UNIVERSIDADE ABERTA INSTITUTO SUPERIOR TÉCNICO

Digital Transformation of Warehouse Management

Miguel Duarte Pereira

Master's in Information and Enterprise Systems
(master's in association)

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Dissertation supervised by Professor Doctor Miguel Leitão Bignolas Mira da Silva

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Resumo

Algumas organizações lidam diariamente com a insatisfação de clientes, perda de dinheiro e tempo devido a problemas de gestão de armazém, tais como erros de picking, atrasos na entrega de pacotes, dados de stock errados, falta de rastreabilidade dos pacotes e processos manuais ineficientes.

Os Sistemas de Gestão de Armazéns (WMS) são utilizados para gerir o inventário. No entanto, estes sistemas têm algumas limitações. Algumas das limitações mais significativas são a falta de rastreabilidade dos movimentos de stock e a exigência de formação e mão-de-obra especializada para operar os software. Estes sistemas são de alto custo e um grande investimento, só se justifica caso a organização tenha um elevado volume de stock.

Nesta investigação será realizada uma revisão bibliográfica sobre os principais WMS existentes, as suas funcionalidades e limitações, sendo então diagnosticados problemas com origem na gestão de armazéns. Consequentemente, será planeada uma solução para as limitações identificadas dos WMS e para os problemas diagnosticados. Posteriormente, a solução será implementada, e os resultados serão avaliados (antes e depois da implementação).

A solução proposta é o desenvolvimento de um WMS que possa resolver as limitações existentes do WMS e os problemas diagnosticados da gestão do armazém, bem como quaisquer outros problemas que possam ser descobertos durante esta investigação. O WMS incluirá uma API que permite a sua integração com outros software, tal como aplicações corporativas existentes.

Este estudo visa melhorar as operações do armazém, reduzir erros, aumentar a satisfação geral de clientes e resolver os desafios identificados, através do desenvolvimento de um WMS que irá transformar digitalmente a gestão do armazém.

Palavras-chave: Warehouse Management System, Digital Transformation, Web Development, Logistics, Warehouse Management

Abstract

Some organizations deal every day with customer dissatisfaction, loss of money and time due to warehouse management issues such as picking errors, package delivery delays, inaccurate stock data, lack of traceability of packages and inefficient manual processes.

Warehouse Management Systems (WMS) are used to manage inventory. However, these systems have some limitations. Some of the most significant limitations are the lack of stock movement's traceability and the requirement of training and specialized workforce to operate the software. These systems are high cost and a big investment, they are only worthwhile if the organization has a high stock volume.

In this research will be performed a literature review about the main existing WMS, their functionalities and limitations, then will be diagnosed problems that originate from warehouse management. Consequently, a solution will be planned for the identified WMS limitations and diagnosed problems. Then, the solution will be implemented and evaluated.

The proposed solution is the development of a WMS that can solve existing WMS limitations and the diagnosed warehouse management problems, as well as any other issues that may be discovered during this investigation. The WMS will include an API that allows it to be integrated with other software, such as existing corporate applications.

This study aims to improve warehouse operations, reduce errors, increase overall customer satisfaction and solve the identified challenges, by developing a WMS that will digitally transform the warehouse management.

Keywords: Warehouse Management System, Digital Transformation, Web Development, Logistics, Warehouse Management

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List of Abbreviations and Acronyms

API	Application Programming Interface
AR	Action Research
ERP	Enterprise Resource Planning
IS	Information System
MTV	Model Template View
PWA	Progressive Web App
RDBMS	Relational Database Management System
SKU	Stock Keeping Unit
SSL	Secure Sockets Layer
SaaS	Software as a Service
TLS	Transport Layer Security
WMS	Warehouse Management System

Chapter 1

Introduction

1. Introduction

Some organizations deal every day with customer dissatisfaction, loss of money and time due to warehouse management issues such as picking errors, package delivery delays, inaccurate stock data, lack of traceability of packages and inefficient manual processes.

With an increasingly technological world, it is necessary to meet the needs found on a daily basis that can be satisfied by implementing Information Systems. Warehouse Management Systems are Information Systems that are mainly used to manage stock inventory.

The main Warehouse Management Systems has some limitations. Some of the most significant limitations of these systems are the lack of stock movement's traceability and the requirement of training and specialized workforce to operate the software. These systems are considered high cost and a big investment, and only worthwhile if the organization has a high stock volume.

In order to gain a more comprehensive comprehension of Warehouse Management, this study starts with a research background in section 2 where is defined warehouse management, digital transformation and warehouse management system.

In section 3 is conducted a literature review using the Systematic Literature Review methodology, where are defined and answered research questions. The questions answer which are the main existing WMS, their functionalities and limitations.

In section 4 is defined the research methodology, due to my proximity with the object of study, Action Research (AR) is my research methodology of choice, since AR is ideal when the investigator and the object of study are intrinsically tied to the day-to-day of the work environment.

The following sections are part of the action research cycle: Diagnosing, Action Planning, Action Taking and Evaluating.

Diagnosing (section 5) is where the research problems are identified. The problems can be identified from the proximity with the object of study, in this case warehouse management issues and the need of warehouse management systems.

Action Planning (section 6) where is described the objectives, and planned the actions necessary to achieve them. That includes planning a solution for the identified WMS limitations and diagnosed problems, from the Diagnosing (section 5) and the Literature Review.

In Action Taking (section 7) is implemented the plan where the proposed solution is developed, a warehouse management system. This section describes every part of the development, from the software design - requirements and system architecture, to the user interface.

Evaluating (section 8) where the solution is evaluated. The solution implemented was evaluated by testing the software with a two month pilot test. At the end of the pilot test the 8 practitioners were interviewed and the evaluation results were analyzed.

Finally, section 9 concludes the document, including limitations as well as plans for future work.

Chapter 2

Research Background

2. Research Background

The research background of the Digital Transformation of Warehouse Management is an important factor to consider in the development of a Warehouse Management System. This chapter will provide an overview of the various technologies and concepts that will be relevant to the design and implementation of the WMS.

2.1. Digital Transformation

The digital transformation of companies is a current reality resulting from the pressures of technologies, markets, the economy, collaborators, and society itself. Consumers and citizens' adherence to information and communication technologies puts pressure on economic organizations to adapt information systems (IS) and internal operations to the specific nature of the market and customers[11].

Digital transformation is a continuous, complex undertaking that can substantially shape a company and its operations. It is therefore important to assign adequate and clear responsibilities for the definition and implementation of a digital transformation strategy. Firms need to find procedures for formulating, implementing, evaluating, and – if necessary – adapting digital transformation strategies[17].

Warehouse Management Systems (WMS) are information systems used to manage warehouses and can be an essential part in a Digital Transformation of Warehouse Management.

2.2. Warehouse Management

A warehouse is a facility that provides temporary storage for many different products (stock keeping units, SKUs) on many physically different locations. The purpose of a warehouse is to fulfill customer orders. Fulfilling an order involves collecting a specific set of stored products and shipping them to the customer. In a typical warehouse, many customer orders are handled simultaneously[7].

Warehouse management confronts different problems, such as control problems that typically deal with the sequencing of order picking and storage/retrieval operations, and hence with the routing of manual order pickers, the allocation of products to storage positions in a class-based or random location system, the internal movement of items to more attractive retrieval positions, and others[19].

2.3. Warehouse Management System

Warehouse Management System is a management system where its base is a software that aims to improve the operations of a distribution center. The main purpose of this system is to increase the accuracy of inventory information, increase the speed and quality of distribution center operations, and increase the productivity of warehouse personnel and equipment[12].

Warehouse management systems can be either part of an Enterprise Resource Planning (ERP) system or an independent software solution.

WMS can be a Software as a Service (SaaS), a SaaS is a software delivery model, which provides customers access to business functionality remotely (usually over the internet) as a service. The customer does not specially purchase a software license. The cost of the infrastructure, the right to use the software, and all hosting, maintenance and support services are all bundled into a single monthly or per-use charging[18].

Chapter 3

Literature Review

3. Literature Review

A Systematic Literature Review (SLR) is a means of evaluating and interpreting all available research relevant to a particular research question, topic area, or phenomenon of interest. Systematic reviews aim to present a fair evaluation of a research topic by using a trustworthy, rigorous, and auditable methodology[20].

This research is based on Kitchenham's Procedures for Performing Systematic Reviews, which has the following three steps [7]:

1. Planning – specification of the research questions and development of a review protocol;
2. Conducting – selection of studies and data extraction using the developed review protocol;
3. Reporting – usage of the extracted data to report the results.

3.1. Planning

Research Questions

Before proceeding with the development of the software it is important to answer the following questions, in order to analyze the current WMS software, their functionalities and limitations.

RQ1: What are the main warehouse management systems?

RQ2: What are their main functionalities?

RQ3: What are their main limitations?

Review Protocol

The next step in creating a Review Protocol is to define the Search String that will be used to search the selected Data Sources in order to find the greatest number of papers on the subject. I used the following in our research:

- Search String: (“warehouse management system”) – searching only in the abstracts and title;
- Data Source: EBSCO Information Services - Procedia CIRP, Emerging Economies Cases Journal, Procedia Manufacturing, Economics & Culture, Future Studies Research Journal: Trends & Strategies, Wireless Personal Communications, International Journal of Logistics: Research & Applications, 8th International Conference on Reliability, Infocom Technologies and Optimization (Trends and Future Directions), 14th Symposium on Neural Networks and Applications.

The upcoming step was to define Inclusion and Exclusion Criteria and apply them to the collection of papers I had obtained in the first step. I established the following criteria:

- Inclusion:
    - Full Text
    - Peer Reviewed
    - Academic Journal
    - Conference Papers
- Exclusion:
    - Duplicates
    - Different subject
    - Unable to get full document

I have analyzed the abstracts and conclusions of all the papers after applying the defined criteria and obtaining a first set of papers to determine whether they were relevant to our research.

The resulting set consisted of the chosen documents, which were then thoroughly read in order to obtain the final set of chosen papers. To make this process easier, I used the online tool Rayyan.ai, which is designed to help researchers conduct literature reviews.

3.2. Conducting

Selection of Studies

Obtained approximately 220 documents after selecting the Data Sources and applying the defined Search String with the previously defined Criteria.

Later filtered down to a set of 34 documents after reading the Abstract and Conclusions, this set of documents will be used to answer the Research Questions.

Data Extraction Analysis

The next figure displays and explains the process of extraction of the data from the literature review to answer the research questions.

