TECNOLOGIAS
E ARQUITETURA

Augmented Reality on the factory floor
Use of AR technologies by maintenance teams in industrial environments / shopfloor

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Master in Digital Technologies for Business

Supervisor:
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“Que os tempos de estudante, para sempre façam parte da sua história”

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Resumo

A transformação digital tem sido uma prioridade para muitas empresas nos últimos anos, especialmente aquelas que operam no setor da indústria. Neste sentido, tecnologias disruptivas como a Realidade Aumentada (RA) têm sido cada vez mais utilizadas para melhorar a eficiência operacional, reduzir custos e aumentar a segurança em ambientes de chão de fábrica.

A utilização de RA na manutenção de equipamentos industriais é uma aplicação interessante desta tecnologia. Através da integração com sistemas de gestão de ativos, é possível fornecer informação relevante em tempo real às equipas de manutenção, permitindo-lhes tomar decisões mais informadas e realizar reparações mais rapidamente. Outras aplicações também estão em vigor, como a assistência remota a especialistas e fornecedores externos. Com a tecnologia RA, é possível compartilhar informações em tempo real com especialistas localizados em outras partes do mundo, permitindo que forneçam suporte especializado sem a necessidade de estarem fisicamente no local. Isto pode resultar numa resolução mais rápida de problemas e uma redução nos custos associados à contratação de especialistas externos.

Para além dos benefícios diretos em termos de eficiência e segurança, a utilização da RA pode também contribuir para a criação de uma base de conhecimentos operacionais. Ao registar informações de operação em tempo real, é possível criar um banco de dados que pode ser usado para formação de funcionários, melhorando o retorno dos investimentos.

O uso de tecnologias disruptivas como a RA pode trazer uma série de benefícios para as empresas que operam em ambientes de chão de fábrica e, ao integrar essa tecnologia com os sistemas de gestão e supervisão existentes, é possível melhorar a eficiência operacional, reduzir custos e aumentar a segurança. Adicionalmente, a RA pode também contribuir para a criação de uma base de conhecimento operacional, permitindo às empresas formar os seus colaboradores e reduzir o volume de negócios.

Nesta investigação iremo-nos focar num caso de estudo onde a utilização de tecnologias de RA reduz o tempo de inatividade dos equipamentos e permite à entidade manter uma operação eficaz.

Palavras-chave: Augmented reality; shop floor; Maintenance Team; Case study.

Abstract

The digital transformation has been a priority for many companies in recent years, especially those operating in manufacturing sectors. In this sense, disruptive technologies such as Augmented Reality (AR) have been increasingly used to improve operational efficiency, reduce costs, and increase safety in factory floor environments.

The use of AR in industrial equipment maintenance is an interesting application of this technology. Through integration with asset management systems, it is possible to provide relevant real-time information to maintenance teams, allowing them to make more informed decisions and perform repairs more quickly. Other applications are also in place, like remote assistance to specialists and suppliers. With AR technology, it is possible to share information in real time with specialists located in other parts of the world, allowing them to provide expert support without the need to be physically pre-sent. This can result in faster problem resolution and reduced costs associated with hiring external specialists.

In addition to the direct benefits in terms of efficiency and safety, the use of AR can also contribute to the creation of an operational knowledge base. By recording real-time operation information, it is possible to create a database that can be used for employee training and reducing turnover.

The use of disruptive technologies such as AR can bring a series of benefits to companies operating in factory floor environments and by integrating this technology with existing management and supervision systems, it is possible to improve operational efficiency, reduce costs, and increase safety. Additionally, AR can also contribute to the creation of an operational knowledge base, allowing companies to train their employees and reduce turnover.

In this research we will focus on a real case study where the use of AR Technologies reduced equipment downtime and allowed the company to maintain an effective operation.

Keywords: Augmented reality; shop floor; Maintenance Team; Case study.

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CHAPTER 1

Introduction

Industrial operations are composed by several elements, being the maintenance department one of them, so before anything else, it is important to define it. Paulo Samuel de Almeida, states in his book (Samuel de Almeida, 2018), that Industrial maintenance management has as main purpose: the reduction of production interruptions due to equipment failure, anticipation of potential failures and elimination of eventual anomalies in the operation of the machines on the factory floor.

Currently, the area of Industrial Maintenance is key to all operations and can contribute decisively to the economic viability of organisations (Amari, 2016). It is also an area that still suffers from disinvestment (financial, human, or even technical resources) and is not always given its due relevance (Eswaran & Bahubalendruni, 2022). The maintenance management is not a "mere" way of maintaining equipments, but a key aspect for the future wellbeing of the general industries (Bardhan, 2016). This can be achieved through the introduction of new technological means that allow facilitating the technician's operation, as well as modernizing the function itself (Nascimento, 2020). The purpose of this digital transformation will be to allow seeing maintenance management as an investment in an organised management system, capable of guaranteeing the fulfilment of the equipment's functions, minimising the cost of its life cycle.

Industrial maintenance management needs to be seen as a strategic area for an organisation. It is this area, that guarantees the safety of the shop floor and that maintains the proper pace of operations, preferably without delays or waste that could create impacts on the company's profit (Bevilacqua, 2017). So, what are the main problems that can be avoided with industrial maintenance management?

The maintenance management team in any industry faces a variety of challenges and issues that can impact the efficiency and profitability of the business. By addressing and solving some of these challenges, industries can obtain efficiency gains, like efficient resource structure, control of operational costs and compliance with standards and regulations (Park, 2013).

Providing assistance, simulation and support, immersive technologies such as Augmented Reality (AR) and Virtual Reality (VR) have revolutionized industrial processes, and affordable AR/VR devices and software algorithm enhancements have led to their universal adoption (Eswaran & Bahubalendruni, 2022).

Industrial implementation of AR/VR focuses on training semi-skilled workers to improve task efficiency and these solutions can add virtual information on real-world objects to support users. AR also offers users sensory modalities including touch, hearing and visibility (Eswaran & Bahubalendruni, 2022).

This research aims to demonstrate how the use of AR technologies can be used as a promoter for digital transformation, particularly in a manufacturing environment within the maintenance teams and how, currently, it can be used to guarantee efficiency and improve overall performance. The research applies a practical demonstration, where the use of AR helps maintenance teams on their day-to-day functions, solving issues and providing a quick, more safe and effective way to operate, preventing prolonged stoppages, thus improving the shop floor turnout and creating knowledge base for future applications, and also providing information for future worker training.

To assist on the understanding of this document, the same is organized into several chapters, each serving a specific purpose in the overall study. The structure of the dissertation is as follows:

Chapter 1 – Introduction: This chapter provides an overview of the research topic, outlining the context and significance of the research.

Chapter 2 – State for the art: This chapter provides a context to better understand the challenges that maintenance management teams are facing and what technologies can be used to solve them.

Chapter 3 – Research Methodology: This chapter justifies the Case Study as the preferred method to demonstrate the use of AR technologies in factory floor, by maintenance teams.

Chapter 4 – Presentation of the case study: This chapter presents the implementation an AR solution on factory floor, by the maintenance technicians and the evaluation of its effectiveness. It includes all organisational contexts and resumes the issues and problems that will be addressed by the technical solution.

Chapter 5 – Conclusion: This chapter provides a summary of the research, reflecting on the objectives and findings of the study. It discusses the implications of the findings, the limitations of the research, and provides suggestions for future research

CHAPTER 2

State of the art

2.1. Maintenance Management

According to the report “Digital Industrial Revolution with Predictive Maintenance” (CXP Group, 2018), as shown on Figure 1, European companies, the foremost hurdles lie in dealing with unplanned downtime and emergency maintenance, which accounts for a significant 90% of the difficulties. Additionally, the ageing of IT infrastructure and technology poses a considerable obstacle, making up 88% of the challenges. A critical aspect of effective asset management involves the connection of modern assets and the subsequent analysis of data, which accounts for 76% of the obstacles faced. Retrieving asset data presents its own set of challenges, contributing to 40% of the difficulties. Furthermore, connecting legacy assets and obtaining necessary data proves to be a hindrance, comprising 29% of the obstacles. Managing maintenance cycles and ensuring their efficiency constitutes an additional challenge, representing 24% of the difficulties. The connection of assets in remote locations adds to the complexity, accounting for a notable 24% of the obstacles. Real-time asset monitoring remains a crucial aspect but poses a challenge, comprising 22% of the difficulties. Lastly, effective collaboration with suppliers proves to be a vital, yet challenging component, accounting for 20% of the obstacles faced. Overcoming these multifaceted challenges require a strategic and integrated approach to ensure successful asset management practices.

