



## Human-centred design integration on product development

JOSÉ PEDRO CARDOSO DE ALMEIDA

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# **Human-Centred Design integration on product development**

**José Pedro Cardoso de Almeida**

**Dissertation to fulfil the requirements to obtain the Master's degree in  
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Industrial Management**

**Supervisor: Raul Duarte Salgueiral Gomes Campilho**

**Co-supervisor: Flávia Vieira Barbosa**

**Jury:**

President:

Eduardo Jorge Casal Cardoso Martins

Vowels:

Raul Duarte Salgueiral Gomes Campilho

Pedro Filipe Lima Marques

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## **Abstract**

This dissertation exposes Human-Centred Design methodologies applied to product development engineering. Human-Centred Design is an approach that prioritizes the needs, behaviour and experience of the user, allowing the development of products that are aligned with user's expectations. This method integrates user's feedback into the product development process, enabling the implementation of specific requirements that increase user's acceptance and satisfaction. The goal is to propose a structured methodology for engineering teams to follow in the development of new industrial or consumer products, to improve not only functionality, but also intuitiveness and accessibility, resulting in an increased acceptance and satisfaction among users. To create this methodology, Industry 5.0 was analysed, to understand the role of Human-Centred Design as one of its three pillars, providing relevant inputs regarding the identified challenges and how this methodology can be designed to overcome these main issues or limitations. The state-of-the-art methods and tools were compiled from the literature review and arranged into the most appropriate timing in product development, between the stages of detail design, prototyping, and testing and refinement. With such methodology, qualitative and quantitative methods were applied to two distinct case studies, highlighting two contrasting approaches to Human-Centred Design: human-machine interaction and user-product interaction. The uses cases were selected based on the needs identified by a Portuguese ceramic company, and all the work was conducted in partnership, including tests in the shopfloor with workers. Several user testing sessions took place throughout the mentioned product development stages, extracting user requirements from assessments including questionnaires, ergonomics and technologies such as augmented reality and eye tracking, to optimize product design on each product. This approach enabled the collection of valuable data to validate the proposed methodology, emphasizing the added value of Human-Centred Design in product development. By prioritizing user satisfaction, it enhances market acceptance and increases the success of new products. When integrated into the shop floor, this approach allows to increase new technology adoption, increasing productivity and decreasing worker's injuries. The dissertation aims to contribute to product development practice by highlighting the potential of emerging technology in facing the challenges of Human-Centred Design, in a scalable methodology encompassing the development of industrial and consumer products.

**KEYWORDS:** Human-Centred Design, product development, Industry 5.0, human-machine interaction, user-product interaction



## Resumo

A presente dissertação expõe a aplicação da abordagem de *design* centrado no ser humano no desenvolvimento do produto. O *design* centrado no ser humano (*Human-Centred Design*) é uma abordagem ao desenvolvimento de soluções para produtos que dá prioridade às necessidades, ao comportamento e à experiência do utilizador. Requer o envolvimento dos utilizadores no processo de desenvolvimento, com o objetivo de compreender a sua perspetiva privilegiada como utilizador ou consumidor, através da recolha sistemática de opiniões e dados relativos à utilização do produto. O objetivo da presente dissertação é propor uma metodologia para o desenvolvimento de novos produtos industriais ou de consumo, para melhorar não só a sua funcionalidade, mas também a intuitividade e a acessibilidade, resultando numa maior aceitação e satisfação dos utilizadores. Para criar esta metodologia, foi analisado o contexto da Indústria 5.0, para compreender o papel do *design* centrado no ser humano como um dos seus três pilares. A revisão bibliográfica culmina numa compilação dos métodos e ferramentas mais utilizados, bem como daqueles que apresentam maior potencial para futura aplicação. Estes foram organizados de acordo com o momento mais adequado para integração no desenvolvimento do produto, entre as fases de definição de conceito, prototipagem e teste e otimização. Seguindo esta metodologia estruturada, foram aplicados métodos qualitativos e quantitativos a dois casos de estudo distintos, destacando duas abordagens distintas do *design* centrado no ser humano: a interação homem-máquina e a interação utilizador-produto. Foram realizadas múltiplas sessões de testes com utilizadores ao longo das fases de desenvolvimento do produto descritas, que possibilitaram a extração de requisitos dos utilizadores a partir de métodos como questionários, análise de ergonomia e tecnologias como realidade aumentada *eye-tracking*. As diferenças nos produtos em cada caso de estudo expõem a utilização de diferentes ferramentas e tecnologias emergentes. A dissertação tem como objetivo contribuir para a prática do desenvolvimento do produto, destacando-se o potencial de tecnologias emergentes para enfrentar os desafios do *design* centrado no ser humano, numa metodologia escalável que abrange o desenvolvimento de produtos industriais e de consumo.

**PALAVRAS-CHAVE:** *Design* centrado no ser humano, desenvolvimento do produto, Indústria 5.0, interação homem-máquina, interação utilizador-produto



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## Acronyms and Symbols

### Acronyms

AI	Artificial Intelligence
ANSI	American National Standards Institute
AOI	Area of Interest
AR	Augmented Reality
BS	British Standard
CPPS	Cyber-Physical Production Systems
DfA	Design for Assembly
DfE	Design for Environment
DfER	Design for Emotional Response
DfErg	Design for Ergonomics
DfL	Design for Logistics
DfLC	Design for Lifecycle
DfM	Design for Manufacturing
DfMaint	Design for Maintainability
DfQ	Design for Quality
DfRecycle	Design for Recycling
DfRel	Design for Reliability
DfReman	Design for Remanufacturing
DfS	Design for Service
DfSafe	Design for Safety
DfSust	Design for Sustainability
DfUF	Design for User-Friendliness
DfX	Design for X
DT	Digital Twin
EN	European Norm
HCD	Human-Centred Design
HCI	Human-Computer Interaction
HFES	Human Factors and Ergonomics Society
HiTL	Human in The Loop
HMI	Human-Machine Interface

HoTL	Human on The Loop
HRC	Human-Robot
I4.0	Industry 4.0
I5.0	Industry 5.0
IEC	International Electrotechnical Commission
IoT	Internet of Things
ISEP	Instituto Superior de Engenharia do Porto
ISO	International Standardization Organization
KPI	Key Performance Indicator
LM	Lean Manufacturing
LPD	Lean Product Development
NASA	National Aeronautics and Space Administration
PSS	Product-Service System
QFD	Quality Function Deployment
SDG	Sustainable Development Goals
SUMI	Software Usability Measurement Inventory
SUS	System Usability Scale
TLX	Task Load Index
UTAUT	Unified Theory of Acceptance and Use of Technology
UX	User Experience
VR	Virtual Reality

### **Symbols**

$r$	Pearson correlation coefficient
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# 1. Introduction

## 1.1. Framework

During the fourth industrial revolution, manufacturing became digitalised, connecting humans and machines in a working network. As a result, automation and digitalization truly revolutionized the industry for the better, enhancing efficiency and mass production. But these developments also brought new problems and limitations to the shop floor and to the consumer, as mass production processes are not the most flexible, even though consumer needs are always evolving. This challenge presents an opportunity for development on industrial processes. Actually, as automation and mass production become widespread, other areas of development will become the differentiating factors between companies.

The interaction between human and machine is becoming increasingly frequent, both in the average person's day to day life, and in the industrial context. With more time spent using robots, machines and interactive systems, there are various concerns to be addressed when designing interactive products. Health and safety have been considered when developing products, but these are not always enough to make sure that users are fully satisfied. The Industry 4.0 (I4.0) goals of efficiency and productivity can sometimes lead to job displacement, worker stress and fatigue, due to lack of consideration for human factors in the product and process development. Profit-driven decision making can often disregard social and environmental sustainability, while fast digitalization is subject to ethic concerns about data security and privacy. These shortcomings create a need for a more balanced approach, with renewed goals of integrating people in a more pleasant technological environment.

The transition to Industry 5.0 (I5.0) implies a new focus on the interaction between humans and systems, in which sustainability, resilience and Human-centredness are the goals. As humans will always be involved, the future does not lie in full automation. For this reason, there is a need for more human-centred processes, preserving ethics, human values and global needs through the fast-changing environment of current times, instead of boosting consumerism and profit with disregard for the long-term sustainability of consumers and workers. Therefore, to change the outcome of future products, aiming for the mentioned goals, the design process should accommodate Human-centred values systematically.

## 1.2. Objectives

Being Human-centred design (HCD) an emerging topic in the context of the I5.0, there is currently a need to fully understand how to integrate the methodology into product design.

This research is meant to address this concern and respond to a specific research question “How can structured Human-Centred Design methodologies improve technology acceptance among shop-floor workers and enhance user satisfaction with new market released products?”

To answer this question, the present dissertation aims to develop a structured methodology based on HCD strategies that facilitates the development of products that respond to the human needs, increasing user satisfaction and contributing for their acceptance when new and innovative technologies are integrated into the shop-floor.

To achieve this goal, a literature review will be conducted to identify and characterize HCD approaches and tools that can be relevant to design a methodology that will integrate qualitative and quantitative methods. To highlight the potential of emergent technologies to enhance the implementation of HCD in product development, augmented reality and eye tracking systems will be applied. To achieve these goals, two case studies are explored: a) Human-Machine Interaction focusing on the development of an innovative defect detection machine that uses Artificial Intelligence; and b) User-Product Interaction focusing on packaging designed with circularity principles, intended to have a second life after its initial use.

### **1.3. Methodology**

The research is divided in two complementary areas: product development and HCD. For each of these themes, a literature review was conducted with the goals of understanding the base concepts, and exploring the most recent and relevant advancements, especially in the integration of HCD into the product development process. To this end, thorough research was conducted in several scientific databases, namely on Web of Science, B-on, and Google Scholar, aiming to collect information from indexed, peer-reviewed articles within the upper relevance quartiles, whose authors had the highest possible H-Index. Other sources included standards, books and websites. In this research, more emphasis was placed on analysing recent articles, being the most frequently cited articles from 2024, while older articles are progressively less frequently cited.

Building on the literature review, a HCD methodology for product development was created and applied in the industrial context. The application consisted of two distinct products and development stages, with the goal of exposing the different approaches and challenges to each case study. For this purpose, the methodology was dedicated to human-machine interaction on the first product, and to user-product interaction, for the second. The case studies consisted of the development and accomplishment of user testing sessions to promote HCD throughout product development. Along with the designated HCD assessment methods, each case study also highlighted the use of emerging technologies, with augmented reality being explored as a tool to improve human-machine interaction, and an eye tracking device for user-product interaction assessment. The framework application results are presented afterwards, along with the due interpretations and implications for the product. Each case study generated qualitative and quantitative results that were combined into new requirements, expected to improve both products, and their users’ acceptance and satisfaction through HCD.

## 1.4. Structure

The dissertation structure consists of five sections: The present section, 1, is an introduction for the conducted work, presenting the framework, objectives, methodology, structure and host company, which support the following work. In section 2, the literature review is conducted, serving as the scientific foundation for all subsequent sections. Section 3 builds on the literature review towards its practical application, describing the methodology that was applied in the case studies. In this section, the two case studies are characterized, and the approach to each one is described, focusing on analysing each of the applied methods. The following section presents and discusses the results that derived from each case study. The qualitative results are statistically analysed to uncover the relevant findings, while quantitative results are also treated according to the proposed methodologies and data gathering techniques, to combine the results into clear takeaways and requirements. The fifth section is the conclusion, gathering the relevant considerations, the accomplishment of the proposed goals, and a critical analysis of the dissertation.

## 1.5. Host institution

The present work reports on an internship at *Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial (INEGI)*, a national reference for research and innovation in the Portuguese scientific and technological context. This institute was founded in 1986 by the *Departamento de Engenharia Mecânica e Gestão Industrial (DEMEGI)*, of the *Faculdade de Engenharia da Universidade do Porto (FEUP)*, to connect the scientific research and innovation developed in the University with the demands of the industry. In 2008, the current INEGI building opened, being now closer and more attractive for workers and engineering students, inside the FEUP campus, hosting more than 300 employees. INEGI supports national and international companies with innovative scientific and technological solutions and consulting in the fields of mechanical and industrial engineering, while maintaining the connection to the university and enriching its activity. The institute comprises 13 different business units, and this dissertation was developed within the Product and System Development unit. This work was developed at INEGI in partnership with VISTA ALEGRE® company under the project PRODUTECH R3 – “Agenda Mobilizadora para a Fileira das Tecnologias de Produção para a Reindustrialização”.



## 2. Literature Review

### 2.1. Design and product development

This chapter provides an overview of product design and development. It begins with a discussion on a methodological approach to product development, focusing on user-driven products. Following this, the phases of product development are outlined in detail. Finally, a review of the historical and methodological evolution of product development is presented from an industrial perspective. It is important to clarify the distinction between design and product development, as these are distinct concepts. The product development process starts earlier and encompasses the design process as one of its integral stages.