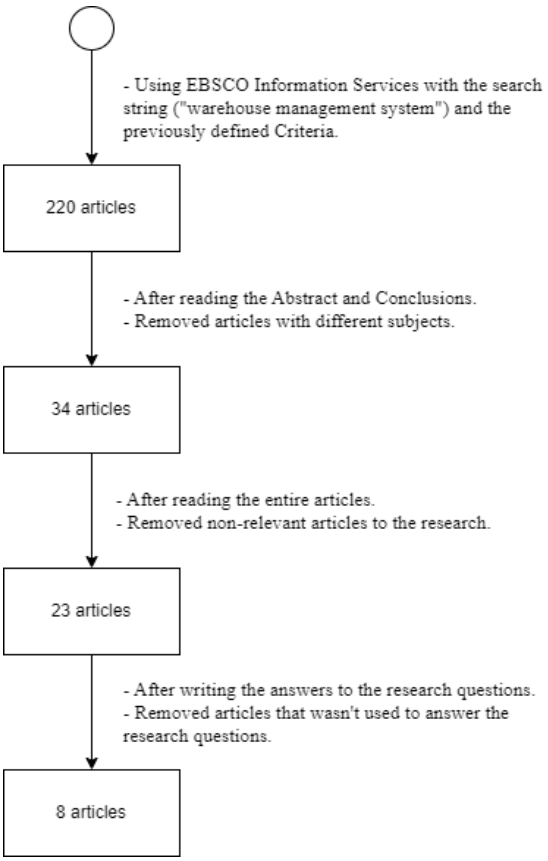

Fig. 1. Data extraction process

In Figure 3 is displayed the years and numbers of articles used to answer the research questions.

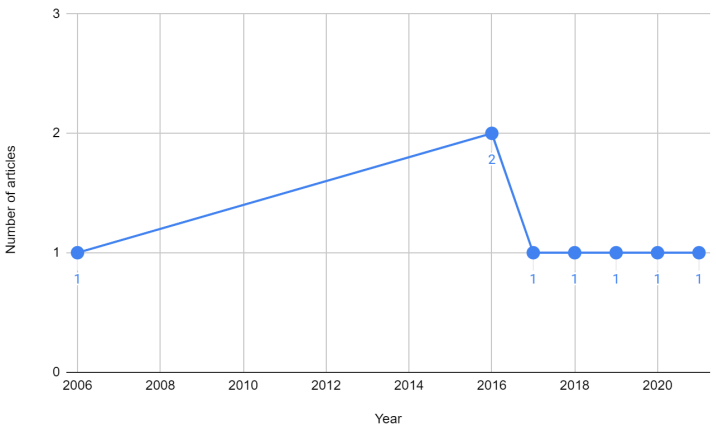

Fig. 2. Number of articles by year

3.3. Reporting

RQ1: What are the main warehouse management systems?

Warehouse management systems can be either part of an Enterprise Resource Planning (ERP) system or an independent software solution. There are hundreds of WMS software vendors (at least 375), none of which has more than a 10% market share[14]. Despite this, my research has revealed that there are some popular WMS software.

According to the authors Bhattacharjee, D. (2019), Carujo, S. (2021), the main warehouse management systems are SAP Extended Warehouse Management (previous version was SAP Warehouse Management System) from SAP SE (part of an ERP); RedPrairie from JDA WMS (now Blue Yonder); Oracle (part of an ERP); Eye Peak from Primavera BSS (part of an ERP); xLog; Easy WMS from Mecalux.

Each of these WMS software has common and distinct functionalities, as well as its own environment, requirements, and limitations.

Tab. 1. Main warehouse management systems

WMS	Paper
Easy WMS from Mecalux	Carujo, S. et al. (2021);
Eye Peak from Primavera BSS (part of an ERP)	Carujo, S. et al. (2021);
Oracle WMS (part of an ERP)	Bhattacharjee, D. (2019);
RedPrairie from JDA WMS (now Blue Yonder)	Bhattacharjee, D. (2019);
SAP Extended Warehouse Management (previous version was SAP Warehouse	Bhattacharjee, D. (2019); Fávero, L. et al. (2016);

Management System) from SAP SE (part of an ERP)	
xLog from Tecnibite	Carujo, S. et al. (2021);

RQ2: What are their main functionalities?

Despite the distinct features of every WMS I've collected from my literature review the following main functionalities of a warehouse management system.

According to Atieh, M. (2016), Warehouse Management Systems are used to reduce costs through effective warehouse processes, capture data in real-time (item movements and others), to automate the warehouse and logistic operations. WMS has barcode and printer integration.

Bhattacharjee, D. (2019) claims that the main functionalities of a WMS are the ability to manage stock and storage locations, bin management, implementation of placement and removal strategies, picking, replenishment, storage unit management, yard management, tasks and resources management, expected goods receipt, cross-docking, unloading of transport units, slotting re-arrangement, labor management and an analytical dashboard to interact with the warehouse management system.

The author Fávero, L. (2016) describes a WMS as software who has this main functionalities: traceability of operations in real time, rotating and general physical inventories, capacity planning and control, definition of the use characteristics of each storage location, classification of articles, lot control, quarantines and quality control, picking, Customer/supplier interface, calculation of shipping packaging and contents list, route control and vehicle loading.

Min, H. (2006), indicates that the main functionalities of a warehouse management system are: Advance Shipping Notification, Scanning, Self-check of receipt information, Notification of inspection requirements, Confirmation of product inspection, Dedicated,

random, or hybrid storage, Back-up storage, Cross-docking, Shelf-life monitoring, Batch and serial number tracking, Operator location, Replenishment, First-In-First-Out (FIFO)/Last-In-First-Out (LIFO), Inventory Relocation/Consolidation, Inventory quarantine, assignment, release, Cycle counting, Stock rotation, Order planning/scheduling, Front-end picking area replenishment, Kitting/pick and pack, Order/pick confirmation, Carrier scheduling, Yard management, Load sequencing, Manifesting, Cargo receipt generation, Traffic, Customer service reporting, Inventory/order accuracy reporting, Space Utilization Reports, Labor Productivity Reports and Item Activity Reports.

The main functionalities of a warehouse management system are briefly identified as a software which allows stock planning, manage receiving, manage locations, order picking and shipping, according to the author Zunic, E. (2018).

Tab. 2. Main WMS functionalities

Functionality	**Paper**
Analytical dashboard for interaction with the system	Bhattacharjee, D. (2019);
Article classification and quality control	Fávero, L. (2016);
Barcode and printer integration	Atieh, M. (2016);
Batch/serial number tracking	Min, H. (2006);
Capacity planning and control	Fávero, L. (2016);
Cycle counting, stock rotation, and order planning/scheduling	Min, H. (2006); Zunic, E. (2018);
Inventory quarantine, assignment, and release	Min, H. (2006);

Order picking and shipping	Min, H. (2006); Zunic, E. (2018);
Receiving management, FIFO/LIFO, inventory relocation/consolidation and slotting re-arrangement	Min, H. (2006); Zunic, E. (2018); Bhattacharjee, D. (2019);
Route control, vehicle loading, calculation of shipping packaging and contents list	Fávero, L. (2016);
Stock and storage location management	Bhattacharjee, D. (2019); Min, H. (2006); Zunic, E. (2018);
Storage unit management	Bhattacharjee, D. (2019);
Task, resources and labor management	Bhattacharjee, D. (2019); Min, H. (2006);
Traceability and real-time data capture of operations in real-time	Atieh, M. (2016); Fávero, L. (2016);

RQ3: What are their main limitations?

According to the authors Fávero, L. (2016), Caridade, R. et al. (2017) and Wanganoo, L. (2020), the main limitations of warehouse management systems are the requirement of training and specialized workforce to operate the software, the need to be integrated with another management system, the transportation issues like the lack of traceability of packages.

The author Fávero, L. (2016) considers that the installation of a WMS is only worthwhile if the company has a high stock volume. Bhattacharjee, D. (2019) identifies WMS as high cost and a big investment.

Tab. 3. Main WMS limitations

Limitation	Paper
High cost and a big investment.	Bhattacharjee, D. (2019);
Installation of a WMS is only worthwhile if the company has a high stock volume	Fávero, L. (2016);
Need to be integrated with another management system	Fávero, L. (2016); Caridade, R. et al. (2017); Wanganoo, L. (2020);
Requirement of training and specialized workforce to operate the software	Fávero, L. (2016); Caridade, R. et al. (2017); Wanganoo, L. (2020);
Transportation issues like the lack of traceability of packages	Fávero, L. (2016); Caridade, R. et al. (2017); Wanganoo, L. (2020);

Chapter 4

Research Methodology

4. Research Methodology

In this chapter will be described the chosen research method and respective tasks and stages. This research is dependent on day-to-day work experience to collect results about the study object and to obtain feedback about the application of the solution developed.

In my day-to-day work environment I have direct interaction with the research problem, this allows me to investigate and test different solutions until I reach the research objectives defined above.

Due to my proximity with the object of study, Action Research (AR) is my research methodology of choice since AR is ideal when the investigator and the object of study are intrinsically tied to the day-to-day of the work environment.

4.1. Action Research

Action Research (AR) is a flexible research method[1], composed of a framework with the ideal structure for investigating topics associated with day-to-day work environments[2]. It is characterized by relating practice to concepts and ideas that aim to satisfy problems identified by the real world[3].

AR is suitable for solving problems identified in the real world[4] as it provides a great interaction between the researcher and the object of study[5]. This proximity between the researcher and the object of study (problem identified in the real world) makes it possible to act and, consequently, to critically reflect on the results and generate new knowledge about the problem.

Action Research is a cyclic process that seeks improvements in each iteration based on the knowledge acquired in the previous iterations[5]. The five phases that are part of the cycle are[6]:

- Diagnosing - identifying problems;

- Action Planning - describing and planning the actions necessary to achieve the objectives;
- Action Taking - implementation of the plan;
- Evaluating - post implementation evaluation;
- Specifying Learning - formalization and reflection of the action regardless of whether successful or unsuccessful;

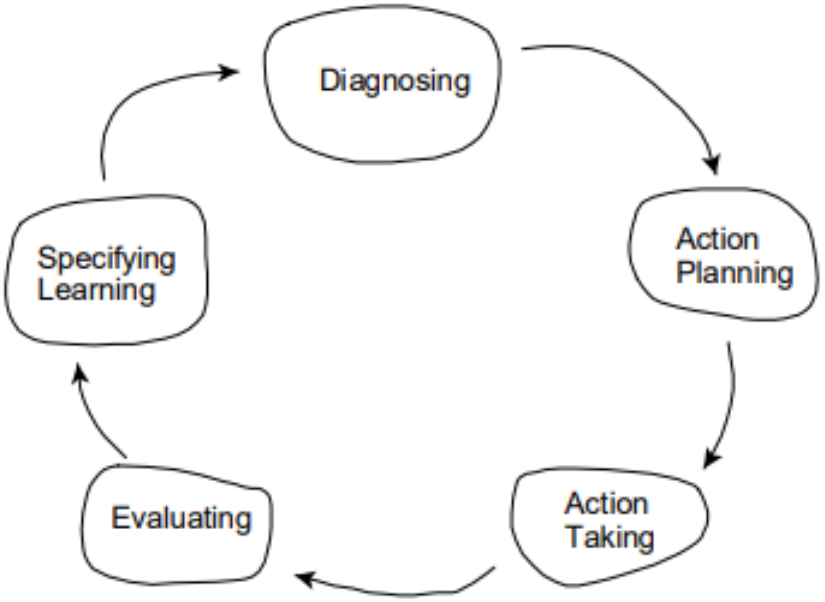

Fig. 3. The Action Research Cycle [6]

Chapter 5

Diagnosing

5. Diagnosing

Some organizations deal every day with customer dissatisfaction, loss of money and time due to warehouse management issues such as picking errors, package delivery delays, inaccurate stock data, lack of traceability of packages and inefficient manual processes.