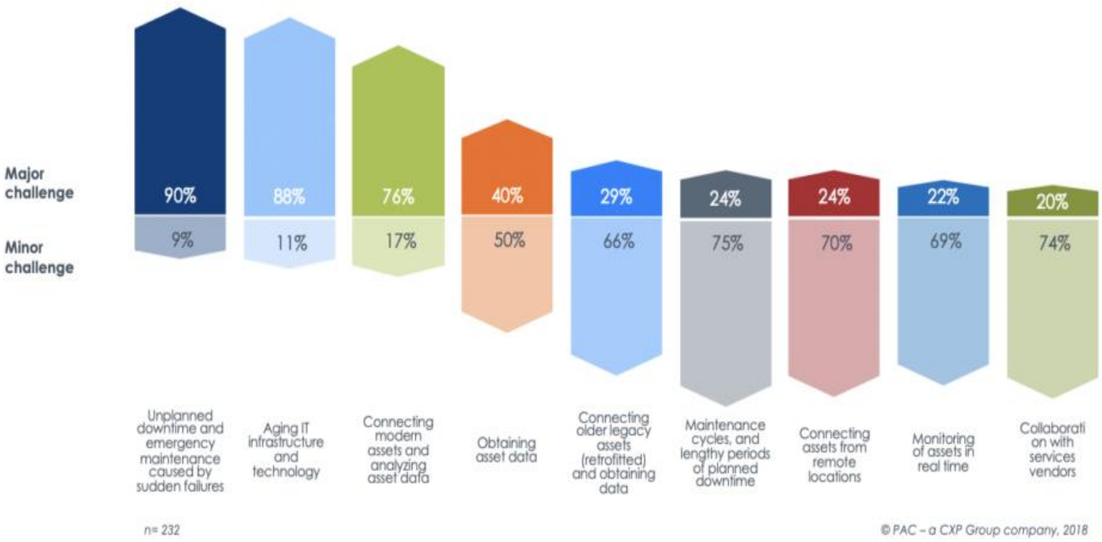


Figure 1 - Digital Industrial Revolution with Predictive Maintenance (CXP Gtoup, 2018)

This can be confirmed by analysing the GE Oil & Gas report on The Impact of Digital on

Unplanned Downtime (General Electric Company, 2016), that estimates the cost of unplanned downtime across all companies in €164K/hour - in 2016 that figure shot up 60% to €260K/hour and states that, on average, organisations are seeing technician turnover of 31.5%. Additionally, an increasing number of service technicians are outsourced.

Table 1 shows the analysis of the current market numbers (Statista, 2023) regarding budget and maintenance efficiency:

Table 1 - market numbers regarding budget and maintenance efficiency (Statista, 2023)

Category	**Percentage of Companies/ Factories**
Budget Allocation for Cleaning & Maintenance Equipment/Materials (US)	
1-20% of Operating Budget	35.79%
21-40% of Operating Budget	42.5%
41-60% of Operating Budget	16.78%
61-80% of Operating Budget	3.36%
More than 80% of Operating Budget	1.57%
Maintenance Budget for Factories	
Less than 5% of Annual Budget	17%
5-10% of Annual Budget	29%
11-15% of Annual Budget	24%
More than 15% of Annual Budget	17%
Uncertain about Budget (McLeman, Smith, & Parker, 2021).	13%
Outsourcing of Maintenance Operations (Facilities)	
Percentage of Facilities Outsourcing	Approximately 88%
Average Percentage of Tasks Outsourced (McLeman, Smith, & Parker, 2021)	23%
Weekly Maintenance Hours in Factories	
More than 40 hours a week (McLeman, Smith, & Parker, 2021).	44%

The maintenance management team in any industry faces a variety of challenges and issues that can impact the efficiency and profitability of the business (Ismail, Khater, & Zaki, 2017). Some of these challenges include the breakdown of assets in the middle of the production process, resulting in delays and potentially lost revenue. Prolonged periods of "downtime" can also occur, causing significant disruption to operations. Additionally, the waste of raw materials and other resources such as energy and people can lead to increased costs (Roy, Stark, Tracht, Takata, & Mori, 2016).

Non-programmed corrective maintenance can also result in unforeseen costs, impacting the bottom line. Accidents at work are another concern, as they can lead to injuries, lost productivity, and potential legal issues. Possible anomalies can also create environmental impacts, harming the planet and the reputation of the business. Loss of quality is another issue that can arise, as the breakdown of quality standards in final products can lead to customer complaints, returns, and ultimately, loss of contracts. Delays in deliveries can also be a challenge, as can complaints and returns of goods.

A good shortlist of these challenges is presented by (Albukhitan, 2020) on his research, presented on Table 2.

Table 2 - Transcript of Table 1. List of Top Challenges Faced by Manufacturing for DT (Albukhitan, 2020)

Challenges	Description
Traditional Processes	With everything connected digitally, it is challenging to rely on traditional paper-based processes and operate in silos; there is no longer a place for manual, time-consuming processes.
Resistance to Change	Where does the organization sit on change? Most employees are so entrenched in traditional processes of daily duties that, when the time comes to improve processes and incorporate new technology, they resist. They see change management as a challenge to their roles/responsibilities, at best, and a threat to their job security, at worst. Many people resist change to their work environment since it affects their comfort zone and since digital disruption is experienced as a threat to many employees in manufacturing.
Legacy Business Mode	Manufacturers have become very comfortable in their legacy systems.
Limited Automation	Many repetitive, redundant and time-consuming tasks are performed manually by a task force that consumes a huge number of man-hours which results in high cost.
Budget restrictions	A substantial investment is required to lead a manufacturing facility through the digital transformation journey. The benefits are multiple, both short and long-term, but it is important to remember that each company is different, especially when it comes to systems of revenue and cost.
Absence of relevant knowledge	Without relevant knowledge, the introduction of technology alone is not enough to make it work. Enhancing employees' knowledge is an essential part of integrating digital technologies into manufacturing
Inflexible company structure	The introduction of industrial internet of things (IIoT) to a manufacturing site is similar to the other transformation task and it is more than just small improvement. There is a need for the organization to have new technologies and business models to work properly. Although this may be scary, it can lead to a lot of positive results as the organizational structure is reset and retested, creating an opportunity to improve employee status and other improvements.
Security	Cybersecurity is a major concern for any digital transformation project since the operation network and systems will be exposed to the internet.

Many of these appear simultaneously, creating barriers to the digitalization process. It is very common to see that "Resistance to Change" and "Traditional Processes" are always on the mind of business owners. As Christoph Pierenkemper and Jürgen Gausemeier (2021) mention in his paper (Pierenkemper & Gausemeier, 2021), *(…)" One frequently cited reason is that there is only a vague idea of which digitalization solutions from the wide range of existing approaches are actually promising for the specific situation. Due to this uncertainty, companies also have difficulties in drawing up a superior plan in the form of a strategy. They need support to ensure their long-term competitiveness. (…) "*.

By addressing and solving some of these challenges, industries can obtain efficiency gains. A correct industrial maintenance management can provide very relevant advantages for the industrial unit like the ones included on Table 3.

Table 3 - Advantages of a correct maintenance management

Advantage 1: Efficient resource structure	With a well planned and executed maintenance management, the plant can have a stable operational flow, without unforeseen interruptions.
	The correct communication between the Production Manager and other operational teams helps define the best time and format for maintenance.
	Execution of complete and detailed schedules is an efficient resource management tool.
	Processes like Kanban can aid technicians and operators in visualizing the operation structure.
Advantage 2: Control of operational costs	Careful maintenance planning allows better cost forecasting, including the purchase of parts and consumables needed to keep equipment running.
	It facilitates managing stocks to cover unscheduled stoppages during the manufacturing process.
	Correct maintenance management helps maintain predicted costs without unexpected financial burdens.
Advantage 3: Compliance with standards and regulations	Organizations with certifications (e.g., ISO 9001) need to ensure compliance with processes to retain their differentiating status.
	Compliance extends to internal standards and legal obligations like environmental and occupational safety standards.
	Ensuring equipment is in optimal condition is integral to the certification process, guaranteeing quality and benefiting the organization.

As seen above, Industry management teams still restrain investments on new technologies, which poses a challenge to all stakeholders. This often leads to underperforming environments and prevents factory efficiency. As we'll see in the next chapter (2.2), not all challenges have the same resolution and there are some where technological renewal and transformation will not be the best answer. On the other hand, there are challenges where this strategy will be the most appropriate, so the key will be to provide teams with knowledge so that they can make informed decisions.

As we'll see in chapter 2.3, technology can be a great help in solving some of the challenges addressed, and one of them is AR.

2.2. Types/formats of industrial maintenance

After identifying some of the problems and the current state of the art, it is important to distinguish the different types/formats of industrial maintenance. According to (Nunes, Santos, & Rocha, 2023), five types can be identified:

a. **Preventive maintenance -** Type of maintenance aimed at preventing possible failures and stoppage of machines/equipment, through periodic reviews involving the exchange of parts, lubrication, cleaning, and equivalent processes. An important characteristic is also the performance tests, to evaluate the General Efficiency of the equipment - typically defined by OEE (Overall Equipment Efficiency), one of the most popular KPI in manufacturing. This was first introduced by Seiichi Nakajima (1988) in the late eighties in Nippondenso - a Toyota supplier - and later became a pillar of the Toyota production system’s continuous improvement strategy).

b. **Predictive maintenance -** Predictive maintenance consists in the systematic application of analysis techniques, using supervisory means, practices and methodologies with the aim of predicting and acting in advance on possible failures in production lines. Predictive maintenance works through a culture of constant monitoring (adopted by all operators and maintenance technicians).

c. **Detective maintenance -** Unlike predictive maintenance, this type of maintenance consists in "in fact" inspection of equipment on the shop floor, which can then be complemented with the help of computerised systems that test equipment components to find faults at an early stage that have not been noticed by the operators.

d. **Corrective maintenance -** As the name implies, this type of maintenance aims at correcting a problem/anomaly after it has occurred. Actions will be triggered to repair the equipment(s) after failure. If the failure does not present risks to the production or to the operator, it can be solved via scheduled corrective maintenance, with scheduled date and time, whereas unscheduled corrective maintenance is coducted if the equipment becomes inoperative or offers risks to the operation.

e. **Total Productive Maintenance (TPM) -** Maintenance process that, in the processes of conservation and maintenance of equipment, involve all employees. This process involves constant training and is based on the idea that all workers should participate in day-to-day maintenance, rather than passing all responsibility to maintenance technicians. The objective of this type of maintenance is to never stop production, to produce without defects, to eliminate unplanned stoppages and to create environments without accidents at work. If we analyse how these types of maintenance strategies are being implemented, we can see that different approaches, achieve different results.