#### 2.1.1. Product development phases

The product development process is a sequence of organizational steps that are employed to conceive, design, and commercialize a product (Ulrich et al., 2020). Different organizations may use different processes, and even within the same organization, slightly different processes are used for each product. However, it is possible to create a generic product development process, as shown throughout this chapter. It is important to define the development process, for matters of quality assurance, coordination, planning, management, and improvement. The steps are presented in Figure 1, and described in the following subsections (Ulrich et al., 2020).



Figure 1 - Product Development Phases, adapted from Ulrich et al. (2020).

#### Planning

The goal of this phase is to identify market opportunities, plan the development stages and the respective milestones, which enables management to evaluate the plan and its priority against other projects, and to allocate the necessary resources (Ulrich et al., 2020). Once the market opportunity is identified, it is necessary to combine the efforts from the various teams to assess the hypothetical feasibility, viability, and desirability of the project. Constraints in this stage are market objectives, technology developments, production constraints, research, finances, and other resources. The results are combined into the mission statement, i.e., a summary of the strategies for the product, on the different functional areas of the enterprise.

### **Concept Development**

This stage is divided into three main phases: identifying user needs, concept generation, and concept testing (Ulrich et al., 2020).

- Identifying user needs

To identify user needs it is required to gather information, which can be done through three common methods, namely interviews, focus groups, and observation. Alternative methods include the analysis of consumer and expert online reviews, as Wang et al. (2024) experimented with. The collected data is analysed to extract and sort out user needs by importance.

- Concept generation

Concept generation begins with translating user needs to product specifications. The user needs are usually generic, while product specifications need to be objective and measurable (Ulrich et al., 2020). In this stage, the product is divided into sub-systems, and each one is analysed against existing concepts, as well as the possibility for new concepts. Different solutions for sub-systems are combined to create multiple solutions. Some solution alternatives start to be defined and structured.

- Concept testing

In this stage, the generated concepts are compared and tested to decide on a solution (Ulrich et al., 2020). Each concept is evaluated on the accomplishment of the designated product specifications. The selection methods vary from intuition to prototype testing results.

### **System-level Design**

This is the phase when a physical design starts to be addressed. It is a complex stage, in which designers give form to the product concept, considering all the previous phases, applicable target design methodologies, standards, and intellectual property (Ulrich et al., 2020). Multi-disciplinary teams are required to combine efforts in addressing all the important factors to the development of a design. At this phase, ideally the fundamental interactions are defined, but non-fundamental interactions are subject to iterations. With the technical design development, a cost model is developed, product specifications are refined, with possible trade-offs or adjustments (Ulrich et al., 2020).

### **Detail Design**

To begin this phase, product specifications and architecture are generally set. The detail design stage is focused on parallelly enhancing the remaining non-functional but valuable product characteristics, which have an impact on the designated target design methodologies. This phase consists of an iterative process involving particular components or part interactions, with an influence on any aspect of product performance (Ulrich et al., 2020).

### **Prototyping**

Prototypes are the first physical result of the product development process. At this stage, it is possible to use the prototype to learn more about the product, whether it accomplishes all the designated specifications, and if it meets the customer's needs. It is useful to visualize if all the

parts assemble and interact as expected, and a working prototype is an important milestone for management and for clients (Ulrich et al., 2020). To optimize the design quality, multiple prototypes should be created iteratively, as early as possible in the development process, focusing on experimenting with specific design goals (Menold et al., 2017).

#### **Testing and Refinement**

At this stage, field testing takes place, to evaluate the overall performance, reliability, durability and environmental impact of the product. Fabrication, assembly, and quality control processes are refined. Some design changes may be required. Workforce starts training for production tasks, and suppliers should be ready to deliver (Ulrich et al., 2020).

#### **Production Ramp-up**

This phase is the final validation stage, in which the manufacturing process is scaled up, to ensure quality at full operational capacity. The goal is to refine the processes and prepare supply chain for continuous production. This stage is not going to be explored further in this work.

### **2.1.2. Structured methodology of product development**

Product development is a response to the market's needs, which are constantly evolving (Araci et al., 2021). A product's development begins with the acknowledgement of such needs by the engineering team (Ulrich et al., 2020), and extends throughout the design process, following up on production and supply. Before dissecting the different phases of product development, it is worth mentioning transversal principles, which should be present throughout the process. The following methodologies are useful across all the stages of the product development process, helping to reduce waste, mistakes, and discrepancies that might only be noticed during production or user interaction. These methodologies result in a higher quality product and a competitive advantage over other companies.

#### **Lean Product Development (LPD)**

In manufacturing, the combination of I4.0 and the inherent technological advancements with the needed human skills and knowledge enable the faster satisfaction of the user's needs (Synnes & Welo, 2016). Therefore, product development must be efficient and effective at creating a product that quickly corresponds to the demand. One of the methods to achieve success in product development is the implementation of LPD, which is an application of Lean Thinking focused on creating value for customers through an optimized product development (U. Dombrowski & S. Schmidt, 2013).

Lean Manufacturing (LM) is proven to improve production systems by reducing waste and variability, focusing on quality and value adding processes (Marodin et al., 2018). LPD is an extension of LM to the product development process and the application of lean principles early in the product development has the potential to influence all the necessary processes and activities for the rest of the lifecycle (Dombrowski & Schmidt, 2013). It is proven that the product development stage is crucial as it can lead to systematic problems and substantial waste in later stages (Marodin et al., 2018). Therefore, the application of LPD principles can lead

to earlier optimization of factors such as number of components, and their interactions and properties, thereby reducing waste and adding value through reduced time to market and improved product innovation (Kirinić & Hegedić, 2023). Some practices to contribute to LPD are (Marodin et al., 2018):

- Concurrent Engineering

Concurrent engineering is the parallel focus on multiple product properties and lifecycle phases when developing. This methodology requires teams from all fields of operation - marketing, design, process planning, manufacturing, and assembly - to work simultaneously, and the team leaders to constantly share information and co-operate to reach the set goals. This approach reduces development time and costs and enhances efficiency (Rihar et al., 2021).

- Product Modularity and Standardization

Product Modularity is a design strategy that aims to create and assemble distinct modular systems that add up to the final product (Takeishi & Fujimoto, 2001). This concept promotes easier replacement of individual modules, encouraging reusability of components across products when needed, as well as product innovation, through the possibility of prototyping single modules. The concurrent engineering of multiple modules simplifies production and assembly processes, further supporting LPD. The modularity also facilitates the standardization of components across different products, thereby reducing costs and reducing waste (Ericsson & Erixon, 1999).

- Customer Involvement

Gathering, analysing and considering customer feedback as early as possible in the product development process, aligns the product's specifications to the real customer needs, avoiding later iterations, further reducing costs and waste, while adding value to the product.

### **Design for X (DfX)**

Engineering design defines component geometries, materials, and tolerances of the product and all its components (Favi et al., 2016). To achieve an optimized product design that aligns with the proposed goals, engineers face multiple restrictions during design. To address specific design requirements, target design methodologies were developed in a collaborative effort between industries and academia through the years. DfX is a general term for an engineering design target, being the "X" representative of each goal for the part or assembly (Formentini et al., 2022). Each DfX provides rules and guidelines, helping engineers adhere to the best practices for the development of each product, according to the designated goal (Favi et al., 2016).

A valuable tool to address the success of a design goal is a Key Performance Indicator (KPI), a measurable index used to quantify the success in achieving a specific target. Specific and well-defined KPIs in the context of a given target are powerful tools to assess the benefit of each design solution (Favi et al., 2022). Table 1 describes the most common DfXs.

Table 1 – DfX and aims, adapted from Favi et al. (2022) and Dombrowski et al. (2014)

DfX	Aim
Design for Assembly ( <b>DfA</b> )	Reduce the number of parts, assembly tasks, and assembly process complexity.
Design for Manufacturing ( <b>DfM</b> )	Avoid unfeasible manufacturing processes and reduce expensive materials and processes.
Design for Service ( <b>DfS</b> )	Facilitate installation, commissioning, and maintenance.
Design for Recycling ( <b>DfRecycle</b> )	Increase the use of recyclable materials and reduce material variety.
Design for Remanufacturing ( <b>DfReman</b> )	Enable product remanufacturing, including disassembly, assembly, cleaning, testing, repair, and replacement.
Design for Quality ( <b>DfQ</b> )	Eliminate defects and meet customer requirements.
Design for Reliability ( <b>DfRel</b> )	Consider the reliability of both hardware and software.
Design for Environment ( <b>DfE</b> )	Consider environmental, safety, and health concerns.
Design for Logistics ( <b>DfL</b> )	Decrease time and cost of product related logistics.
Design for Maintainability ( <b>DfMaint</b> )	Reduce repair time and isolate faults, while simplifying maintenance processes.
Design for Safety ( <b>DfSafe</b> )	Eliminate safety risks associated with the product or its operation.
Design for User-Friendliness ( <b>DfUF</b> )	Ensure that product interface is easy to access, intuitive, and responsive.
Design for Lifecycle ( <b>DfLC</b> )	Reduce lifecycle cost and environmental impacts.
Design for Ergonomics ( <b>DfErg</b> )	Fit the user ergonomic needs during interaction with the product, to reduce physiological and biomechanical stress.
Design for Sustainability ( <b>DfSust</b> )	Reduce ecological impacts, enhance resource efficiency, and promote circularity throughout a product's lifecycle.

### Responsible Innovation

During the product development process, the ideas, concepts, and decisions have been commonly guided by the desirability, viability, and feasibility of the product, being economic viability often the most important factor (Shapira et al., 2017). The desirability factor mainly considers the end user's desires for the immediate interaction with the product, while the continued use of such product may still end up harming the user through health or environmental impacts that the user is not necessarily aware of. Thus, this approach often fails to serve the user in a holistic manner, by not considering ethical and environmental values. Responsible innovation is the result of design proposals that carefully consider environmental

and ethical values alongside technology, business, and human concerns, as early as possible in the product development process, extending the human-centred approach to product development into a fourth dimension – responsibility (Borthwick et al., 2022).

An example of this necessity was the invention of the “like” button in social media. Justin Rosenstein and his team at Facebook, in 2009, created the feature with the intention of allowing users to spread positivity for the community with a simple click. However, the invention resulted in negative consequences, such as addictive behaviour, for exploiting psychological mechanisms like dopamine release, and mental health impacts, contributing to anxiety and self-esteem problems (Stjernfelt & Lauritzen, 2019). Later, Rosenstein and the former Facebook executive Chamath Palihapitiya publicly expressed regret for the consequences of their company’s invention. This case was a result of not considering ethics in the design of the product, and the designers’ regret emphasizes the importance of responsible innovation when developing technology that can influence human behaviour.

### Lean DfX

Lean DfX is a framework that combines Lean Thinking and DfX, managing multiple and complex design targets, applying just the strictly necessary resources to reach the product goals. This process, represented in Figure 2, is based on the following pillars (Baptista et al., 2018):

1. Product break down: Decreasing product complexity by using modular design principles.
2. Selection of “X” domains and their specific design indicators: Assessing the best suited design targets, and the variables to analyse for each.
3. Simple visual management attributes: Using a visual grading system with percentages and colours to represent the efficiency and effectiveness of the design.
4. Aggregation of efficiency and effectiveness through product modular hierarchy and “X” design domains: The efficiency and effectiveness assessment for each design target is made from single parts, through modules, and converges into the complete product.

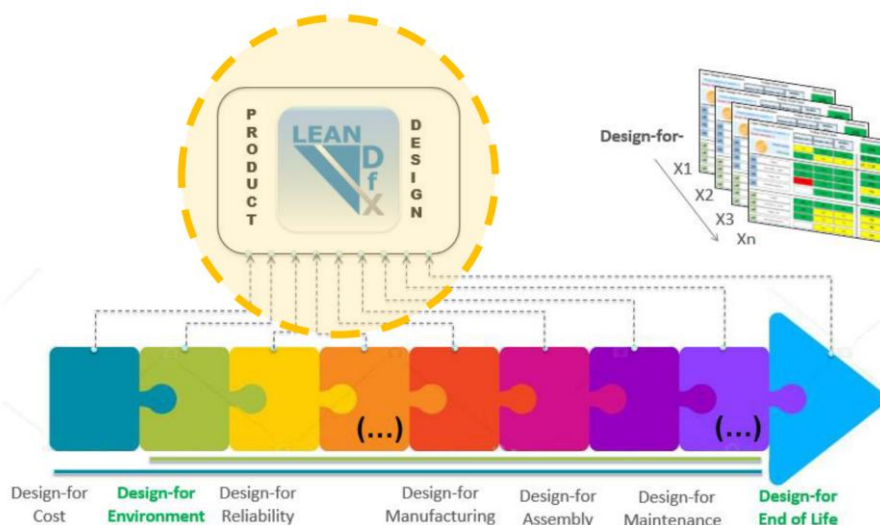


Figure 2 - Lean Design for X (Atilano et al., 2019)

The presented methodologies contribute to more effective, sustainable and human-centred product development, through structure methodologies. The integration of the methods in a structured product development process provides product development teams a framework to consistently create desirable and justifiable products in complex and dynamic markets.