Warehouse Management Systems (WMS) are used to manage inventory. However, these systems have some limitations. Some of the most significant limitations are the lack of stock movement's traceability and the requirement of training and specialized workforce to operate the software. These systems are high cost and a big investment, they are only worthwhile if the organization has a high stock volume.

These problems could lead an organization to serious difficulties, since warehouse operations have a big impact on customer satisfaction, costs, and time.

Although, with a proper WMS the warehouse management can be digitally transformed and part of these problems and limitations can be defeated.

Chapter 6

Action Planning

6. Action Planning

In this section is described and planned the actions necessary to achieve the research objectives.

6.1. Objectives

This study aims to improve warehouse operations, reduce errors, increase overall customer satisfaction and solve the identified challenges, by developing a WMS that will digitally transform the warehouse management.

6.2. Research Proposal

With the knowledge acquired from answering the research questions and with the objectives to solve the research problems, will be developed a software, a warehouse management system.

The proposed solution is the development of a WMS that can solve existing WMS limitations and the diagnosed warehouse management problems, as well as any other issues that may be discovered during this investigation.

What distinguishes this WMS from the existing ones analyzed are the idealistic approaches in which it is going to be developed, the proposed software will fight WMS's current limitations (defined in research question 3) and the limitations identified in the research problem.

The idea behind this WMS is to be infinite, in other WMS users have stock locations in a predefined pattern, in the proposed software users should be able to create the locations in every way that users might want. For example, an existing stock location can be W0A10.1 which means warehouse W, zone 0, row of racks A, rack 10, shelf 1 - the other WMS are restricted to a limited design pattern. With the proposed software, users create their own design patterns, or can just give names to the locations. The goal is to

make this software as user-friendly and versatile as possible and to make this work anywhere, even in a home kitchen for example, not just warehouses.

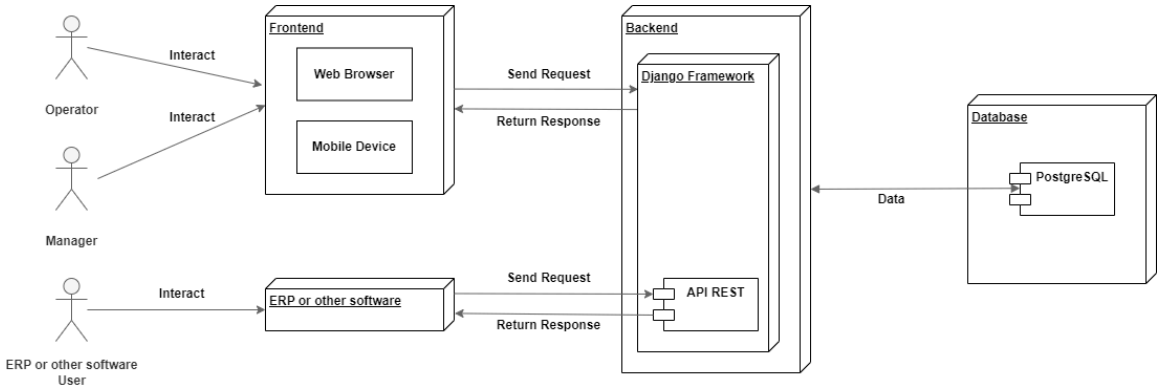

Fig. 4. Proposed system architecture

Given the approach, it is important to define the system architecture (figure 5). The proposed software will be a Software as a Service (SaaS) - is cheaper to the companies/individuals, pay-as-you-go, no need for a costly enterprise server and specialized workforce; will be a web based application - work anywhere from anywhere, PWA for mobile installation; will have an API so it can be integrated with existing ERP systems and others - not mandatory to use the WMS.

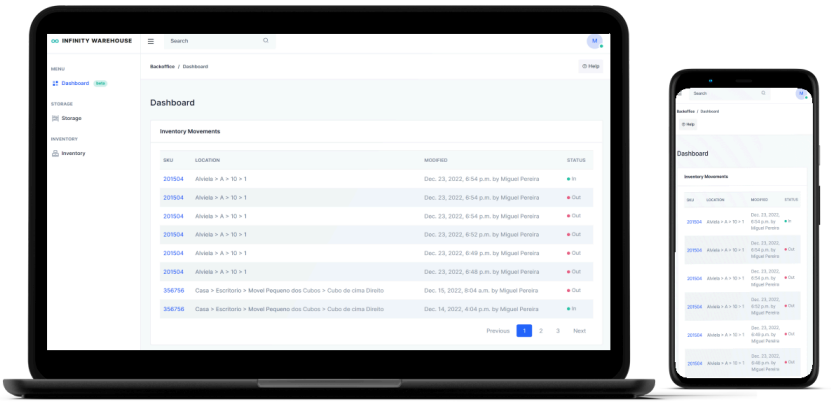

Fig. 5. Proposed user interface

Tab. 4. Main functionalities of the proposed software

Functionality
Barcode and printer integration
Stock and storage location management
Storage unit management
Analytical dashboard for interaction with the system
Traceability and real-time data capture of operations in real-time
Batch/serial number tracking
Order picking
Search by products or location
Team management
Operations log

Chapter 7

Action Taking

7. Action Taking

This section reports on the implementation of the plan: development of a warehouse management system, the software Infinity Warehouse.

7.1. WMS Design

Software design is essential to the process of developing software because it offers a methodical way to convert requirements into well-structured software systems. According to the author Jaiswal, M. (2019), software design significantly impacts the quality, maintainability and overall success of software systems.

7.1.1. Requirements

Software requirements include both functional and non-functional aspects that drive software system development. Functional requirements define specific features and functionalities that the software should have, such as user interactions and system behavior. Non-functional requirements have attributes like performance, reliability, security and usability.

Functional Requirements

The next list displays the implemented functional requirements for the Infinity Warehouse. The requirements are grouped by software parts and subparts:

Public (public website):

- Homepage: the Homepage should provide an overview of the SaaS product, highlighting its key features and benefits.
- About: the About page should include mission, history, and team members involved in the SaaS product.

- Pricing: the Pricing page should present the different pricing plans or subscription options available for the SaaS product.
- Contact: the Contact page should provide a clear and user-friendly contact form for visitors to submit inquiries.

Documentation (API and functionalities documentation): the Documentation should provide a clear explanation of API usage and of any other feature that might require a detailed explanation.

API (Application Programming Interface for integrations with other systems):

- Miscellaneous:
    - The system should provide a list of the latest API calls with details (date, path, payload, query and response).
    - The system should provide an API token for each team.
- Item: the API should have an endpoint that provides stocks, latest movements and detailed information about a requested item.
- Movement: the API should have an endpoint that allows to create inventory movements.
- Storage:
    - The API should have an endpoint that allows to create storages.
    - The API should have an endpoint that provides stocks, latest movements and detailed information about a requested storage.
- Picking Orders: the API should have an endpoint that allows to create picking orders.

Mobile App (application for mobile devices like smartphones and tablets): the Backoffice should be accessed through a mobile app that can be installed as a PWA or via Google Play Store.

Backoffice:

- Actions:
    - The system should have 3 actions: Picking, Restocking and Stocktaking.
    - For each interaction in an action the system should create an inventory movement.
    - The action Picking should randomly attribute a picking order to the picker.
    - The action Picking should display the order number, customer, salesperson, carrier and order description.
    - The action Picking should allow the picker to stop picking an order.
    - The action Picking should list the items to pick by location, ordered by the shortest path. Each item on the list should have a picking status, location, quantity, SKU, name and description.
    - The action Picking should display an errors section with the list of products without enough stock for the requested unit type.
    - The action Picking should have the ability to mark a certain item as picked.
    - The action Picking should allow the picker to finish picking and mark the order as picked.
    - The action Restocking should allow the user to search for a storage to restock. The user should be allowed to type the storage location or id, or use a barcode reader.
    - The action Restocking should display the list of existing items in stock on the chosen storage.
    - The action Restocking should have an input box per item for the user to write the quantity to restock of the chosen item with a certain unit type.

    - The action Restocking should provide a section to add items that are not already in the chosen storage. To input the item SKU the user should be able to use a barcode reader. To input the quantity the user should be able to choose between the created unit types.
    - The action Stocktaking should allow the user to search for a storage to restock. The user should be allowed to type the storage location or id, or use a barcode reader.
    - The action Stocktaking should display the list of existing items in stock on the chosen storage.
    - The action Stocktaking should have an input box per item for the user to write the quantity to be changed of the chosen item with a certain unit type.
    - The action Stocktaking should provide a section to add items that are not already in the chosen storage. To input the item SKU the user should be able to use a barcode reader. To input the quantity the user should be able to select between the created unit types.
    - The action Stocktaking should provide the option to remove items from a storage.
- Authentication:
    - The system should provide secure user authentication mechanisms, with email/password authentication.
    - The system should have a login and register page.
    - The system should support different user roles with varying levels of access rights, managers and operators.
    - The system should allow the user to recover the password.
    - The system should allow the user to change first and last name, to leave a team and to logout.

- Dashboard:
    - The Dashboard page should display the 3 actions shortcuts.
    - The Dashboard page should display a warnings section and the last inventory movements if the user is team manager.
    - The Dashboard warnings should list the following: Items that will expire in less than a month, API calls that failed in the last month and Products that got out of stock in the last month.
- Inventory:
    - The Inventory page should list all the inventory movements performed by the team, ordered by the most recent movement. Each movement of the list should have a SKU, quantity, status, location and description.
    - If the user is team manager, or the user performed the chosen movement of the list, he should be able to edit or remove the movement.
    - The user should be able to create inventory movements.
    - When creating inventory movements the system should allow users to choose or create a new item, select the storage, indicate the type of movement (In or Out), the quantity and unit type, movement description, dimensions, the item expiration date and the item serial number.
    - When creating a new inventory movement the user should be able to use barcode reader to select the storage and the item.
    - The Inventory Item page should display the details (stock, name, description and dimensions) for a given SKU. It should list the stock quantities and locations and the last item movements.
    - If the user is a team manager, should be able to edit or remove inventory items.

    - The team managers should be able to create, edit and remove unit types for quantity for item movement.

- Miscellaneous:
    - The system should have a search bar always visible with a barcode reader. This search bar should return a list of matching storages and items.
    - The system should have a 404 page and an access denied page.
    - The system should allow customization for each team by allowing them to add a custom logo and custom JavaScript code to the software.

- Picking Orders:
    - The Picking Orders page should list all the orders. Each item of the list should have a status, picker, order number, customer, salesperson, carrier and description.
    - If the user is team manager, he should be able to edit (change status and unassign picker) or remove the chosen order of the list.
    - The Picking Orders page should allow the user to view the details of an order and display the status of each picking item.

- Storage:
    - The system should allow the user to create, edit and remove storages if he is a team manager.
    - The creation of a storage should include a storage name, storage type, description, storage parent, dimensions and position.
    - The system should display the storages by parent and list their details, stock, latest movements and child storages.
    - The system should generate a label for each storage (should include location path and barcode) and allow it to be printed.

        - The team managers should be able to create, edit and remove storage types. Each storage type should have a name, dimensions and description.

- Team:

    - The user should be able to create a team or to be added to an existing team by a team manager (team admin).