This next table (Table 4 – (McLeman, Smith & Parker 2021), demonstrates how these types of maintenance can be addressed and how different are the strategies followed.

Table 4 – (McLeman, Smith & Parker 2021)

Maintenance Approach	**Percentage of Companies**
1. Preventive Maintenance	88%
2. Run to Failure Approach	52%
3. Preventive Maintenance with Analytical Tools	40%
4. Reliability-Centered Maintenance (RCM)	22%
Association with CMMS	**Percentage of Companies**
1. CMMS Associated with Increased Productivity	80%
Preferred Maintenance Strategy	**Opinion**
1. Best for Reducing Downtime and Failure Probability	Predictive Maintenance
2. Best for Overall Equipment Effectiveness	Reliability-Centered Maintenance (RCM)

- Eighty-eight percent of industrial facilities follow a preventive maintenance strategy; 52% have a computerized maintenance management system (CMMS) and 51% use a run-to-failure method.
- Forty-six percent of facilities allocate up to 10% of their annual operating costs to maintenance processes; 41% devote more than 10% of this budget to maintenance. The average facility spends 33 hours each week on scheduled maintenance.

- Production equipment, rotating equipment (motors, power transmission, etc.) and fluid power systems (air, hydraulic, etc.) are the three areas where facilities dedicate the most maintenance support, followed by material handling equipment and internal electrical distribution systems.
- Eighty-eight percent of facilities outsource some or all maintenance operations; the average facility outsources 23% of their maintenance operations. Leading causes for outsourcing are an existing agreement with a manufacturer or supplier, lack of skills among current staff and lack of time/manpower to dedicate to maintenance.
- Maintenance teams are mostly trained on basic mechanical and electrical/electronic skills, as well as safety. Other types of training include motors, gearboxes, bearings and lubrication.
- The most common technologies facilities use to monitor and/or manage maintenance are CMMS, in-house created spreadsheets/schedules and automated maintenance schedules.
- The leading cause of unscheduled downtime within industrial facilities remains aging equipment, followed by mechanical failure, operator error and lack of proper training. More than half of facilities are planning to upgrade their equipment to decrease unscheduled downtime.
- The top challenge for improving maintenance at industrial facilities is aging equipment. Other obstacles include a lack of understanding of new options and technologies, lack of resources or staff and outdated technology.
- Forty-eight percent of facilities allow the use of connected devices when monitoring production equipment for machine data capture, analysis and improvements across maintenance.

Industries focus their investments mainly on computerized maintenance management system (CMMS), which currently are being included on the ERP (Enterprise Resource Planning) software's, and that all investments (on maintenance areas) are still focused on people, rather than transforming technologies, like Augmented Reality (AR).

By analysing the report (MRO, 2018), 94% of companies consider Maintenance, Repair, and Operations (MRO) extremely or somewhat important to avoid downtime, follow lean practices, and manage preventive maintenance. Among the surveyed companies, 37% handle all MRO tasks manually, while 27% have automated 25-50% of the tasks, 21% have automated 50-75%, 9% are predominantly automated, and 6% are fully automated. In the context of industrial maintenance, over 60% of companies associate preventive maintenance with improved productivity, reduced downtime, and increased safety.

The importance of determining the type of maintenance a particular factory has is decisive when considering the type of technology to adopt. This is why it was important to present this list of maintenance types.

2.3. Technology in Maintenance Processes

As previously mentioned, the digitalization of processes that came with the designation Industry 4.0 (Bartodziej, 2016) have brought technologies that can greatly help in the management of industrial maintenance (Leitão, Colombo, & Stamatis Karnouskos, 2016).

Augmented Reality (AR) (Manuri & Sanna, 2016) , Big Data, Machine Learning, artificial intelligence, immersive technologies are today decisive for the smart factory to work "full throttle". These technologies allow the integration of information from various sectors, in real time, which guarantees much more agility, organisation and productivity. Meanwhile, the data being verified at the time of its collection allows the maintenance manager to make assertive decisions, knowing the status of the equipment in use. With mobile maintenance management software, the person in charge can follow the calendar of activities from any point of the production line.

In this way, the whole process becomes more reliable and secure, and the tasks on the factory floor flow in a stable and continuous manner. This is because current technologies enable many data and indicators to be processed in real time, providing just-in-time interpretations and analyses. With these technologies, it is possible to create a value offering, based on maximizing the operation of assets and simultaneously increasing the performance and knowledge of workers operating around industrial maintenance. This offer is achieved using Intelligent Networks, data-based information and using immersive experiences.

- Real-time monitoring, predicting problems in critical assets, providing them with intelligence to generate actions, ensuring the right intervention at the right time, reducing unplanned failures, and ensuring proactive maintenance actions.

- Increasing the capabilities of maintenance technicians, supporting their performance, and providing information of exactly where and what to do, considering their work orders.
- Accelerating training and immediate access to critical knowledge, boosting diagnosis and resolution the first time, always focusing on the technician's safety

Digital technologies have played a critical role in the rapid growth observed by various Industry sectors (J.Gimeno, P.Morillo, JM.Orduna, & M.Fernandez, 2013). The emergence of immersive Virtual Reality (VR) and AR technologies (X.Wang, S.K.Ong, & A.Y.C.Nee, 2016) has particularly revolutionised the way business is conducted in a wide range of sectors of the economy, such as Energy and Oil & Gas, Infrastructure projects, Manufacturing, Healthcare, Aviation, Education & Training, Tourism and so on.

It then becomes relevant to identify the different types of immersive technologies, because generically, for the sake of simplicity, it is common to refer to two essential components of immersive technologies such as VR and AR, it will be useful to understand what is meant by three basic terms commonly used, namely Virtual Reality, Augmented Reality and Mixed Reality (MR).

Virtual Reality (VR) is an immersive or computer-simulated multimedia environment that mimics physical presence in the imaginary world. VR also allows the user to interact with that world. VR can artificially create sensory experiences, which may include sight, hearing, touch, and/or movement.

Augmented Reality (AR) provides a live view of the physical 'real world' where digital elements are overlaid or superimposed by computer-generated graphics, sound, haptics, or GPS data. AR can also provide new ways to interact with digital information within a user's field of vision - including voice control, head movement, hand gestures and touch.

Mixed Reality (MR) (P.Milgram & F.Kishino, 1994) is an enhanced version of AR in which the user can interact with virtual objects that are superimposed on real objects and can navigate in this mixed environment.

A good representation of these concepts is shown on Figure 2.

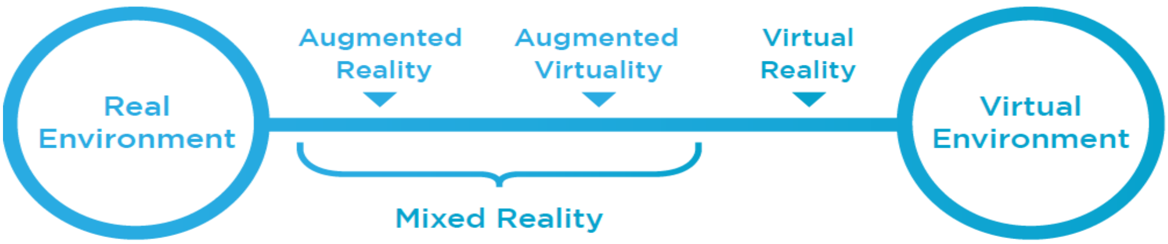


Figure 2 - Mixed Realty by (P.Milgram & F.Kishino, 1994)

The main reasons for using VR technologies are that they offer a rich, immersive, and interactive experience, creating a novelty effect that ensures engagement and curiosity in adoption, fostering emotional connections, and providing access to unique experiences depending on the content library. Additionally, VR technologies provide realistic experiences, exposing users to rare and unique situations through simulations, all within a zero-risk environment. They also facilitate learning, based on exploration and experimentation, reducing learning curve times, enabling learning by "trial & error" minimizing errors, and allow the ability to reinterpret. Moreover, VR technologies enable the analysis of user behaviour and offer several gains in operational efficiency.

On the other hand, the main reasons for using AR/MR technologies include their ability to provide performance support, focusing on function effectiveness, reducing onboarding and live training times, ensuring real-time activity quality control, offering contextualized support and specialized remote assistance, overall reducing activity time, overcoming language barriers, and integrating with other applications such as ERP, mobile apps, CRM, and more.

Additionally, AR/MR technologies deliver a user-centered experience by enabling hands-free processes and incorporating scripts based on users' experiences rather than solely relying on theoretical models. Furthermore, they allow for the analysis of user behaviour and provide several gains in operational efficiency.

As the name "Virtual" suggests, the headsets used for Virtual Reality allow viewing only the "virtual" World, while the real environment is completely blocked from the user's view. When the user uses VR, he/she is taken into the midst of an entirely new and imaginary environment that he/she can interact with. Figure 3 shows examples of devices suitable for VR applications.

Figure 3 - Representation of VR devices.

Among the popular brands of devices for AR/MR are Microsoft "Hololens" developed by Microsoft, "HMT-1" developed by a company called RealWear and "Blade" developed by Vuzix representative few; there are several more popular brands. All these devices give the user an AR compared to Smartphones, where users interact spatially using a 2D screen. These devices are suitable for the outdoors and can be worn along with hard hats or helmets. Figure 6 shows examples of devices suitable for MR/AR applications.

Figure 4 - Representation of AR/MR devices.

The next table (Table 5 - AR/VR devices advantages & disadvantages) represents a comparison between the most known devices, whit some advantages and disadvantages.