### 2.1.3. Product design evolution in the industry

During I4.0, the manufacturing process has been transformed into a collaboration between technology and people through digitalization. Although technology has been the primary focus for I4.0, the human factor still plays a crucial role that is often overlooked (Horvat et al., 2024). However, the fast evolution of industrialization results in worker health and safety issues (Leng et al., 2022). The focus for I5.0 is on human-centred, resilient, and sustainable design. Thus, emphasizes the interaction between the operator and the machine working together in a sustainable manner, instead of technology replacing or harming people. While machines can be entitled to repetitive tasks, humans can be allocated to more creative tasks, supervision, or higher responsibilities (Maddikunta et al., 2022). To achieve this result, there is an opportunity for development in human-machine interaction (HMI), particularly integrating the new age technologies. According to Kasinathan et al. (2022), the 10 technologies with the most predicted potential for the current decade, as technological enablers for the value-driven development of I5.0, are: artificial intelligence (AI); big data analytics; drones; robotics; cybersecurity; robotic process automation; cloud computing; internet of things (IoT); augmented reality (AR); virtual reality (VR); autonomous vehicles.

Novel applications of this kind of promising technologies into product design are described in Table 2, in which DfX, user needs, prototyping, parametric design and simulation are highlighted.

Table 2 - State-of-the-art in product development

Application	Description
<b>DfX in CAD</b> (Favi et al., 2022)	The article presents a novel methodology to integrate DfX engineering guidelines into 3D CAD modelling. The authors propose it as the first step to develop a software tool to support product development. Given the lack of CAD-integrated DfX methods, the proposed framework aimed to capture, retrieve, and suggest design rules for each design context and objective. Applying the proposed method on a case study, the method allowed to assess the compliance of a 3D CAD assembly and its features against the 74 collected rules for the chosen DfX. The same procedure can be applied to more complex assemblies and multiple target design methodologies.

Table 2 - State-of-the-art in product development (continued)

Application	Description
<b>Identifying user needs: Machine learning on online reviews</b> (Wang et al., 2024)	The authors propose a novel hybrid approach between group decision making and consumer preference needs for the concept development of new products. In the proposed approach, a machine learning prediction method is used to combine user and expert preferences into a set of product specifications, improving decision-making. To collect user data, a novel method for data analysis is also proposed, extracting and weighting product features and their perceived importance for users, based on online reviews. The use of machine learning tools enabled enhanced accuracy and understanding of consumer needs, proving the potential to aid product development.
<b>Prototyping: AI on Additive manufacturing</b> (Liu et al., 2022)	Particularly used in the prototyping stage, additive manufacturing has gained traction across the industry. The authors present the utility of AI on this manufacturing process, specifically on the design, fabrication, and assessment stages of human-centred products. These products usually present a challenge to traditional design approaches due to complex geometry and component interaction. However, AI is able to account for multiple complex restraints and present solutions that are difficult to discover using traditional design methods. Therefore, AI is a promising solution to improve Design for Additive Manufacturing on these products, through design search and optimization in a fast and cost-efficient way. The tool is also efficient in optimizing the fabrication process and assessing quality performance of the product.
<b>Parametric design and Simulation</b> (Hong et al., 2024)	This case study made use of parametric design to optimize architectural design of a building. The goal was to adapt the building and the surrounding square to human behaviour, both physical and social. Simulation tools, combined with Anthropomorphic AI, enabled the virtual creation of users and their behaviours through the building and surrounding space. Generating such complex behaviours in a simulation allowed the discovery of unexpected pathways and design errors. A parametric design tool enabled designers to optimize the building according to simulation data, resulting in statistically better ergonomic appropriateness and usefulness scores.

15.0 brings promising concepts for both industrial and consumer products. New technology has potential to support the product development process. Simulations and digital twins allow for early optimization before prototyping, the collaboration between humans and AI can boost efficiency and development time, and AR and additive manufacturing can support user testing and customization. However, to take advantage of the emerging technology and still innovate

responsibly, the product development process should be adapted, pushing to enhance the sustainability, resilience and Human-centredness of new products.

## 2.2. Human-Centred Design fundamentals

The second chapter is the compilation of HCD fundamentals for industrial product development application. In the first topic there is a brief introduction on the HCD approach. In the second topic, it is possible to find a compilation of principles that constitute the HCD philosophy and are the foundation for the standards and methodologies presented further ahead. The third topic consists of the most important standards to adhere to when using the HCD approach on product development. In the fourth topic, the HCD's role in the fifth industrial revolution is debated. Finally, the state-of-the-art research is presented, underlining the most relevant recent research to provide information for the chapter's development.

### 2.2.1. Introduction to Human-Centred Design

This chapter begins with the history of HCD and the related disciplines and concepts, and transitions into the definitions and current guidelines, provided by the ISO 9241-210:2019 – *Ergonomics of human-system interaction – Part 210: Human-centred design for interactive systems*, to integrate the HCD approach.

HCD has evolved through time, reflecting the humanity's priorities, as well as technological and cultural evolutions. Once the first machines were developed, the foundation was laid for the study of HMI (Jain et al., 2024). When the industrial revolution started, especially during the Second World War, the root concepts of HCD were formalized with the foundation of the Ergonomics Research Society, starting to place the user in the centre of product design, with the goal of minimizing errors, particularly when designing military machinery, in which preventing human errors was of critical importance (Waterson, 2011). A few years after, with the appearance of the first computers, HCD obtained a new branch in Human-Computer Interaction (HCI). In the late 20<sup>th</sup> century, the field of User Experience (UX) was introduced, and ergonomic requirements were formalized as a core principle in product development, with the publication of the standard ISO 9241 – *Ergonomics of human-system interaction*, further establishing HCD (ISO 9241-210, 2019; ISO 9241-220, 2019). More recently, in the 21<sup>st</sup> century, HCD expanded beyond physical products, to a framework that considers human factors in the design, development and implementation of solutions and organizational practices, not only by meeting functional requirements but also by improving human well-being, capabilities, skills and work conditions (European Commission, 2024).

Nowadays, **HCD** is a product or service design methodology that promotes UX, and aims to respond to user requirements, optimizing their interaction with a product (Bechinie et al., 2024). According to the ISO 9241-210:2019 standard, the HCD approach enhances usability by applying human factors, ergonomics, and usability knowledge and techniques. This methodology improves human well-being, user experience, accessibility and sustainability; and

counteracts possible adverse effects of use on human health, safety and performance (ISO 9241-210, 2019).

**UX**, according to ISO 9241-210:2019, is defined by “*user’s perceptions and responses that result from the use and/or anticipated use of a system, product or service*” (ISO 9241-210, 2019). UX is one of the main research areas in HCD (Bechinie et al., 2024), as it considers all the interaction between user and a product or system, from the user point of view. The study of UX ensures a product that aligns with user needs and behaviour, being more intuitive and enjoyable to use, enhancing satisfaction and product adoption.

**Ergonomics** is a relevant scientific discipline for HCD because it specializes in non-functional requirements for products, providing guidelines and constraints for the design by studying human factors, and the interaction with the product (ISO 6385, 2016). Considering ergonomics in the early design stage can improve the UX as well as system performance, while reducing the probability of later complicated design iterations. The discipline of ergonomics can be divided into three distinct branches (Sun et al., 2019): Physical, Cognitive and Organisational Ergonomics. Physical ergonomics studies the human anatomy, along with anthropometric, physiological and biomechanical characteristics. This discipline can assist the design of workstations and tools with the goal of reducing physical strain and optimizing posture and efficiency, as well as the design of safety systems and controls. Cognitive ergonomics studies of human perception, memory and decision-making processes, enabling the optimisation of the interface development and preventing excessive cognitive load for the user. Organisational ergonomics focuses on organizational policy and workflow, to optimize the workers’ efficiency. This branch can promote collaboration and communication between workers, teams and departments, as well as managing fatigue and minimizing exhaustion (Karwowski, 2005).

**Universal Design** is the designation of a design that considers not only the average user, but a truly representative sample of users, enabling people in a wide range of abilities to take advantage of the product (Umbrello, 2019). This concept means considering for example younger, older, taller, shorter, less-abled people, and all the different potential users in an early design phase, resulting in a more accessible product that ideally excludes nobody from using it properly (Pullin & Higginbotham, 2010). This has an impact on product aesthetics, functionality, adaptability and, ultimately, on people’s acceptance and feelings towards the product (Wilkinson & De Angeli, 2014).

### **HCD principles**

HCD has evolved from functional craftsmanship into a multidisciplinary practice in product development. Currently, design teams should have a wide range of abilities and knowledge to develop human-centred products. According to ISO 9241-210:2019, the key HCD principles that allow the integration of HCD in all products and design levels are (ISO 9241-210, 2019):

***“The design is based upon an explicit understanding of users, tasks and environments”***

User research should be conducted through interviews, surveys, and field observations. Different scenarios and personas should be created to represent the real-world context. The user activities should be broken down into steps and understood through task analysis. This approach is useful to develop a clear evidence-based understanding of the real constraints and

user behaviours, avoiding assumptions that may lead to ineffective designs (Lindgaard et al., 2006).

***“Users are involved throughout design and development”***

Participatory design methods should be applied, in which the end users collaborate with the design team, since early-stage brainstorming and prototyping. User feedback should be collected regularly, during and after product development, to maintain the alignment of the product with the expectations. Considering user requirements and input only in the optimization phase is an important cause of UX problems (Sun et al., 2019). Instead, the participatory design approach improves product performance by considering user information earlier and throughout every stage of the design process. This approach involves users, designers and stakeholders since the product conceptualization phase, to collect requirements, develop prototypes, and implement and evaluate solutions. Given the correct tools, every involved participant should be able to add valuable information for design iterations (Wilkinson & De Angeli, 2014). The continuous involvement of users helps finding new requirements, validating assumptions and ensuring their needs are satisfied effectively.

***“The design is driven and refined by user-centred evaluation”***

Usability testing enables the observation and analysis of the interaction between users and prototypes or products. Usability is defined by the ISO 9241-210:2019 standard as *“the extent to which a system, product, or service can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use”*. Heuristic evaluation or cognitive walkthroughs are examples of techniques to assess design solutions against best practices. The regularly collected feedback informs design refinement until the usability goals are met. The evaluation aims to find usability problems and ensures the product design is evolving to address them.

***“The process is iterative”***

The first iterations are low-fidelity prototypes and should be tested early, to enable improvements that increase the product’s fidelity. The development process should be flexible to the possible changes that may occur at every iteration due to user testing findings. An iterative approach allows responding to user feedback, addressing new challenges, and continuously improving.

***“The design addresses the whole user experience”***

Traditionally, UX analysis in the industrial context mainly considers ergonomic issues, deriving from posture assessment methods. Previous regulations brought more attention to cognitive ergonomics, but to truly address the whole UX, means to consider the combination of the physical postures assumed, the executed actions, the mental workload, the subjective impressions, and the perceived usability (Peruzzini et al., 2017).

***“The design team includes multidisciplinary skills and perspectives”***

The team should include expert stakeholders from multiple disciplines and promote a collaborative environment. The use of cross-functional workshops, in which different perspectives are shared, allows the team to stay aligned with the goal. This kind of team

provides a wide range of insights and solutions by addressing different types of factors with expertise.

The described principles ensure that technology development prioritizes human well-being, usability and responsibility, playing a key role in accomplishing the 15.0 goals.

### 2.2.2. Human-Centred Design’s role in Industry 5.0

The shift from I4.0 to I5.0 represents a progression from focusing mainly on automation, efficiency, and digitalization to a more human-centric, sustainable, and resilient approach. I5.0 builds on the technological foundation of I4.0 but emphasizes collaboration between humans and machines, ethical practices, and the integration of Sustainable Development Goals (SDG) (Kasinathan et al., 2022). This chapter analyses the three pillars of I5.0 - sustainability, resilience and human-centricity – and then extends on the HCD’s role in the industry by exploring its main research themes and concepts in recent times.

#### Sustainability

Since 2015, the United Nations established the SDGs, a set of 17 global objectives, as shown in Figure 3, which represent a collective commitment to face the most important challenges for humanity and the planet Earth. Originally, the goals were defined to be achieved in 2030, accelerating the global progress in critical areas, such as climate change, peace and security, inequalities among and between countries, among others (United Nations, 2015). The need to work towards these goals promotes the transition to I5.0, shifting the focus from efficient automation and productivity to the three pillars of I5.0: human-centricity, sustainability and resilience.