    - The team manager should be able to edit the team name, logo and description.

    - The user should be able to leave the team if he is not the only team manager.

    - The team manager should be able to add and remove members. Should be able to edit the role of members (Operator or Manager).

    - The Team page should display the members list and analytical information about the usage of the system.

Non-functional Requirements

The next list displays the implemented non-functional requirements for the Infinity Warehouse.

- Performance:
    - The system should be capable of handling a large volume of data and transactions without significant performance degradation.
    - Response times for critical operations (such as order picking, stocktaking, and restocking) should meet predefined performance targets.
- Reliability:
    - The system should be highly reliable and available, ensuring minimal downtime for essential functions.
- Security:

- Role-based access control should be implemented to restrict unauthorized access to critical functions and data.
- The system should employ strong authentication mechanisms to ensure only authorized users can access the system.

- Usability:
  - The system should have an intuitive and user-friendly interface, ensuring ease of use for both technical and non-technical users.
  - The user interface shall automatically adjust its layout, content, and navigation to accommodate different screen sizes and resolutions, including desktop computers, laptops, tablets and smartphones.
- Integration:
  - The system should offer an API (Application Programming Interface) to enable integrations with other systems.

7.1.2. System Architecture

The Infinity Warehouse follows the proposed system architecture defined in the research proposal.

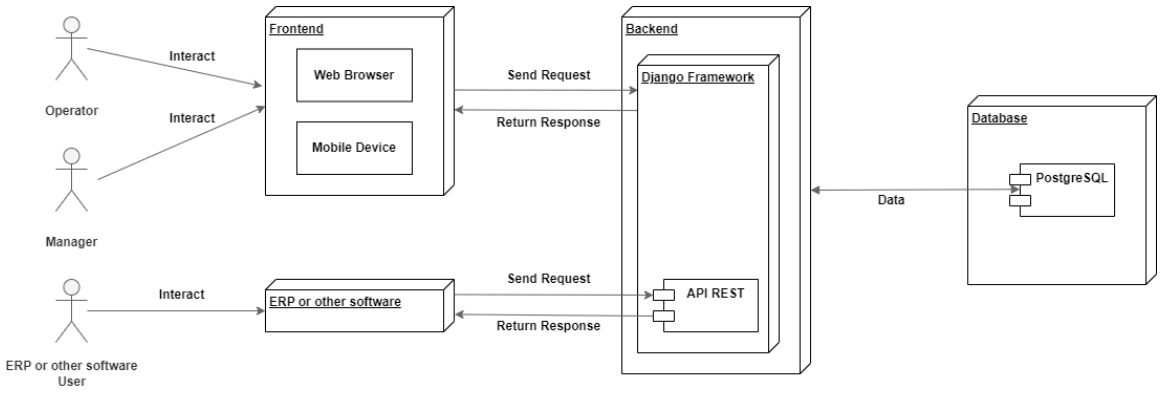

Fig. 6. System architecture

The main technologies used to develop the WMS are the Django Framework with PostgreSQL.

Django is a full stack web framework based on Python that allows writing Python code that dynamically generates HTML. Enables fast development of secure and scalable apps. Django supports PostgreSQL natively, which is a relational database management system (RDBMS). This framework has an MTV (Model Template View) architecture that divide in three main parts:

- Models: A set of tools that make working with databases easy.
- Templates: For frontend, to design user interface.
- Views: For Backend, handles the communication between the user and the database with logic.

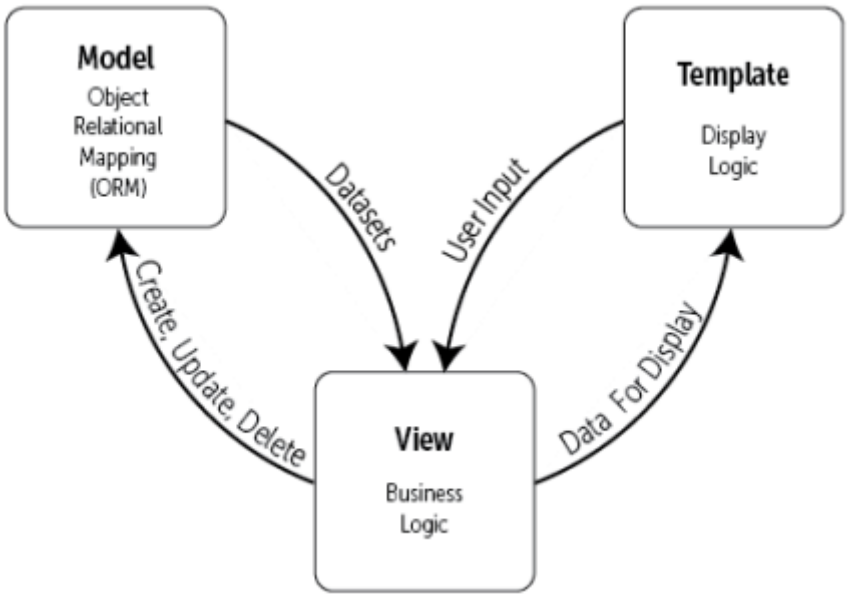

Fig. 7. MTV architecture [22]

Django is versatile, it also allows creating REST APIs that return JSON data, to integrate with other software.

For the mobile app, was used the library Django PWA that makes a Django app into a PWA (Progressive Web App). Progressive Web Apps are web applications that use modern web technologies to provide an app-like experience, allowing users to access them through a browser while having camera functionality and to have home screen installation. With the development tool Bubblewrap from Google it's possible to publish PWAs on the Google Play Store, to have an installation like a native Android App. In other mobile operating systems, like iOS, users can use the home screen installation.

Database

The RDBMS used is PostgreSQL. For the creation of the database tables were used the Django Models, to be easier and faster to stage database changes with Django Migrations.

The database was designed with the idea that users should have the freedom to create storage locations without a predefined pattern. This allows the users to create storages with Infinite sub-storage levels - this the reason the WMS is named the Infinity Warehouse.

To avoid stock errors, the stock value of a storage or item is never stored, it’s calculated according to the movements of a certain item in a storage with determined unit type.

The following image is the database diagram. The diagram displays the tables in the Infinity Warehouse database, with columns and respective data types.

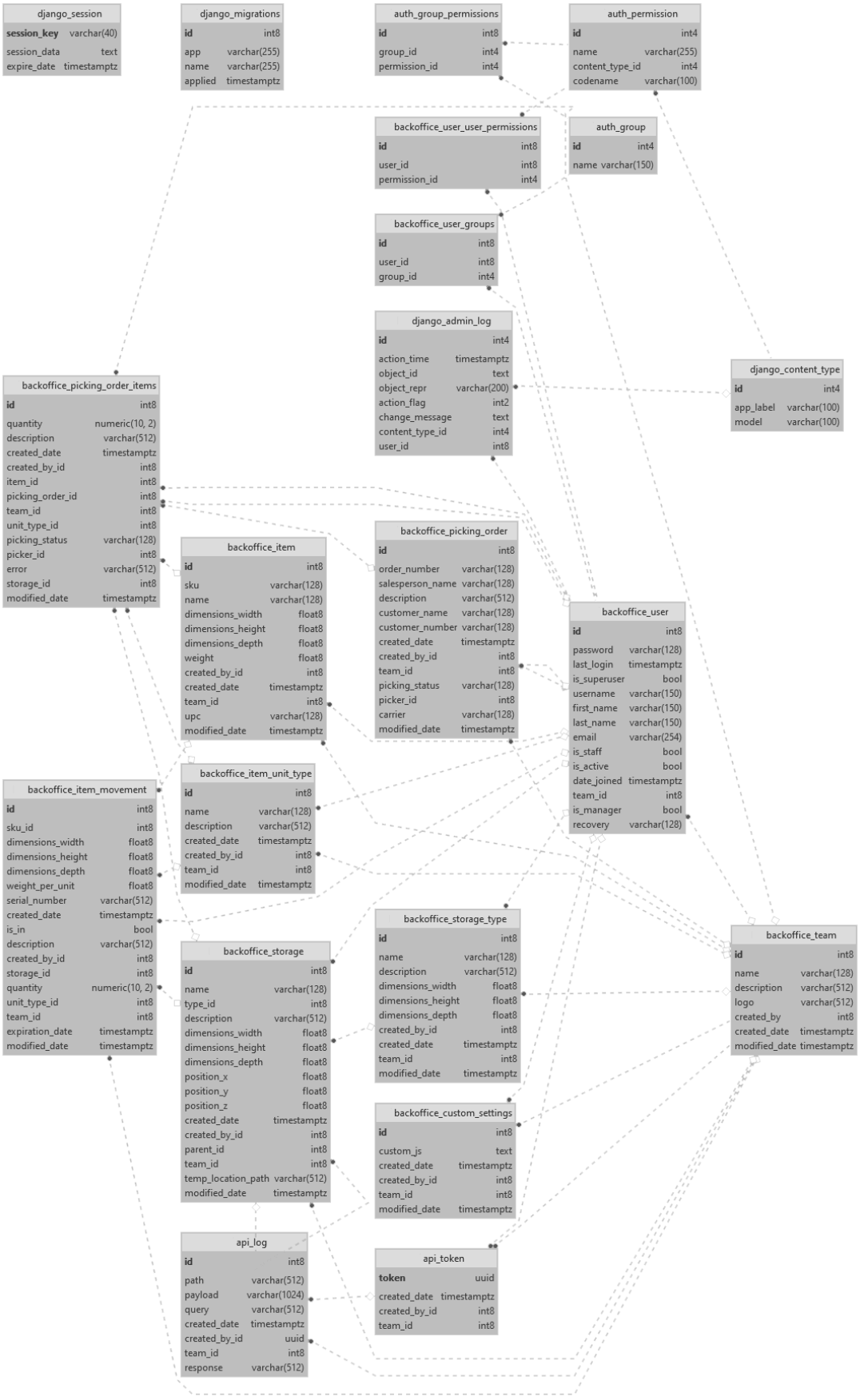

Fig. 8. Database Diagram

Backend

The backend is built using the Django Views. The REST API is part of the backend, and is organized into a Django App.

A Django Project is divided into Django Apps like shown in the image below.

