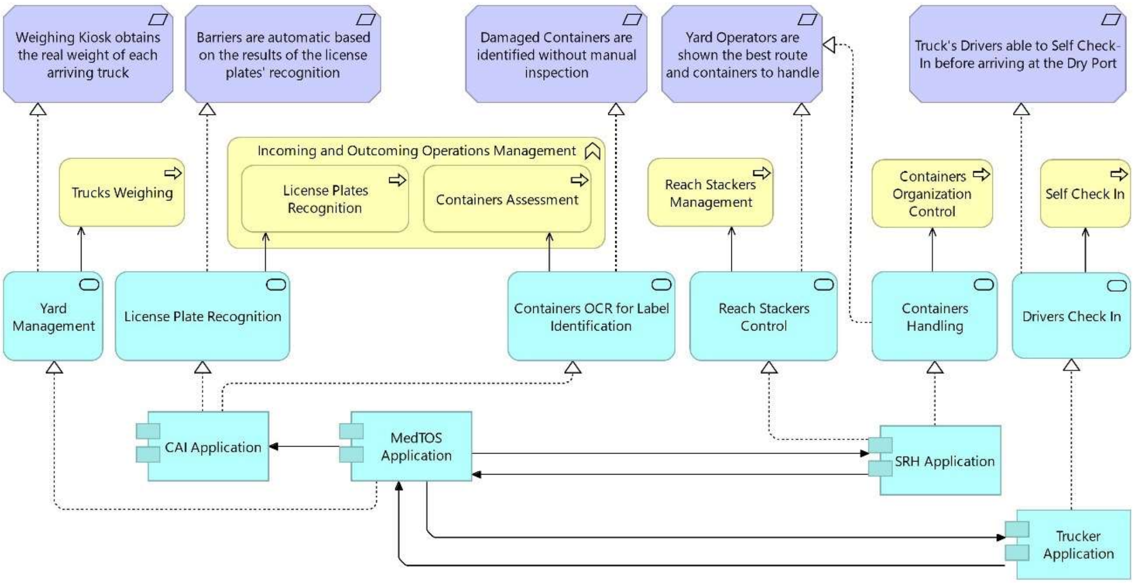

Figure 12. Entroncamento's Dry Port Technology Requirements Realization View

6.2.4.3 Application Requirements Realization View

The application requirements describe some of the Digital Twins' capabilities, considering the data that composes this infrastructure and its limitations (e.g., providing easier access to information to various stakeholders and showing warnings regarding operations). Figure 13 relates each of the requirements to the application services and business processes. For instance, the Digital Twin Application communicates with the TDI Application when presenting the data stored in the Blockchain. In the case of real-time indicators' visualization and interaction with the 3D scenario, those features are guaranteed by the Digital Twin Application.

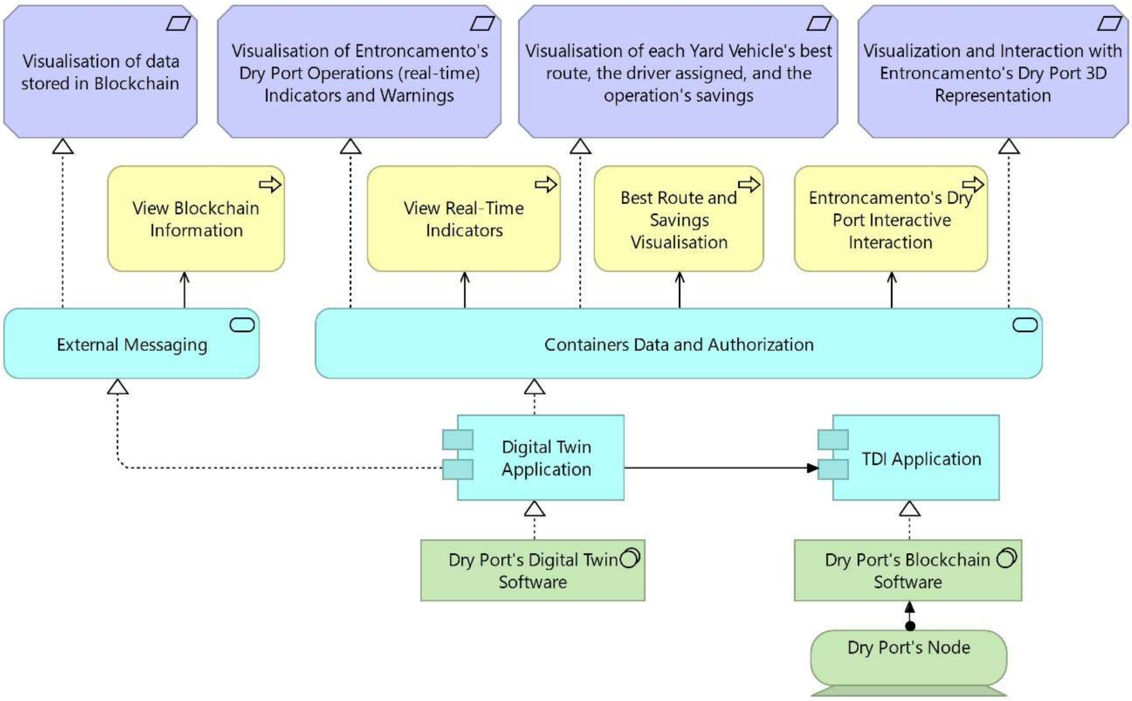

Figure 13. Entroncamento's Dry Port Application Requirements Realization View

6.2.5 Application Usage View

One improvement of Entroncamento's Dry Port processes is the adoption of various technological additions and applications, which reduce the need for direct contact between actors in operations such as container assessment or truck driver check-in. In this section, three processes are presented and explained from an Application Usage perspective, as they directly relate business elements with application elements: export process, import process, and reach stackers management process. With this view, it is possible to describe how each application guarantees the business functions.

It is important for the Port's Administration to understand each of the processes that compose Entroncamento's Dry Port's functions to clearly identify the steps needed to realize them. The NEXUS Agenda Consortium and Fordesi's priorities rely on the identification of opportunities to optimize processes through technology.

6.2.5.1 Export Process

JUL and MedTOS exchange, among other information, loading orders and the updated cargo's location (whether it has been dispatched or not). After receiving the loading order, the unit announcements are created, and the loading order is shared with the truck drivers and yard operators using the Trucker Application. The entry is authorized, and the cargo's handling instructions are shared with the yard operators through the MedTOS Tablet interface linked to the SRH Application. With the cargo's exit, its state and location are updated in JUL (Figure 14).

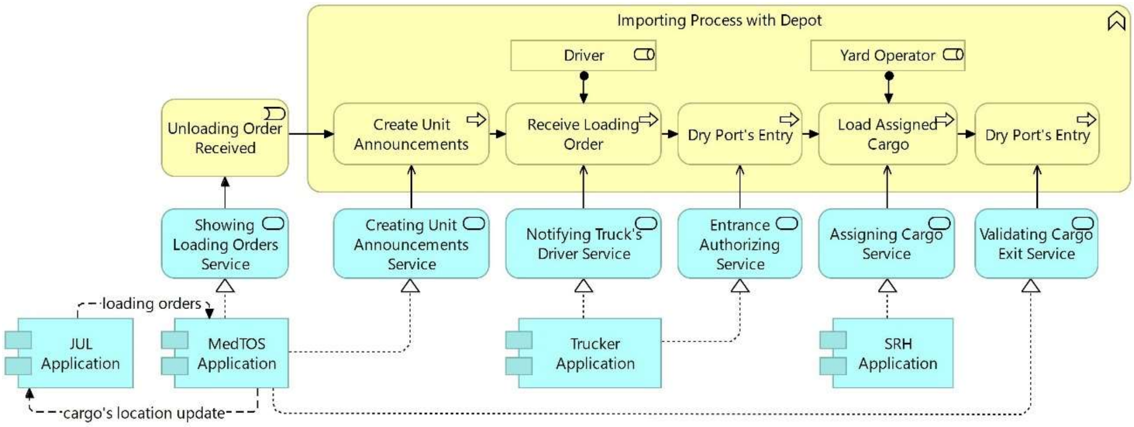

Figure 14. Entroncamento's Dry Port Export Process View

6.2.5.2 Import Process

The import process shares various steps with the export process, differing in the need to confirm the availability of space to store the cargo. After the arriving schedules are received and updated by JUL, customs are granted and the gate authorization is provided. This confirmation is done with license plate recognition, explained in the next section. If there is no space to store the cargo, it leaves Entroncamento's Dry Port and JUL updates its state. If there is storage space, the cargo is unloaded by a yard operator.

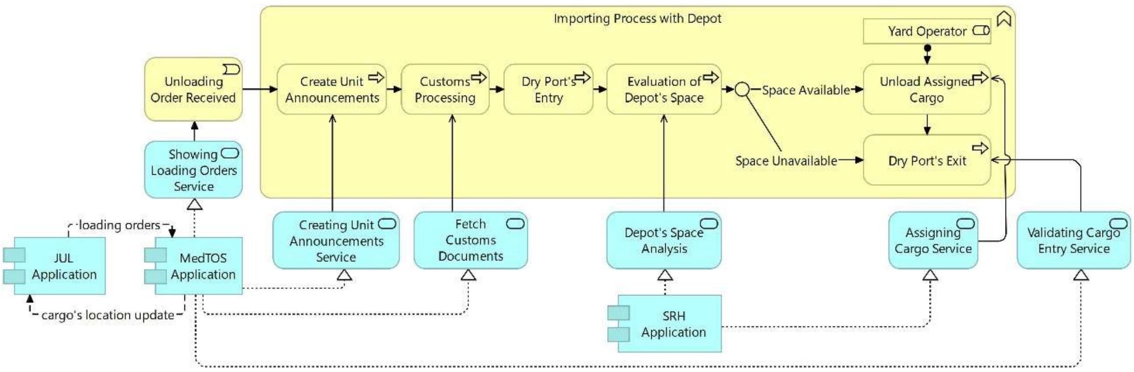

Figure 15. Entroncamento's Dry Port Import Process View

6.2.5.3 Reach Stackers Management

Container handling in Entroncamento's Dry Port was inefficient. Based on a case-by-case analysis, the operation prioritized each container's priority, dimensions, and weight, possibly leading to waste (e.g., time wasted fetching containers, longer periods of assigned yard operators and reach stackers and higher fuel consumption). Figure 16 depicts the function of *Rail Handling*, focusing on loading trains about to leave the Dry Port.

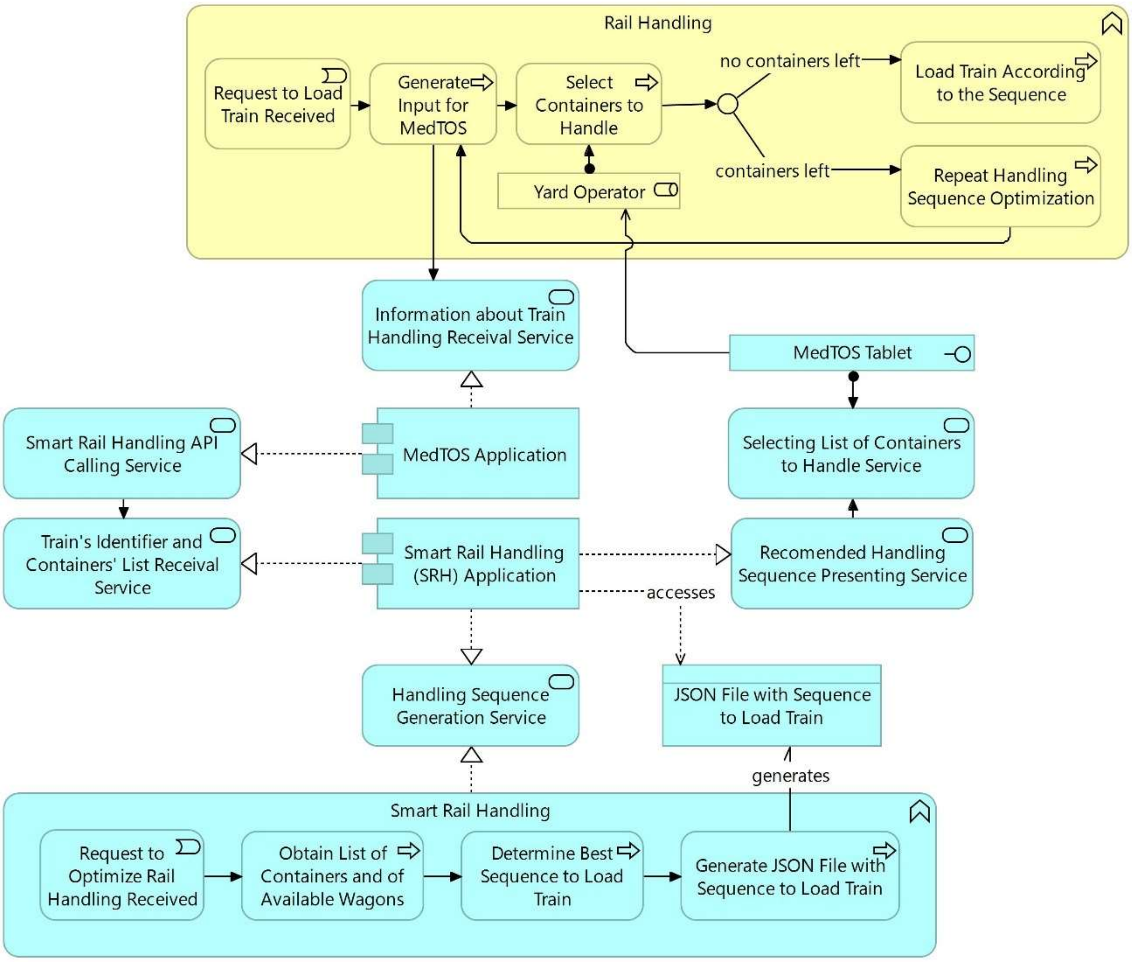

Figure 16. Entroncamento's Dry Port Reach Stackers Management View

With a request to load a train from JUL, MedTOS calls the Smart Rail Handling Application to generate the optimized sequence of containers to load. To obtain the best sequence to handle the containers, both the available wagons on the train and the sequence of containers to load are considered. Based on the distances of each container to the train and their position within piles of containers, a JSON file, with the succession of containers and corresponding wagons, is generated. Yard operators access the MedTOS Tablet to visualize the proposed sequence of containers and wagons and select the containers to handle. If there are containers left to load, the sequence of steps starts again, with the succession of available wagons and containers to load updated. If and when all containers have been loaded, the train leaves Entroncamento's Dry Port.