Table 5 - AR/VR devices advantages & disadvantages

Criteria	Microsoft HoloLens 2	Magic Leap 1	Vuzix M4000	RealWear HMT-1
Display Type	Waveguide	DLP Lightfield	Waveguide	N/A (Head-mounted display)
Field of View	~52° horizontal	~50°	~20°	20° diagonal (Equivalent to 7" tablet at 14")
Resolution	2048 x 1080	1280 x 960	854 x 480	854 x 480
Display Size	N/A	N/A	N/A	0.49" Microdisplay
Tracking	Inside-out	Inside-out	GPS, GLONASS, IMU	N/A (Head-tracking)
Battery Life	2-3 hours	3 hours	8 hours	8 hours
Weight	~566g	~316g	~120g (with batteries)	380g
Operating System	Windows 10 IoT Core	Lumin OS	Android	Android
Use Cases	Manufacturing, Healthcare, Field Service	Enterprise, Spatial Computing	Field Service, Remote Assistance	Industrial Maintenance, Training
Advantages	- Advanced hand and eye tracking	- Impressive spatial awareness	- Wide range of compatible apps	- Rugged design suitable for industrial settings
	- Comfortable to wear for extended periods	- Lightweight design for all-day use	- Long battery life	- Hands-free operation allows for multitasking
	- Extensive app ecosystem for various industries	- Wide range of potential enterprise applications	- Robust build suitable for industrial environments	- Voice control enables hands-free operation
disadvantages	- High price point	- Limited field of view	- Limited field of view	- Limited display size may impact usability
	- Limited field of view	- Limited app ecosystem	- Limited app ecosystem	- Limited field of view
	- Limited app ecosystem	- Price may be prohibitive for some businesses	- Relatively heavy compared to other options	- Limited resolution may affect clarity

It is relevant to mention that Smartphones are also a tool relevant to AR use cases, so it is important to complement this comparison with an android smartphone typically used by technicians (the Samsung Galaxy was the chosen device). Table 6 show this comparison.

Table 6 - AR/VR devices advantages & disadvantages (smartphone included)

Criteria	Microsoft HoloLens 2	Magic Leap 1	Vuzix M4000	RealWear HMT-1	Samsung Galaxy S21 Ultra
Display Type	Waveguide	DLP Lightfield	Waveguide	N/A (Head-mounted display)	N/A (Smartphone Display)
Field of View	~52° horizontal	~50°	~20°	20° diagonal (Equivalent to 7" tablet at 14")	N/A
Resolution	2048 x 1080	1280 x 960	854 x 480	854 x 480	Depends on model
Tracking	Inside-out	Inside-out	GPS, GLONASS, IMU	N/A (Head-tracking)	ARCore
Battery Life	2-3 hours	3 hours	8 hours	8 hours	Depends on usage
Weight	~566g	~316g	~120g (with batteries)	380g	N/A
Operating System	Windows 10 IoT Core	Lumin OS	Android	Android	Android
Use Cases	Manufacturing, Healthcare, Field Service	Enterprise, Spatial Computing	Field Service, Remote Assistance	Industrial Maintenance, Training	General
Advantages	- Advanced hand and eye tracking	- Impressive spatial awareness	- Wide range of compatible apps	- Rugged design suitable for industrial settings	- Large, high-resolution display for immersive AR
	- Comfortable to wear for extended periods	- Lightweight design for all-day use	- Long battery life	- Hands-free operation allows for multitasking	- Powerful processor for smooth AR experiences
	- Extensive app ecosystem for various industries	- Wide range of potential enterprise applications	- Robust build suitable for industrial environments	- Voice control enables hands-free operation	- Access to ARCore for diverse AR experiences
Disadvantages	- High price point	- Limited field of view	- Limited field of view	- Limited display size may impact usability	- Limited to smartphone form factor
	- Limited field of view	- Limited app ecosystem	- Limited app ecosystem	- Limited resolution may affect clarity	- Limited battery life may require frequent charging
	- Limited app ecosystem	- Price may be prohibitive for some businesses	- Relatively heavy compared to other options		- Limited field of view may restrict immersion

The choice of the type of equipment is crucial to the success of transformative projects, but factors such as cost, adaptability, "hands-free", resistance and the ability to integrate with other software already in operation must also be considered.

Two other important aspects with AR/VR solutions, particularly when talking about industry and factory floor use cases (as the one addressed in by this document), are the integration capability with mobility software tools and the ability not to be a "hindrance" to the technician who will be using it.

The software aspect is also important to take into account. Since most factories use SAP ERP (integrates various business processes such as production planning, inventory management, procurement, and order processing. It provides real-time visibility into operations, enabling better decision-making and resource allocation. The module for Manufacturing Execution System (MES): SAP MES helps streamline shop floor operations by providing tools for monitoring, tracking, and controlling manufacturing processes. It enables real-time data collection, production monitoring, and quality management to improve efficiency and quality), it is important to detail some of the current available software that guarantee its integration with the device.

- **Neptune Software** - is a low-code app development platform primarily focused on creating SAP-integrated applications.
    - strong contender for businesses with a significant SAP footprint and a need for rapid application development
- **OutSystems**: OutSystems is a popular low-code development platform that allows you to create, deploy, and manage custom enterprise applications quickly and efficiently.
- **Appian**: Appian offers a low-code automation platform that enables businesses to build powerful applications and workflows with minimal coding.
- **Mendix**: Mendix is a low-code platform that allows users to create web and mobile applications using drag-and-drop components and model-driven logic.
- **Kony Quantum**: Kony Quantum is a low-code platform for building enterprise-grade applications across various devices and platforms.
- **Microsoft Power Apps**: Microsoft Power Apps is part of the Microsoft Power Platform, offering a low-code solution for building custom business applications, integrations, and workflows.
- **Zoho Creator**: Zoho Creator is a low-code application development platform that allows users to build custom applications for their business needs without coding.
- **Quick Base**: Quick Base is a low-code platform that enables users to create customized business applications and workflows to streamline processes and improve productivity.
- **Salesforce Lightning Platform**: Formerly known as Salesforce App Cloud, this platform offers low-code tools for building custom applications and integrations on the Salesforce platform.

- **AppSheet (by Google Cloud)**: AppSheet is a no-code platform acquired by Google Cloud that allows users to create mobile and web applications using data sources like Google Sheets, SQL databases, and more.
- **Kintone**: Kintone is a low-code platform that enables teams to create and customize business applications for various use cases, including project management, CRM, and workflow automation.

Finally, one important aspect of all technical implementations on factory floors related to communications. How can we effectively develop projects that are increasingly dependent on data connectivity?

Data connectivity on the shop floor poses numerous challenges due to the complexity of industrial environments and the diversity of equipment and systems involved. One significant challenge is interoperability, as the different machines and systems often use proprietary protocols or standards, making it difficult to integrate and exchange data smoothly. In addition, harsh factory operating conditions, such as high temperatures, dust and electromagnetic interference, can interfere with wireless communication and degrade signal quality, leading to connectivity problems. Ensuring the security and privacy of data transmitted on factory networks is another major concern, especially as cyber threats become increasingly sophisticated. In addition, old equipment and outdated infrastructure may not have built-in connectivity features, requiring adaptation or additional hardware to enable data collection and transmission. To overcome these challenges, robust solutions that address interoperability, environmental factors, security and the integration of legacy systems are needed to unlock the full potential of data-driven information and optimisation in plant operations and most of this solutions are expensive, creating barriers to invest. One solution is creating Industrial Internet of Things networks (IIoT) based on Wifi 6, or adopt a strategy to create IoT Gateways, scattered around the shop floor and acting as information aggregators. In this model, there is no need to invest in access points and a structured network, since communication is carried out from the machines to the gateways and these, via mobile cards, send all the information to the central systems. This communication can even be secured so that it is not available on the internet and, as it uses LTE/GSM communications, it has guaranteed security and encryption.

2.4. Critical Thoughts

As mentioned above, the challenges that industries face are many, and there is no "one size fits all" approach, but it is certain that the way forward is through Digital Transformation. It is also certain that in some cases this process can be quite daunting, since it involves resources (financial, human and technological) that most of the times have to be outsourced, but that cannot be a deterrent for change, and this is precisely the awareness this case study tries to demonstrate. It applies a practical demonstration where the use of AR can help maintenance teams on their day-to-day functions, solving issues and providing a quick, more safe and effective way to operate, preventing prolonged stoppages, thus improving the shop floor turnout and creating knowledge base for future applications, also providing information for future worker training.

There is no single approach to address maintenance issues within factories, so this case study is just one possible solution that hopes to add to the body of knowledge already in place. It operates in a specific context and indicates that, by applying a correct maintenance management strategy, supported on an appropriate technology, it is possible to obtain efficiency gains that will justify a generic adoption of a digital transformation process in a factory shop floor.

Within this subject, the state of the art is not closed, and it is always evolving, so there is always room for something more, and that is what we will try to do with this research.

CHAPTER 3

Research Metodology

3.1. Case study methodology

Yin (2009) defines case study as "(…) *an empirical inquiry which investigates a phenomenon in its real-life context* (…)". Also, as Arya Priya (Priya, 2021) states, in a case study research, several methods of data collection are used, as it involves an in-depth study of a phenomenon.

It must be noted, as highlighted by Yin (Yin, 2009), a case study is not a method of data collection, rather is a research strategy or design to study a social unit.

Gary Thomas (Thomas G. , 2015) also wrote that "(…) *Case study is not a methodological choice but a choice of what is to be studied … By whatever methods, we choose to study the case. We could study it analytically or holistically, entirely by repeated measures or hermeneutically, organically or culturally, and by mixed methods – but we concentrate, at least for the time being, on the case*. (…)".