Figure 3 - Sustainable Development Goals (United Nations, 2015)

### **Resilience**

After the effect of the COVID-19 pandemic, economic crises, international tensions and increasing conflicts, a lack of preparedness for risk and crisis management in manufacturing has been exposed, creating awareness for the need to balance technological advancements and social needs (Carayannis et al., 2024). To create resilience in I5.0 workforce, technology integration can be directed into four goals (Romero & Stahre, 2021): a) To avoid similar disruptions in the future, combining advanced data analytics with human intuition can create a more capable and effective data-driven judgement to manage risks; b) To resist disruptions, workers should be trained in managing risk, crisis, and stress, while their physical and cognitive workload and stress is systematically monitored; c) To react to unexpected changes, the workers are the most adaptable, while technology needs to evolve to be ready for most new circumstances. d) To recover from crisis, the ability to restore the original state should be combined with the capacity to learn from the disruption and actively prepare for the future challenges. Assisted, collaborative, or augmented work can be proposed as a solution, particularly to goal c), being AI, exoskeletons, and AR glasses, examples of enabling technologies (Kasinathan et al., 2022). From the enterprise strategy point of view, resilience should be pursued with business, supply chain and economic resilience as the three most important objectives, with dynamic simulation, cognitive AI and big data as potential enhancers of adaptability and responsiveness (Ghobakhloo et al., 2022).

### **Human-centricity**

Using HCD to complement the benefits of new technology can have positive economic and social impacts, in the direction of the SDGs 3, 4, 8, 9, 10, and 12, while enriching engineering management practice (Castagnoli et al., 2024). For industrial products, designing an effective and efficient human-centred machine interface implies an understanding of user needs and requirements, from the perspectives of human factors, context, tasks, information and interaction (Panter et al., 2024). Addressing the mutual impact of human-machine interaction since the early stages of product development reduces the number and the complexity of design iterations in later stages, provides a more pleasant user experience and can reduce time-to-market (Sun et al., 2019). In a manufacturing context, the effective combination of process and human requirements can significantly improve productivity, flexibility and user well-being (Papetti et al., 2021).

To drive towards this reality, a cultural change is required, to rethink production models and create sustainable industrial ecosystems, through a redesign of workplaces, in which innovation should be reoriented to workers instead of products and processes (Castagnoli et al., 2024).

As a response to the needs of the fifth industrial revolution, HCD is emerging across disciplines and industries in different levels of analysis: product, workstation, company and society. The main emerging HCD research themes in the I5.0 context are (Nguyen Ngoc et al., 2022), (Horvat et al., 2024) :

- Product-service system (PSS)

PSS is a combination of products with services into a unified solution, focusing on sustainable value creation through the lifecycle of the product. This product strategy enables the satisfaction of both existing trends and long-term goals while promoting medium-long-term sustainability. There are three types of PSS (Beuren et al., 2013):

1. Product-oriented PSS consists of a product that, when acquired, includes an extra service. The company focuses on selling a product, in the traditional way, but offers a related service, such as maintenance or warranty, to add value to the product and enhance UX.
2. Use-oriented PSS is a type of PSS in which the product remains as the company's property, while its use or availability is sold to the consumer, in the form of renting or leasing. The company provides access to the product rather than ownership, allowing customers to benefit from the use while retaining responsibility for the maintenance and lifecycle management.
3. Results-oriented PSS means the company sells the user the opportunity to achieve certain task or result, instead of the ownership of a product. When acquiring this kind of PSS, the user does not have full access to a product but is able to buy the result of the usage of such product.

PSS's shift the focus from product ownership to value creation, promoting the I5.0 values. These systems are especially valuable for the reduction of overproduction and overconsumption, supporting responsible resource use (SDG 12) and contributing to climate action (SDG 13), among other SDG's.

- Human-robot collaboration (HRC)

Integration of humans and robots in shared tasks, enhancing each other's advantages such as the robot's precision and the human's decision-making, to achieve a common goal through knowledge sharing and social negotiation. Collaborative robots, or cobots, are designed to work safely alongside people, creating a dynamic, flexible and quickly adaptable environment (Gervasi et al., 2020).

- Human-in/on-the-loop (HiTL/HoTL)

HiTL refers to systems in which machines execute specific tasks after human decision making, and subjacent command, implying real-time control from a supervisor. HoTL refers to more autonomous systems that can make decisions and execute tasks independently, with the human supervisor only providing their expertise when needed (Nahavandi, 2017).

- Human-Machine Interface (HMI)

In the evolution from I4.0 to I5.0, higher focus on HMIs was given, due to advancements in HCI. The technologies from I4.0 are connected to the worker's problem-solving skills and creativity, leading to flexible production systems that can adapt to new goals, such as the SDGs. The application of HCD in HMI is able to empower operators with enhanced capabilities, to be more autonomous, creating a more sustainable workforce (Panter et al., 2024).

- Digital Twin (DT)

A DT is a virtual dynamic model of a physical system or process, and it is continuously updated, mirroring the state, behaviour and performance of its real-world counterpart in real time. DTs can be created to mirror assets, people, factories or production networks. Applying this concept enables remote analysis and optimization without direct interference with the physical counterpart, promoting efficiency and safety by allowing remote access and providing real-time insights that inform decision-making. DT is an enabling technology for the IoT and promotes worker empowerment by allowing simulations to replicate system operations, for training and skill developing without the safety risks and associated costs (Lu et al., 2020).

- Artificial Intelligence (AI)

AI is a tool that can simulate human intelligence processes such as learning, calculating, perceiving, decision-making, and understanding. This tool requires complex algorithms, large amounts of data and significant computing power to operate, but it can perform tasks that traditionally require human intelligence. Thus, it has potential to automate routine tasks, liberating workers to do more pleasant and specialized work. Even if AI can make calculated decisions, the most resilient solution is a hybrid approach, in which AI and humans collaborate. The scenario in which AI can consider human's emotions and physical health to make informed decisions can reduce reliance on experts and their personal experience, but it presents a challenge to implement, due to data heterogeneity, data monitoring and its integration (Zhang et al., 2023).

- Internet of Things (IoT)

The IoT enables continuous, seamless, and smart interactions between systems, devices, and people, collecting and sharing real-time data through embedded sensors and software. Apart from these direct benefits, the IoT promotes collaborative decision-making between humans and machines, with potential for the personalization and adaptability of systems. The implementation of this technology promotes human-centricity and empowers users with information and enhances UX. The private and secure connection of humans, machines and things in a shared manufacturing environment can be challenging, but cybersecurity is another emerging topic, and solutions like blockchain have been pointed out to solve this issue in the industrial IoT (Zhang et al., 2023).

- Cyber-Physical Production Systems (CPPS)

CPPS are enabled by the IoT, and consist of production systems that integrate both physical and digital components, creating a smart production environment. These systems combine multiple 15.0 technologies and principles, making them able to track and locate items and exchange data through workstations, with management, and even with suppliers or clients (Fernandez-Carames & Fraga-Lamas, 2018).

All of the above-mentioned technologies have potential to change industrial practice into a more human-centred one. However, to drive the required cultural change, and avoid the prioritization of productivity and technological development at the expense of human values,

HCD guidelines are needed. The next section presents some of the standards that contribute to HCD by ensuring the development of safer and more ergonomic industrial products.

### 2.2.3. Safety and Ergonomics standards in industrial product design

Adding on to the HCD principles, considering safety and ergonomics standards is essential to minimize risks and further promoting user well-being. To achieve these goals, it is important to conform to the relevant standards. In this chapter, the main safety and ergonomics standards are analysed in terms of their role and applications in industrial product design. Failing to address the safety standards increases the accident probability, while not addressing ergonomics standards contributes to operator fatigue and errors (ISO 6385, 2016). Not adhering to standards in general can result in legal and financial penalties for the company (ISO 12100, 2010). Therefore, the following Table 3 presents the recommended safety and ergonomics standards to be considered since the early stages of product development, to ensure the company's compliance with the existing regulations.

Table 3 - Safety and Ergonomics standards in industrial product design

Standard	Key Elements	Application in product development
ANSI Z535 (2017)	A series of 7 American standards regarding specifications for safety signs.	Standardized colours, symbols, and text formatting.
BS EN 614-1+A1 (2009)	A European standard that applies to user interaction throughout the lifecycle, considering user health, safety and well-being.	A set of guidelines for universal design and ergonomic principles to be followed during the design stage of machinery.
IEC 60204 (2023)	A series of standards for design to promote safety, consistency, control and ease of operation of electrical equipment in machines.	Requirements for electrical equipment in machines.
ISO 12100 (2010)	A framework for risk assessment and reduction in machinery design.	Conducting and maintaining records of risk assessments.
ISO 13849-1 (2023) and ISO 13849-2 (2012)	A framework for the design (part 1) and validation (part 2) of safety-related parts of control systems that perform safety functions, including software.	Specification of safety functions, design considerations, software safety requirements, validation.

Table 3 - Safety and Ergonomics standards in industrial product design (continued)

ISO 6385 (2016)	A framework for the ergonomic design of work equipment, considering the various limits of human capabilities.	Design guidelines for work systems, integrating human, social and technical requirements.
ISO 9241-210 (2019)	A framework to manage HCD for the development of interactive systems, concerning ergonomics in both software and hardware to enhance human-system interaction.	Requirements and recommendations for the development of interactive systems.
ISO 9241-220 (2019)	A standard focused on the implementation of processes and practices that can improve HCD within organizations.	Guidelines for the integration of HCD into existing processes such as product development.

It is worth to mention the ANSI/HFES 100:2007 standard, which is currently discontinued, but a new version of this standard is set to be released soon. It is a collaboration between the ANSI, and the Human Factors and Ergonomics Society (HFES), and it has provided specific guidelines for the installation of computer workstations for a wide variety of users.

#### 2.2.4. State-of-the-art

The following Table 4 presents an analysis on the most significant articles on HCD, through a state-of-the-art review. The synthesized contributions offer an understanding of HCD and its fundamentals and lay the foundation for further work and exploration. The selection criteria for the articles was based on the relevance of each article in the HCD context, and the goal was to provide an holistic view of the current research themes on the topic, considering sustainability, resilience, enabling technologies and emerging challenges.

Table 4 - State-of-the-art on HCD fundamentals

Author(s)	Synthesis
Borthwick et al. (2022)	The review paper defends an expansion of HCD from a user-focused perspective to a broader concept that is sustainable in the long term, not only for humans but for the whole environment. The authors argument that design proposals must take into account not only feasibility, viability and desirability, but also the responsibility that comes with designing a new product. Acknowledging environmental and ethical values of each design alongside technology, business and human concerns, results in responsible innovation. In the current framework, shareholders dominate corporate policy and the company uses profit as the measure for success, creating a barrier to the proposed "life-centred design".

Table 4 - State-of-the-art on HCD fundamentals (continued)

Author(s)	Synthesis
Pacheco & Iwaszczenko (2024)	<p>The study conducted a literature review to understand the human-centricity challenges deriving from the adoption of I5.0. The authors develop a framework that organizes 20 human-centricity challenges in the manufacturing context. Resolution strategies include: Intelligent automatization of manufacturing systems, reducing repetitive tasks; Application of I5.0 maturity models to promote human-centricity systems; Adoption of customized I5.0 frameworks; Incorporating decision models for performance-fatigue balance; Developing new technologies to aid workers; Full transformation to digital landscapes; Mass customization approach of the products; New tools to aid workers at the digital workplace; Upskilling of manufacturing workers; And developing new decision models, approaches, concepts and frameworks.</p>
Horvat et al. (2024)	<p>The authors explore the combination of competence management and emerging technologies to promote product innovation in the Industry 5.0 context. The research is focused on ecological and digital product innovation, considering them as crucial for Industry 5.0. The research offers valuable insights for managers in manufacturing companies into establishing and implementing human-centred I5.0 strategies, applying them to enhance product innovation outcomes. The relevant technologies for I5.0 are cyber-physical production systems, intelligent robots and the use of AI at various stages of the production process. It is necessary to train employees to increase their I5.0 relevant capabilities. The most important aspect for human centric I5.0 is the combination of smart technologies and suitable competence training for employees. I5.0 oriented companies have higher capacity for innovation, and digital and sustainable transitioning.</p>
Castagnoli et al. (2024)	<p>This article analyses the role of the human-centric approach in Industry 4.0 and 5.0 through a literature review. According to the reviewed literature, the human-centric approach: Is under investigated in management and mainly ergonomically approached in engineering; Enables response to the challenges of an aging population; Positively impacts economic and social sustainability; And should be investigated through a transdisciplinary approach. Future firms' strategies, governments' policies, and standards face several challenges for the cultural change into the human-centric approach. The challenges are presented, falling into one of three focuses: Cultural change, Redesign and Empowerment.</p>

After analysing the state-of-the-art articles, it is clear that a change in frameworks is needed to accommodate human-centred values systematically in the transition towards I5.0. The following chapter presents a condensation of the most valuable HCD enabling methods and tools at the disposal of engineering teams, to develop I5.0 products and practices.