6.2.6 Technology View

The Technology View relates the system, software, and hardware elements that support Entroncamento's Dry Port technological solutions. Figure 17 describes green elements, for the technological components, and blue elements, for the applications.

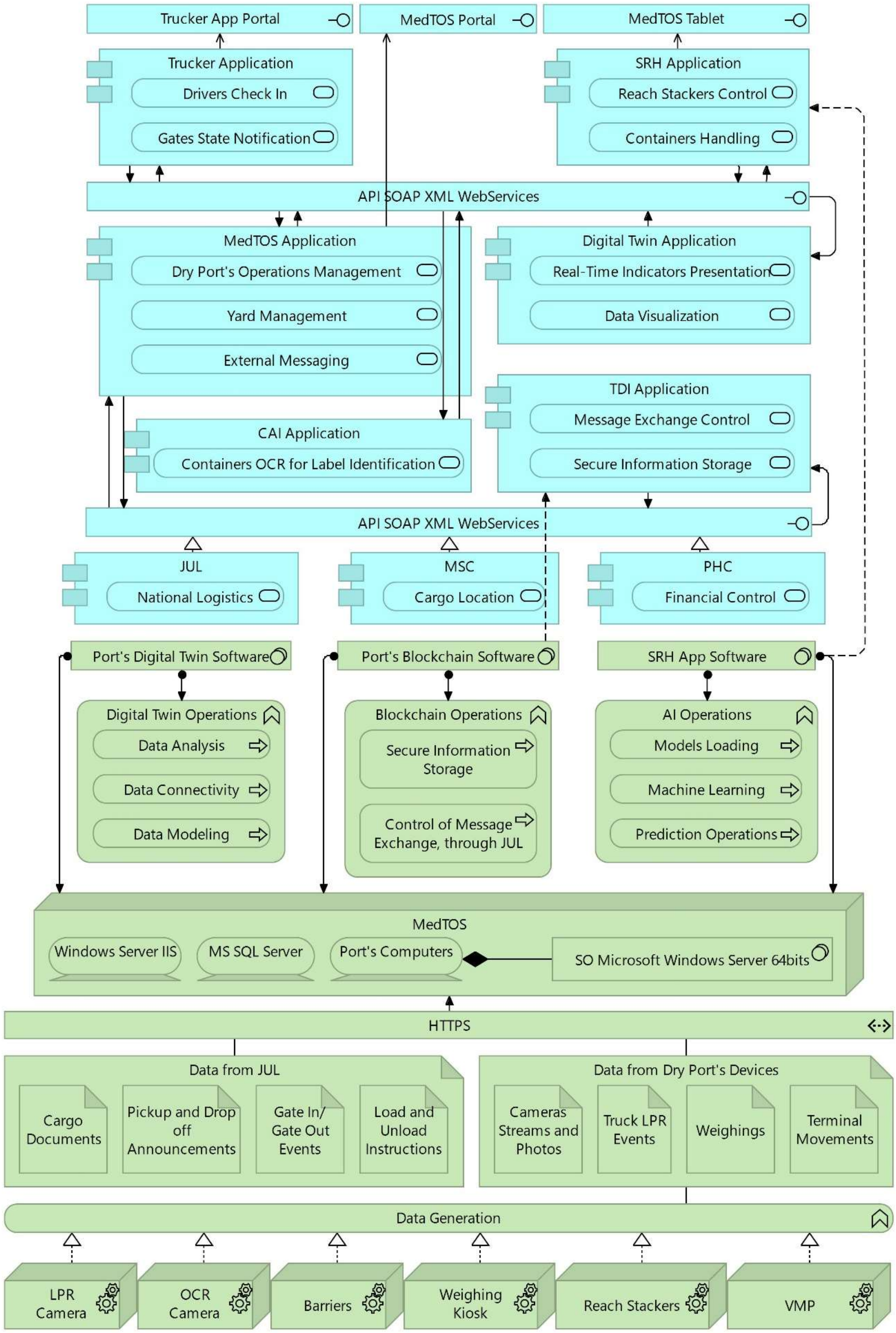

Figure 17. Entroncamento's Dry Port Technology View

The first elements, in blue, illustrate the three interfaces used by actors to access the application services: (i) the Trucker App Portal, accessed by truck drivers to realize self-check-in, (ii) the MedTOS ENT Portal utilized by yard operators to view the best sequence of containers to handle, and (iii) the MedtTOS Tablet, used by reach stackers. The MedTOS Portal is accessed by Entroncamento's Dry Port management and clients, allowing operations control. JUL, MSC, PHC, TDI Application, SRH Application, CAI Application, and Digital Twin Application are all APIs accessed by MedTOS to ensure various services. JUL centralizes exchanged information, facilitating its perception by the national Ports, MSC provides data about the containers' properties, and PHC is used for financial and tax control. Both the TDI Application and the CAI Application are described in detail in the next section of the Technology Usage View. At the same time, the SHR Application has been explained in the Application Usage Views Section (Figure 16).

The green elements relate to the technological infrastructure of Entroncamento's Dry Port and include the IoT devices (at the bottom), which are responsible for generating the data that can either be stored in the MedTOS servers or the Blockchain. The Digital Twin operations include data analysis, data connectivity, and data modeling, which were identified during the research regarding this technology. The Blockchain operations regard the storage of damaged containers' photographs, and the guarantee of nonrepudiation, immutability, and reliability of the information. The SRH operations realize machine learning, related to optimizing the sequence of containers to handle.

6.2.7 Technology Usage View

The Technology Usage View focuses on relating technological elements to their use. This section describes two additions to Entroncamento's Dry Port: the adoption of Blockchain to store critical information and the real-time recognition of license plates and container identifiers. Another addition predicted to be implemented by the NEXUS Agenda is damage detection in arriving containers, whose images are stored in the Blockchain. It is not described because it was not implemented in time for the architecture modeling.

6.2.7.1 Message Sending View: From Entroncamento's Dry Port to another Port

When Entroncamento's Dry Port sends a message to another Port through JUL, there is the need to guarantee that the critical information being exchanged (e.g., cargo leaving/entering a Port, arriving/departing of a vessel) is not altered during and after the transmission, and is stored securely. As there are various steps to send messages and to confirm them when received, Figure 18 focuses on the sending operation process.

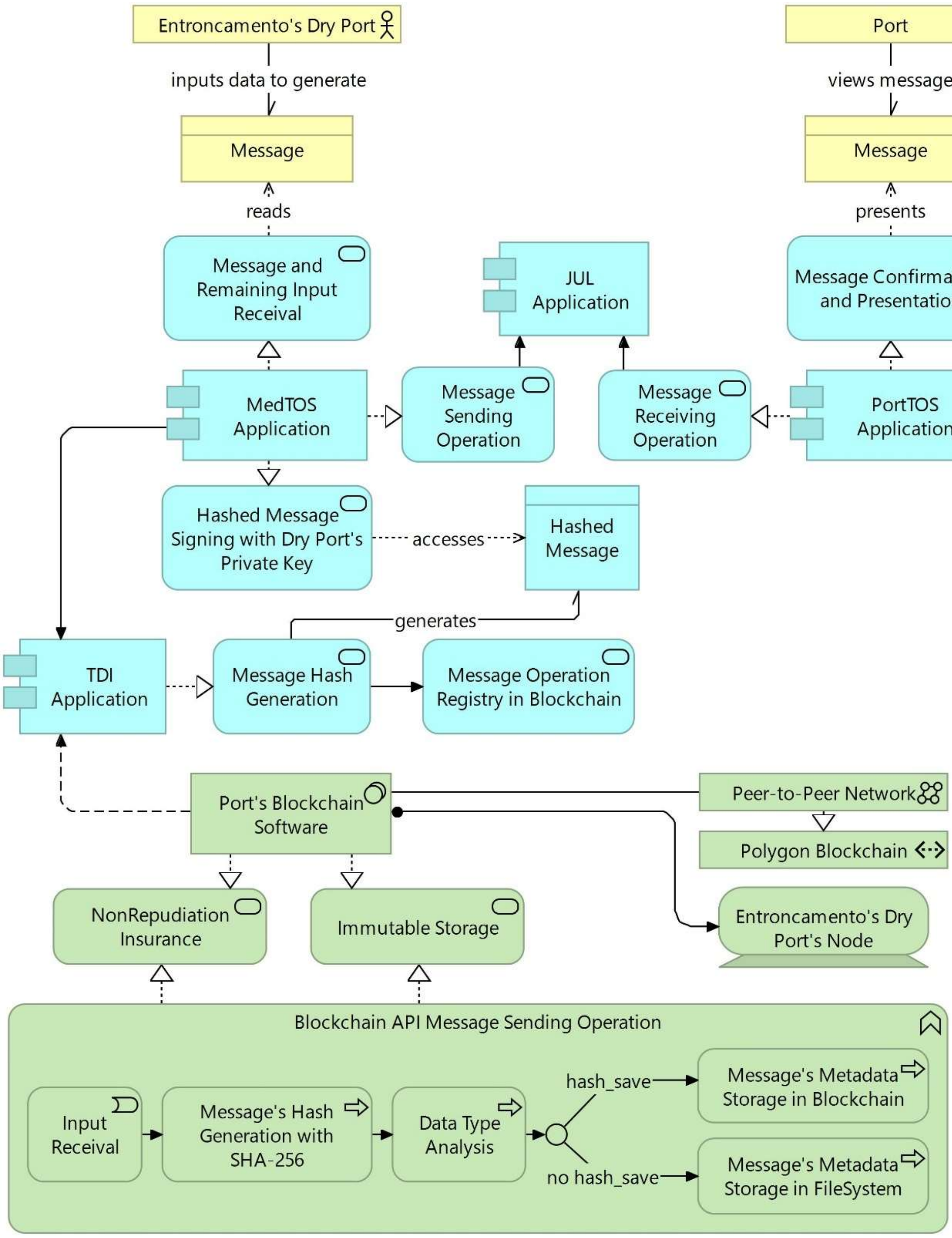

Figure 18. From Entroncamento's Dry Port to another Port (Message Sending View)

Firstly, MedTOS receives the required input, i.e., a message to exchange through JUL and its metadata, such as the message's identifier and type, the token associated with the user, the system's source ID, the date, and the time. MedTOS makes a call to the TDI Application with the input data. The TDI Application uses the hash function SHA-256 to generate the message's hash.

It then records the sending operation with its identifier, signed hashed version, and Entroncamento's Dry Port public key. This registry is dependent on the input type provided initially, which can be *hash_save* (to store the metadata in the Blockchain) or *no_hash_save* (to store the metadata in the MedTOS servers). MedTOS signs the hashed message with Entroncamento's Dry Port's private key to eliminate the need to share the Port's private key with the TDI Application. Then, JUL sends the message to the destination's PortTOS Application, which confirms its reliability, nonrepudiation, and immutability. This confirmation is described next, in more detail.

6.2.7.2 Message Receiving View: From Entroncamento's Dry Port to another Port

The TDI Application guarantees nonrepudiation, reliability, and immutability. It decrypts the signed hashed message with the sender's public key and compares it with the original hashed message. If the two do not match, an error message is generated, and the operation is canceled. If they match, the operation progresses to the next confirmation step. It also allows immutable storage, where each block of a sequence includes data about the previous blocks and new ones are appended to the chain's sequence, making the removal and/or update of any block impossible without any trace of change.

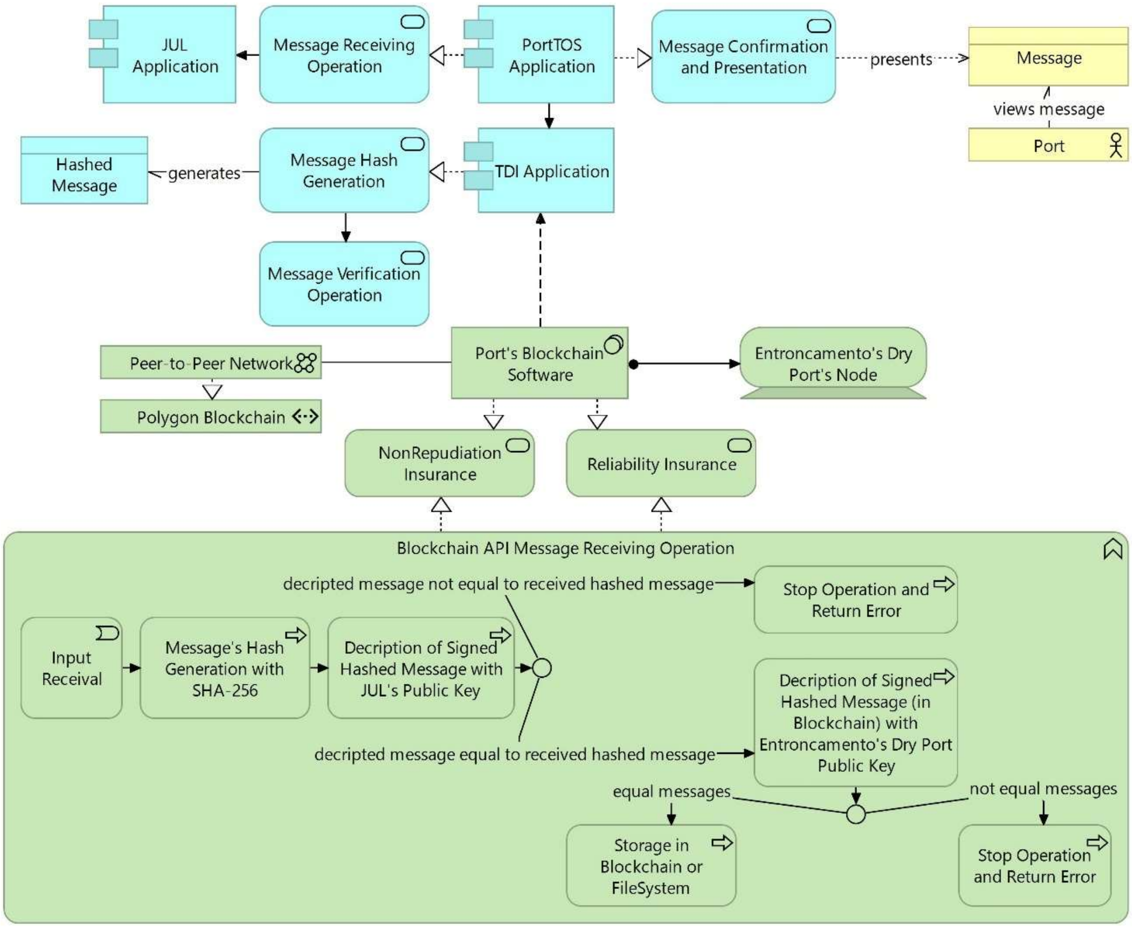

Figure 19. From Entroncamento's Dry Port to another Port (Message Receiving View)

Security measures must be guaranteed when analyzing the message exchange from the receptor's perspective. Figure 19 shows the operations conducted by the TDI Application to confirm both the message reliability and nonrepudiation. Starting with a call to the TDI Application, done by the PortTOS Application, the received message's hash is generated and compared with the decrypted hashed message, previously signed using Entroncamento's Dry Port public key. If the two are equal, then nonrepudiation is confirmed, and the message was sent by Entroncamento's Dry Port. With the metadata stored in the Blockchain and the message's identifier, the sent message's hash, signed by Entroncamento's Dry Port, is decrypted using its public key and then compared with the hash of the received message. If those are equal, then the reliability of the message has been proven, guaranteeing it is genuine.