The essential components of a case study design encompass: (a) the study's intended objective; (b) the nature of research chosen, contingent upon whether it is exploratory, explanatory, or descriptive in nature; (c) the research inquiries posed; (d) the selection between a singular case investigation or multiple cases, influenced by the study's intent, research queries, and available resources like personnel, finances, and time; (e) the epistemological foundations that guide the case study's trajectory in the respective field; (f) an inclusive review of existing literature; (g) the process of sampling; (h) the techniques employed for gathering data; (i) the scrutiny of collected data; and (j) the coherent and effective presentation of analysed data, aimed at enriching our understanding.

By asking specific questions like, "how can we help operations in the manufacturing sector to become more efficient?" and "how can we use technology to achieve it?" it was clear to the researcher that this was the most suitable methodology to apply, describing the field to study, research questions, method of data collection and data analysis.

Taking all this in consideration, a case study was shown to be the best way to demonstrate the application of a predetermined technique, to solve a specific problem, in a specific industry.

Using Gary Thomas's (Thomas G. , 2015) classification diagram (as showed in Table 7), it is easier to demonstrate what investigative path a case study may take.

Table 7 - Kinds of case studies - simplified (Gary Thomas)

Subject	**Purpose**	**Approach**	**Process**	
Special or outlier case Key Case Local Knowledge case	Intrinsic Instrumental Evaluative Explanatory Exploratory	Testing a theory Building a theory Drawing a picture, illustrative Descriptive Interpretative Experimental	Single or Multiple	Nested Parallel Sequential Retrospective Snapshot Diachronic

The subject and the case study purpose were specific, so this method was chosen because it was the most effective way to demonstrate that the use of technologies, like AR, assisting the maintenance department of an industry, can be used to reduce equipment downtime, increase team efficiency, and to create content for a future knowledge library, allowing the company to maintain its production at higher levels. In short, the case study was the preferred method for answering the research question “Augmented Reality on the factory floor – how the use of AR technologies by maintenance teams in industrial environments / shopfloor can help the overall efficiency”.

CHAPTER 4

Case Study

4.1. Industry and Organizational context

This research will demonstrate a case study for a digital transformation on a factory shop floor, that was performed in a specific industry , that processes tobacco leafes. So, it is relevant to contextualize the industry and the organization on itself.

According to (Clancy, 2013) and (Thomson & Wilson, 2017), the tobacco industry is mostly a worldwide industry, with well-known brands and multinational organizations.

The industry can be seen in terms of the transferring of profits from the sale of tobacco products in poorer countries to shareholders in richer countries (Mlinarić, Schreuders, Graen, & Lessenich, 2020) . Except for a few state monopolies, businesses that are dependent on tobacco sales seek to increase their assets and the profits on the capital invested. In some countries, the laws for business companies and corporations require that the company officials must act to maintain and increase profits.

(Thomson & Wilson, 2017) indicate that a small number of companies dominate the global tobacco industry, selling over 70% of the total tobacco volume sold. Tobacco manufacture and marketing increasingly requires economies of scale and large investments in brand development. Tobacco companies face increasingly effective lawsuits, the development of international law to control their activities, and the possibility of more attractive nicotine consumption alternatives.

World tobacco sales are now relatively static after decades of growth. Tobacco industry markets are growing in the developing world, where women are increasingly targeted by the industry. Smuggled tobacco may account for over 30% of all cross-border tobacco trade.

The presented case study was made for one of the biggest companies. The factory plant first opened on the middle of the 20th century. In addition to producing specific tobacco products for the european and international markets, it is one of the major manufacturing facilities in the EU today. It also exports semi-finished tobacco products to other businesses and affiliates.

Continual investments in the plant, the use of continuous improvement approaches, and dedication to attaining excellent outcomes have been essential to boosting goods' manufacturing quality, production capacity, and competitiveness.

Production volume at the factory has more than tripled in the past 20 years, thanks to an average yearly investment of 15 million euros.

4.2. Current problems – case study maintenance teams

For this case study, most of the challenges described in the previous chapters are also present in the factory and its maintenance team identified them very clearly. We can summarize them on Table 8:

Table 8 - Case study challenges and current issues

Priority issues	Id.
Reduce equipment downtime	1
Problems with inadequate OEE	2
On-time response to corrective maintenance	3
Training and knowledge transfer	4
Shop floor accidents	5
Technician access for specific applications	6
Inadequate access to on-time information	7
Outdated data	8

4.3. Applied Solution

Following and applying the Gary Thomas (Thomas G. , 2015) methodology, presented on CHAPTER 3, these were the steps taken to develop the practical case study.

a) Research Design

For the construction of the case study, several meetings were held with the maintenance teams. The first meeting involved the top maintenance managers, followed by meetings with the teams (section chiefs and technicians). Information was then gathered through shopfloor observation, documentation (in paper format) shared by the technicians, and questionnaires were passed to the teams, in order to gather information on the main issues (see "asset management and performance management" questionnaires included in the ANNEXES).

b) Sampling

The case study focused specifically on optimizing the technical maintenance teams on the factory floor, so the selection criteria for participants were predefined. The sample used consisted of 25% of the total maintenance team. All members were male, with varying levels of seniority in the company (20% with less than 2 years, 40% with less than 5 years, and 40% with over 10 years) and different levels of education (35% with technical vocational training, 25% with high school education, and 30% with university degree or equivalent). Since there are maintenance shifts defined for the operation (two shifts per day and a third shift is added when operations need a 24-hour production cycle), it was also important to guarantee responses from technicians from all shifts to determine the current working methods (with evidence from day-to-day operations).

c) Data Collection

Data collection was based on floor observation, documentation (in paper format) shared by the technicians (factory methodologies and rules), and by meetings/interviews (see "asset management and performance management" questionnaires included in the ANNEXES, from which the necessary data for the quantitative analysis that served as the basis for the case study was extracted.

d) Data Analysis

After collecting the information, the data were processed based on a matrix of functions vs. hours worked vs. expected results to determine the study base and define the relevant indicators for the case study.

Function.

Type of maintenance - Predictive/Corrective.

Type of technician.

Impact on operation (in hours and parts costs).

e) Validity and Reliability

The interviews were conducted in two separate sessions, by two different interviewers, and the results were compared - According to J.M. Moreira (Moreira, 2004), an instrument (questionnaire) is considered to have good reliability when the obtained results are precise or reliable, meaning they vary relatively little from one occasion or context to another. Otherwise, we can infer that the reliability of the obtained results refers to the consistency of the overall results. A conclusion can be made that the same test, applied twice to the same subjects, under the same conditions, will yield very similar results.

f) Ethics

Full anonymization of all names, contacts, internal methodologies in the factory and all other data not relevant to this case study, was assured.

All development and integrations with Neptune and SAP were performed jointly with the Axians Portugal, Digital Consulting development team. The Mock-up video (showed on 4.3.1) was also made in coordination with Axian team.

g) Limitations

The limitations were those originated by technological issues, like access to SAP ERP (for real time information on the machine telemetry). Nevertheless, the data obtained were still valid and relevant for the case study.

4.3.1. Detailed approach

To provide a deeper understanding of the case study, a High-Level design diagram is presented on Figure 5.

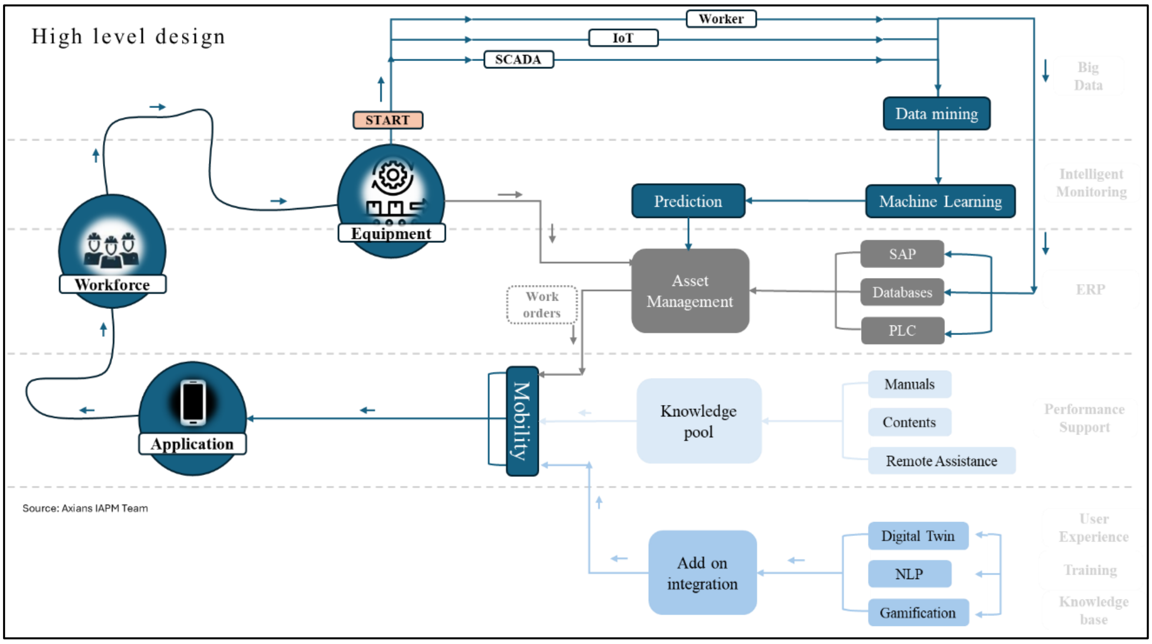


Figure 5 - Case Study High-Level Design

In detail, the business requirement was aligned with the research question - "Augmented Reality on the factory floor – how the use of AR technologies by maintenance teams in industrial environments / shopfloor can help the overall efficiency". The main requirements were that the solution worked on existing devices (and not deploy any new hardware for the field technicians to use), that it could integrate natively with SAP ERP (already in place) and that could provide information that users could rely on, in a quick and accessible way. Then, the key performance indicators were defined, as indicated on Table 8 - Case study challenges and current issues. As for system components (and Interactions), the main one was the Neptune Software (since it is a software designed to simplify the development process for creating Fiori-like applications that run on SAP systems, such as SAP ERP, SAP S/4HANA, and SAP BTP). All other required components (Machine schematics, Smartphones & SAP) already existed. So, as technology, Neptune DXP SAP Edition was the choose low code application. This version enabled the team to create applications using a visual drag-and-drop user interface, without the need for extensive coding. It provided a set of pre-built templates and UI components that are already optimized for SAP systems, allowing us to quickly create applications that adhere to SAP's UI design guidelines. It also provided seamless integration with SAP systems, allowing access and manipulation of SAP data, directly from the application interface.