## **2.3. Human-Centred Design methods and tools for product development**

This final chapter of the literature review, combines concepts of the previous two chapters. Firstly, the product development process stages are linked with HCD methodologies, aiming to propose an integrated guide for the development of human-centred products. Then, for the next two topics, the HCD methods and their function in product development are explained in detail, beginning with the data acquisition methods, and continuing with the user testing methods. In the last topic, the enabling tools are presented, completing the analysis of the HCD integration into product development.

### **2.3.1. HCD integration into the product development process**

The increase of consumer demands, the fast technological advancements and the increasing competitiveness are leading to shorter product lifecycles (Huisman, 2012). Therefore, the product development process needs to keep up with this fast pace, creating a need for an efficient and structured methodology. The iterative HCD upon analysis of user data can improve workstation ergonomics (Caputo et al., 2019), accessibility, safety, usability, reduce costs and process time (Grandi et al., 2020). To tackle the challenges presented across the lifecycle, as well as the I5.0 goals, HCD enabling tools can be integrated in product development through four methodology groups (Nguyen Ngoc et al., 2022):

#### **Discovery**

User impressions and behaviours dictate the success of a HCD process. These human emotions are mostly subjective, and to create a human-centred product, these need to be captured through discovery methods. These consist of data acquisition methods, employed to discover human needs and requirements, gathering useful information for design iterations.

The appropriate discovery method should be selected and/or designed to promote the collection of relevant information for the current design stage of the project and the desired analysis sphere (Nguyen Ngoc et al., 2022). Each discovery method presents distinct advantages and limitations, which are analysed in section 2.3.2. Before implementing a prototype, to address motivation, engagement and well-being when interacting with digital products, user needs should be considered in the following spheres of analysis: technology adoption, interface interaction, technology-specific task experience, technology-supported behaviour, and overall life experience, which can extend into a society sphere (Peters et al., 2018). For the HCD prototype to be successfully integrated in an industrial context, user cognitive and cultural acceptance of technology is required (Castagnoli et al., 2024). To overcome adoption conflicts during prototyping of a new product, user experience needs are evaluated (Ulrich et al., 2020). In this phase, HCD user testing methods can be performed, the most common being questionnaires, surveys and task analysis (Hsieh et al., 2024).

### **Clean-up**

Mathematical models and data analysis methods that enable the conversion and understanding of the acquired data, avoiding subjectivity, imprecisions and vagueness in human ideas. The challenge of cleaning up this kind of data is dealing with subjectiveness, prioritization, complexity, imprecision and vagueness. The following models allow the classification of design requirements according to priority, supporting decision making on design alternatives with quantifiable data (Nguyen Ngoc et al., 2022):

- Analytic Network Process (ANP) (Saaty, 1999): This tool ponders on the best decision by breaking down the problem, considering the influence of factors on each other, comparing and weighting each factor, and calculating the best choice accordingly.
- Law of Comparative Judgments (LCJ) (Thurstone, 1927): As people struggle to give absolute ratings, and find it much easier to make comparisons, instead of rating items, this principle makes pairwise comparisons. The results from extensive comparisons are statistically analysed and an absolute value for each item derives from the analysis.
- Fuzzy Set Theory (Zimmermann, 2001): This theory allows elements to have partial membership in a category, represented by values between 0 and 1. This is a useful approach for characterizing subjective concepts in which boundaries are not clearly defined, reflecting the ambiguity of concepts such as emotional response.

In parallel with the discovery and clean-up of user data, empirical knowledge of human factors and ergonomics should be employed to evaluate user interaction.

### **Engineering**

Methods for the conversion of requirements into product characteristics and properties, establishing design goals;

- QFD: This method identifies the impact of design elements on customer needs, helping in prioritising design elements based on their importance.
- Kano model: The Kano model distinguishes product requirements into categories, identifying from the essential to the indifferent product characteristics.
- DfX: By defining a clear design goal, the DfX method defines clear and measurable design goals based on the proposed requirements.

All the referred methods in this section are explained in detail throughout the literature review.

### **Experiment**

Design analysis methods to understand the different configuration possibilities and visualize the improvements or disadvantages on each solution.

To respond to the I5.0 needs, and support development in human-centred products, the methodology that is presented next, is an attempt at merging the existing HCD tools and methods with the product development process. This framework does not consider all the existing challenges and stages of product development. Instead, it aims to isolate only the

relevant methods and tools to address HCD's specific challenges. For instance, planning techniques and design tools were not considered, as they are not specific to human-centred product development. Relatively to the previously mentioned methodology groups, the clean-up methods will not be considered as there is no dedicated mathematical or statistical method for HCD. Thus, the proposed methodology combines the discovery, engineering, and experiment groups, and apply to two critical stages of product development: concept development and prototyping. It is also relevant to note that, especially in HCD products, the development is iterative, and validation is required in between stages. The results of the validation may force an iteration at any step of the development process or the product lifecycle. Table 5 presents the proposed methodology, adapted from the successfully tested method for ergonomic design proposed by Papetti et al. (2021), adding principles and methods reviewed by Hsieh et al. (2024), Nguyen Ngoc et al. (2022), Sun et al. (2019), Borthwick et al. (2022) and Bechinie et al. (2024). The goal is to guide not only the ergonomic design, but the more holistic process of HCD.

Table 5 – Summary of HCD tools in product development

Stage	Task	HCD Method	HCD Tools	
Concept development	Identifying user needs	Survey	Interview	
		Field study	Questionnaire	
	Concept generation	Co-design		Observation
				Brainstorming
		Product requirement analysis		Focus groups
				Kano model
Prototyping	Virtual prototyping	Simulation	QFD	
	Physical prototyping	Technology acceptance		<i>Kansei Engineering</i>
				VR
		Usability testing		UTAUT
				SUS
				SUMI
				Task load index
				Heuristic evaluation
				User journey map
	Field testing		Cognitive Walkthrough	
		Eye-tracking		
		AR		
		Task analysis		

### 2.3.2. Data acquisition methods in Human-Centred Design

To create systems that meet the user's needs across the product lifecycle, data acquisition methods are used. These methods allow the deep understanding of the product's end users, their insights, behaviours, preferences and difficulties (Nguyen Ngoc et al., 2022). The following methods are useful to collect data to provide information for the definition of product requirements.

### **Interview and Questionnaire**

Interviews and questionnaires are both essential methods to understand users. Both methods can be implemented for users to express themselves about the product or the previous system, identifying their needs, preferences and opinions. The collected information is then statistically analysed to ensure that the product is developed according to the real needs. Both methods collect quantitative and qualitative data. The interview is conducted as a conversation in the context of product use, being the collected data much richer. It is more useful when fewer participants are involved, due to being time consuming, and it provides clearer data. Questionnaires consist of a series of questions that promote extensive data collection, are more time efficient and cost effective, but might induce misinterpretations as they are answered remotely. These methods are the most used in collecting subjective, self-assessed data. Application examples are examining acceptance, usability, workload, situation awareness, discomfort, and comparison between products (Hsieh et al., 2024).

### **Observation**

A field study is a data acquisition method based on the observation of users in their environment, to gain a general perception of the context of product use. The application of this method enables the perception of user behaviours, needs, motivations and struggles, to inform decision making and to validate assumptions. It can include informal and open questions to the users. The main advantage of this method is that it can obtain rich data about cultural, social and physical contexts of the users in an empathetic way. However, due to the subjective data, it can induce bias in research conclusions (Nguyen Ngoc et al., 2022).

### **Brainstorming**

A brainstorming session is a creative problem-solving technique, consisting of a stakeholder meeting, in which every participant generates the largest possible volume of solutions or ideas for the product concept or for specific solutions within the product. These meetings are conducted by a moderator who encourages the collaborative idea generation and takes note of every idea without making any judgement. This creative exercise useful to quickly create a large solution space and the adopted solution often derives from one or more ideas (Wilson, 2013).

### **Focus group**

Focus groups consist of a guided meeting, including users, engineers, managers, and all the relevant stakeholders, to identify the needs or opinions of each interested part. These meetings are guided by a moderator that promotes information sharing and conducts the group to in-depth exploration of product requirements or solutions (Hsieh et al., 2024). This method can be useful both in identifying user needs and in concept generation, being the main advantage the efficiency in information sharing.

### 2.3.3. User testing: From virtual models to physical prototypes

In this chapter, the most used methods for virtual and physical prototype testing are presented, introducing the need for the HCD tools that are proposed in Table 5 and developed further in chapter 2.3.4.

#### Usability Testing

The evaluation of a product usability considers the user context, goals and outcomes when interacting with the product. A product's usability is defined by a combination of factors (Jordan et al., 1996):

- *Learnability*: Users should be able to achieve an acceptable performance after using the system for a specified period.
- *Effectiveness*: A defined proportion of users should be able to achieve an acceptable performance on a determined number of tasks and environments.
- *Attitude*: The desired performance should be reachable without inducing unacceptable levels of fatigue, stress, frustration, discomfort and dissatisfaction on the users.
- *Flexibility*: Different tasks should be achievable with the same product, beyond those first specified.
- *Usefulness*: Whether a product is going to be desired and effectively used in the real-world context, as the other factors may not translate directly to the product being actually used.
- *Task match*: The user's needs and requirements should be properly matched by the system's provided functionalities.
- *Task characteristics*: The user must be able to perform and modify tasks with a reasonable frequency.
- *User characteristics*: The usability concerns different knowledge, skill and motivation levels, as perceived usability is variable across different users.

For an HCD product, user testing should be frequent. This concept allows development teams to evaluate the performance and understand the user's feedback, for further optimization. To gather information on virtual models or product concepts, an acceptance test can be helpful, while for a physical prototype, usability tests should be performed. After developing a prototype, the evaluation of a product's usability is made by the user, who is going to be interacting regularly with the product, and may already be familiar with similar products, or have certain expectations for it.

#### Simulation

Simulation is a valuable tool across the product development process. By modelling and simulating use conditions, it is possible to find problems and mitigate risks early in the design and throughout product development, reducing costs, technical and schedule risks (Boy & Narkevicius, 2014). It is also useful to validate designs or discover new solutions without the

costs of producing physical prototypes, adding value to the product with fewer resources (Hong et al., 2024).

### **2.3.4. Tools for iterative design: feedback and optimization**

This chapter explains in detail the remaining HCD tools proposed in this methodology. These have potential to promote the iterative HCD approach by systematically addressing user feedback for UX optimization.

#### **Kano model and QFD**

The Kano model is a systematic method that classifies the product requirements into categories according to their priority, and how they affect user satisfaction. This methodology was proposed by Kano et al. (1984) to study the different natures of customer requirements. The model has been used since then, and some modifications have been proposed to optimise this approach into specific applications. In the original model, to classify the customer requirements, the categories are the following:

- **Must-be (M):** These product requirements are taken for granted by the user, i. e., if these are not met, the user becomes dissatisfied.
- **One-dimensional (O):** The user satisfaction is directly correlated with the existence of these features in the product.
- **Attractive attributes (A):** These features are usually unexpected. As a result, the user becomes more than proportionally satisfied with their presence. However, the absence of these product requirements does not cause dissatisfaction.
- **Indifferent (I):** Users are indifferent to these features.
- **Reverse (R):** The customer is dissatisfied with the presence of this attribute.
- **Questionable (Q):** These product features do not meet the customer's expectations.

The categorization of the requirements provides a more usable format to integrate the requirements effectively into product design. This procedure is useful both in the development of new human-centred products and in the optimisation of existing products (Zhao et al., 2020).

The Quality Function Deployment (QFD) method is a well-established and systematic method that has been used to translate user needs into product requirements throughout the product development process. The method allows for the classification of requirements, identifying which ones are critical, to align the product with the user's priorities, as well as identifying design conflicts. The QFD tool consists of a matrix known as the House of Quality, which combines customer needs with technical requirements for the product (Bergquist & Abeysekera, 1996) and can also include a column for the Kano model category in each product requirement.

### **Kansei engineering**

*Kansei* is a Japanese word that represents the concept of sensing a situation or an artifact and building an individual emotional response. *Kansei* Engineering is a method to translate the user's subjective impression into a design (Lévy, 2013). This is not a new technology or a method, instead it consists of a combination of multiple existing tools to quantify user's feelings towards a new product (Schütte et al., 2004). It is useful to evaluate and quantify user feedback, translating subjective feelings and impressions into a structured dataset. Information can be displayed on tables, graphics, vectors and clusters, which facilitates its reading and, crucially, processing.