6.2.7.3 License Plate Recognition

Entroncamento's Dry Port operators used to manually control trucks, requiring drivers to provide the necessary information upon arrival. Those steps might inevitably result in increased congestion and higher waiting times. Significant changes were implemented to mitigate those consequences, from a remote check-in application for truck drivers to adding a portico equipped with OCR and LPR cameras to serve both trucks and trains.

The existing LPR and OCR cameras are capable of recognizing license plates and capturing containers' images from various angles. However, the high costs linked to the software licensing and installation of those cameras justified the development of a solution that captures and delivers the necessary information to MedTOS. The solution to be implemented will consider live captured videos of both trucks' and trains' arrival at Entroncamento's Dry Port and generate a JSON file with the identified license plate information to be used by MedTOS for its operations.

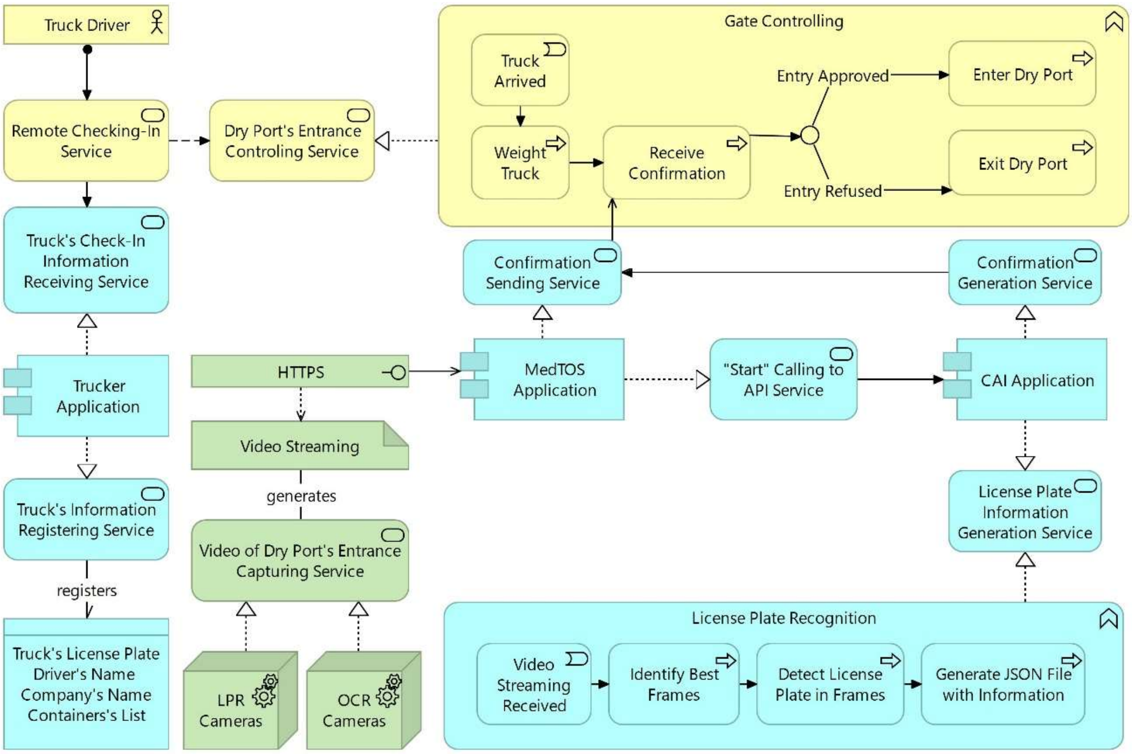

Figure 20. Entroncamento's Dry Port License Plate Recognition (Truck's View)

According to a previously established ring-fence value in the Trucker Application, when any truck is within that distance remote check-in is allowed and the driver can register information such as the truck's license plate, its name, the name of the company carrying the cargo, and the list of containers. That information is registered in MedTOS and utilized upon arrival. When the truck arrives at Entroncamento's Dry Port, it is weighted and goes through the new lane with two LPR cameras that capture the front and back license plates of the truck and three OCR cameras responsible for capturing the video of the various container sides. MedTOS triggers the CAI Application and shares the live recorded video streams. Those streams are used to identify the region of interest of the container plates, and the best frames are selected for further analysis.

A previously trained model is used to extract relevant data from the streams (e.g., the container license plate). It generates a JSON file with that information, following a structure easy for MedTOS to read. MedTOS compares that information with the one provided by the driver at check-in and confirms if the truck is allowed to enter Entroncamento's Dry Port, as shown in Figure 20. The process is similar to the one done upon train arrival (remote check-in is not applicable in that case).

6.2.8 Information Structure and Access View

Several digital solutions are transforming Entroncamento's Dry Port. However, to answer the stakeholders' needs, the information shown by the Digital Twin has to be selected based on its relevance to controlling variations over time. This includes load orders, the reach stackers' location, or the number of trucks refused entry at the Dry Port.

In Figure 21, the data is split into four groups. "Data from JUL" describes the data exchanged through JUL, including the loading orders, containers' announcements, and containers' release orders. "Data from IoT Devices" depicts all the information provided by the devices composing Entroncamento's Dry Port infrastructure. "Data from MedTOS" includes all the information used to ensure this infrastructure's operations. Finally, "Data for Digital Twin" describes information whose variation over time is analyzed and presented to specific actors by Entroncamento's Dry Port Digital Twin.

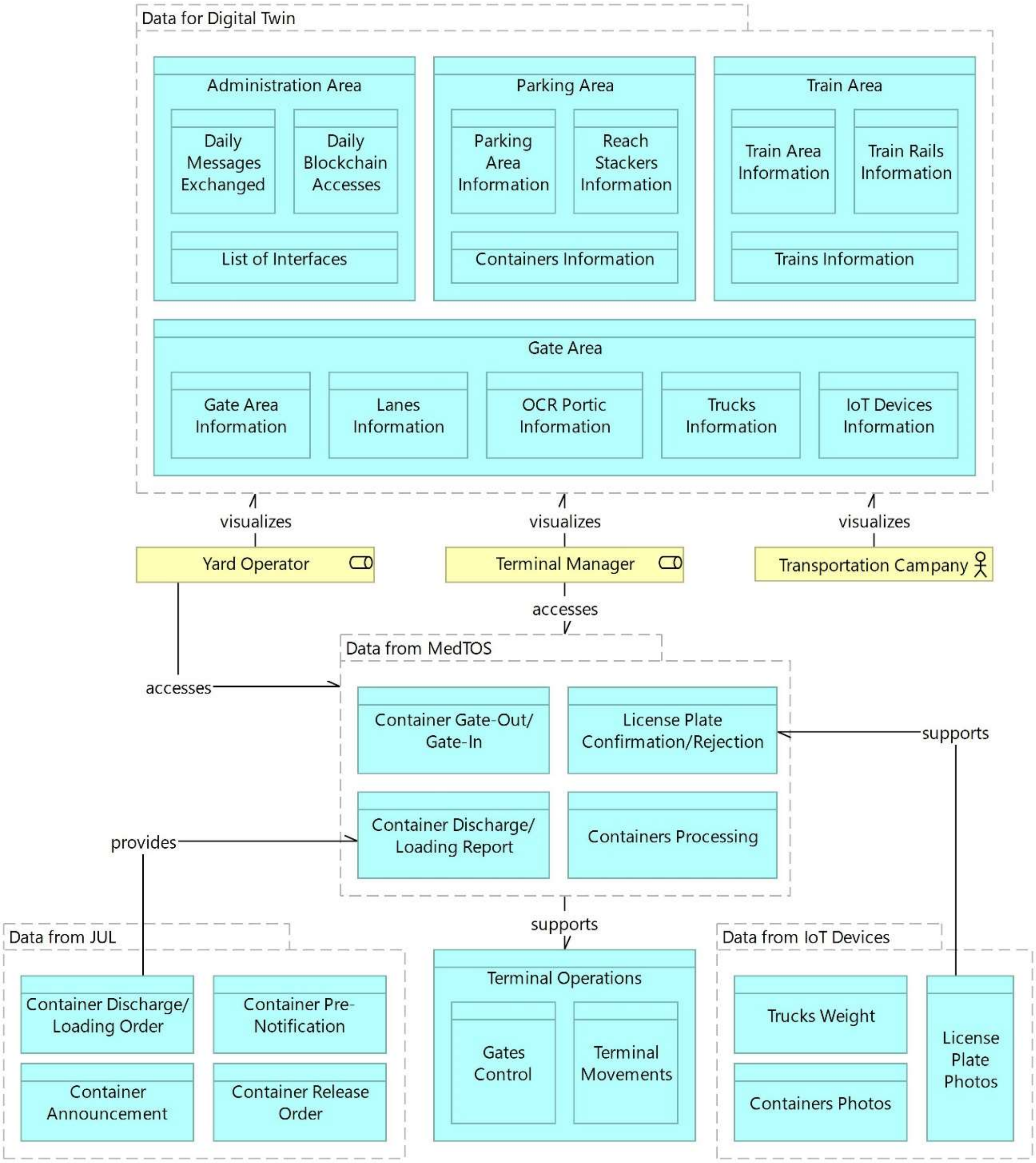

Figure 21. Entroncamento's Dry Port Information Structure and Access View

The license plate photographs support gate control by ensuring that only authorized trucks can enter. Orders to load/discharge containers exchanged through JUL are reported, and they influence containers' handling by MedTOS. The information that composes MedTOS is responsible for supporting terminal operations, including gate control and movement optimization. Alongside the information, it is fundamental to identify the actors and how each one interacts with the data. Yard Operators and Terminal Managers can visualize information from MedTOS, while Transportation Companies only access data presented by the Digital Twin.

Throughout this section, each view selected as crucial to describe the overall components of the architecture was modeled. It started with a High-Level View of the Dry Port, offering a general perspective on the new technological components and their relation to existing infrastructure features. This was followed by a sequence of views, each focusing on different layers. Because requirements are fundamental to guarantee that all stakeholders' needs are met, Goal Realization and Requirements Realization views are provided where prerequisites are related to the new application and business services. Next, the Application Usage Views are shown, describing three major business processes that are realized by Entroncamento's Dry Port. This includes import and export processes and reach stackers management. The Technology View illustrates the relationship between technological and application elements. The Technology Usage Views depict the relation between Blockchain and the exchange of messages through JUL and the License Plate Recognition process. Finally, the Information Structure and Access View relates crucial information to the relevant applications and actors.

All the views together provide a detailed description of Entroncamento's Dry Port. Given that this area of research is still under-explored, even though these infrastructures have been recognized as relevant within the logistics chain, the next section presents a list of Design principles related to modeling an ArchiMate architecture for any Dry Port Digital Twin.

6.3 Design Principles

The methodology adopted is DSR, whose main goal is to create knowledge by designing artifacts in real-world settings. In the case of this research, one of the challenges identified was the lack of existing architectures of Dry Port's Digital Twins, which justified the need to provide guidelines to adequately model the corresponding architecture. A Dry Port's Digital Twin architecture ensures alignment between digital transformations and the business services provided [53] [54]. Design principles are rules to consider when modeling an architecture, ensuring alignment and interoperability between levels, ranging from business to technological solutions [53], and serving as recommendations to model any Dry Port's Digital Twin architecture, adopting ArchiMate. The following Design principles emerged from the research conducted in the scope of the NEXUS Agenda:

- Design Principle 1 (DP1) – *Identify, analyze, and align Stakeholders' needs with the Digital Twin capabilities*. The Dry Port's Digital Twin architecture is meant to be accessed by various stakeholders with differing needs and priorities. To meet their expectations accurately, it is essential to identify their goals. Based on the knowledge regarding the operations and actors involved in the Dry Port, it is possible to align the Digital Twin capabilities with the existing data and applications. An example of this is the identification of "Optimize the Dry Port's Reach Stacker's movements" as a goal of Entroncamento's Dry Port, which then leads to multiple assessments and the identification of a potential solution (the definition of an Artificial Intelligence algorithm to optimize the Reach Stackers' movements when handling containers, and the capture of updated data regarding the vehicle's state and number of assignments, allowing their maintenance and replacement). The approach taken when modeling a Dry Port's Digital Twin must be user-centered, focusing on answering each of the interested parties' needs.

- DP2 – *Identify the needed layers, their elements, and interactions, focusing on their dynamic alignment*. The High-Level View of any Dry Port's Digital Twin considers the alignment between business and technological elements, recognizing that this alignment can change over time. Information is fundamental for an adequate Digital Twin, as it is utilized to detect patterns, predict behaviors, and justify decision-making. Based on a framework [19], adopted within multiple smart contexts [55] [53], seven layers allow an adaptable and adequate description of a Dry Port Digital Twin, leading to a clear connection between its main elements: the services provided to various actors, the applications used within the landscape of this infrastructure, the IoT devices considered, and the information produced. Each layer can be extended with new elements or have existing ones removed, as all are organized following a hierarchical order (services have functions, which are described by processes, for instance).
- DP3 – *Ensure the information flows between elements and layers*. Information is crucial for Digital Twins, as it helps to identify the indicators to consider. Therefore, all elements and layers must be interconnected: ArchiMate provides various types of relationships between elements, and interfaces can ensure the connections between layers.
- DP4 – *Describe the information structure and access*. Digital Twins consider multiple sources of information to detect patterns and justify decisions. Because of that, it is critical to ensure that the information produced and utilized by the Dry Port's operations is reliable and immutable, which can be guaranteed through multiple technologies (e.g. storage of damaged containers' pictures and messages exchanged between Ports, through JUL, in the Blockchain). To identify critical data and the information that needs to be monitored for variation, the "Information Structure and Access" view should be modeled in the Digital Twin. This view connects all information to the corresponding applications and to the actors who have access to specific application capabilities.