As a deployment Strategy the project involved the successful installation of Neptune DXP - SAP Edition on a SAP NetWeaver 7.x ABAP web application server. This implementation was executed seamlessly, on a standalone system specifically designated for Neptune DXP - SAP Edition. No additional components were required beyond the ABAP web application server. Moreover, for the management of mobile applications developed with the App Designer, SAP Afaria was utilized as part of SAP's comprehensive mobile platform. Throughout the project, it was observed that it was a typical operational environment. The full project was designed so that fifty Neptune users utilized resources (equivalent to that of a single WebDynpro user), demonstrating efficient resource allocation and optimization within the system. In terms of mobile client operation systems, the minimum requirements were defined (iOS: 7 or higher, Android: 7 or higher).

The project successfully implemented the Neptune DXP - SAP Edition, leveraging its prominent feature, the App Designer. This low-code Integrated Development Environment (IDE) utilizes the UI5 framework to efficiently develop and manage Neptune Applications.

The implementation of Neptune DXP - SAP Edition showcased its seamless integration with SAP systems, leveraging the SAP Internet Communication Framework (ICF) for HTTP traffic with minimal abstraction. Through the utilization of Data Provider Classes, Neptune established direct access to SAP data, ensuring swift data transfer without reliance on the SAP OData layer, although this layer remains available if needed. The connection between the frontend and backend was facilitated by the Neptune ABAP Interface, enabling the frontend to efficiently utilize data types from the ABAP backend through a single HTTP call, thereby enhancing communication efficiency and system interoperability, guaranteeing the required speed of information to the final user. This was the hey feature that allowed the field technician to have quick and reliable data (as showed on the weblink on chapter 4.3.1). One other feature was the ability to have “offline capabilities”, for mobile use. Since it allowed that all structures and tables were enabled for offline use, ensuring system-wide data consistency and allowing end-users to work uninterrupted if there were connectivity issues.

As part of the project, the implementation of Neptune applications was seamlessly extended to end users through the integration of the Neptune Launchpad. Serving as a centralized platform, the Launchpad facilitated the organization and execution of applications and resources, structured within a top menu hierarchy and presented through screens containing multiple sections and individual tiles. These tiles, designed as cards, offered specific actions to launch Neptune Applications or trigger URLs and SAP transactions, with access to each tile being highly customizable through standard SAP roles and authorization objects. Additionally, a mobile variant of the Launchpad, known as the Mobile Client, was developed to operate natively on Android or iOS devices (its highly responsive nature ensured smooth functionality on mobile browsers with the possibility of enabling Progressive Web App (PWA), providing offline functionality and app-like features without the need for traditional mobile app downloads.

The Mobile Client, designed as a native hybrid app, capitalized on device hardware capabilities and was configured through the Cockpit, with native Android and iOS installation files built using the Neptune Mobile Build Service to guarantee that the application worked with all screen sizes and device types.

In terms of security and quality assurance it was guaranteed that there were no personnel data gathering. Neptune Software's privacy practices reflect global principles and standards on handling personal information. It was also guaranteed that no personal data was collected. All authentications, authorizations, and encryptions, to ensure the protection of sensitive SAP data were compliant with SAP security standards. One relevant component was the security regarding the mobile devices, so since Neptune can also work as Mobile application manager, the installed Neptune DXP server, which runs as an add-on inside the SAP server, has been further improved with CORS implementation for added security (CORS is a security mechanism built into clients (browsers and WebViews) to only allow secure cross-origin requests and data transfers between clients and servers). It was also guaranteed that all application access was made via user authentication and VPN traffic (between mobile and the server was in place) – this feature was made available since the mobile SIM cards were in a private VPN).

Scalability and Maintainability is also easily achieved since Neptune DXP - SAP Edition encompasses far more than just the Low-Code App Designer and the Launchpad. It stands out as the sole SAP UI5 and ABAP-based solution that provides comprehensive support across every stage of the SAP Fiori application development lifecycle (SDLC) and this very important because the project will support future SAP upgrades, since the Neptune components are fully independent.

An important part of the project was to guarantee that the IT department could be autonomous on managing the solution, so it was included in the design, a possibility to deploy a feature for the Neptune DXP, called Cockpit. Cockipit serves as a centralized platform tailored to address the diverse needs of users, facilitating the management and monitoring of applications developed with the App Designer. It allows admins to seamlessly oversee, optimize, and administer Neptune Software applications throughout their lifecycle. With this it was possible to encompass application deployment, enabling effortless deployment across various environments and facilitating version control and change tracking. Real-time application monitoring capabilities empower administrators to track performance metrics, usage statistics, and error rates, leveraging dashboards and analytics for insightful observations and optimization opportunities. Additionally, robust application security features, including user authentication, role-based access control, and integration with corporate authentication systems, ensure data integrity and confidentiality.

The Cockpit further streamlines application configuration management, facilitating effortless adjustments across different environments for database connections, API integrations, and other settings. Comprehensive lifecycle management functionalities encompass versioning, release management, and rollback capabilities, enabling developers to orchestrate updates, patches, and releases efficiently. In summary, the Neptune Software Cockpit emerges as an indispensable tool, offering a holistic approach to managing and monitoring applications within the Neptune Software DX Platform, empowering users to deploy, monitor, secure, and oversee the entire lifecycle of Neptune Software applications seamlessly.

To better understand the Case study, a demonstration was created, using a "Mock-up", which can be seen in this web link - https://www.youtube.com/watch?v=7s5PrJJW9hE (which is property of Axians Portugal, Digital Consulting) and it is used to fully demonstrate the potential of the technology. All company footage and references were removed, to guarantee complete anonymity and no image of the shop floor was used.

Despite existing several devices for MR applications, as show in Figure 6, it was mandatory (for the protection of the financial business case, and, to minimize impact on the number of devices used by the maintenance teams) that the solution should rely on existing devices. So, the decision to use smartphones was a logical one.

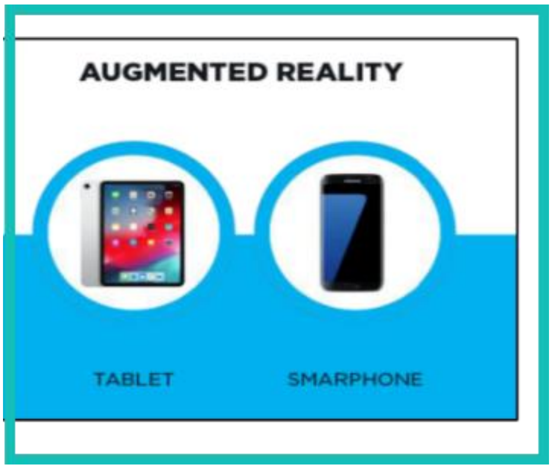
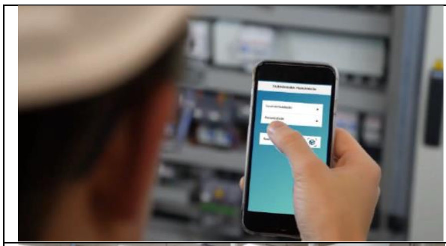
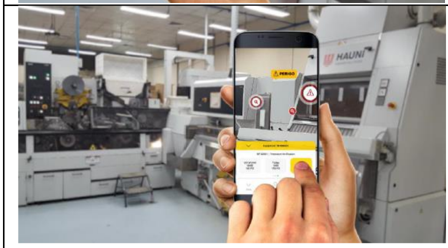


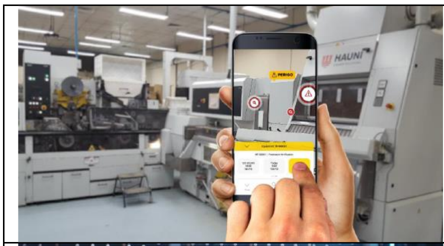
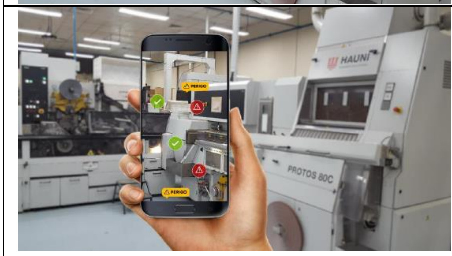
Figure 6 - Representation of used AR/MR devices

Following this process, a video mapping of the shop floor was made, and was then integrated in the Neptune Software solution, so that the virtual representation of the hardware was accurate.