### **Unified Theory of Acceptance and Use of Technology (UTAUT)**

For the HCD approach to be successfully integrated in an industrial context, both individual and cultural acceptance of technology is required (Castagnoli et al., 2024). The UTAUT model is the most widely used technology acceptance study method, and it aims to guide technology implementation by predicting how the user will behave. To accomplish this task, it is necessary to understand the factors that influence user decision of accepting and using new technology. This model was developed to explain and predict the user acceptance and level of use of new technology, through a combination of eight previously existing theories and models. The model measures the four key variables that influence the user's intention to use and the actual use of the product: performance expectancy, effort expectancy, social influence, and facilitating conditions. These are affected by four moderating variables, also to be measured: gender, age, experience, and voluntariness of use. The combination of these variables as shown in Figure 4 composes the behavioural intention and the real use behaviour. Each of the variables are quantified through a survey and statistical analysis of the data. The collected information provides crucial results to align product features with the user's intentions and actual behaviour (Stiegemeier et al., 2023). However, different application contexts of the model may create the need for adaptation of the basic UTAUT (Stiegemeier et al., 2023).

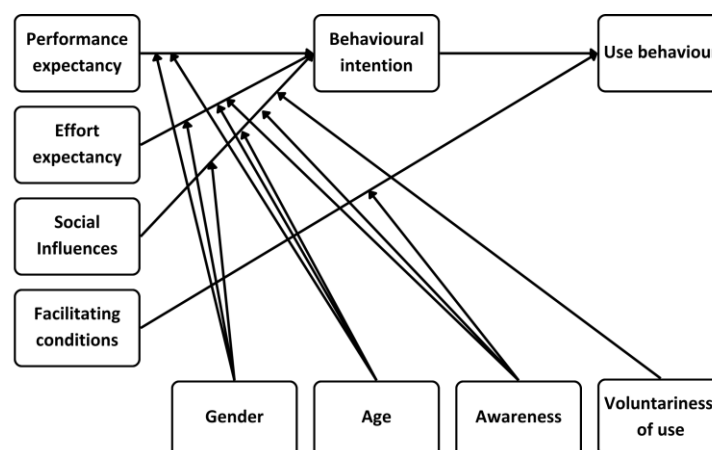


Figure 4 - UTAUT model (adapted from Attuquayefio & Addo, 2014)

### **System Usability Scale (SUS)**

SUS was developed by John Brooke and presented in Jordan et al., (1996) and it consists of a simple ten question survey to evaluate the usability of interactive systems. This method is useful

to collect data from large amounts of users, without the need for vast expenses or efforts. The questions are general and can be applied to assess the usability of software, websites and interactive systems. This method consists of a set of ten statements, in which users can select a degree of agreement from 1 (strongly disagree) to 5 (strongly agree). The survey can be presented in physical format or digitally, or through an interview or questionnaire. The SUS is generally used after the participant has had the opportunity to interact with the system, but without any debriefing or discussion about the experience. The response time is supposed to be short, to capture the user's impressions, without the effect of overthinking about the questions. There should be at least 50 to 60 responses to grant a reliable result. For data analysis purposes, every statement should have a response. Even if the user cannot formulate an opinion, he should answer on the central value, meaning that he does not agree nor disagree (Soegaard, 2024).

### **Software Usability Measurement Inventory (SUMI)**

SUMI was developed by Kirakowski and published in 1993 (Kirakowski & Corbett, 1993), as a method to evaluate the user's perspective on software quality. It consists in a 50-statement psychometric questionnaire, meant to capture the user's subjective feedback on their interaction with a new system. Similarly to the SUS, the questionnaire takes place immediately after the test on the prototype (Jordan et al., 1996).

### **Task Load Index (TLX)**

Developed by NASA in 1986, the TLX measures the intensity of the workload through a series of procedures. Since the meaning of workload can be subjective, the procedure includes a weighting system to moderate the importance of the various factors that influence the perceived workload (NASA, 2014).

### **Heuristic Evaluation**

A heuristic evaluation is a usability inspection in which a small group of evaluators systematically compare the product against usability principles and best practices, i.e., heuristics. The main advantages of this method are low cost and time efficiency, while the main disadvantages are the relatively low quality of the results, lack of user involvement, and the need for availability of experts (Vredenburg et al., 2002). The most widely used principles are Jakob Nielsen's 10 usability heuristics (Nielsen, 1994):

- *Visibility of system status;*
- *Match between system and the real world;*
- *User control and freedom;*
- *Consistency and standards;*
- *Error prevention;*
- *Recognition rather than recall;*
- *Flexibility and efficiency of use;*

- *Aesthetic and minimalist design;*
- *Help users recognize, diagnose, and recover from errors;*
- *Help and documentation.*

### **Cognitive Walkthrough**

Cognitive walkthrough is a usability assessment method that promotes HCD by focusing on the user's cognitive process in their first interactions with the product. The goal is to identify issues and errors in the interaction, which can lead to the identification of usability problems. Separate tasks are divided into steps and executed, and the steps in which errors occur should be noted. The cognitive walkthrough provides information of the user's understanding of the system's functions, feedback and guidance, providing an estimation on the ease of learning (Mostafazadeh Davani et al., 2018).

### **User journey map**

The user journey map is a detailed visual guide of the needed steps to complete a task using a system. This tool presents not only the steps to a task, but also a more detailed description of every interaction between user and system, data about the user, their actions, emotions and difficulties. This map can complement a cognitive walkthrough, with the detailed step-by-step description, or it can be useful on its own, to identify opportunities for optimization.

### **Augmented Reality (AR) and Virtual Reality (VR)**

AR is a system that supplements the real world with overlaid digital content, enhancing the users' perception and interaction with the surroundings. In the industrial context, AR can be useful to actively share expert knowledge with the user, i.e., to provide explanations of the features or the tasks to be performed, access to system data or information (van Lopik et al., 2020). VR, in turn, does not require a physical basis, providing fully virtual content. These systems engage users and provide an immersive training experience. Other functions for this technology involve the creation of a virtual prototype and are useful to explore the design and its implementation in the real-world scenarios as if the prototype was physical, facilitating validation, UX understanding, and accessibility and inclusivity testing. The main difference between AR and VR lies in the need of a physical component for the AR, and the level of immersion being higher in VR with the simulation of both the product and the environment.

### **Eye-tracking**

An eye-tracking tool allows the design team to unequivocally observe the user's ocular behaviour when interacting with the prototype. It is most useful when users are not able to express their experience verbally, or struggle to do so. As eye tracking data is always clear and measurable, it provides objective and quantifiable data about user behaviour. It is possible to discover where users direct their sight, which is helpful to identify elements that are wrongly attracting or failing to attract the user's attention. Furthermore, since eye movements are indicators of cognitive load and confusion (Ball, 2006), eye tracking allows the detection of usability problems and gives valuable information to enhance the intuitiveness of the system.

However, eye tracking technology can be expensive, and requires specific skills on data gathering and analysis that may discourage design teams from using this tool.

#### **Key Performance Indicator (KPI)**

KPIs are used to measure the performance of a system, based on a set of measurable categories that are considered to characterize its activity. Some HCD-related KPIs are (Fantini et al., 2020): percentage of physical activities, percentage of non-value-added activities, percentage of activities with high or medium social interaction, and percentage of activities with high or medium innovativeness. To measure a KPI, a clear objective should be defined, and the relevant data should be monitored and analysed. Comparing the results with previously set goals should provide an insight into the areas that need to be improved. Using this tool, the benefit of each design solution can be measured, informing decisions for iterative design.

#### **Task analysis**

Task analysis is a method to evaluate the accomplishment of a given task with a product. Each task is divided into steps and each one is analysed individually, to identify potential errors, difficulties or design optimization opportunities. For instance, tracking the time expended on each step of the interaction, as well as the system's response time, can be useful to identify bottlenecks, i.e., critical phases that limit the effectiveness of the process, which should be the focus for optimization. The thorough analysis of every step leads to an avoidance of redundancies, optimized workflow and a risk reduction. This tool can also be useful for the conceptualization of a new product, through the analysis of the existing one (Hsieh et al., 2024).

By employing these three methodology groups, i.e., data acquisition, user testing and iterative design, the product development process benefits from a continuous feedback loop to inform decision making for the iterative design cycles. This approach results in incremental improvements to the product that align with user needs and functional requirements, reducing development risks, shortening the development duration and resulting in effective and human-centred products.

### **2.3.5. State-of-the-art**

The state-of-the-art research concerning the integration of HCD methods and tools into product development is presented in Table 6. The research provides an insight into the latest practices, as well as emergent technologies and tools with potential to enhance HCD.

Table 6 - State-of-the-art on HCD methods and tools for product development

Author(s)	Synthesis
Hsieh et al. (2024)	<p>The review article compiles the role of HCD in system design and evaluation studies, conducted in maritime systems. The authors analyse the number of studies, along with the number of HCD tools used in the reviewed studies and divide HCD methods into objective and subjective methods. With the findings, a HCD framework is proposed, comprising three stages: identifying user needs, designing and developing prototypes, and evaluation or validation. The main conclusions were that usability plays a key role in safety and workload of operators, usability evaluations must be conducted with sufficient participants and should consider testing in a real-world environment, and organizational and management aspects are critical to the implementation of HCD.</p>
Egeonu & Jia (2024)	<p>This article reviews computer vision as an emergent technology that has potential in replacing observational and self-assessment methods for estimating physical workload. The review explores computer vision-based measurement of physical workload, addressing ergonomic risks. This tool estimates workload in a non-invasive way, through cameras, deep neural network algorithms and force sensors. The review presents, analyses and compares the three most common frameworks for workload estimation with computer vision-based models. Furthermore, it addresses advantages and challenges of this tool, as well as the application fields. Several case studies are presented, applying this technology in HCD in construction, medical, medical rehabilitation and manufacturing industries. It is possible to conclude that the tool can perform equally well as traditional methods, with the main advantages being low cost, non-invasiveness, flexibility, and automatic assessment. The main challenges and limitations were camera obstructions, lack of research data, and the limitation of measurable parameters.</p>

Table 6 - State-of-the-art on HCD methods and tools for product development (continued)

Author(s)	Synthesis
Urquhart et al. (2022)	This case study presents generative design as a tool that shows potential in design exploration, enabling the translation from product requirements into creative design solutions, as well as the refinement of designs, with human factors and ergonomics inherently programmed as a constraint. The article develops a framework for the design process that is oriented towards human factors and ergonomics, while accommodating digital tools and optimisation strategies. The suggested design stages are specification/ideation, conceptualization, embodiment, and realization. The method is applied to a hand physical therapy device, and it promoted the creation of designs that were both viable and functional.
Gernez et al. (2023)	The article explores two cases studies on the use of VR as a HCD tool for industrial maritime applications. The research focused on discovering which design activities were benefitted from the use of VR, and which were the main alternative tools that could be used instead of VR. The main use for VR was to communicate a design and collect user feedback. It is argued that VR provides a unique ability to immerse the user in a realistic experience of the design, creating opportunities for early test for a design. The authors conclude that VR deserves further research to make the method more accessible, and more integrated into design practice by enabling real-time content sharing with 3D modelling tools.

### 3. Methods and Applications

#### 3.1. Human-centred design approach for product design and development

This research focuses on the implementation of a structured methodology that integrates qualitative and quantitative methods that allow the development of products that respond to human needs, increasing user satisfaction and acceptance towards the product. With this approach, this work intends to: a) improve the acceptance of workers when new technologies are implemented into the shop-floor, and b) to enhance the user satisfaction when a new product is released into the market. To achieve these goals, two case studies are explored: Human-Machine Interaction to answer goal a) and User-Product Interaction to respond to goal b).

To this end, this section presents the methodology designed to address HCD and its implementation into the case studies. Figure 5 highlights the main stages of HCD implementation and suggests associated user testing methods for the two types of product.

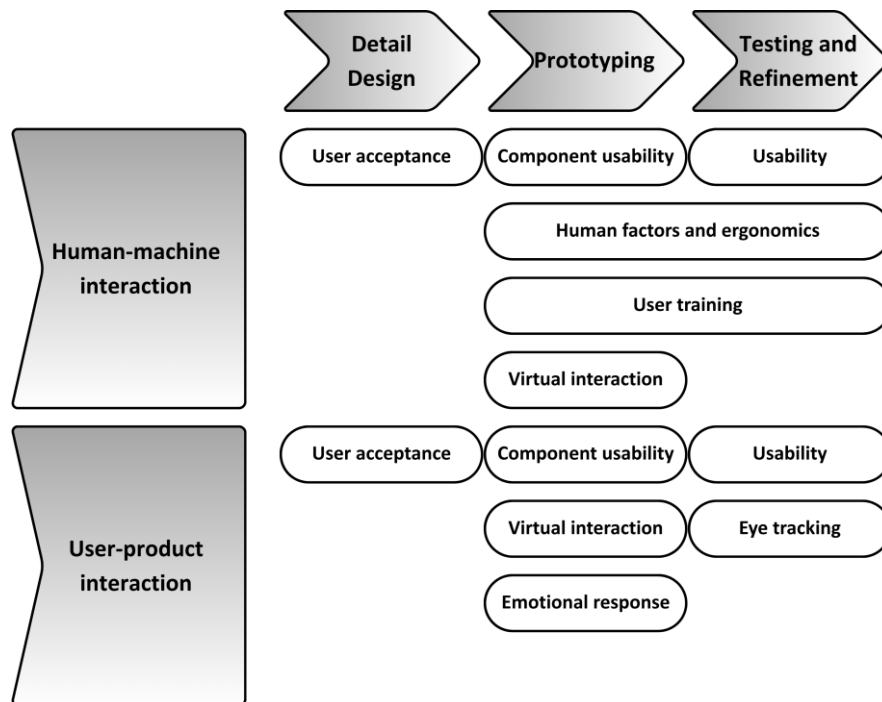


Figure 5 - HCD approach to product development

As proposed by Castagnoli et al., (2024), user acceptance of technology emerges as a potential hindering factor for implementing I4.0 technology with a human centred approach. This issue creates the need for more data gathering and analysis in this field, considered essential for the effectiveness of the HCD approach. Users' conscious and active role in the implementation process should lead to a more human-centred implementation. Following these propositions, user acceptance is included in the methodology as a transversal approach as early as the detail design stage.