This chapter began by exploring fundamental views describing Entroncamento's Dry Port, modeled using the ArchiMate modeling language. Afterward, a list of Design principles was recommended to guide the modeling of any Dry Port's Digital Twin, contributing to the lack of guidelines in the literature related to this topic. In the next chapter, the implementation of Entroncamento's Dry Port Digital Twin is described, starting with the identification of areas and information whose variation is deemed crucial to control over time, followed by various images of the scenario modeled, with elements changing colors and presenting warnings, based on the variation of data.

Chapter 7
Prototype Implementation and Demonstration

Azure Digital Twins was the platform selected to create Entroncamento's Dry Port Digital Twin prototype, based on its capabilities, and extensive documentation, in comparison with other Digital Twin implementation platforms, discussed in Chapter 4. One of the crucial advantages of Digital Twins is the increased awareness provided to organizations, presenting data's variation in real-time, performance indicators, and user guidance/warnings. Therefore, the data presented must be chosen wisely, according to the needs of stakeholders, which explains the study of Entroncamento's Dry Port.

To define the prototype's requirements, some of Dry Ports' challenges (described in Chapter 3), insights provided during an in-person visit to Entroncamento's Dry Port, information gathered during meetings with the remaining members of the WP3, and the architecture modeled, were the sources considered. Each project meeting allowed the comprehension of each application's capabilities and the level of awareness provided. Complementarily, the viewing of Entroncamento's Dry Port tasks in person revealed specific limitations and how sparse and difficult it is to have a visual overview, in real-time, of its operations. The architecture model provided a more detailed description of Entroncamento's Dry Port processes, data, and IoT devices, easing the organization of the 3D scenario, representing this infrastructure.

This chapter documents the implementation and demonstration of the prototype, starting with the description of the functional requirements in Section 7.1 and followed by the identification of the elements that compose the prototype in Section 7.2. In Section 7.3, each of the implementation steps is described, finishing with the demonstration of the prototype in Section 7.4.

7.1 Prototype Requirements

Implementing Entroncamento's Dry Port Digital Twin prototype aims to enhance the NEXUS Agenda partners' knowledge about the advantages and capabilities (e.g., increased awareness and optimization of operations) when adopting this technology.

Requirements are crucial in software development, supporting the communication between the end-user and the people responsible for the implementation of the solution, as well as easing the final product's quality and response to the needs and expectations of stakeholders [56]. Requirements can be of four types: business, user, system, and process, while system requirements can be further split into two categories, which are functional and nonfunctional [56]. Functional requirements describe the functionalities of the software being implemented, while nonfunctional requirements represent the solution's quality attributes, like performance, reliability, efficiency, or availability [56].

Regarding Entroncamento's Dry Port Digital Twin prototype, the requirements are mainly functional since the proposed solution is not meant to be implemented within the application's landscape of this infrastructure but rather to explore possible advantages of adopting a Digital Twin in Dry Ports. The stakeholders identified as future users of the Digital Twin include the terminal manager, who controls the state of the terminal operations, and yard operators, who visualize the real-time location of reach stackers, trains, and containers. Additionally, the authorized entities, which can be any of the external stakeholders with access permissions (e.g., National Government, Logistics Companies, and Fordesi), to visualize, in real-time, each of the elements that compose Entroncamento's Dry Port.

Table 9 to Table 15 identify the User Stories describing the prototype's requirements. The corresponding actor is identified for each requirement, followed by the priority, user story, and acceptance criteria. The latter is crucial for the evaluation phase of this work.

Table 9. User Story 1 - Information in the Blockchain

<table>
<tr><td>US1</td><td>Requirement
Allow the configuration to visualize information stored in the Blockchain</td><td>Actor
Authorized Entity</td><td>Priority
Must Have</td></tr>
<tr><td colspan="4">User Story
As an Authorized Entity,
I want to be able to configure the visualization of information about the Dry Port's operations stored in the Blockchain,
So that I can verify the information's accuracy and immutability.</td></tr>
<tr><td colspan="4">Acceptance Criteria
Given that the Azure Digital Twin platform allows the addition of links,
When adding a widget "Link",
Then it is possible to be redirected to any external website, which can be configured to show information stored in the Blockchain.</td></tr>
</table>

Table 10. User Story 2 - Messages Exchanged Through JUL

<table>
<tr><td>US2</td><td>Requirement
Allow the configuration to visualize messages exchanged through JUL</td><td>Actor
Authorized Entity</td><td>Priority
Must Have</td></tr>
</table>

User Story As an Authorized Entity, I want to be able to configure the visualization of messages exchanged between Entroncamento's Dry Port and other Ports, through JUL, So that I can increase my awareness regarding the data exchanged, and its reliability.
Acceptance Criteria Given that the Azure Digital Twin platform allows the addition of links, When adding a widget "Link", Then it is possible to be redirected to any external website, which can be configured to show messages exchanged through JUL.

Table 11. User Story 3 - Scenario's Visualisation

<table>
<tr><td>US3</td><td>Requirement
Visualize Entroncamento's Dry Port elements, in real-time</td><td>Actors
Yard Operator, Terminal Manager, and Authorized Entity</td><td>Priority
Must Have</td></tr>
<tr><td colspan="4">User Story
As a Yard Operator, Terminal Manager, or Authorized Entity,
I want to be able to access a top view of the entire Entroncamento's Dry Port, modeled in Three Dimensions (3D),
So that I can view all of the areas and the infrastructure's elements (reach stackers, containers) movements.</td></tr>
<tr><td colspan="4">Acceptance Criteria
Given that the Azure Digital Twin platform has the 3D Scenes Studio,
When adding a 3D scenario,
Then it is possible to visualize and interact with all of its elements, in real-time.</td></tr>
</table>

Table 12. User Story 4 - Operations' Visualisation

<table>
<tr><td>US4</td><td>Requirement
Visualize Entroncamento's Dry Port operations' indicators, in real-time</td><td>Actors
Yard Operator, Terminal Manager, and Authorized Entity</td><td>Priority
Must Have</td></tr>
<tr><td colspan="4">User Story
As a Yard Operator, Terminal Manager, or Authorized Entity,
I want to be able to visualize all of the properties of each element within the scenario,
So that I can increase my awareness regarding the operations' state.</td></tr>
<tr><td colspan="4">Acceptance Criteria
Given that the Azure Digital Twin platform has the 3D Scenes Studio,
When visualizing a 3D scenario,
Then it is possible to interact with all of its elements and see their property values, being updated in real-time.</td></tr>
</table>

Table 13. User Story 5 - Color's Variation Visualisation

<table>
<tr><td>US5</td><td>Requirement
Visualize the color variation of Entroncamento’s Dry Port’s elements, in real-time</td><td>Actors
Yard Operator, and Terminal Manager</td><td>Priority
Must Have</td></tr>
<tr><td colspan="4">User Story
As a Yard Operator or Terminal Manager,
I want to be able to visualize the color variation of elements within the scenario,
So that I can note the state’s update of certain elements, in real-time (e.g., a reach stacker in the color red means it is assigned to an operation, and the OCR Portico in the color green means it is working accordingly).</td></tr>
<tr><td colspan="4">Acceptance Criteria
Given that the Azure Digital Twin platform has the 3D Scenes Studio,
When configuring rules for each of the object’s properties,
Then it is possible to associate different colors of the elements to their properties values.</td></tr>
</table>

Table 14. User Story 6 - Movements' Visualisation

<table>
<tr><td>US6</td><td>Requirement
View the movements within Entroncamento’s Dry Port</td><td>Actors
Yard Operator, and Terminal Manager</td><td>Priority
Could Have</td></tr>
<tr><td colspan="4">User Story
As a Yard Operator or Terminal Manager,
I want to be able to visualize the path of each reach stacker through a colorful arrow in the scenario.
So that I can be aware of the location of each reach stacker in real-time, and contribute to the avoidance of accidents.</td></tr>
<tr><td colspan="4">Acceptance Criteria
Given that the Azure Digital Twin platform has the 3D Scenes Studio,
When creating the scenario’s animation,
Then it is possible to associate a path to the moving reach stackers, based on the best sequence of movements to handle the containers.</td></tr>
</table>

Table 15. User Story 7 - Warnings' Visualisation

<table>
<tr><td>US7</td><td>Requirement
Visualize warnings</td><td>Actor
Yard Operator, and Terminal Manager</td><td>Priority
Must Have</td></tr>
<tr><td colspan="4">User Story
As a Yard Operator or Terminal Manager,
I want to be able to visualize warnings in Entroncamento’s Dry Port elements,
So that I can be aware of existing problems and try to solve them quickly.</td></tr>
</table>

Acceptance Criteria Given that the Azure Digital Twin platform allows the addition of badges, When establishing rules based on the properties values, Then it is possible to notice possible dangerous or critical data regarding certain objects within the scenario.

Considering these requirements, the remaining sections of this chapter detail the implementation of Entroncamento's Dry Port Digital Twin prototype.

7.2 Entroncamento's Dry Port Digital Twin Models

The Azure Digital Twins platform enables the creation of models that define the data structure of particular concepts within the work environment being created. Each model has a name and includes other properties, components, and relationships that describe its capabilities. Models are created using the Digital Twins Definition Language (DTDL), JSON-based. They can be utilized by other Azure applications and contain various descriptive fields, including an identifier, type, context, display name, properties, relationships, and components.

Entroncamento's Dry Port was divided into four areas, each corresponding to a specific model: the Administration Area, Parking Area, Train Area, and Entry Area. Each has properties and relationships with other models, as shown in Table 16, Table 17, Table 18, and Table 19. Their identification was based on information gathered throughout the project with various entities.

One of the models, "TrainArea", represents the location of trains within the Dry Port. It includes information about the number of train rails, daily loaded and unloaded trains, and real-time train operations. Figure 22 shows an extract of the JSON file for this model, with its properties and relationships. The model includes two relationships: "dryport_has_trainarea" and "dryporttrainarea_has_trainrail", with the latter describing that a train area can have various train rails. This model has four properties. The two shown are the number of train rails at the Dry Port and the number of trains currently loading/unloading, both integers. The other two properties are the daily number of loaded and the daily number of unloaded trains.

```
{
  "@id": "dtmi:example:TrainArea;1",
  "@type": "Interface",
  "displayName": "TrainArea",
  "contents": [
    {
      "@type": "Relationship",
      "name": "dryport_has_trainarea",
      "displayName": "dryport_has_trainarea"
    },
    {
      "@type": "Relationship",
      "@id": "dtmi:example:TrainArea:dryporttrainarea_has_trainrail;1",
      "name": "dryporttrainarea_has_trainrail",
      "displayName": "dryporttrainarea_has_trainrail",
      "target": "dtmi:example:TrainRail;1"
    },
    {
      "@type": "Property",
      "name": "NumTrainRails",
      "schema": "integer"
    },
    {
      "@type": "Property",
      "name": "CurrentlyUnloadingLoadingTrains",
      "schema": "integer"
    },
```

Figure 22. "TrainArea" Model for Entroncamento's Dry Port Digital Twin Prototype

Each of the models was identified based on information gathered from meetings with partners, a visit to Entroncamento's Dry Port, and the architecture design stage.

Table 16. Administration Area Model - Entroncamento's Dry Port Digital Twin Prototype

Administration Area		
Description	Based on the business function named "Dry Port Operations Control" in the High-Level view of the architecture, it considers various information regarding some of the operations.	
Properties	Interface List, Daily Messages Exchanged, Daily Messages Error, Daily Photos in Blockchain, and Daily Messages in Blockchain Error.	
Relationship	Dry Port	
	Description	Identifies the Dry Port's features.
	Properties	Location, Number of Gates, Date, Number of Parking Areas, and Number of Train Rails.

Table 17. Parking Area Model - Entroncamento's Dry Port Digital Twin Prototype

Parking Area	
Description	Based on the business function "Reach Stackers Control" in the High-Level view of the architecture, it considers information regarding both the containers and the reach stackers.
Properties	Parking Area Name, Parent Parking Area Name, Number of Containers, Area Maximum Capacity, Maximum Stack Height, Occupation

Relationships	Container	
	Description	Identifies the container's features.
	Properties	Plate ISSO, Client Acronym, Full/Empty, Danger, State, Reefer Use, Waiting Time, Customs Regime, Location, Authorization, Gross Weight, Transportation's Type, and Transportation's Identifier.
	Reach Stacker	
	Description	Identifies the Reach Stacker's features.
	Properties	Code, Name, Yard Operator's Name, State, Location.

Table 18. Train Area Model - Entroncamento's Dry Port Digital Twin Prototype

Train Area		
Description	Based on the business function "Reach Stackers Control" in the High-Level view of the architecture, it considers information regarding trains, train rails, and reach stackers.	
Properties	Number of Train Rails, Currently Loading/Unloading Trains, Daily Loaded Trains, and Daily Unloaded Trains.	
Relationships	Reach Stacker	
	Train Rail	
	Description	Identifies the Train Rail's features.
	Properties	Rail Number, Rail Length, State, Train Number.
	Train	
	Description	Identifies the Train's features.
	Properties	Number, Service, Information, Time, Operator's Name, Wagon's Number, State, Containers List, TEUS (general unit of cargo capacity), Total Length, Weight.