A script was then made, to better demonstrate all steps implicated on a maintenance process. This can be seen on the next table (Table 9).

Table 9 - Demo/Mock-up Script

	Animated photo of a maintenance technician receiving his daily maintenance order on his Smartphone his daily maintenance order. Launches Augmented Worker feature.
	The Service Technician points the smartphone at the Hauni machine and the representation of digital of digital elements in Augmented Reality about: - Points/Areas to be intervened (in this case oil change) - Danger Areas.
	By clicking on one of the areas to intervene you can have access to: - Date of last oil change. - Videos and manuals of procedures contextual to the point in question and maintenance routine in question. - Contact of the specialist indicated for this routine.

	The Maintenance Technician after the oil change, inserts into the AR solution. The record of the operation, being immediately available in SAP.
	We can see the update of the SAP record in the control center.
?	How to streamline an unforeseen downtime process? (we'll demonstrate Scenario 2 described on slide 8).
	Alarms sound and an emergency icon appears.
	The Maintenance Technician points the smartphone to the equipmentwith the anomaly in question and opens the ticket, registering and attaching at the same time the following evidence: -Pictures. -Videos. - Audio Narration. - Notes.
	The Technician has access and executes the contact to the Specialist and Supplier (Evidence and differentiated contact accelerate the efficiency of first-time fixes and if there is displacement to the ground all the logistics is suitable for intervention)
	Machine operational again in a fraction of the time.
	Display with the main benefits and impact of the solution on the customer's business.

Note: This *mock-up* is property of Axians Portugal, Digital Consulting.

This case study used a smartphone for the field technician, integrated with SAP ERP by the Neptune software

4.4. Results

As identified on Table 8, the case study addressed several issues, so it is now relevant to detail how each one was addressed and solved.

Reduce equipment downtime – ID 1
As previously mentioned, one of the big issues, in terms of industrial maintenance challenges is the impact that equipment downtime has in the total outcome of the operation. On this case, the study focused on a specific equipment (e.g., Hauni device), that has an estimated production of 12,000 units per minute. With 2 daily shifts, these are the maximum production levels. • 720,000 units per hour -> 2 shifts (8h each) = 5,760,000 units per shift / 11,520,000 2 shifts. The average downtime for this equipment was around 5 hours in case of corrective maintenance, and 2h for preventive maintenance (which occurs two times a month). By focusing on this problem, the applied solution reduced the downtimes to the following numbers. From 5h to 2 hours - by type of corrective maintenance • With an impact of 5h, we have a total of 2.160.000 units/shift that are produced -> representing a 63% reduction in daily production. • By reducing the intervention time to 2h, we have a total of 4.320.000 units/shift -> which corresponds to a 25% reduction in daily production. • In terms of daily production, the impact will be a reduction of 7,200,000 units, to a reduction of 2,880,000. From 2h to 1h - by type of preventive maintenance. • With an impact of 2h, we have a total of 4.320.00 units produced/day -> which represents 2.880.000 units in daily production. • By reducing the intervention time to 1h, we ensure that the daily production is 10.080.000 units compared to the previous production of 8.640.000 (reducing the impact from 25% to 13% in production/day.

Problems with inadequate OEE – ID 2

One of the issues is the time each machine is down, due of an inefficient maintenance resolution and which in turn, undermines the OEE rates. So, by addressing the downtime issues of the equipments, the solution allows for a more optimized level of production, making it more effective and allowing operations to have a better control of the shop floor key performance indicators.

We can see, on Figure 7 that, by using this solution, the overall efficiency increases, and the reduction of machine downtime is directly proportional with a production increase.

							Estimated values			considering 330 production days
Maintenance types	Units/Min	Units/hour	Units/Shift (8h)	Units/day (2 shifts)	dif%	dif #units/day (2 shifts)	production price cost (20 units bundle)	Total €	dif €/day (2 shifts)	Annual values
Normal	12 000	720 000	5 760 000	11 520 000			0,10 €	1 152 000 €		345 600 000 €
Corrective 5h	12 000	720 000	2 160 000	4 320 000	-63%	-7 200 000	0,10 €	432 000 €	-720 000 €	129 600 000 €
Corrective 2h	12 000	720 000	4 320 000	8 640 000	-25%	-2 880 000	0,10 €	864 000 €	-288 000 €	259 200 000 €
Preventive 2h	12 000	720 000	4 320 000	8 640 000	-25%	-2 880 000	0,10 €	864 000 €	-288 000 €	259 200 000 €
Preventtive 1h	12 000	720 000	5 040 000	10 080 000	-13%	-1 440 000	0,10 €	1 008 000 €	-144 000 €	302 400 000 €

Figure 7 – Calculations for 1 machine.

With this solution, the Production manager can have a better control on the OEE of each equipment and solve overall production problems in the factory.

On-time response to corrective maintenance – ID 3

By using this solution, we can give better information, with real time data, to the maintenance technician. With quick access to the problem at hand, they can better access the issue and its quick resolution. Addressing this access guarantees a reduction on resolution time (from an average of 5h to 2h in terms of a corrective maintenance ticket) and assures the maintenance technician a complete overview, reassuring him on the best way to solve a specific problem. This is directly related with issue ID 6.

Training and knowledge transfer – ID 4

The solution allows for a better Knowledge Management, because the information is recorded, and history is available for future analytics (to help in predictive maintenance, for example). Also, it facilitates training sessions and by using VR techniques we can use the models created to address the most common types of failures. This also allows knowledge to be maintained within the company and not only with the older technicians, guaranteeing an effective knowledge management.

Shop floor accidents – ID 5
By using AR technology, the solutions provide to the maintenance technicians a better understanding of where the problem is located and allow them a more direct way to address a specific area of the equipment. This avoids a more “empirical” approach to problems, reducing the probability of accidents and human errors to occur. With this solution, we can help the factory on work related accidents (a goal set for all Production Managers).

Technician access for specific applications – ID 6
Two of the main issues are the way and speed maintenance technicians access information regarding the shop floor equipment. Most of the time, they access to the manufacturing ERP (like SAP) to obtain information – this process alone can take up to 2 hours (each technician needs to check machine metrics and must go to a specific workstation to access data and cannot print any documentation – they can take notes and must manually check all relevant maintenance points). The reduction of production ERP (SAP) access times (for field team information) was one big problem solver, since all relevant data is now available via the smartphone, and the Augmented worker solution. There are also efficiency gains in information access. It is guaranteed the possibility to create tasks directly in SAP, reducing the steps that each technician must do between the detection of the problem, the resolution of the anomaly, and the eventual opening of new tickets (for hardware or other parts orders, for example).

Inadequate access to on-time information – ID 7
With this solution, all information is available “near real time”, to the maintenance technician, avoiding the need for double or triple checking, The Augmented Worker solution allows for a quick way to access data, that is directly placed on the factory ERP, where all data is correctly gathered.

Outdated data - ID 8
Since the information is gathered directly from the ERP (SAP), all data is updated. All shop floor machines are continuously registering KPI’s (temperature, times, pressures, etc…) on the ERP and there is no risk on accessing “out of date” data, or from previous versions, since the system only gathers the last information registered.

Also, it guarantees that each technician has access to previous interventions and can determine what was made. They can also update information directly on SAP, create tickets and place comments on specific issues, making sure that all information is completely updated.

4.5. Synthesis

In short, we can synthesize the case study results by identifying the applied solutions to each challenge and representing the specific impact and its effective result. The following Table 10, is a resume for this.

Table 10 - Case Study Synthesized report.

Challenges	Applied Solutions	Impact
Equipment Downtime (ID 1)	Reduced corrective maintenance downtime from 5h to 2h and reduced preventive maintenance downtime from 2h to 1h	These reduction on the maintenance impact times may allow for a 63% impact and 25% (corrective or preventive) on daily production
Inadequate OEE (ID 2)	Optimized production through efficient maintenance resolution	Increased overall efficiency and production, proportional to reduced downtime
On-time Response to Corrective Maintenance (ID 3)	Real-time data access for maintenance technicians Reduced resolution time from 5h to 2h	Faster issue resolution and enhanced technician overview
Training and Knowledge Transfer (ID 4)	Knowledge management with recorded information and history VR training sessions	Effective knowledge management and continuous technician training
Shop Floor Accidents (ID 5)	Utilized AR technology for precise problem location Reduced accidents and human errors	Lower probability of accidents and errors on the shop floor
Technician Access for Specific Applications (ID 6)	Reduced access time through smartphone and Augmented Worker solution Streamlined task creation in SAP	Faster access to information, reduced steps in issue resolution
Inadequate Access to On-time Information (ID 7)	Real-time access to data via Augmented Worker solution and factory ERP	Near real-time data access, eliminating the need for multiple checks
Outdated Data (ID 8)	Data gathered directly from ERP (SAP) Technicians can update information and create tickets	Access to updated information, elimination of outdated data

It is now clear what has been implemented and the possible benefits, but it is also relevant to mention that this case study was born out of a clear approach on the part of everyone involved on how AR technology would be ideal for solving the maintenance teams' problems.

Throughout the process, the main difficulties were more behavioural than technical. It was necessary to overcome the "mental" barrier of the AR reliability and to provide evidence of the technology's maturity. This was the most time-consuming process, but it was necessary in order to ensure confidence in how the case study would be carried out with the least possible impact on day-to-day operations, while guaranteeing confidentiality. As soon as it was guaranteed that there would be no intrusion into existing systems or the need to interconnect with applications already in production, the whole process ran smoothly and without the need for any corrections or changes. The case study was based on a single piece of equipment and access to the site was very limited, but this did not hinder it in any way. The fact that there was a very clear idea of what was wanted to demonstrate helped at every stage of the project.