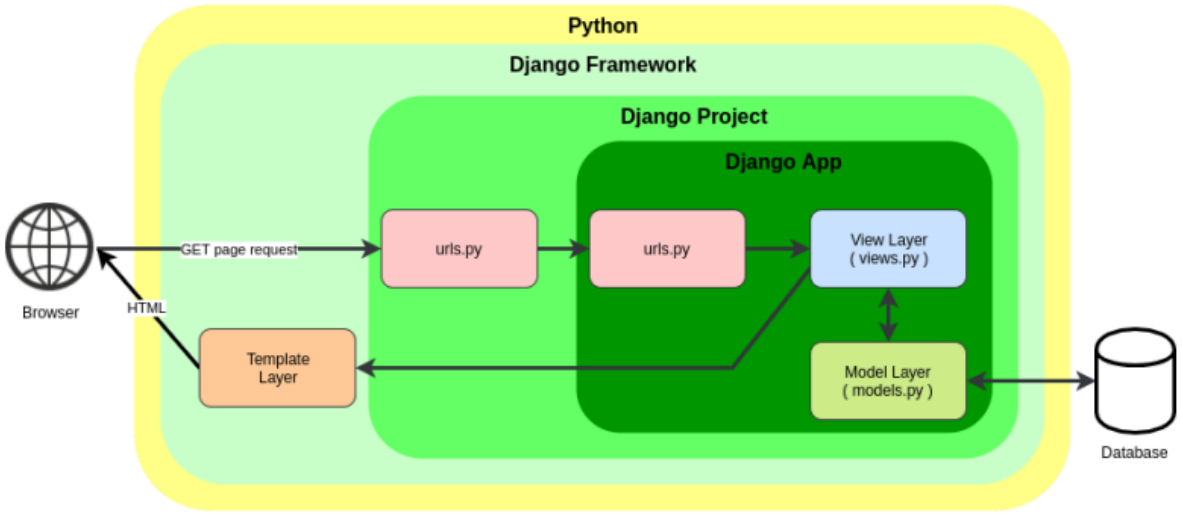

Fig. 9. Components and Layers of a Django Project [23]

The Django Project of the Infinity Warehouse has apps and sub-apps for better code organization. This is the folder structure of the project:

- api: Django App responsible for the API that allows integration with other software;
- backoffice: Django App for the Backoffice (has sub-apps)
- config: Django Project settings
- docs: Django App for the Documentation of the API and functionalities;
- public: Django App for the Public website;

- static: Django static files for frontend (e.g. images, JavaScript, CSS);
- templates: Django frontend templates.

The sub-apps of the backoffice are responsible for the logic of the warehouse management system, the functionalities and responsibilities of each sub-app are described in the Requirements section.

Frontend

The frontend is built using the Django Templates. Django dynamically generates HTML based on the templates and the data from the view.

The templates are responsible for displaying data and sending user input to the backend with a user-friendly interface. Later on this document will describe the user interface of the frontend.

7.2. User Interface

The user interface of the Infinity Warehouse is responsive - automatically adjusting its layout, content, and navigation to accommodate different screen sizes and resolutions, including desktop computers, laptops, tablets and smartphones; and customizable - each team can add a custom logo and custom JavaScript code to the software.

The following images display screenshots of the Infinity Warehouse Backoffice (WMS).

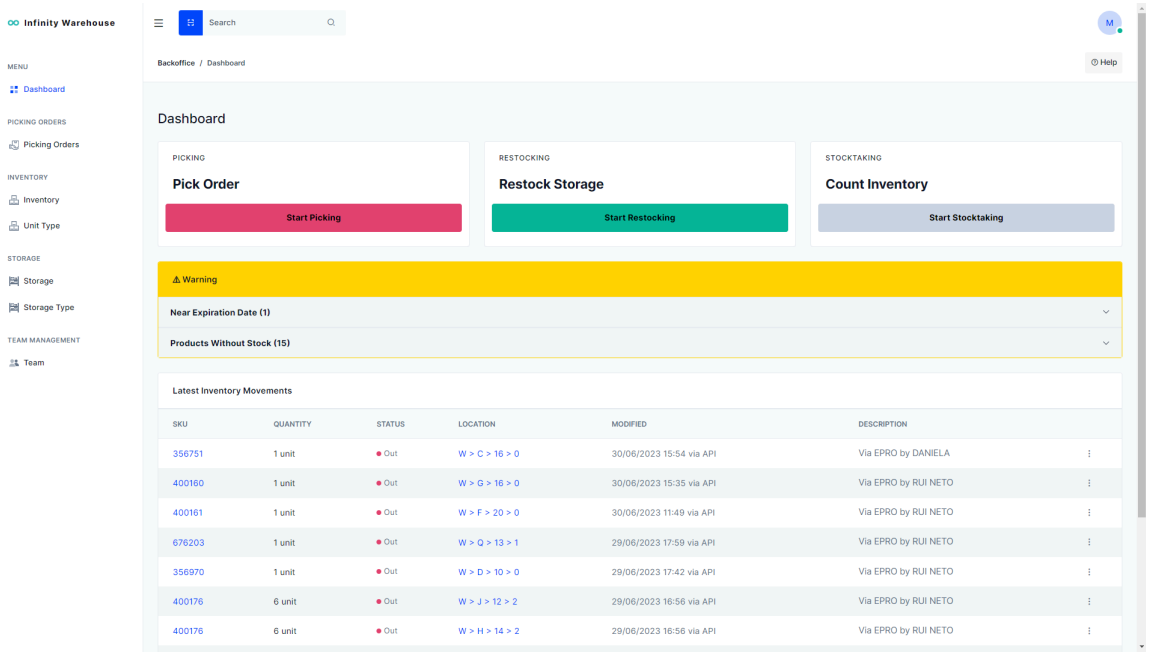

Fig. 10. Infinity Warehouse Backoffice - Dashboard (as Team Manager)

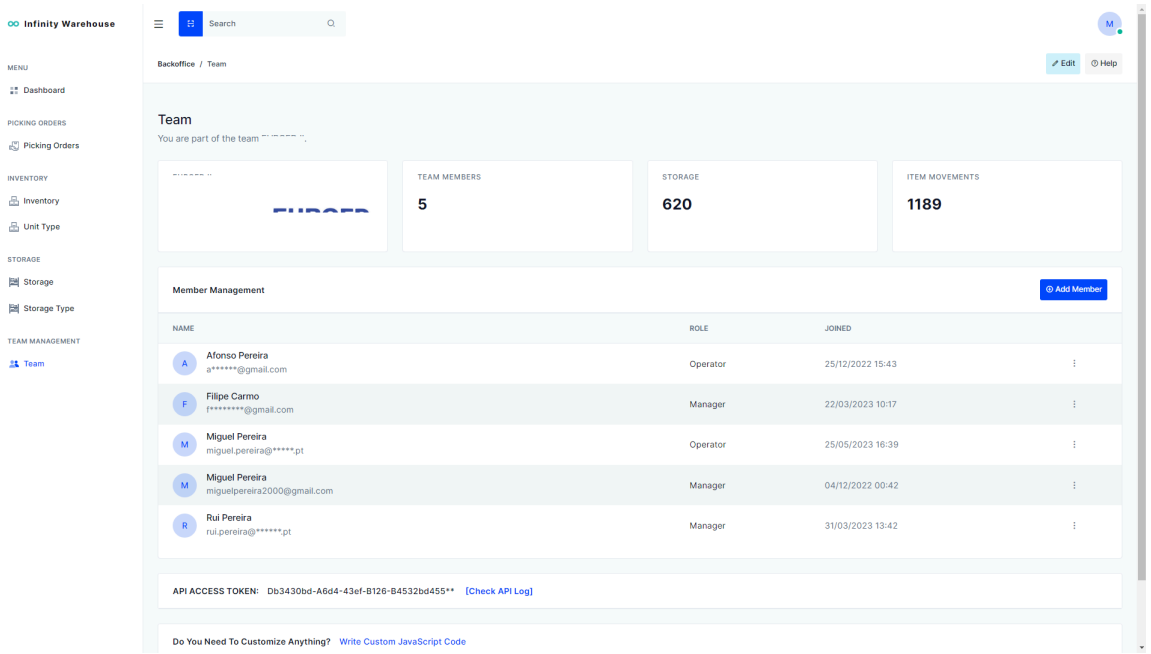

Fig. 11. Infinity Warehouse Backoffice - Team (as Team Manager)

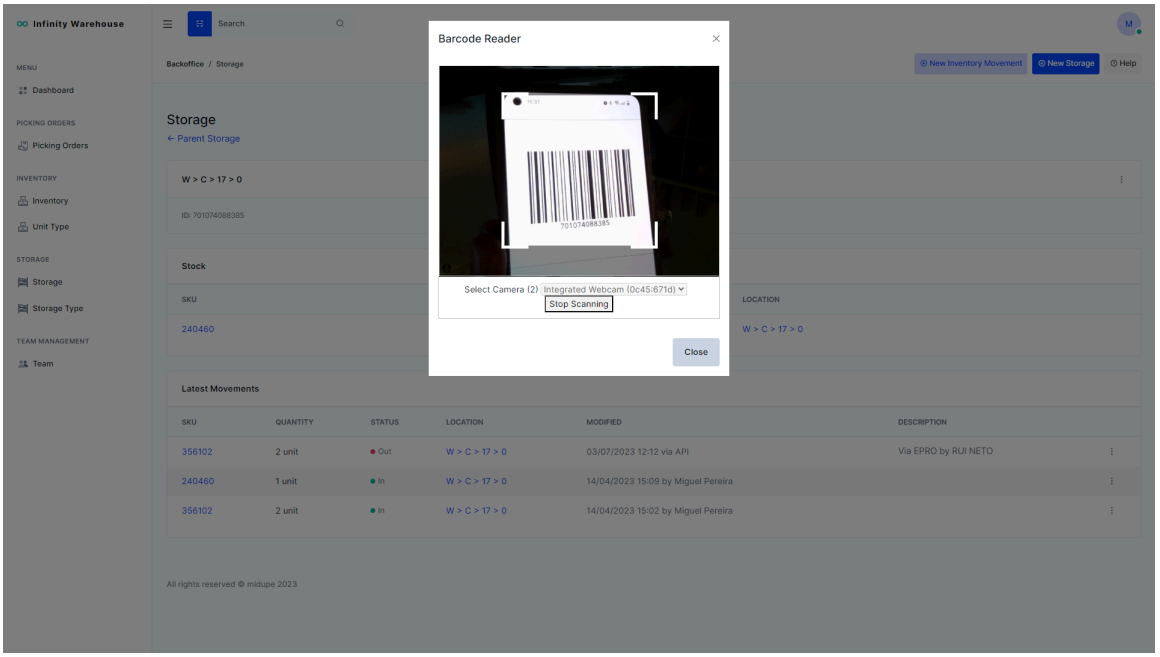

Fig. 12. Infinity Warehouse Backoffice - Search with Barcode Reader (Storage Details in the background)

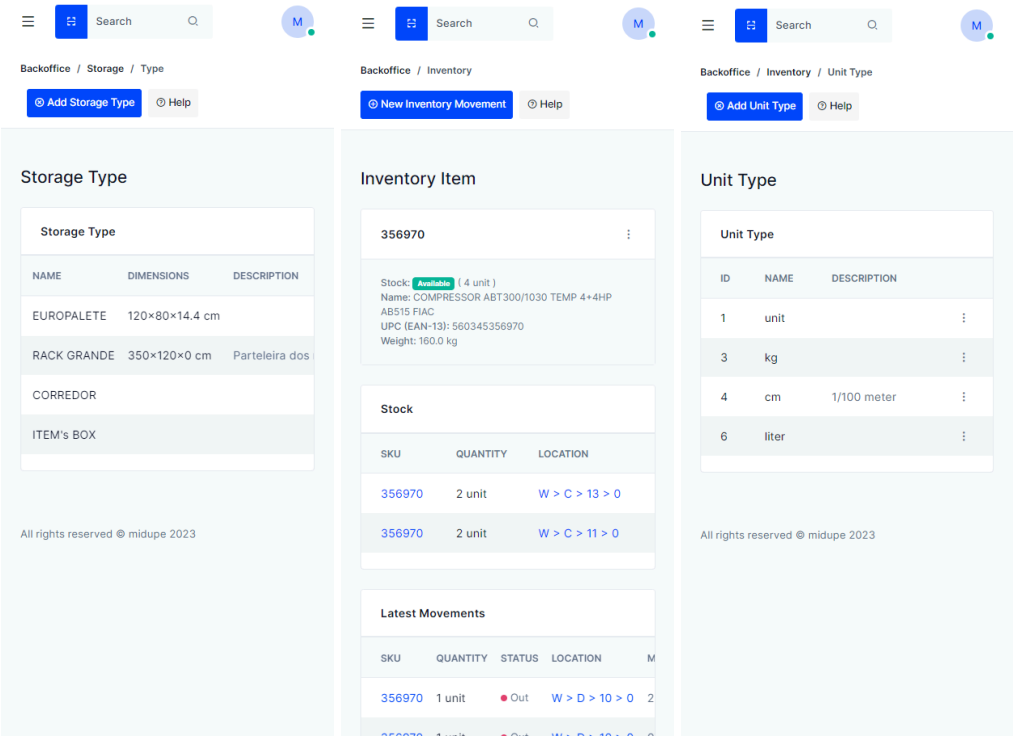

Fig. 13. Infinity Warehouse Backoffice (Mobile) - Storage Type (on the left); Inventory Item Details (in the center); Unit Type (on the right)

Chapter 8

Evaluating

8. Evaluating

With Action Taking complete, the system implemented was evaluated by testing the software with a pilot test.