Table 19. Entry Area Model - Entroncamento's Dry Port Digital Twin Prototype

Entry Area	
Description	Based on the business function "Gates Control" in the High-Level view of the architecture, it considers information about the gates, trucks, and the OCR Porticos.
Properties	Number of Accepted Trucks, and Number of Refused Trucks.
Relationships	Gate

	Description	Identifies the Gate’s features.
	Properties	Name, and Location.
	Lane	
	Description	Identifies the Lane’s features.
	Properties	Name, Type, Has a Weight Bridge, Order, and State.
	OCR Portico	
	Description	Identifies the OCR Portico’s features.
	Properties	Name, Daily Number of Trucks, Status, State, Daily Number of Containers, Daily Number of Trucks not Identified, and Daily Number of Containers not Identified.
	Truck	
	Description	Identifies the Truck’s features.
	Properties	License Plate, Driver’s Name, Carrier’s Name, State, Service, Containers’ List, Arrival.
	IoT Device	
	Description	Identifies the IoT Device’s features.
	Properties	Code, Type, IP Address, Status, State.

Each table describes the area, its properties, and its relationships with other models. For example, the Entry Area has relationships with the Gate, Lane, OCR Portico, Truck, and IoT Device models. In contrast, the Parking Area has relationships with the container and reach stackers models. Figure 23 identifies each area on a top-view picture of Entroncamento’s Dry Port.

Figure 23. Entroncamento's Dry Port Areas

In the Azure Digital Twins platform, a Digital Twin is the instance of a model that can be linked with other models through relationships, forming a Twin Graph representative of the entire environment. This set of nodes and their connections can be seen using Azure Digital Twins Explorer, a tool for visualizing and interacting with the models. It is easy to update over time, allowing the removal/addition of models and relationship updates.

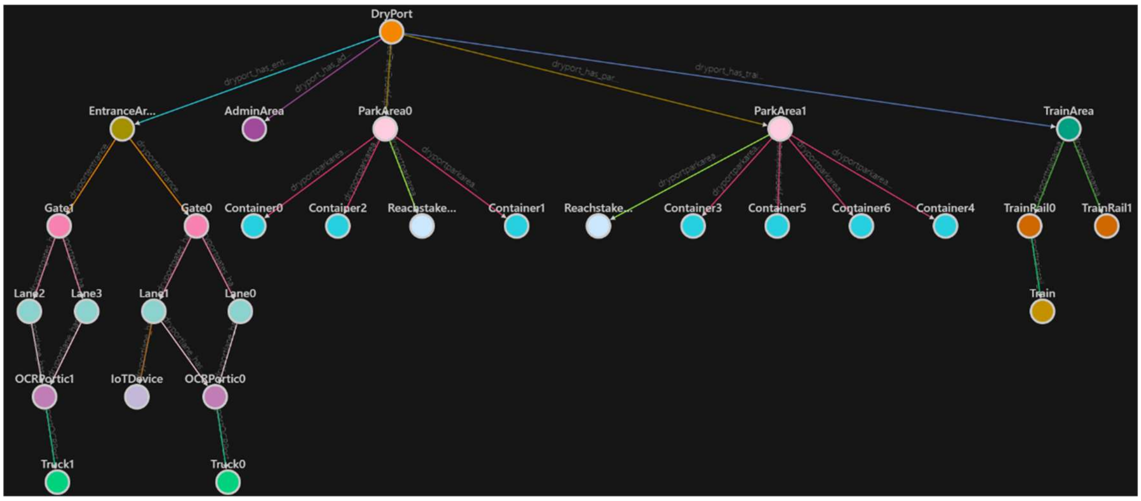

Figure 24. Entroncamento's Dry Port Digital Twin Prototype Twin Graph

Figure 24 presents the Twin Graph of Entroncamento's Dry Port Digital Twin, relating the models presented in Tables 16-19. From the root, the Dry Port's model splits into five models: the Administration Area, two models of Parking Areas, the Train Area, and the Entry Area. Each of the Parking Areas leads to Reach Stacker models and various Container models, while the Train Area includes two Train models. The Entrance Area leads to two Gate models, each with Lane models, and subsequently, OCR Portico models with Truck models. This hierarchical representation explains the relationships between models and the overall structure of Entroncamento's Dry Port.

7.3 Entroncamento's Dry Port Digital Twin Implementation

The implementation started with the configuration of Azure resources, followed by the scenario's modeling using Blender to represent the Dry Port's elements visually. Sample information was generated to assess the variation of the visual rules established.

7.3.1 Azure Digital Twins Configuration

The Microsoft Azure Digital Twins platform utilizes multiple resources to implement Digital Twins, including Storage, an Event Hub, and an Azure Data Explorer Cluster. The Storage Container is used to configure 3D Scenes Studio, allowing the visualization of a scenario representing the Digital Twin and its elements' color variation based on established property values and rules.

The Event Hub is a cloud data streaming service that can stream multiple events per second from any source to any destination. Data is crucial for Digital Twins, driving real-time analytics and responding to events as they occur. The information can originate from multiple sources, from files to IoT devices, and then be considered by multiple analysis services, from insights generation with Azure Stream Analytics to exploring streaming data utilizing Azure Data Explorer. The advantages of this resource include flexibility, scalability, and the capacity to manage larger flows of streaming data. As previously mentioned, the information considered for this prototype is synthetic and generated by code. Only in the later stages of the NEXUS Agenda is it planned to capture data from APIs, particularly those used by Entroncamento's Dry Port.

Azure Data Explorer is a big data analytics platform capable of facilitating the analysis of high volumes of data in near real-time. Using a traditional relational model, it organizes data into tables, which can then be used to generate key insights, identify patterns and trends, and create forecasting models. This solution is scalable and secure. It is used in this prototype to store variables' values over time and show them in graphs to monitor their evolution.

7.3.2 Sample Data Generation

Entroncamento's Dry Port Digital Twin prototype aims to provide preliminary insights into the advantages of digital twins, increasing this infrastructure's operations awareness through warnings and easier access to certain information.

Using the C++ programming language, a script was developed to generate new data for each model's properties. The first lines of code include a link to the Azure Digital Twin's instance being considered, followed by a while loop, where multiple functions are called, each responsible for generating data for a specific model's properties. Two examples are provided. For instance, as shown in Figure 25, the model "Gate" is updated by calling the function *GateUpdate*. This function starts by confirming that the Twin Graph's instance calls either Gate0 or Gate1 and creates an Azure.JsonPatchDocument object to add the updated information, including the gate's name and its location.

```
private static async Task GateUpdate(DigitalTwinsClient client, int s)
{
    BasicDigitalTwin digitalTwin = await client.GetDigitalTwinAsync<BasicDigitalTwin>($"Gate{s}");
    var jsonPatch = new Azure.JsonPatchDocument();

    jsonPatch.AppendReplace("/GatesName", global.GatesName[s]);
    jsonPatch.AppendReplace("/GatesLocation", global.GatesLocation[s]);

    await client.UpdateDigitalTwinAsync($"Gate{s}", jsonPatch);
    Console.WriteLine($"Gate{s} Information Updated!");
}
```

Figure 25. *GateUpdate* Function to Update Gate's Model Information

Figure 26 shows the function *VehicleUpdate* which updates the "ReachStackers" model's properties.

```
private static async Task VehicleUpdate(DigitalTwinsClient client, int a)
{
    BasicDigitalTwin digitalTwin = await client.GetDigitalTwinAsync<BasicDigitalTwin>($"Reachstaker{a}");
    var jsonPatch = new Azure.JsonPatchDocument();

    Random random = new Random();
    var randomNumberState = random.Next(0, 2);
    string[] randomReachstakersCode = { "AD12EF", "QW45RT" };
    string[] randomReachstakerName = { "John", "Mark" };
    string[] randomReachstakerLocation = { "37.533569-127.014111", "37.521374-126.960551" };

    jsonPatch.AppendReplace("/ReachstakersCode", randomReachstakersCode[a]);
    jsonPatch.AppendReplace("/ReachstakersName", $"Reachstaker{a}");
    jsonPatch.AppendReplace("/YardOperatorsName", randomReachstakerName[a]);
    jsonPatch.AppendReplace("/ReachstakersState", randomNumberState);
    jsonPatch.AppendReplace("/ReachstakersLocation", randomReachstakerLocation[a]);

    await client.UpdateDigitalTwinAsync($"Reachstaker{a}", jsonPatch);
    Console.WriteLine($"Reachstaker{a} Information Updated!");
}
```

Figure 26. *VehicleUpdate* Function to Update Reach Stacker's Model Information

After guaranteeing that the information was being updated in the correct models represented in the Twin Graph (Figure 24), the next step was to link each of the models' properties variation to visual rules, a feature of Azure 3D Scenes Studio described in the next section.

7.3.3 Visual Rules Definition

Azure 3D Scenes Studio enables the association between Digital Twin's models and their corresponding 3D objects on a modeled scenario. For Entroncamento's Dry Port Digital Twin prototype, a representation with all identified areas and animated elements was modeled with Blender. Visual rules were defined after linking each of the created models with their fitting objects in the scenario. Visual rules represent perceived changes in the elements that compose the modeled scenario, including color variation and badges, based on the result of customized rules regarding each property.

To define each rule (presented in Table 20), properties whose value variation was deemed relevant to monitor were selected and split by areas (Parking Area (P), Train Area (T), and Entry Area (E)). The only area not considered was the Administration Area, as its elements in the scenario do not have dynamic properties variation, thus no visual rules.

Table 20. Visual Indicators - Entroncamento's Dry Port Digital Twin Prototype

Area	Model	Properties	Rule	Indicator
P	Parking Area	Occupation	70 < Occupation < 100	Warning Badge (High Occupation)
		Number of Containers and Area Maximum Capacity	NumberOfContainers – AreaMaxCapacity < 0	Colors
	Container	Reefer Use	Reefer Use > 1	Notification Badge (Using Power)

Area	Model	Properties	Rule	Indicator
		Danger	Danger > 1	Notification Badge (Dangerous Goods)
		State	0 < State < 5	Colors
	Reach Stacker	State	0 < State < 2	Colors
T	Train Area	Currently Unloading/Loading Trains	0 < CurrentlyUnloading LoadingTrains < 2	Colors
	Train Rail	State	0 < State < 3	Colors
		Train Number	TrainNumber > 0	Notification Badge (Arriving Train)
	Train	State	0 < State < 3	Colors
E	Lane	State	0 < State < 2	Colors
	OCR Portico	Status	0 < Status < 2	Colors
		State	State > 1	Warning Badge (OCR Portico Error)
	Truck	Service	0 < Service < 3	Colors
	IoT Device	Status	0 < Status < 2	Colors
		State	State > 1	Warning Badge (IoT Fault)

The rules consider the sample data sent to each model's properties and either show the corresponding badges over the elements or change their colors. For instance, if the OCR Portico property named "State" has the value 1, a warning badge appears over the corresponding object in the scenario, while no visual elements appear when the value of "State" is 0. The next section of this chapter demonstrates the prototype of Entroncamento's Dry Port, focusing on its main capabilities.

7.4 Entroncamento's Dry Port Digital Twin Demonstration

The Azure Digital Twins platform allows for the definition of scene layers, each showing certain elements of the scenario and their corresponding behaviors. This layering approach helps simplify the understanding of the entire environment. In this prototype, four layers were defined, based on the previously described areas: "Parking Areas Information", "Train Area Information", "Entrance Area Information", and "Administration Area". Selecting each area displays the corresponding information, coloring, and badge variations.

Figure 27. Administration Area View from Entroncamento's Dry Port Digital Twin Prototype

Figure 27 depicts the Administration Area. The information regarding the selected building (cube with blue edges) is shown on the right side of the image. The two top links can redirect users to external websites to visualize daily captured photos of containers and truck licenses, and messages stored in the Blockchain. The widgets at the bottom show the number of daily errors related to message exchanges and Blockchain storage. If they point to the green area, the number of errors is adequate according to the threshold. When they point to the red area, the number of mistakes is higher than expected. The components of the Parking Area include reach stackers, containers, and park area markers.

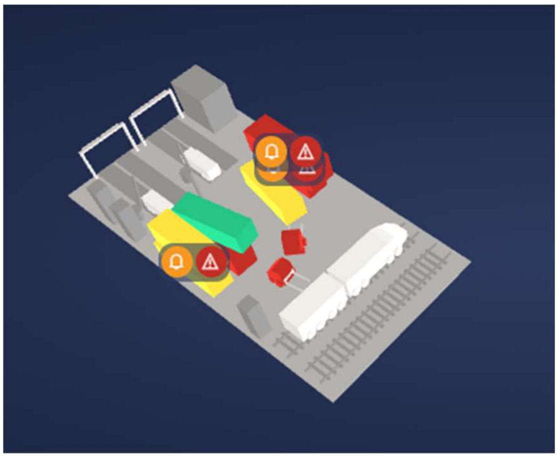

Figure 28. Park Area View from Entroncamento's Dry Port Digital Twin Prototype

Figure 29. Park Area View from Entroncamento's Dry Port Digital Twin Prototype, with Explanation

As shown in Figure 28, containers are color-coded, and warnings related to their state and the type of goods they carry are displayed. In Figure 29, hovering over the symbols shows a message explaining their meaning: the orange symbol with a bell represents the containers that need to be connected to power, while the red warning symbol identifies containers carrying dangerous goods. Containers can be one of five colors: yellow when checking in, orange when unloading, red when blocked, green when parked, and blue when loading. Another important indicator of containers is their waiting time, as the Dry Port charges container operators based on the time and space used at the terminal.

Reach stackers handle Entroncamento’s Dry Port containers and can be presented in two colors: green when available or red when assigned to tasks. In Figure 30 and Figure 31, a graph shows the variation of each of the reach stackers’ states over time, which could help identify, for instance, which vehicles are used more frequently. That information could be crucial for the prediction of maintenance needs and the optimization of vehicle allocation.

Figure 30. Reach Stacker View from Entroncamento's Dry Port Digital Twin Prototype

Figure 31. Reach Stacker View from Entroncamento's Dry Port Digital Twin Prototype, with Timestamps

In the Train Area, each train rail can have one out of three states, each represented by a different color: green for “in use”, orange for “active”, and red for “inactive”, plus a warning (the orange bell symbol, in Figure 33), announcing trains about to arrive. The colored vertical cube includes all the general data about this area, from the number of existing train rails to the announcement of a train loading (in red) or unloading (in green). Trains in the scenario can have different colors, depending on their state: green when announced, yellow when loading, or red when unloading.