CHAPTER 5

Conclusion

The adoption of new technologies, such as AR, can be an optimized strategy for industries to achieve quick efficiency gains, empower maintenance teams, and ensure that knowledge is kept within the company.

In this research, the aim was to demonstrate that the use of AR technology is already mature enough to guarantee immediate benefits in industries. The use of this type of technology, combined with the computational and graphic capabilities of the mobile devices used by maintenance teams (smartphones or tablets), is already a reality that can be implemented.

One can conclude that AR presents opportunities in the area of industrial maintenance applications through the presentation of contextualized information and access to end-user data. The validation process has shown that this Augmented Worker solution has the potential to enhance maintenance efficiency significantly. This research primary contributions, pertaining to maintenance efficiency and the field of AR, encompass several aspects:

- Enhancing maintenance personnel productivity through adaptive data management: An Augmented Worker solution contributes to research in authoring tools for AR by introducing an innovative framework that addresses the information requirements of such tools. It also introduces a new method for generating real-time overlaid animations automatically.
- Enabling non-high tech users' access: Reduces the resource barriers associated with developing AR animated content.
- Innovating context awareness modules: The Augmented Worker presents a fresh approach to achieving context awareness in AR.

There are, still, some limitations to these sort of projects, not related to AR and VR cost but to its integrations. Factories have legacy systems, that most time are closed ecosystems with low integration capabilities, i.e., it is difficult and costly to integrate external systems. An ERP like SAP can be a limitation for the massification of this technology on factory floors, since it has high acquisition, development, and maintenance costs (not affordable for most companies).

Also, to guarantee integration with all mobile ecosystems, middleware is also a necessary component (development platform that digitizes and optimize business processes and user interfaces, like Neptune that was used on this case study) and their cost can also be a considerable investment since it needs be acquired and requires specific resources for a correct implementation.

These software are relatively expensive to acquire and need specific know-how, not available to many, making their adoption also dependent on specific technicians (that also increase the costs), so for this reasons, the adoption of AR Technologies can be slower than expected. It is not a technical limitation itself but more a need that other parts of the ecosystem adapt themselves to these new technologies (specifically in terms of software integration).

One other considerable limitation is the wireless connection on factory floors. Since all this ecosystem is based on the already used smartphone for maintenance teams, it is necessary to guarantee a high response network (with good latency levels and guaranteed coverage), which have high deployment costs. To create a Wifi 6/7 network or an Industrial IoT dedicated wifi network or even a Mobile private network, requires a vast financial investment, that will negatively impact the project Return of investment (ROI) calculations.

As part of future work, there is a need to explore new approaches for integrating AR with Information Systems, facilitating the dynamic capture of multiple user feedback for reuse in subsequent maintenance sessions. It is imperative to focus on how continuous data management can be realized to minimize implementation costs while augmenting organizational knowledge related to maintenance tasks. Furthermore, additional experimentation is warranted to compare efficiency gains with similar systems that lack information contextualization, thereby substantiating the findings from testing. Moreover, further research should delve into interfaces designed to present contextualized information and assess their added value in enhancing maintenance efficiency by reducing cognitive overload.

AR, as part of a digital revolution, can virtualize a variety of ecosystems and could be a tool that managers should treat as a potential disruptor and not just as another communication gimmick or technology trend. It is a potent tool that can help smart industrial operators, and it will undoubtedly be included into factories in the future. The ability to provide users with information that their senses alone could not have obtained from reality—and to do it in a context that makes sense—is what makes AR so powerful.

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BIBLIOGRAPHY

Albukhitan, S. (2020). Developing Digital Transformation Strategy for Manufacturing. *Institute of Data Semantics. Jubail Industrial City, 31961, Saudi Arabia.*, 665.

Amari, H. M. (2016). The role of maintenance in improving companies' performance: An analysis of empirical studies. *Journal of Quality in Maintenance Engineering*, 1-100.

Bardhan, S. e. (2016). "Criticality analysis and maintenance priority decision support for physical assets". *Reliability Engineering & System Safety*, 1-100.

Bartodziej, C. (2016). *The concept Industry 4.0: an empirical analysis of technologies and applications in production logistics.* Wiesbaden, Germany: Springer Gabler.

Bevilacqua, M. e. (2017). "The impact of maintenance practices on operational performance: A meta-analysis". *International Journal of Production Economics*, 20-50.

Clancy, L. (2013). *Interventions for Addiction.* Academic Press.

CXP Group. (2018). *Digital Industrial Revolution with Predictive Maintenance.*

Eswaran, M., & Bahubalendruni, M. (2022). Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review. *Journal of Manufacturing Systems*, 260-278.

Eswaran, M., & Bahubalendruni, M. V. (2022). Challenges and opportunities on AR/VR technologies for manufacturing systems in the context of industry 4.0: A state of the art review. *Journal of Manufacturing Systems*, 260-278.

General Electric Company. (2016). *The Impact of Digital on Unplanned Downtime.* General Electric Company.

Ismail, M. H., Khater, M., & Zaki, M. (2017). Digital Business Transformation and Strategy: What Do We Know So Far? *University of Cambridge, Working Paper ITWeb IoT Survey*.

J.Gimeno, P.Morillo, JM.Orduna, & M.Fernandez. (2013). A New AR Authoring Tool Using Depth Maps for Industrial Procedures. . *Computers in Industry* , 1263-1271.

Leitão, P., Colombo, A. W., & Stamatis Karnouskos. (2016). *Industrial automation based on cyber-physical systems technologies: Prototype implementations and challenges.* Computers in Industry.

Manuri, F., & Sanna, A. (2016). A Survey on Applications of Augmented Reality. *Computer Science*.

McLeman, A., Smith, J., & Parker, K. (2021). *2021 PE Maintenance Repor.* CFE Media and Technology/Advanced Technology Services (ATS).

Mlinarić, M., Schreuders, M., Graen, L., & Lessenich, S. (2020). *Transnational tobacco companies and the mechanism of externalization: A realist synthesis,.* Health & Place.

Moreira, J. (2004). *Questionários: Teoria e Prática.* Lisboa: Almedina.

MRO. (2018). *Annual Maintenance Repair and Operations (MRO) Survey 2018: Spending on the rise.* Retrieved from Materials Handling MRO and Modern Materials Handling magazines: https://www.logisticsmgmt.com/article/annual_maintenance_repair_and_operations_mro_survey_2018_spending_on_the_ri

Nakajima, S. (1988). An Introduction to TPM. *Productivity Press*.

Nascimento, A. R. (2020). "Industry 4.0 and the digital transformation of maintenance: A systematic literature review". *Journal of Manufacturing Technology Management*, 1-50.

Nunes, P., Santos, J., & Rocha, E. (2023). Challenges in predictive maintenance – A review. *CIRP Journal of Manufacturing Science and Technology*, 54-63.

P.Milgram, & F.Kishino. (1994). Taxonomy of Mixed Reality Visual Displays. *IEICE Transactions on Information and Systems*, 1321-1329.

Park, Y. D. (2013). "Challenges and barriers in implementing maintenance management systems in SMEs". *Journal of Quality in Maintenance Engineering*, 1-100.

Pierenkemper, C., & Gausemeier, J. (2021). Developing Strategies for Digital Transformation in SMEs with Maturity Models. In *Management for Professionals* (pp. 103–124). Springer International Publishing.

Priya, A. (2021). Case Study Methodology of Qualitative Research: Key Attributes and Navigating the Conundrums in Its Applicatio. *Sociological Bulletin*, 94-110.

Roy, R., Stark, R., Tracht, K., Takata, S., & Mori, M. (2016). Continuous Maintenance and the Future – Foundations and Technological Challenges. *CIRP Annals*, 667-688.

Samuel de Almeida, P. (2018). *Maintenance Management applied to industrial, building and electrical areas.*

Statista. (2023). *Facility management: budget spent on cleaning/maintenance equipment and supplies in the United States 2017-2023*. Retrieved from www.statista.com: https://www.statista.com/statistics/799977/share-of-operating-budget-spent-on-cleaning-or-maintenance-equipment-and-supplies/

Thomas, G. (2015). *How to Do Your Case Study.* SAGE Publications.

Thomas, G. (2017). *How to Do Your Research Project - third edition.* SAGE Publications Ltd.

Thomson, G., & Wilson, N. (2017). *Global Tobacco Industry.* Academic Press.

X.Wang, S.K.Ong, & A.Y.C.Nee. (2016). A comprehensive survey of augmented reality assembly researc. *Advances in Manufacturing*, 1-22.

Yin, R. K. (2009). *Case study research: Design and methods (Vol. 5).* sage.

ANNEXES

ASSET MANAGEMENT ASSESSMENT

What are the Operation's Critical Assets?

Do you have an Asset Management Solution, which one? (SAP)

What are their Estimated Downtime?

How do you Monitor your Assets (Events, SCADA)?

What's the Financial Impact of the existing Downtime

How do you create your Preventive Maintenance Orders?

How do you predict Asset Failure?

PERFORMANCE SUPPORT ASSESSMENT

How many Maintenance Technicians do you have?

What is your Estimated Training Duration and Cost for these profiles?

How many workers are responsible for Asset Monitoring Activities?

Each technician is Skilled to work in how many Equipments in Average?

What is your Annual average Turnover of these two profiles?

How do you leverage your Experienced and Specialized workers?

What’s the average age of your Experienced and Specialized workers?

How many sick leaves do you have related to work accidents for these two profiles?