A total of 8 practitioners, all belonging to the same organization and that work at the same warehouse, accepted to participate in the pilot test. The pilot test was performed in a real life environment, at a warehouse, during two months. The warehouse in which the test occurred, is used by the organization mainly as a backup storage and to restock the other warehouses.

The pilot test is divided into two parts, before and after implementing the developed software.

8.1. Before

In the first month, statistical data was recorded before implementing the software.

The organization provided a warehouse fails reports from July 2023, that, due to the organization's privacy policy, only included some indicators.

- Total number of warehouse fails: 122
- Number of products with stock, but no storage in the system: 23
- Number of products who have storage in the system, but no stock: 7
- Number of products who have storage in the system, but these storages do not exist: 9
- Number of products who have storage and stock in the system, but can’t be found: 83

The organization used custom software to manage the warehouse. This software didn’t control item units per storage and item movements, just recorded total stock units and the name of the storages for each item.

8.2. After

In the second month, data was collected with the software implemented and then the practitioners were interviewed to evaluate the solution.

Two weeks before the pilot test started (while still recording data for the “before” part of the pilot test), the software was configured and, in the warehouse where the tests occurred, the storage names were reformulated by the practitioners to avoid future errors and improve operations. This part of the test occurred in August (slower month) to avoid disrupting the working environment.

Once we had the before software implementation fails report with some indicators, we collected the data with the new system and same indicators. In this way, we could compare the impact of the implemented software, in reducing the warehouse failures.

This second part of the test was conducted in August 2023:

- Total number of warehouse fails: 4
- Number of products with stock, but no storage in the system: 0
- Number of products who have storage in the system, but no stock: 4
- Number of products who have storage in the system, but these storages do not exist: 0
- Number of products who have storage and stock in the system, but can’t be found: 0

These warehouse failures were detected on the last day of the pilot test while manually stocktaking. The warehouse manager later reported that the 4 items that have storages in the system, but no stock, was not a software error. Someone has picked the items and did not use the software to register the stock movement.

According to the authors Matt, C. et al. (2015), part of the digital transformation depends on people - is an alignment of different strategies, and cooperation between various people.

Other data collected from the system during the pilot test:

- Number of total inventory movements created: 276
- Number of inventory in movements created: 164
- Number of inventory out movements created: 112
- Number of total item quantities moved: 18218

8.2.1. Interviews

Were conducted interviews with the 8 participants in the pilot test to evaluate the solution.

Was used a semi-structured interview[24] type, with three phases. In the first phase of the interview the participants answered a set of questions about their demographic characteristics. The second phase included a group of closed questions and the third phase an optional open question.

Demographic Characteristics

In the first phase of the interview the participants answered the following questions about their demographic characteristics:

1. What is your age?
2. What is your education level?
3. What is your professional position?
4. How many years of experience do you have in the area?

The answers to these questions can be observed in the following table.

Tab. 5. Demographic information of interviewed participants

I) What is your age?	II) What is your education level?	III) What is your professional position?	IV) How many years of experience do you have in the area?
46	High School	Warehouse Manager	20+
46	Bachelor Degree	Sales Director	25

45	Pos-Graduation	Operations Director	15+
66	6th Grade	CEO	40+
51	9th Grade	Warehouse Operator	+-30
38	High School	Warehouse Operator	12
29	High School	Warehouse Operator	8
35	High School	Warehouse Operator	~10

Quantitative Evaluation

In the second phase of the interview, the solution was evaluated through a group of four questions. The questions were answered using the 5 point Likert with the points representing levels of agreement: 1- Strongly disagree, 2 - Disagree, 3 - Neutral, 4 - Agree, 5 - Strongly agree.

This phase has the purpose to validate this solution with the identified WMS limitations at the literature review (section 3.3) and in the diagnosing (section 5). The questions asked in this phase were:

1. What is your level of agreement with the statement that the Infinity Warehouse does not lack stock movement's traceability?
2. How strongly do you believe that the Infinity Warehouse does not require training and specialized workforce to operate the software?
3. How much do you agree with the statement that the Infinity Warehouse is not only worthwhile if an organization has a high stock volume?
4. To what extent do you believe that the Infinity Warehouse is not a high cost and a big investment?

The attributed scores can be visualized in the next figures.

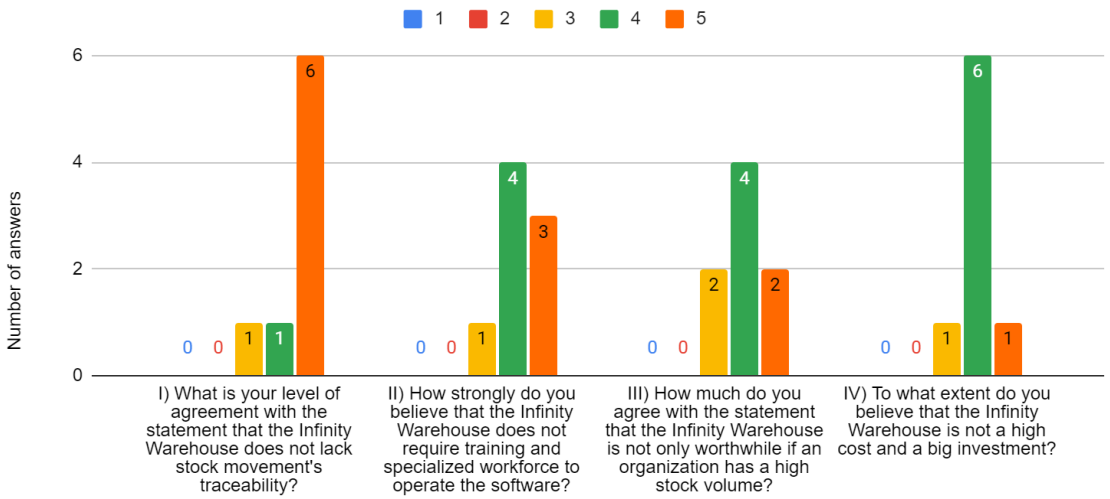

Fig. 14. Quantitative Evaluation Scores

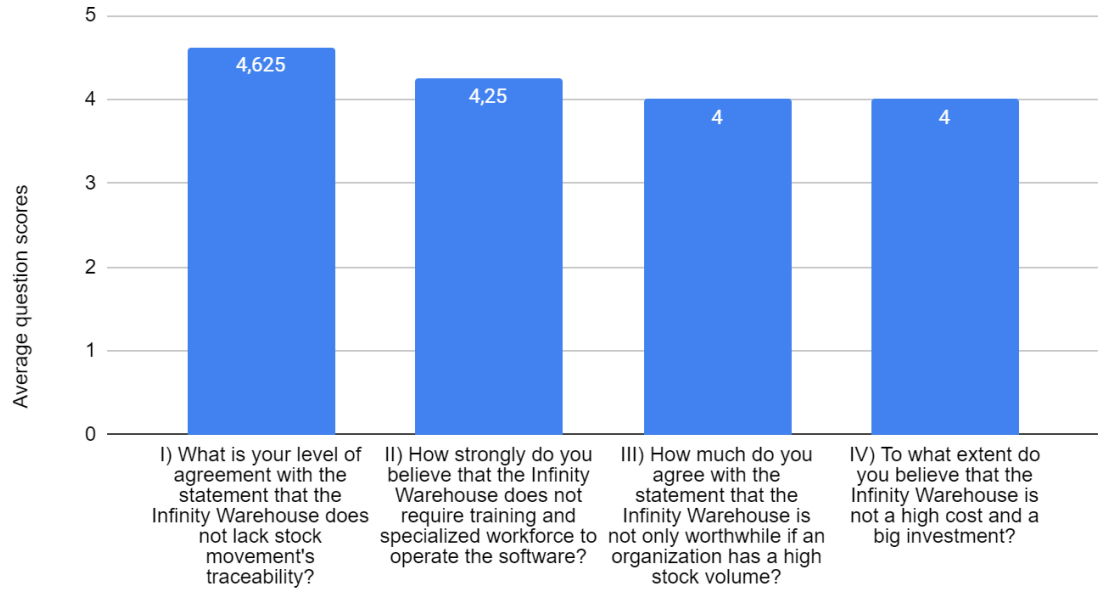

Fig. 15. Average Evaluation Scores

Discussion

The third phase - qualitative feedback - is an optional phase that allows the participants to generally, or specifically, criticize and to reason their scoring decisions. This phase, along with the previous analysis of the other phases, helps to analyze and discuss the results of the implemented solution.

Question 1 - What is your level of agreement with the statement that the Infinity Warehouse does not lack stock movement's traceability?

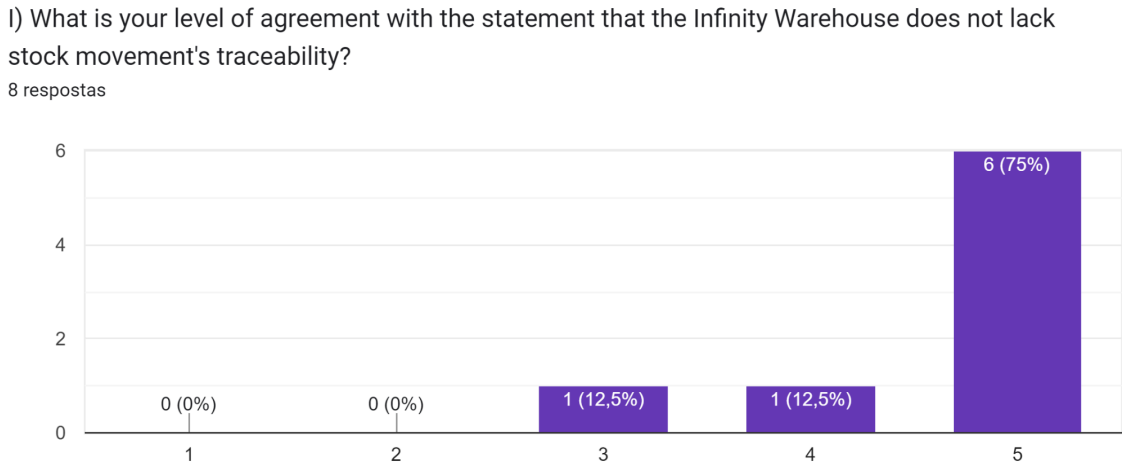

Fig. 16. First question of the second phase of the interview

The quantitative data from question 1 indicates a high level of confidence in the solution to effectively trace stock movements. The majority of the participants (6/8) gave the highest score in the Likert scale (5/5), one participant expressed a “Agree” response, and the other one a “Neutral” response. These answers suggest that most participants perceive the system as robust in stock traceability, but there might still be room for small improvements.