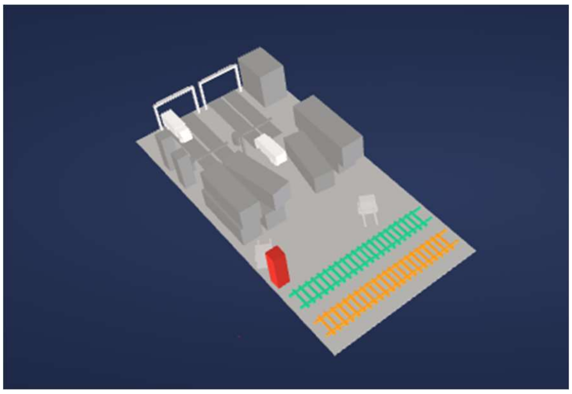

Figure 32. Train Area View from Entroncamento's Dry Port Digital Twin Prototype

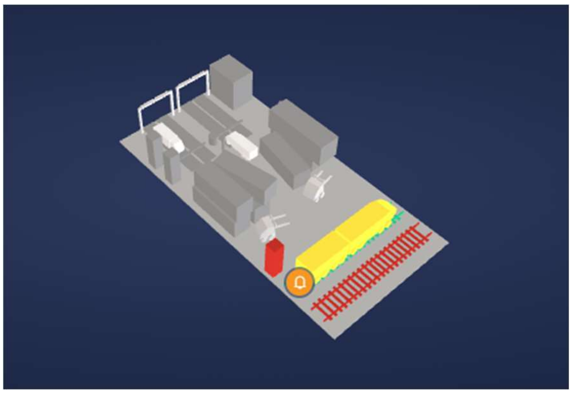

Figure 33. Reach Stacker View from Entroncamento's Dry Port Digital Twin Prototype, with a Warning

The elements of the Entry Area include the OCR porticos, lanes, trucks, and the entry/exit gates. In Figure 34, on the right, two widgets show the number of daily accepted and rejected trucks compared to an established limit, indicating whether these values are concerning. For instance, when the number of rejected trucks is higher than expected, the pointer will move toward the red color, signaling a problem. Possible causes for rejections may include failures in the LPR and OCR cameras. Each truck is color-coded according to its state: red for “loading”, orange for “unloading”, and yellow for “loading and unloading”. The lanes are also color-coded: green when opened, and red when closed.

Figure 34. Entrance Area View from Entroncamento's Dry Port Digital Twin Prototype

In Figure 35, one of the two OCR porticos is selected. These porticos are responsible for the first control of arriving trucks, capturing images of each container’s side and the truck’s license plates. One of the indicators on the right shows the number of faults that occurred during truck identification, and a warning appears if any of the IoT devices in this infrastructure stops working.

Figure 35. Entrance Area View from Entroncamento's Dry Port Digital Twin Prototype (OCR Portico View)

Figure 36 presents the overview of Entroncamento's Dry Port Digital Twin prototype, displaying essential information about the operations and scenario. The left side shows the elements and their corresponding information.

Figure 36. Entroncamento's Dry Port View from Entroncamento's Dry Port Digital Twin Prototype

This chapter described the implementation and demonstration of Entroncamento's Dry Port Digital Twin prototype using the Azure Digital Twins platform. The corresponding Twin Graph was modeled by identifying and creating each necessary model, followed by the implementation steps. Platform resources were configured, a terminal scenario was modeled using Blender, a C++ script was written to generate data, and visual indicators were established. The demonstration explored each area of the prototype, the visual rules of each element, and the linked widgets.

Despite the extensive use of Digital Twins to represent particular objects (e.g., a machine or an airplane engine), the application of Digital Twins to organizations is relatively new, especially in the logistics sector, including Ports and Dry Ports. The Digital Twin prototype presented in this chapter was created in close collaboration with various teams participating in WP3 of the NEXUS Agenda, including Fordesi, which has a commercial interest in improving their offerings to Dry Ports, and DEI/FCTUC researchers working on particular areas and features to be presented in the Digital Twin. The next chapter describes the evaluation steps used to validate Entroncamento's Dry Port Digital Twin architecture and the prototype.

Chapter 8
Evaluation

This chapter discusses the evaluation steps of Entroncamento's Dry Port Digital Twin architecture and prototype. Section 8.1 describes the evaluation approach adopted. Section 8.2 presents the results of the evaluation of the architecture based on the insights provided by the project partners of the NEXUS Agenda. Finally, Section 8.3 analyses the data gathered during Entroncamento's Dry Port Digital Twin prototype evaluation.

8.1 Evaluation Approach

One of the key phases of DSR methodology is artifact evaluation. This involves testing procedures and considering expert feedback to refine the work and provide a solution that addresses the identified problem more effectively. The selected validation and comparison mechanisms must provide accurate and useful insights, especially considering the complexity of projects adopting this method. This complexity can be of multiple forms, from the need to interact with real end-users and stakeholders to adapt to constant changes over time [57], which ultimately affects the effectiveness of the evaluation.

The Framework for Evaluation in Design Science Research (FEDS) is widely adopted in IS research [58], providing guidelines for an evaluation strategy consisting of four essential steps:

- *Explain Evaluation Goals* – describe the identification and characterization of the evaluation objectives, impacting the adopted strategy. In [58], the four objectives proposed are rigor, uncertainty and risk reduction, ethics, and efficiency.
- *Select Evaluation Strategy* – Select the evaluation strategy to adopt based on the needs and resources of the project. Four possible evaluation strategies include "Quick and Simple" (adopted when the artifact is simple, with low social and technical risk uncertainty, establishing one evaluation episode), "Human Risk and Effectiveness" (used when the artifact's main risks are user-oriented, defining evaluation episodes throughout the project, in a real context), "Technical Risk and Efficacy" (adopted when the artifact's risks are technically-oriented, or when the priority is to establish that the improvement was due to the solution proposed, suggesting simulations and laboratory experimentation on the early stages of development, and then evaluation episodes with users), and the "Purely

Technical" (considered when the artifact is not meant to be utilized by users, making the evaluation step irrelevant).

- *Identify Properties to evaluate* – identify the artifact's features, goals, and requirements that are subject to the evaluation.
- *Design Individual Evaluation Episodes* – design the evaluation process, identifying the number of episodes needed, and how each will happen, based on the available time, and resources.

The next sections, from 8.1.1 to 8.1.4, detail how the four FEDS' steps apply to the specific case of Entroncamento's Dry Port Digital Twin. Starting by identifying the evaluation goals, the strategy selected is justified, followed by the description of each property to evaluate, and finishing with the explanation of the evaluation episodes.

8.1.1 Evaluation Goals

When designing the evaluation phase of the DSR methodology, it is crucial to identify its main goals. Depending on the artifact being validated, the evaluation goals should respond to its priorities, which, in the case of this dissertation, ensures rigor and efficiency. Rigor in representing Entroncamento's Dry Port Digital Twin architecture and the prototype proposed, and efficiency in guaranteeing that the evaluation occurs according to resources available.

A rigorous evaluation prioritizes the relationship between the artifact and the context of the problem it addresses, guaranteeing that the proposed solution works in a real-world context. On the other hand, an efficient evaluation prioritizes the resources available for conducting it, including stakeholder availability and the time needed to complete all the tasks. Therefore, to design the evaluation phase of the DSR methodology adopted in this dissertation, it is fundamental to guarantee that it is rigorous (establishing enough steps to ensure the artifact's alignment with the identified problem) and efficient (conducted in the limited period available).

8.1.2 Evaluation Strategy

The strategy adopted to evaluate Entroncamento's Dry Port Digital Twin architecture and prototype was an adapted version of "Human Risk and Effectiveness", often used to guarantee a final evaluation of the artifacts by experts and to establish the benefits of implementing the proposed artifact. This strategy has multiple evaluation episodes, initially focusing on progressively improving the artifact and later analyzing the alignment between the proposed artifact and end-users' expectations. The evaluation trajectory of this strategy implies frequent evaluation episodes, directly dependent on the partners' availability, and contributes to rigorous and summative control of the artifact's evolution.

The main risks of Entroncamento's Dry Port Digital Twin architecture are incomplete or incomprehensible representations, while the prototype's main risks involve the lack of accuracy and incompleteness of the elements and information presented. Therefore, gathering feedback from the project's partners regarding their understanding of the modeled architecture and the completeness of the implemented prototype ensures that the artifacts are progressively aligned with expectations, rather than relying solely on a final evaluation episode.

8.1.3 Properties to Evaluate

With the evaluation goals and strategy selected, it is key to establish which properties will be validated. This involves choosing the artifact's features and requirements that will be subject to evaluation. As the choice of these properties depends on the artifact, its context, and its purpose, different authors have proposed various properties to prioritize [58]. In this dissertation, there are two different artifacts to evaluate. Therefore, different properties were chosen for each case. In the case of the architecture, the approach adopted was based on the ISO standard, proposed in [59], which focuses on the comprehension of models based on characteristics such as their usability, security, and readability. Because the architecture is to be exchanged between stakeholders and facilitate information sharing, the properties selected were:

- Utility – differentiate the architecture from the existing representations of this infrastructure, identifying improvements and advantages of adopting ArchiMate. Identify the crucial views to describe business, application, technological, and strategy elements.
- Readability – evaluate how comprehensible each of the modeled views is, based on how each user understands the processes being represented, their purpose, and the elements being depicted. With information exchange being fundamental, it is essential to guarantee that the architecture promotes a better understanding of this infrastructure's capabilities, limitations, and potential for future improvement.
- Adaptability – assess how easy it is to adapt each view to technological, business, and application changes over time. To model an adequate architecture, it is key to ensure that its existing elements can be replaced, removed, or even attached to other solutions implemented in the future.

For the prototype, three evaluation phases were defined. The first phase focused on confirming if each identified functional requirement was met by the prototype features. The second phase identified the relationships between the prototype's functionalities and the architecture. The third phase assessed properties based on user experience and feedback [58]. The properties selected for evaluation in the third phase were:

- Utility – enhance the potential of the adoption of a Digital Twin in the context of Entroncamento's Dry Port, presenting its capabilities and directly relating them to identified challenges of this infrastructure.

- Usability – assess how easy it is for users to comprehend each of the prototype's features and capabilities. Other than increased awareness and facilitated access to information being updated in real-time, the proposed prototype must be easily manageable and understood.

8.1.4 Individual Evaluation Episodes

Meetings with the WP3's members were held every two weeks. Initially, these meetings were used to gather information for modeling the architecture. Later, they focused on identifying relevant data to present in the prototype and determining how to organize it. The architecture was evaluated by Fordesi on January 23rd and by the NEXUS Agenda Consortium on February 12th. A final evaluation by Fordesi took place on June 20th. The prototype's first evaluation occurred on June 29th with Fordesi, followed by another evaluation episode with the NEXUS Agenda Consortium a week later.

The following sections discuss the evaluation of both the architecture and the prototype. The first section involves a properties evaluation, while the second section covers requirements validation, the architecture's relationships, and the insights provided by the NEXUS Agenda Consortium, Fordesi, other Work Packages from the NEXUS Agenda, and Medway.

8.2 Architecture Evaluation

The architecture describes the elements that compose Entroncamento's Dry Port, including the new technological additions, and facilitates the discussion between actors with different backgrounds, identifying possible opportunities for improvement. Thus, based on the feedback provided:

- Utility – Fordesi and the NEXUS Agenda Consortium recognized that the High-Level View modeling allowed an overall understanding of all new elements within Entroncamento's Dry Port, and how each technological solution relates to the IoT devices and business services. The possibility of modeling different views, and focusing on multiple processes and capabilities, increases the opportunities to use ArchiMate over time.
- Readability – it was assessed that the High-Level View of Entroncamento's Dry Port Digital Twin allowed a more comprehensive understanding of the elements and their relations, easing the analysis from Fordesi and other potential solution providers. To facilitate each of the stakeholders' understanding, the modeling of views tailored to their knowledge was considered (e.g., requirements realization can be understood by multiple stakeholders, from solution providers with more technological knowledge to administrative personnel), with descriptions of each element presented included.

- Adaptability – the flexibility of both ArchiMate as a modeling tool and the architecture of Entroncamento's Dry Port Digital Twin was highlighted. Throughout the project, there were multiple moments where certain technological additions and their relations with existing applications justified changes in the views (e.g., the Blockchain API was initially being developed focusing on messages' exchange, but it was adapted to have a broader context of use and include images of damaged containers and other types of information), which ultimately were guaranteed through focused and easier alterations.

Overall, the insights from both Fordesi and the NEXUS Agenda Consortium were positive, and the architectural artifacts were included in the final project deliverables. The architecture was also shown to the Nexus scientific committee in a plenary meeting in Sines, with positive feedback. Our evaluation confirmed that all the properties to evaluate were integrated and properly connected.

However, some limitations were noted with the modeled architecture. Firstly, the complexity of the High-Level View implies an understanding and knowledge of Entroncamento's Dry Port, or at least a general overview of its operations. Secondly, ArchiMate has limitations regarding modeling technologies and their relationships. For example, it struggles with concepts like Blockchain and Digital Twin. There are opportunities to extend the ArchiMate notation for a domain-specific context of ports (a master thesis was proposed at DEI/FCTUC for 2024/2025 with this aim).

8.3 Prototype Evaluation

Entroncamento's Dry Port Digital Twin prototype was evaluated in three phases: the first involved confirming whether all functional requirements were implemented as features in the prototype, while the second included identifying relations between the prototype and the architecture views modeled initially. The third phase required insights from both Fordesi and the NEXUS Agenda Consortium to evaluate the prototype's usability and utility.

8.3.1 Evaluation Against the Requirements

Table 21 shows the prototype's evaluation against functional requirements. It details each requirement, its priority level, acceptance criteria, and whether it was implemented.