As described by Barnum, (2021), usability testing is at the core of HCD, validating previous assumptions about human behaviour. This user testing method aims at understanding users' goals, motivation and engagement with the real product. Repeated and informal studies throughout the development process reveal a list of findings to analyse and fix regarding what product features align with users and their goals. Therefore, the proposed methodology includes multiple stages of usability testing, beginning with single components before testing a complete prototype.

Virtual interaction with a product appears as an emerging method typology, relying on AR to present a virtual prototype to users and gather requirements from the interaction with both users and use context. As Kang et al. (2023) concluded, an AR prototype can enable user testing, resulting in similar requirements as physical prototyping, while improving the overall experience for users and avoiding some costs of high-fidelity prototypes. Alternatively, for the discovery of design requirements with lower emphasis on interaction, VR technology is also proposed for this assessment.

The application of HCD methods in the development of new products should be fluid and adaptable to the product being developed, and the available tools. Thus, variations in the methodology appear between its application to industrial products and consumer products.

### **Human-machine interaction**

Regarding industrial products, specific human-machine interaction assessment methods are proposed, beginning at the prototyping stage. A human factors and ergonomics assessment should take place, as well as user training. Both can be addressed since early in the prototyping stage, combining the assessment with virtual interaction testing, and during physical prototype testing and refinement.

A human factors and ergonomics assessment in this stage allows to adjust the prototype details towards users' challenges and preferences. This assessment assumes that all the necessary ergonomics standards are already met, only aiming to improve the users' perception of comfort and safety with the allowed adjustments within the due regulations.

Early user training ensures a step by step learning process, promoting user involvement. At the implementation moment, users should be familiar with the task by being involved in training as early as possible.

### **User-product interaction**

For consumer products in general, a different approach is suggested, with user-product interaction specific assessments.

Emotional response assessment methods include self-report data collection such as questionnaires, physiological measurement and facial expression analysis. The resulting data shows the product development team how effective is the design in eliciting a positive emotional response, reflecting how well user needs are met (Yusa et al., 2023). Eye tracking is emerging as a potential physiological measurement technology, allowing the discovery of emotional response and the improvement of user experience (Guo et al., 2016).

In this context, two case studies will be explored. The research was conducted in partnership with a Portuguese ceramics company in two different contexts. Regarding Human-Machine interaction, the case study focuses on a new machine designed and developed by INEGI, aiming to support workers into a difficult task, which is defect detection in ceramics. The second case study focuses on a new packaging designed with circular principles, intended to have a second-life after use.

## **3.2. Case studies definition**

The following case studies were selected to expose the application of the presented HCD methodology into an industrial product following a Human-Machine Interaction approach and consumer product focusing on User-Product Interaction. The case studies highlight the distinct approaches that apply to different products and settings, and show the potential of emergent technologies in the promotion of HCD in product development.

### **3.2.1. Human-Machine Interaction**

An industrial product, namely a machine, is an equipment that serves a specific purpose and requires continued user interaction. In this case, users do not make the decision to use the product or not. As a result, an industrial product should be carefully adapted to their physiological and ergonomic necessities, considering the user acceptance of the equipment and long-term impacts of repetitive use. As an advantage, the users of industrial products have technical knowledge, being able to input valuable information into the product development process.

This case study exposes an HCD approach for the development of a defect detection machine for a ceramic manufacturer. The machine will use computer vision and AI to identify defects on two different models of ceramic dishes and select a quality category for each one. The goal is to improve the existing quality control process at the factory, which consists of manual and visual inspection for defect detection. This solution aims to improve quality control accuracy and automate this mentally and physically demanding and repetitive task.

As the case study began, the defect detection machine was in the prototyping stage. A prototype concept was under development, with the purpose of being deployed in the factory for data acquisition, to train the AI model. This prototype would require human interaction, to manually feed each dish and the respective quality control data into the system. The system will automatically collect images of the dish and run them against the quality control data introduced by the user. The collected data will be stored, and the resulting database will allow

to feed the AI model to be able to identify each defect only from collecting dish images. The prototype CAD model is represented in Figure 6. The main modules of the prototype are the dish receptor, the image acquisition enclosure and the HMI. The dish receptor module is an additively manufactured *poka-yoke* that supports the two different models of dishes, both facing up and down in a defined position, while keeping the ceramic surface visible for image capturing. Inside the module, there is a motor that spins the dish for image acquisition from different angles, and this assembly is attached to an actuator that drives it towards the image acquisition enclosure. In this closed chamber, multiple cameras and lights are set up to capture detailed images of the entirety of the dish surface. The HMI module consists of a touch screen, and it is not included in the prototype CAD model as its final position in the system is not fully defined yet. This case study will define its final position as well as the prototype's integration at the factory.

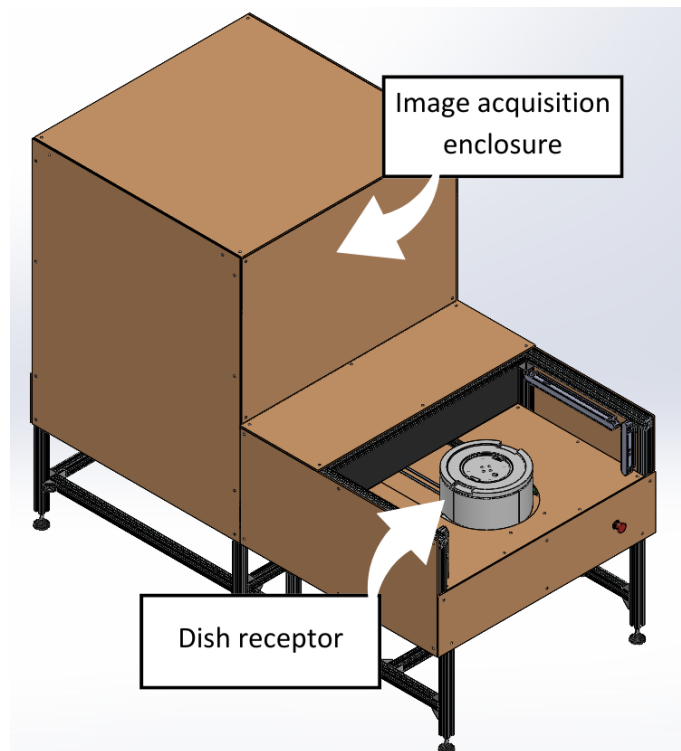


Figure 6 – Prototype model

Users will manually place each dish in the prototype receptor module and use the HMI module to register each defect and dish class in the face of the dish (Figure 7a). Upon command, the receptor module retracts into an image acquisition enclosure, spins the plate for image capturing, and returns (Figure 7b) for the user to flip the dish and register the defects found in the back side (Figure 7c). The receptor module retracts into an image acquisition enclosure, spins the plate for image capturing, and returns again (Figure 7d), for the user to remove the dish (Figure 7e) and be ready to restart the process.

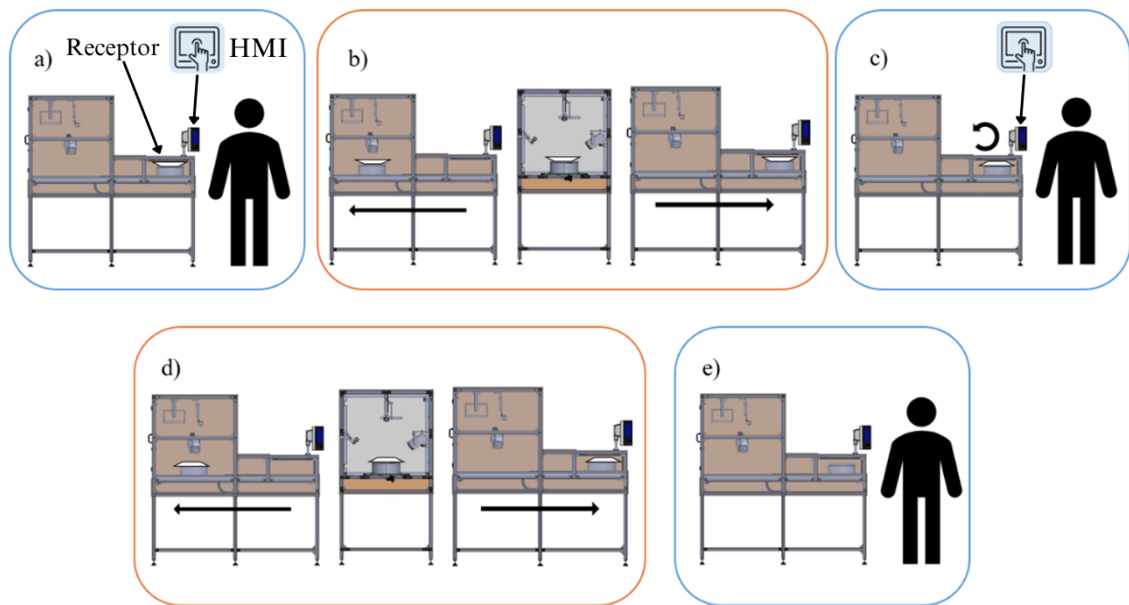


Figure 7 – Task sequence for quality control data storage: a) user feeds a plate facing up and inputs the visible defects, b) the prototype retracts the plate for image capturing, then returns it, c) user flips the plate and inputs the backside defects, d) the prototype retracts the plate for image capturing, then returns it, and e) user removes the plate

At this stage, the system and its functions were generally defined, being the current product development stage the detail design. This case study focuses on the improvements made to the product in the direction of HCD, and how the engineering team discovers relevant data, cleans it up, engineers product requirements and experiments with new product features.

To address the HCD challenge from the detail design stage onwards, a combination of methods was applied, focusing on user acceptance, usability, and ergonomics: three critical factors in industrial product development. User acceptance was evaluated using the UTAUT-for-industry model and a tailored questionnaire to identify and address user concerns early, promoting smoother adoption of the system and reduced resistance to change. Usability was assessed through a questionnaire that merged standard tools like the SUS, SUMI, and NASA-TLX, enabling early feedback on user-interacting components to prevent costly redesigns. An ergonomic analysis was conducted before implementation to understand user preferences and operational challenges. AR prototyping played a key role in this assessment by enabling the presentation, training and ergonomic evaluation in a mixed-reality context, while a physical prototype was not yet developed, enhancing user familiarity with the final product.

### 3.2.2. User-Product Interaction

The second case study contrasts with the first one by approaching the development of a product for consumer personal use. Consumer products, for personal use, are developed for the public or a target audience, being expected to perform their function while having to be marketable and attractive to be effectively used. The need for users' choice of the product over a

competitor's one is relevant for the product development team, causing a prioritization of attractiveness and accessibility instead of acceptance.

The product is a second life packaging concept, which was initially designed to contain a high value ceramic item. Beyond the purpose of protecting and displaying the ceramic piece, part of the package can be disassembled and reused as a decorative object after the initial use, giving the product a second life. Overall, this second life packaging concept is expected to add value to the ceramic product and to create a positive emotional response, to promote its own repurposing and the extension of its lifecycle. The subject for the user-product interaction case study is the packaging system, meant to be repurposed as a decorative picture frame. The existing prototypes are made from laser-cut MDF and polyamide, wrapped in a textile sleeve, as shown in Figure 8. To apply the HCD approach to the development of this product, two prototypes were created, for user testing.



Figure 8 - Second-life package: Box (left) and frame (right)

The approach is part of the first three phases of the Design for Emotional Response (DfER) methodology developed by INEGI, (Gonçalves et al., 2025), to correlate emotions with product features. The method comprises seven distinct phases, presented in Figure 9.