With the open-end response in the qualitative feedback phase, the participants manifested that the solution had a positive impact on stock control and accuracy, indicating that it plays a crucial role in maintaining inventory precision.

This question is absent of negative feedback and had the biggest average score (4.625/5) of all the questions asked to the participants.

In summary, the data reveals that the Infinity Warehouse system is generally perceived as effective in ensuring the traceability of stock movements, which is essential for efficient warehouse management. However, the responses also highlight the importance

of people in warehouse management, this means that people and the software must align and work together to get the best results.

Question 2 - How strongly do you believe that the Infinity Warehouse does not require training and specialized workforce to operate the software?

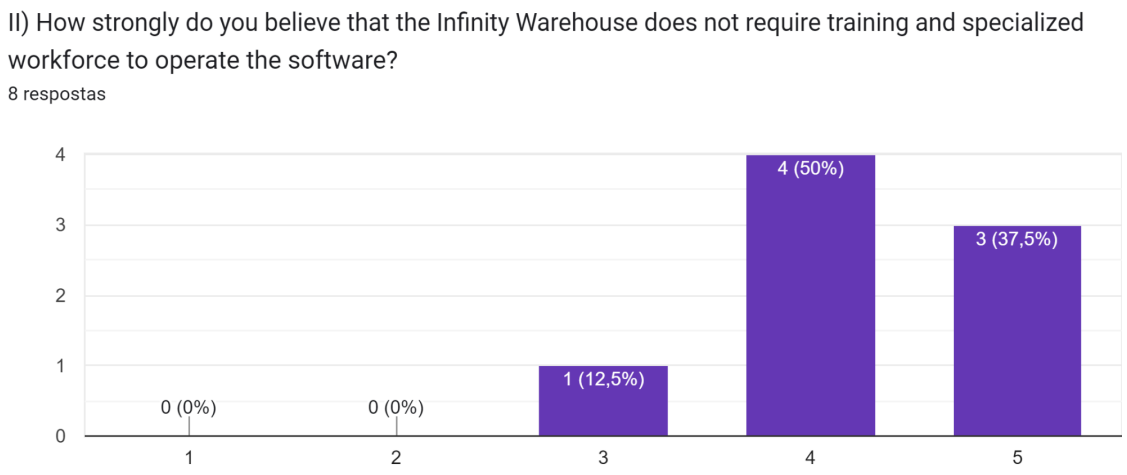

Fig. 17. Second question of the second phase of the interview

The quantitative data from question 2 reveals that most of the interviewees “Agree” or “Strongly Agree” that the solution does not require trained or specialized workforce to operate the software. This indicates that the participants consider that the software is user-friendly and does not strictly require training. On the other hand, the presence of a “Neutral” response might indicate that some training could be nice, but not mandatory, having in mind the majority of the answers.

The diversity of age, and education levels present in this interview can display a possibility of less ease with information systems for some participants. With this, some users could appreciate training to use the software.

Question 3 - How much do you agree with the statement that the Infinity Warehouse is not only worthwhile if an organization has a high stock volume?

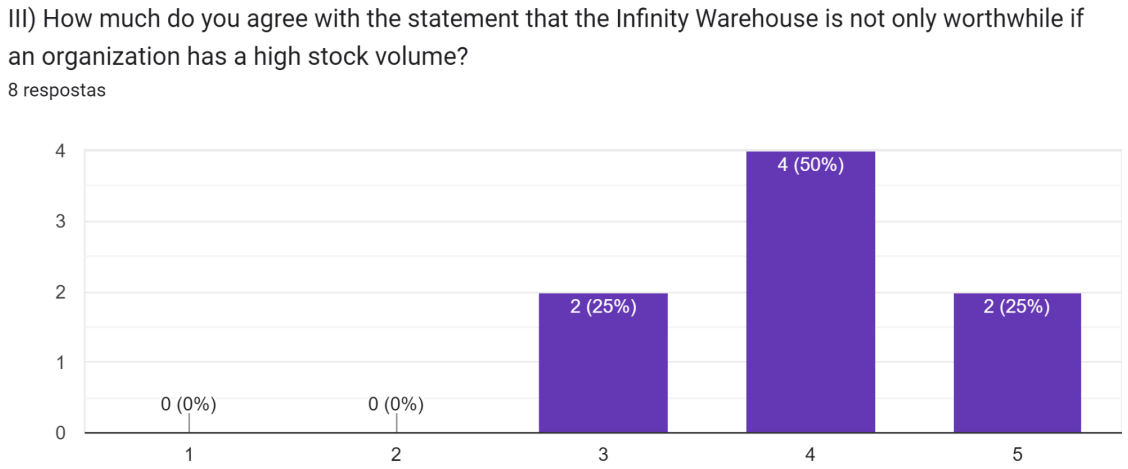

Fig. 18. Third question of the second phase of the interview

The third quantitative question got the most “Neutral” answers (25%), probably because of the unfamiliarity of these participants with the needs of warehouse management systems in other organizations.

Most participants “Agree” or “Strongly Agree” with the solution not being only worthwhile if an organization has a high stock volume. This indicates that the participants believe that the software is flexible and can be useful in different scenarios, including in organizations with less stock volume.

One of the goals of the development of the solution was to create a software as versatile as possible and to work anywhere. The data from this question translates that this goal could have been reached.

Question 4 - To what extent do you believe that the Infinity Warehouse is not a high cost and a big investment?

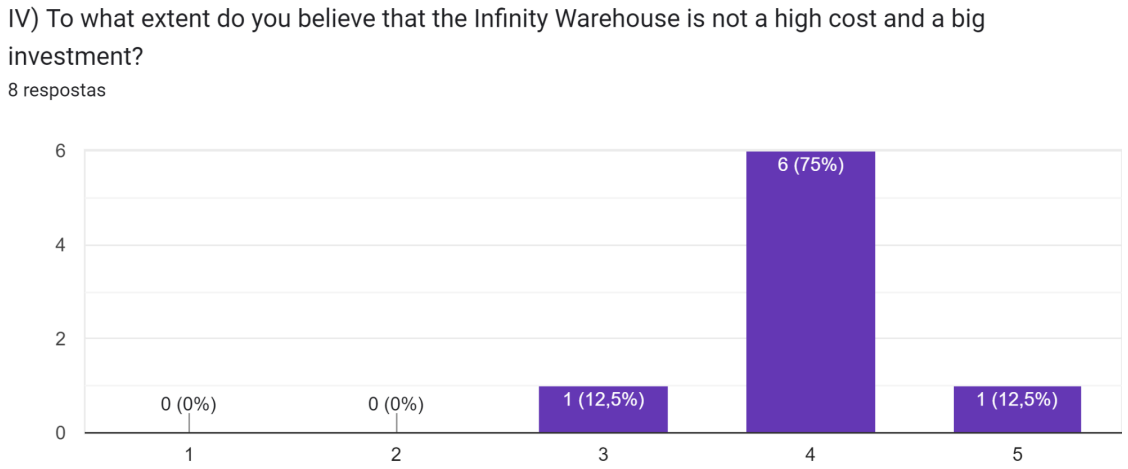

Fig. 19. Fourth question of the second phase of the interview

The quantitative data from question 4 indicates that the participants believe that the Infinity Warehouse is not a high-cost and big investment. This implies that these respondents see the software as a reasonably cost-effective solution. Participants evaluated the solution as being a good tool that allows them to control the warehouse, automate tasks, improve operations and workflows, while reducing warehouse errors and delivery times.

The one “neutral” response probably originated from the unfamiliarity with the costs and the investment of a warehouse management system.

Besides this being a pilot test, the solution was developed as a SaaS and is prepared to be sold as a subscription or pay-as-you-go. Being a SaaS there is no need for a costly enterprise server and specialized workforce to maintain the system, so it’s cheaper to organizations/individuals than other software solutions. This means that this solution does not require a big investment and is not high cost.

Chapter 9

Conclusion

9. Conclusion

At the end of this research work, real life problems (defined in the research problem section) have been reduced and the objectives have been accomplished, a software for managing warehouses (WMS) has been developed, but like any other software for sure it can be improved as will be described in the next paragraphs. Besides the importance of good software, in a digital transformation, people and operations are as important as any system. To successfully implement a new system that digitally transforms an organization, the operations must be reformulated and people must cooperate. Software is just part of a digital transformation. With the development of the warehouse management system it was concluded that the software without people's cooperation does not retrieve the best results.

Limitations of this research work start with the warehouse management systems not being a very popular subject, there are not many documents about it. Even though the results obtained in the literature review were sufficient, the research could be extended with a non-scientific literature review for more complete answers.

For future work the software can be deployed and put to test by integrating it in various real work environments in very distinct organizations, and must be continuously analyzed for improving it, this should allow it to adapt and extend the proposed software (defined in section 6.2) features to each real world scenario. During the time that I've worked in this dissertation I had the opportunity to visit different fairs, one of the most important was the LogiMAT Stuttgart fair, where I saw some of the newest innovations related to WMS that inspired me. One functionality that could be implemented in the future is multi picking, where the warehouse operators can pick multiple orders at the same time. Technology is always evolving, so should WMS.