Table 21. Prototype's Evaluation against the Functional Requirements

ID	Requirement	Priority	Acceptance Criteria	Implemented?
R1	Allow the configuration to visualize information stored in the Blockchain.	Must Have	Given that the Azure Digital Twin platform allows the addition of links, When adding a widget	Yes

ID	Requirement	Priority	Acceptance Criteria	Implemented?
			"Link", Then it is possible to be redirected to any external website, which can be configured to show information stored in the Blockchain.	
R2	Allow the configuration to visualize messages exchanged through JUL.	Must Have	Given that the Azure Digital Twin platform allows the addition of links, When adding a widget "Link", Then it is possible to be redirected to any external website, which can be configured to show messages exchanged through JUL.	Yes
R3	Visualize Entroncamento's Dry Port elements, in real-time.	Must Have	Given that the Azure Digital Twin platform has the 3D Scenes Studio, When adding a 3D scenario, Then it is possible to visualize and interact with all of its elements, in real-time.	Yes
R4	Visualize Entroncamento's Dry Port operations indicators, in real-time.	Must Have	Given that the Azure Digital Twin platform has the 3D Scenes Studio, When visualizing a 3D scenario, Then it is possible to interact with all of its elements and see their property values, being updated in real-time.	Yes
R5	Visualize the color variation of Entroncamento's Dry Port's elements, in real-time.	Must Have	Given that the Azure Digital Twin platform has the 3D Scenes Studio, When configuring rules for each of the object's properties, Then, it is possible to associate different colors of the elements with their	Yes

ID	Requirement	Priority	Acceptance Criteria	Implemented?
			properties and values.	
R6	View the movements within Entroncamento's Dry Port.	Could Have	Given that the Azure Digital Twin platform has the 3D Scenes Studio, When creating the scenario's animation, Then it is possible to associate a path to the moving reach stackers, based on the best sequence of movements to handle the containers.	No
R7	Visualize warnings.	Must Have	Given that the Azure Digital Twin platform allows the addition of badges, When establishing rules based on the properties values, Then it is possible to notice dangerous or critical data regarding certain objects within the scenario.	Yes

Analyzing each row in Table 21 shows that all requirements with higher priority were implemented. R1 and R2, related to the visualization of data stored in various contexts, were granted by an Azure Digital Twins feature, which can redirect the user to external websites. R3, R4, R5, and R7, all related to visual capabilities, were granted by the color rules defined based on the model's properties. Only R6 was not implemented, whose intention was to graphically show the path to be taken by each reach stacker due to the Azure Digital Twin platform limitations.

8.3.2 Evaluation Against the Architecture

Entroncamento's Dry Port Digital Twin architecture, meetings with Fordesi, and a visit to this infrastructure involving Medway experts provided crucial guidance for implementing the prototype. These activities were focused on addressing the infrastructure's real needs using both existing and future technological solutions.

The architecture was crucial to identifying, relating, and organizing the business functions and technological capabilities of Entroncamento's Dry Port comprehensively. Figure 37 illustrates the layers of the prototype, while Figure 38 identifies the business functions that are directly related to each layer.

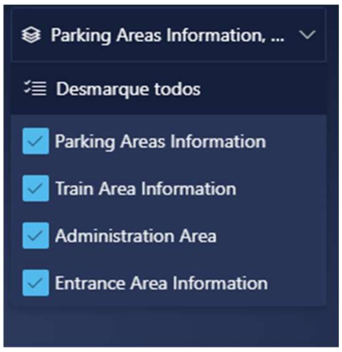

Figure 37. Entroncamento's Dry Port Digital Twin Prototype Layers

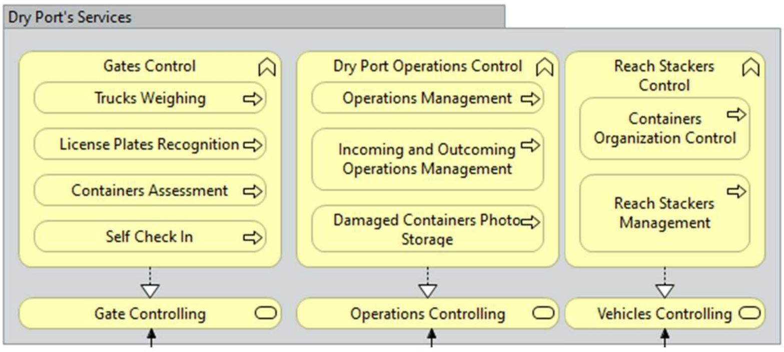

Figure 38. Entroncamento's Dry Port Digital Twin Architecture Business Functions

The areas to split the information on the prototype were identified based on the business functions modeled in the High-Level View of the Dry Port. In the prototype, the "Parking Area Information" and "Train Area Information" layers directly represent the "Reach Stackers Control" business function, which includes the information related to containers' handling and reach stackers' state management. The "Administration Area" layer can be associated with the "Dry Port Operations Control" business function, while the "Entry Area Information" describes the data related to the business processes presented in the "Gate Control".

The architecture also described Entroncamento's Dry Port processes, identifying all the required elements to guarantee each process's functionality. For instance, the view explaining the License Plate Recognition process identifies all of the IoT devices and data, either produced or used, and both the devices and information are critical to consider when implementing the prototype.

Figure 39 depicts the entry area in the scenario with the OCR Portico and the data linked to it, which includes its state (green when working properly and red when failed), the name, the daily number of arriving trucks and containers, and a visual representation of the daily number of faults. Identifying all the needed information was facilitated by the process modeling in the architecture (Figure 20), which recognized the need for controlling the state of each device responsible for capturing video of arriving trucks and considering that information to either allow or deny their entry.

Figure 39. Entroncamento's Dry Port Digital Twin prototype (OCR Portico Focus)

Identifying all data needed for Entroncamento's Dry Port Digital Twin was fundamental to guarantee that the awareness provided contributed to the operations' optimization. For example, the prototype shows a warning sign over IoT devices in the scenario when they fail, reducing the response time to fix it and, subsequently, avoiding congestion at the entrance. Figure 40 shows a section of the "Information Structure and Access View" (fully depicted in Figure 21), while Figure 41 shows the corresponding data within the prototype.

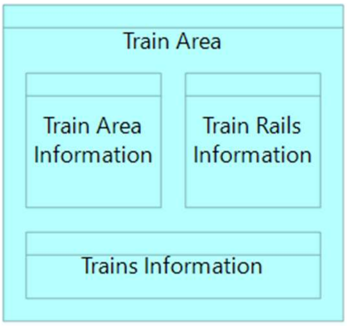

Figure 40. Entroncamento's Dry Port Architecture - Information

Figure 41. Entroncamento's Dry Port Prototype - Information

8.3.3 Evaluation from Fordesi and the NEXUS Agenda Consortium

On June 29th, a final demonstration was held with Fordesi, explaining all the main features of Entroncamento's Dry Port Digital Twin prototype. This meeting provided crucial insights, with Fordesi recognizing the potential improvements that adopting this technology could bring to the infrastructure's operations management.

They found the division into areas appealing and appreciated the ability to select layers within the scenario to focus on specific operational details. The use of colors for the elements in the scenario was also positively received. Following the demonstration, four Fordesi experts answered a questionnaire to evaluate the utility and usability of the proposed prototype.

Table 22 presents the questionnaire questions. The first six questions were rated on a scale of one to five, where one represents complete disagreement, and five denotes total agreement. The last question allowed for open suggestions.

Table 22. Questions to Evaluate Entroncamento's Dry Port Digital Twin Prototype's Properties

ID	Question
Q1	Does the visualization, in 3D, of Entroncamento's Dry Port provide the location and state of each element that composes this infrastructure in real-time?
Q2	The prototype's interface is comprehensible?
Q3	Is the information on each scenario element enough for its accurate description and control?
Q4	Is the color variation of each element within the scenario, according to its state's variation, an adequate way to present changes over time?
Q5	Do the warnings linked to each element within the scenario contribute to awareness and comprehension regarding Entroncamento's Dry Port's state in real-time?
Q6	Are there any features not existing on the prototype but should be added?

- Utility – on a one to five scale, the respondents either agree or completely agree that the 3D visual representation of Entroncamento's Dry Port facilitates the comprehension and identification of each element in this infrastructure, as well as their location, state, and data variation, in real-time. Based on their data's variation, the adoption of different colors for each element's properties was positively received and recognized as better than the "warning" badges. The prototype could be extended to other contexts, a clear example being the focus on work safety, as the infrastructure's overview and its reach stackers' location updated in real-time can reduce the likelihood of accidents.
- Usability – on a scale of one to five, four out of the five respondents agreed that the prototype's usability was easy to comprehend. The interaction with elements and their corresponding information shown by their side, alongside a description of the colors' meanings, was also classified as easy to use.

Even though Fordesi's overall evaluation was positive, the scenario's dimensions on the prototype were considered small and a limitation. This suggests the possibility of configuring the visual representation's scale and dimensions. Another insight was the need for configurable periodicity to access real information in the MedTOS API. One of the possible improvements of the proposed prototype is its configuration to exchange data with the APIs of Entroncamento's Dry Port, and that frequency should be possible to establish. The dissertation conclusion is subsequently presented.

Chapter 9
Conclusion

This chapter starts with Section 9.1, which presents the work conducted during the two semesters. It then moves on to Section 9.2, which discusses the limitations of creating the dissertation's artifacts. Section 9.3 finishes the chapter by presenting future work and opportunities in the field related to Digital Twins in Dry Ports, their architecture, and prototypes.

9.1 Work Summary

This master's dissertation's final artifacts include (1) Entroncamento's Dry Port Digital Twin architecture, modeled with ArchiMate, and critical to describe all technological additions to this infrastructure, facilitating the identification of innovation opportunities and integration of new solutions; (2) Design principles to model the architecture of any Dry Port Digital Twin, using ArchiMate, contributing to reducing the lack of guidelines noted during the research; (3) Entroncamento's Dry Port Digital Twin prototype, implemented with the Azure Digital Twin platform, and enhancing the capabilities and advantages in adopting this technology within the Dry Port.

The work was done over two semesters. During the first semester, the first phase was the research of the Digital Twin, Blockchain, Enterprise Architecture, and Dry Port concepts, and the second phase was the study of their relations, from Digital Twins in Dry Ports to Digital Twin Architecture examples. With insights collected from project partners, several problems were identified with the blueprint of Entroncamento's Dry Port architecture. An improved AS-IS architecture was modeled using ArchiMate. A preliminary identification of the prototype's requirements was also conducted in the first semester, which terminated with the presentation of the Intermediate Report.

During the second semester, the requirements for the prototype were defined, and the Azure Digital Twin platform was used for the implementation. Multiple views of Entroncamento's Dry Port Digital Twin architecture were modeled, design principles to guide the modeling of Dry Port Digital Twin's architecture were proposed, and the prototype was implemented. The evaluation of each artifact was guaranteed by Fordesi, an IT company with a portfolio of technological solutions in various logistics nodes, and by the NEXUS Agenda consortium. This period ended with the writing of the Final Report, delivered on the 8th of July.

Entroncamento’s Dry Port Digital Twin architecture and prototype were part of the deliverables of the NEXUS Agenda, recognized as important for the representation of the Dry Port’s technological and business elements and for the possibilities when adopting a Digital Twin in this infrastructure. The theoretical contribution was in the form of a paper titled “Reference Architecture for Dry Port Digital Twin: Preliminary Assessment”, presented by the dissertation author at the 18th International Conference on Research Challenges in Information Science (RCIS 2024), proposing the TO-BE architecture of a Dry Port Digital Twin, modeled with ArchiMate.

9.2 Limitations

The main goals of this dissertation were accomplished; however, some limitations must be discussed based on the guidelines provided in [60]. These guidelines are based on the core dimensions of communicating a DSR project, which imposes an explanation of the restrictions of the final artifacts.

Starting with the “Input Knowledge and Technology”, which describes the solution proposed to the problem initially identified, there are two artifacts: Entroncamento’s Dry Port Digital Twin architecture and prototype. About the “Research Process”, ArchiMate was the language used to model the architecture, while the Azure Digital Twin platform was adapted to implement the prototype. The evaluation was guaranteed by Fordesi, Medway, and the NEXUS Agenda consortium, which limits the insights provided to the participants of WP3.

The “Resulting Artifact” relates to the features implemented in the final solution, which does not yet comply with 100% of the needs (for instance, evaluation from actual end-users of the prototype and other IT companies, with no knowledge regarding Entroncamento’s Dry Port, could provide a more tailored result). Still, both results are crucial baselines for future improvement, from exploring the advantages of adopting the ArchiMate language to define Dry Ports Digital Twins’ architecture to implementing a Digital Twin in this infrastructure.

Lastly, the “Design Knowledge” provided by this investigation was in the form of design principles to guide the modeling of any Dry Port’s Digital Twin architecture, and a paper proposing a Dry Port’s Digital Twin reference architecture.

A main limitation of this research is related to the tools used. In the case of ArchiMate, the lack of elements and relations to represent more complex relations, such as those of a Dry Port, implies the need for its extension. The Azure Digital Twin platform does not provide tutorials on how to link animation of both the 3D scenario elements with information varying over time.

9.3 Future Work

In [60], a list of future work types is suggested for DSR projects. Table 23 relates each possible type in the first column, with its instantiation in the context of this research in the second column.

Table 23. Future Work Opportunities (adapted from [60])

Type of Future Work	Opportunities
Artifact Development or Improvement	The proposed prototype of Entroncamento's Dry Port Digital Twin provides a realistic representation of the level of awareness given by the sample data variation generated. However, integrating this solution with APIs from Entroncamento's Dry Port (still under development at this stage), with larger and real information streams, can provide insights closer to those of other Dry Ports.
Future Research in Other Contexts	This research's main focus was on exploring the advantages of the adoption of Digital Twins in Dry Ports; however, Seaports and other logistics infrastructures (e.g., using drones for the transportation of small products) are other logistics nodes whose main challenges can be reduced by applying this technology (e.g., vessel interoperability, optimized planning).
Future Research in the Same Context	A major future improvement in the proposed prototype is the direct relation between the data captured in real-time and the animated elements in the scenario. For instance, with real visual awareness regarding the location of reach stackers, the likelihood of accidents between the vehicles and the terminal workers can be reduced (may require the adoption of wearable devices by yard operators).
Outcome Development or Improvement	Entroncamento's Dry Port Digital Twin prototype can be improved by adapting it to other Dry Ports and visualizing the real impact of its adoption (e.g., the time needed to handle containers to and from arriving trains, and the reach stackers' paths, when compared with previous data).
Validate or Instantiate the Artifact	One of the main goals of a Digital Twin is to increase awareness of the system it replicates in real-time. Therefore, insights from actual future users are crucial to guarantee the information's relevance and impact on operations optimization.

Suggestions for the Solution Space	The prototype's indicators are derived from an initial analysis of the information deemed critical in Dry Ports. However, future research can focus on providing predictive information, such as the closest and most adequate reach stacker to consider when handling a certain train, the predicted arrival time, and the assignment of terminal operators based on their availability.
Suggestions for the Problem Space	With the increased awareness provided by a Dry Port Digital Twin, the existence of critical and confidential data must limit access to specific entities.
Emergent Opportunities	Digital Twins have been recognized as a technology responsible for providing easier access to information within complex enterprises and positively impacting the user's experience, focusing on providing data relevant to decision-making. It is important to explore the capabilities and improvements that can be achieved, like economic benefits.
Design Knowledge Accumulation	Dry Port Digital Twins are another contribution to the studies related to Digital Twins in more complex contexts, such as cities and factories. With the logistics field being critical for partially all industries, the expansion of Dry Port Digital Twins to relate clearly with other nodes within the chain can be a priority (e.g., provide an overview of the location of each port and the surrounding ports) as well as their relation with other smart contexts such as Smart Cities and factories.

Overall, all the initially defined objectives for this dissertation were achieved. The project participants' reflections and limitations offer a starting point to propose a comprehensive list of future work opportunities.

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Appendices

Appendix A – First Semester's Work Plan

This Appendix presents the planned and actual work plans for the first semester, in the form of Gantts.

Table 24. Gantt Diagram for the First Semester (Actual)

ID	Task	September	October	November	December	January
T01	Research about Dry Ports					
T02	Research about Digital Twins					
T03	Research about Enterprise Architetcure					
T04	Research about Port Digitalization					
T05	Research about Digital Twin Architecture					
T06	(Preliminary) Research about Digital Twin Platforms					
T07	AS-IS Architecture analysis					D-Day
T08	AS-IS Architecture modeling with ArchiMate					
T09	Prototype Requirements Identification					
T10	Architecture Requirements Identification					
T11	Report Writing					
T12	Report Reviewing					

Table 25. Gantt Diagram for the First Semester (Planned)

ID	Task	September	October	November	December	January
T01	Research about Dry Ports					
T02	Research about Digital Twins					
T03	Research about Enterprise Architetcure					
T04	Research about Port Digitalization					
T05	Research about Digital Twin Architecture					
T06	(Preliminary) Research about Digital Twin Platforms					
T07	AS-IS Architecture analysis					D-Day
T08	AS-IS Architecture modeling with ArchiMate					
T09	Prototype Requirements Identification					
T10	Architecture Requirements Identification					
T11	Report Writing					
T12	Report Reviewing					

Appendix B – Second Semester's Work Plan

This Appendix presents the planned and actual work plans for the second semester, in the form of Gantts.

Table 26. Gantt Diagram for the Second Semester (Planned)

ID	**Task**	Fevereiro	Março	Abril	Maio	Junho	Julho
T01	Report Correction						
T02	Research about Digital Twin Platforms						
T03	Dry Port Prototype elements Identification						
T04	Selection of Digital Twin Platform						
T05	Prototype Implementation						
T06	Prototype Evaluation						**D-Day**
T07	TO-BE Architecture modeling with ArchiMate						
T08	Architecture Evaluation						
T09	Report Writing						
T10	Report Reviewing						

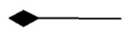
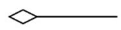
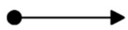
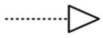
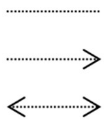
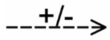
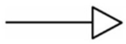
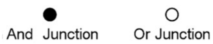
Table 27. Gantt Diagram for the Second Semester (Actual)

ID	**Task**	Fevereiro	Março	Abril	Maio	Junho	Julho
T01	Report Correction						
T02	Research about Digital Twin Platforms						
T03	Dry Port Prototype elements Identification						
T04	Selection of Digital Twin Platform						
T05	Prototype Implementation						
T06	Prototype Evaluation						**D-Day**
T07	TO-BE Architecture modeling with ArchiMate						
T08	Architecture Evaluation						
T09	Report Writing						
T10	Report Reviewing						

Appendix C – ArchiMate's Relationships

This Appendix presents all of the possible relationships between elements when using ArchiMate [61].

Table 28. ArchiMate Relationships

		Notation
	Structural Relationships	
Composition	Indicates that an element consists of one or more other concepts.	
Aggregation	Indicates that an element groups several other concepts.	
Assignment	Expresses the allocation of responsibility, behavior's performance, or execution.	
Realization	Indicates that an entity plays a critical role in the creation, achievement, or operation of an abstract entity.	
	Dependency Relationships	
Serving	Models that an element provides its functionality to another element.	
Access	Models the ability of behavior and active structure elements to observe or act upon passive structure elements.	
Influence	Models that an element affects the implementation or achievement of some motivation element.	
	Dynamic Relationships	
Triggering	Describes a temporal or causal relationship between elements.	
Flow	Models transfer from one element to another.	
	Other Relationships	
Specialization	Indicates that an element is a particular kind of another element.	
Association	Models an unspecified relationship, or one that is not represented by another ArchiMate relationship.	
Junction	Models the connection between relationships of the same type.	

Appendix D – ArchiMate's Elements

This Appendix presents all of the elements from ArchiMate [61].

Table 29. Motivation Elements in ArchiMate

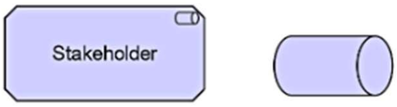
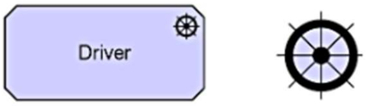
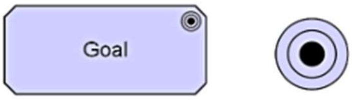
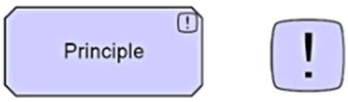
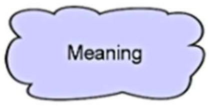
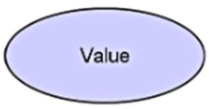
Element	Definition	Notation
Stakeholder	Represents the role of an individual, team, or organization (or classes thereof) that represents their interests in the effects of the architecture.	
Driver	Represents an external or internal condition that motivates an organization to define its goals and implement the changes necessary to achieve them.	
Assessment	Represents the result of an analysis of the state of affairs of the enterprise with respect to some driver.	
Goal	Represents a high-level statement of intent, direction, or desired end state for an organization and its stakeholders.	
Outcome	Represents an end result.	
Principle	Represents a statement of intent defining a general property that applies to any system in a certain context in the architecture.	
Requirement	Represents a statement of need defining a property that applies to a specific system as described by the architecture.	
Constraint	Represents a factor that limits the realization of goals.	
Meaning	Represents the knowledge or expertise present in, or the interpretation given to, a concept in a particular context.	
Value	Represents the relative worth, utility, or importance of a concept.	

Table 30. Application Elements in ArchiMate

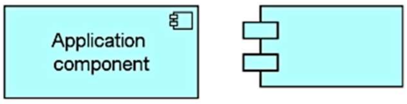
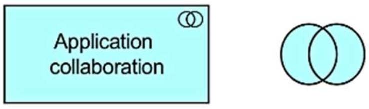
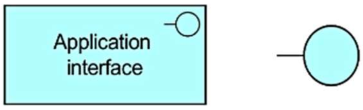
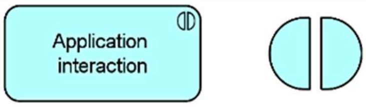
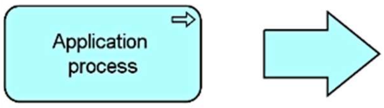
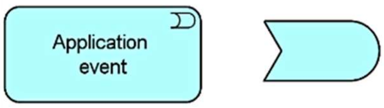
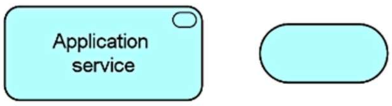
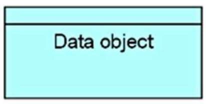
Element	Definition	Notation
Application component	Represents an encapsulation of application functionality aligned to implementation structure, which is modular and replaceable.	
Application collaboration	Represents an aggregate of two or more application internal active structure elements that work together to perform collective application behavior.	
Application interface	Represents a point of access where application services are made available to a user, another application component, or a node.	
Application function	Represents automated behavior that can be performed by an application component.	
Application interaction	Represents a unit of collective application behavior performed by (a collaboration of) two or more application components.	
Application process	Represents a sequence of application behaviors that achieves a specific result.	
Application event	Represents an application state change.	
Application service	Represents an explicitly defined exposed application behavior.	
Data object	Represents data structured for automated processing.	

Table 31. Technology Elements in ArchiMate

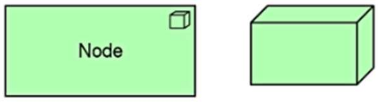
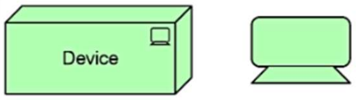
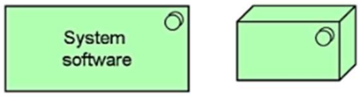
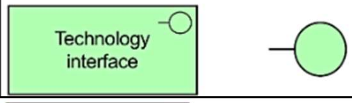
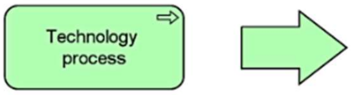
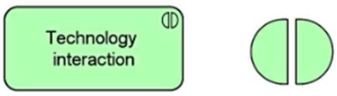
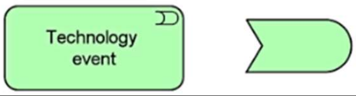
Element	Definition	Notation
Node	Represents a computational or physical resource that hosts, manipulates, or interacts with other computational or physical resources.	
Device	Represents a physical IT resource upon which system software and artifacts may be stored or deployed for execution.	
System software	Represents software that provides or contributes to an environment for storing, executing, and using software or data deployed within it.	
Technology collaboration	Represents an aggregate of two or more technology internal active structure elements that work together to perform collective technology behavior.	
Technology interface	Represents a point of access where technology services offered by a node can be accessed.	
Path	Represents a link between two or more nodes, through which these nodes can exchange data, energy, or material.	
Communication network	Represents a set of structures that connects nodes for transmission, routing, and reception of data.	
Technology function	Represents a collection of technology behavior that can be performed by a node.	
Technology process	Represents a sequence of technology behaviors that achieves a specific result.	
Technology interaction	Represents a unit of collective technology behavior performed by (a collaboration of) two or more nodes.	
Technology event	Represents a technology state change.	
Technology service	Represents an explicitly defined exposed technology behavior.	
Artifact	Represents a piece of data that is used or produced in a software development process, or by deployment and operation of an IT system.	

Table 32. Strategy Elements in ArchiMate

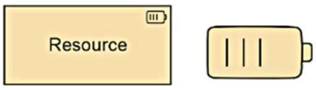
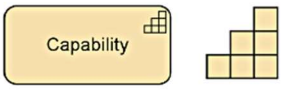
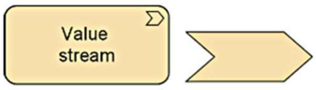
Element	Description	Notation
Resource	Represents an asset owned or controlled by an individual or organization.	
Capability	Represents an ability that an active structure element, such as an organization, person, or system, possesses.	
Value stream	Represents a sequence of activities that create an overall result for a customer, stakeholder, or end user.	
Course of action	Represents an approach or plan for configuring some capabilities and resources of the enterprise, undertaken to achieve a goal.	

Table 33. Physical Elements in ArchiMate

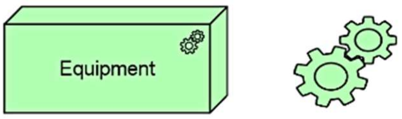
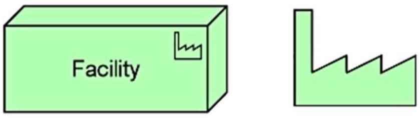
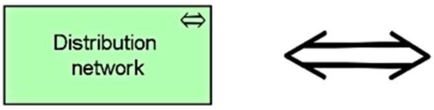
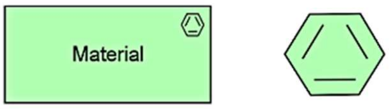
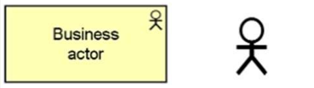
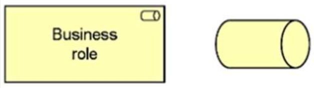
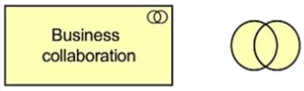
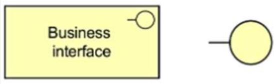
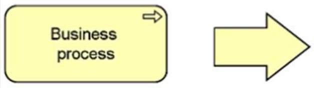
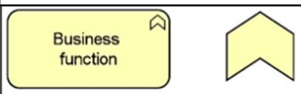
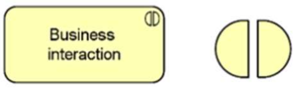
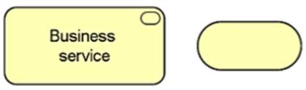
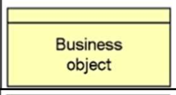
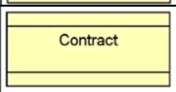
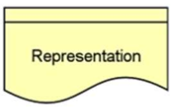
Element	Definition	Notation
Equipment	Represents one or more physical machines, tools, or instruments that can create, use, store, move, or transform materials.	
Facility	Represents a physical structure or environment.	
Distribution network	Represents a physical network used to transport materials or energy.	
Material	Represents tangible physical matter or energy.	

Table 34. Business Elements in ArchiMate

Element	Description	Notation
Business actor	Represents a business entity that is capable of performing behavior.	
Business role	Represents the responsibility for performing specific behavior, to which an actor can be assigned, or the part an actor plays in a particular action or event.	
Business collaboration	Represents an aggregate of two or more business internal active structure elements that work together to perform collective behavior.	
Business interface	Represents a point of access where a business service is made available to the environment.	
Business process	Represents a sequence of business behaviors that achieves a specific result such as a defined set of products or business services.	
Business function	Represents a collection of business behavior based on a chosen set of criteria (typically required business resources and/or competencies), closely aligned to an organization, but not necessarily explicitly governed by the organization.	
Business interaction	Represents a unit of collective business behavior performed by (a collaboration of) two or more business actors, business roles, or business collaborations.	
Business event	Represents an organizational state change.	
Business service	Represents explicitly defined behavior that a business role, business actor, or business collaboration exposes to its environment.	
Business object	Represents a concept used within a particular business domain.	
Contract	Represents a formal or informal specification of an agreement between a provider and a consumer that specifies the rights and obligations associated with a product and establishes functional and non-functional parameters for interaction.	
Representation	Represents a perceptible form of the information carried by a business object.	
Product	Represents a coherent collection of services and/or passive structure elements, accompanied by a contract/set of agreements, which is offered as a whole to (internal or external) customers.