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Annex

Annex 1 - Warehouse Fails Report - July 2023

Warehouse Fails Report - July 2023	
122	Total number of warehouse fails
23	Number of products with stock, but no storage in the system
7	Number of products who have storage in the system, but no stock
9	Number of products who have storage in the system, but these storages do not exist
83	Number of products who have storage and stock in the system, but can't be found

Date	SKU	Stock	Storage
03.07.2023	356325	1	Pg35.1
03.07.2023	359257	5	C7.3 PC51.2
03.07.2023	200464	10	
03.07.2023	348607	2	10E.5
03.07.2023	78791	2	A3.8 CXAMARELA
04.07.2023	342567	20	EXSUC 310.1
04.07.2023	344920	4	
04.07.2023	860008	10	PA33.2
04.07.2023	354999	7	00 24.3
04.07.2023	238602	200	4D.3 7D.2
05.07.2023	359441	3	D3.3
05.07.2023	359095	28	PD42.3 D3.2
05.07.2023	347338	33	18,1
05.07.2023	359440	51	D3.3 PD43.3.
05.07.2023	359030	0	PC43.3 C6.5
05.07.2023	240150	0	PC57.3
06.07.2023	235781	11	
06.07.2023	238573	27	2G.2 TOPO
10.07.2023	203555	2	

10.07.2023	200514	2		
10.07.2023	342890	3		12,3
10.07.2023	343457	4	1F.18	
10.07.2023	775216	25	8J.1	
11.07.2023	344057	5	B1.5*LOJA	
11.07.2023	347633	15		32,5
11.07.2023	204126	2	PC48.4	
11.07.2023	359701	6	PC46.1 RA166.36	
11.07.2023	200327	11	RD127.04 1F102	
11.07.2023	235002	7	PJ15.0	
11.07.2023	920810	10	RA41.02	
11.07.2023	342076	11	12.4 EX147	
11.07.2023	316943	19	50.3LADO	
11.07.2023	359521	25	D3.4 PC49.2	
12.07.2023	774300	2		
12.07.2023	238083	5	3E.2 PB18.0	
12.07.2023	347545	8		105,2
12.07.2023	346173	9	34.4LADO	
12.07.2023	342857	14		77,3
12.07.2023	491557	20	D5.4	
12.07.2023	359675	28	C6.6 PC53.1	
12.07.2023	274794	27		
12.07.2023	500300	0	PI26.2	
13.07.2023	346240	1	B1.4*LOJA	
13.07.2023	362000	1	PA12.1	
13.07.2023	240796	1	PG22.0	
13.07.2023	342654	10		201,2
13.07.2023	490327	29	D5.1 D5.2	
13.07.2023	359034	81	D1-4 PC43.2	
13.07.2023	359037	0	D1.4 PC44.2	

17.07.2023	275153	1	PD50.4	
17.07.2023	271200	100	E284.1	
17.07.2023	203552	6	PH24.0	
17.07.2023	343711	6		23,2
17.07.2023	359701	6	PC46.1	
17.07.2023	345147	6		
17.07.2023	310011	7		
17.07.2023	200327	11	RD127.04 1F102	
17.07.2023	346139	9	10A.5	
17.07.2023	343504	12		46,2
17.07.2023	238479	71	2D.2	
17.07.2023	990726	185		
17.07.2023	359908	324	PC43.2. D1.3	
17.07.2023	201605	577	D7.4	
17.07.2023	265059	0	PA13.0	
18.07.2023	922199	1	RA61.47	
18.07.2023	315728	9		2
18.07.2023	61717	35	PC41.2	
18.07.2023	61540	78	PC40.2 F5.3	
19.07.2023	775001	1	8H.2	
19.07.2023	79059	1		
19.07.2023	343321	1		
19.07.2023	79047	2	ex162	
19.07.2023	79172	2		
19.07.2023	79118	3		
19.07.2023	79146	4		
19.07.2023	929308	10	D7.4	
19.07.2023	79119	4	EX150	
19.07.2023	201066	22		
19.07.2023	775215	43	8J.1	

19.07.2023	359675	28	C6.6 PC53.1
19.07.2023	277001	1871	
20.07.2023	240382	13	
20.07.2023	927095	7	EX09.0 F152.2
20.07.2023	359034	86	D1-4 PC43.2
24.07.2023	272024	1	
24.07.2023	271200	100	E284.1
24.07.2023	343779	5	10A.3LADO
24.07.2023	347749	5	EXSUC2
24.07.2023	242357	8	PD40.3 EX50
24.07.2023	359521	25	D3.4 PC49.2
24.07.2023	238479	71	2D.2
24.07.2023	359901	157	PC42.2 . D1.4
24.07.2023	265063	0	PA14.0
25.07.2023	342890	1	12,3
25.07.2023	310218	1	PC44.5
25.07.2023	344886	4	
25.07.2023	342728	3	18,3
25.07.2023	PD7426150	9	11C.3
25.07.2023	343696	36	95.3 B1.3
25.07.2023	274794	26	LOJA
26.07.2023	359680	2	PC53.2 PH27.3
26.07.2023	347605	3	25,5
26.07.2023	238575	4	3C 3E.1
26.07.2023	343668	15	90,3
26.07.2023	242285	69	EX161
26.07.2023	265059	0	PA13.0
27.07.2023	203555	2	
27.07.2023	356383	3	RC33.8
27.07.2023	202015	3	

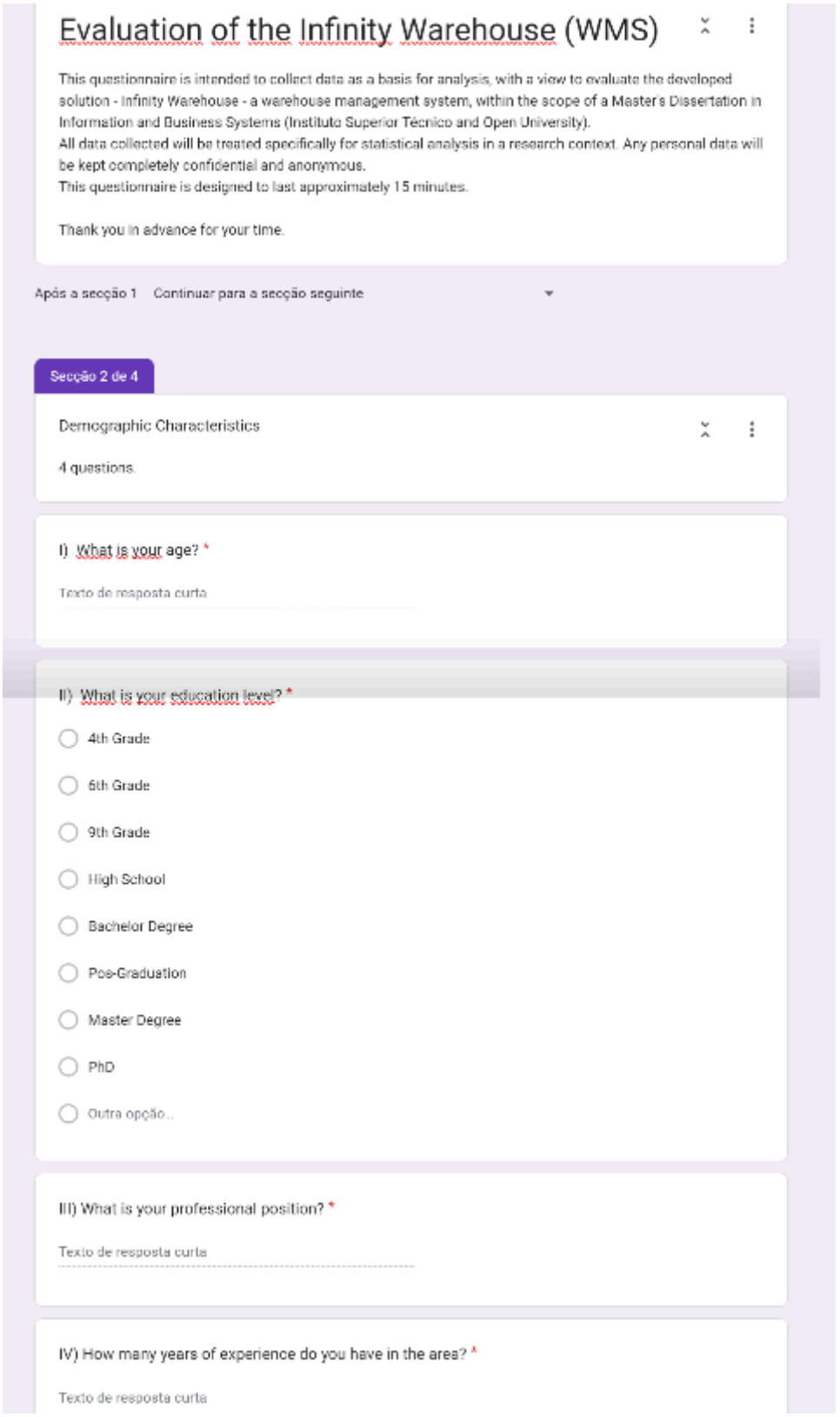
27.07.2023	239528	10	RA29.01 RA29.CX00
27.07.2023	490327	29	D5.2
27.07.2023	200636	21	EX69
27.07.2023	775216	44	8J.1
31.07.2023	347553	1	105
31.07.2023	238609	8	2F.5
31.07.2023	359390	8	PC49.2 C7.7
31.07.2023	235781	11	
31.07.2023	10916	16	C1
31.07.2023	76138	52	A5-5
31.07.2023	347716	47	EXSUC1 300.6
31.07.2023	76100	70	A5-5
31.07.2023	677690	104	C5 CHAO EX143 ATRÁS BALCAO

Annex 2 - Warehouse Fails Report - August 2023

Warehouse Fails Report - August 2023	
4	Total number of warehouse fails
0	Number of products with stock, but no storage in the system
4	Number of products who have storage in the system, but no stock
0	Number of products who have storage in the system, but these storages do not exist
0	Number of products who have storage and stock in the system, but can't be found

Date	**SKU**	**Stock**	**Storage**
31.08.2023	310007	9	WK14.2
31.08.2023	770205	6	WK17.0
31.08.2023	300626	8	WF19.0
31.08.2023	400162	1	WH14.0
- Someone did not use the system to create a stock movement.			
- Fixed on 09/01/2023			

Annex 3 - Survey



Evaluation of the Infinity Warehouse (WMS)

This questionnaire is intended to collect data as a basis for analysis, with a view to evaluate the developed solution - Infinity Warehouse - a warehouse management system, within the scope of a Master's Dissertation in Information and Business Systems (Instituto Superior Técnico and Open University).
All data collected will be treated specifically for statistical analysis in a research context. Any personal data will be kept completely confidential and anonymous.
This questionnaire is designed to last approximately 15 minutes.

Thank you in advance for your time.

Após a secção 1 Continuar para a secção seguinte

Secção 2 de 4

Demographic Characteristics

4 questions

I) What is your age? *

Texto de resposta curta

II) What is your education level? *

- 4th Grade
- 6th Grade
- 9th Grade
- High School
- Bachelor Degree
- Pos-Graduation
- Master Degree
- PhD
- Outra opção...

III) What is your professional position? *

Texto de resposta curta

IV) How many years of experience do you have in the area? *

Texto de resposta curta

Secção 3 de 4

Infinity Warehouse Evaluation

4 questions

Evaluation scale points (Likert):
1- Strongly disagree
2 - Disagree
3 - Neutral
4 - Agree
5 - Strongly disagree

I) What is your level of agreement with the statement that the Infinity Warehouse does not lack stock movement's traceability?

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

II) How strongly do you believe that the Infinity Warehouse requires training and specialized workforce to operate the software? *

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

III) How much do you agree with the statement that the Infinity Warehouse is only worthwhile if an organization has a high stock volume? *

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

IV) To what extent do you believe that the Infinity Warehouse is a high cost and a big investment? *

	1	2	3	4	5	
Disagree	○	○	○	○	○	Agree

Após a secção 3 Continuar para a secção seguinte

Secção 4 de 4

Qualitative Feedback

1 question

I) Write here any relevant comments about the Infinity Warehouse and the reason for your scoring decisions:

Parágrafo

Texto de resposta longa