Figure 9 - DfER methodology phases(Gonçalves et al., 2025)

The first phase focuses on the design of the described second life package, to encourage its reuse to reduce waste and promote circular economy. Phase 2 centres on DfER testing by combining eye-tracking technology with structured questionnaires to capture both objective visual attention data and subjective emotional responses during user interaction with the product. Conducted with unbiased participants from INEGI's Product and System Development department, this approach allowed the team to correlate gaze, fixation and saccade patterns with emotional reactions, developing deeper insights into how specific design features cause emotional engagement and inform future product development. Phase 3 requires statistically

analysing the collected eye tracking data and questionnaire data to identify correlations. The analysis should provide quantifiable insights to guide product design decisions based on users' emotions and eye tracking data. Phase 4 expands the questionnaire to a larger sample of INEGI employees to ensure a 90% confidence level with a  $\pm 5\%$  margin of error. This large-scale study enables deeper correlation analyses between demographics, emotional responses, and product features, for statistically significant, evidence-based decisions. At this point, phase 5 consists of the repetition of the analysis conducted in phase 3. Phase 6 uses the findings from previous phases to create a design methodology linking user emotions, attractive features, and physical product characteristics through evidence based guidelines. This phase aims to help product development teams design emotionally engaging products across various industries and target audiences. In phase 7 a second prototype should be developed by integrating insights from user feedback and statistical analysis, refining features based on emotional and functional responses. This iterative process ensures a more emotionally engaging, user-centred, and functional prototype. The described phases constitute the methodology employed for the development of the prototype. However, for the present case study, the focus will be on the first three stages, leaving the following steps for future work.

The existing prototypes enabled the individual participation of volunteers in user-product interaction sessions, with the goal of capturing emotional response from their interaction with the product, the exploration of each individual component, and the discovery of the second product functionality. The findings from the sessions are expected to show the potential of eye tracking technology in HCD by leading to the discovery of new product requirements that would increase product acceptance and make the product more attractive and usable from the consumer point of view.

### **3.3. Human-Machine Interaction methodological approach**

#### **3.3.1. Qualitative methods**

The first qualitative method consisted in an acceptance assessment, in which the product concept was introduced to users through a presentation and early drafts, and they had the opportunity to express their opinions and concerns about the integration of such product in their workplace through an acceptance questionnaire. The goal for this approach was to adjust the following implementation steps based on the acceptance results, to make sure users would be happy to collaborate in the development and use of the prototype in the future. After analysing the results and advancing through the development process to the prototyping stage, the second user testing session took place at the factory. This session regarded the usability of the prototype modules that would require human interaction, receptor and HMI, and it was scheduled as soon as these two modules became available. For this assessment, the two modules were physically presented to users with a cognitive walkthrough, followed by a period for free exploration and task simulation, and a usability questionnaire for each module at the end. The goal was for users' opinions on module usability to be translated into new requirements that allow optimized modules to be included in the first complete prototype.

### **User acceptance assessment**

After defining the machine purpose, a user acceptance study was conducted to collect requirements about the prototype concept and the implementation process. By understanding the user's acceptance level of the prototype at this early stage, the engineering team found opportunities to adapt the implementation process to enhance human centricity.

The assessment used a modified UTAUT model (Venkatesh et al., 2003), to incorporate industrial factors such as satisfaction with existing technology and perceived safety. The upgraded model, UTAUT-for-industry, developed by INEGI (Sousa et al., 2025) comprised three key groups of factors: personal, external and control variables. The evaluation utilized a questionnaire with a 1 to 5 Likert scale (1-Totally Disagree; 5-Totally Agree), with the possibility for the 11 users (n=11) to add a written comment. The questionnaire is presented in Appendix A and the findings discussed in section 4 are relevant to collect user non-functional requirements.

### **Usability assessment**

As the product design process advanced, and a physical prototype was created for each of the user-interacting modules, a usability test was conducted.

To elevate the quality of the results in the data acquisition stage, for the AI model to learn from experts, it was agreed that only supervisors (n=1) and quality controllers (n=2) would interact with the prototype at the first stage of implementation. A session was prepared with the expected future users at the factory, to interact with the prototype modules for the first time and evaluate their usability, through a semi-structured interview during the experiment and a set of individual questions at the end of the session. Standard questionnaires such as the System Usability Scale (SUS) (Brooke, 1996) and the NASA Task Load Index (NASA-TLX) (Hart & Staveland, 1988) were combined with some added context-specific questions, also limited to a 1 to 5 Likert scale of agreement and an optional written comment. The testing focused on analysing each user-interacting module separately: the receptor module that supports one dish, either facing up or down, retracts into an enclosure for image acquisition, and returns for the user to flip or remove the dish; the HMI module, that consists of a touch screen displaying the prototype software, with instructions, system status, and clickable options for dish classification, defect discrimination and receptor motion into the enclosure.

The usability test aimed to obtain data for each module regarding ease of use, usefulness and user satisfaction, to inform the introduction of design iterations. During the session, users participated in a cognitive walkthrough before completing the questionnaire. The questionnaire is presented in the Appendix B and results are discussed in section 4.

### **3.3.2. Quantitative methods**

As previously mentioned in the literature review, emergent technologies are relevant to promote HCD to be systematically introduced into the product development process. AR is implemented in this case study at the prototyping stage, enabling users to interact with a virtual prototype in the shop-floor environment, integrating physical prototype components. This

enabled the human factors and ergonomics analysis, as well as user training to take place before a physical prototype was complete. This approach was employed to collect detailed information regarding workstation layout and measurable ergonomic requirements.

### **Augmented Reality testing**

As a quantitative method to address Human-Machine Interaction, the AR technology was selected and explored as an HCD enabling tool. This emerging technology allows the visualisation of design solutions in the shop-floor context, and the interaction with the product and the surrounding environment. Thus, providing a platform for users to interact with a virtual prototype based only on its CAD model, which allows earlier collection of user feedback regarding human-machine interaction.

Following the previous usability assessment, the receptor and HMI design was optimized. In this stage, a virtual prototype was modelled, comprising the receptor module, the HMI module, and the outer structure, including all the stationary devices. The complete virtual prototype was then available for the next user testing session, addressing UX in interacting with the complete prototype. Although in virtual format, using the complete machine could make users more familiar with the prototype and create the opportunity to gather more user feedback regarding design, functionality and ergonomics.

To offer users a realistic workplace environment experience, an AR testing session was developed. AR technology enabled users to interact with some components of the prototype, while having the perception of interacting with the complete system. To achieve each task, users only physically touch the dish, the receptor module and the HMI, so these components were physically present. The other prototype components were added virtually, along with animations and annotations. The goals for this session were: a) training users on interacting with the prototype; b) ergonomic evaluation; c) validation of layout and shop-floor integration alternatives; and d) exploring the benefits of AR testing before the implementation of a physical prototype.

The virtual prototype was converted from CAD to the Unity software, as shown in Figure 10, to enable interaction and animations, and the Magic Leap 2 AR headset was used, along with the included controller and battery pack shown in Figure 11, to provide the AR experience. For the test to be realistic to users, it took place in the factory at the final location for the prototype at the production line. The virtual model was programmed to be superimposed to the physical receptor and HMI modules through a QR code. This required precise positioning of the modules at the shop floor, to dictate the correct position of the whole virtual prototype. With this solution, users could interact with the physical modules of the prototype while visualizing the complete system in action. In parallel, a set of instructions was added to the virtual environment, so users could be immersed in the experience and follow along, completing the task autonomously.

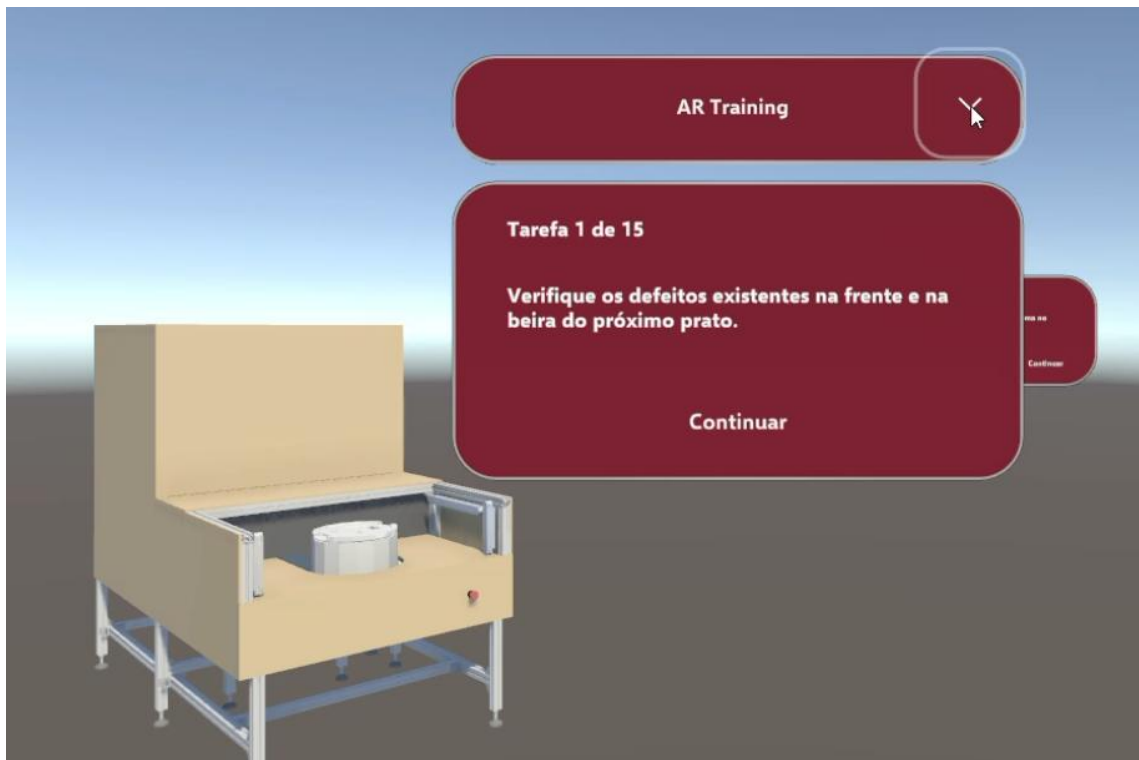


Figure 10 - AR environment



Figure 11 – Magic Leap 2 AR device

For evaluating the AR testing session, a questionnaire was developed to quantify users' opinions towards the session and its goals. The questionnaire is presented in the Appendix C. Four different layout options were developed, to be evaluated during the session. The four different layouts are presented next in Figure 12.

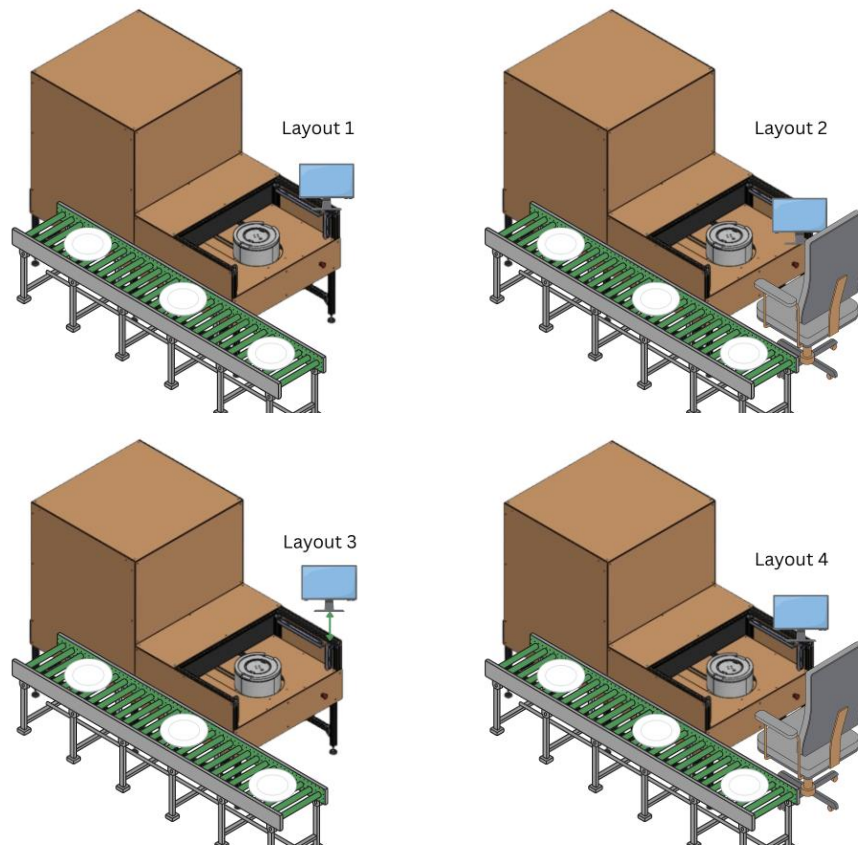


Figure 12 - Workstation layout options

Layout 1 was the first to be developed, with the HMI sitting on the prototype structure, at an adequate height to work while standing but anticipating the possibility to work sitting. The second layout was adapted from the first, to optimize the workstation for working while sitting, with a lower HMI height and an added chair. Layout 3 was an adaptation towards the opposite direction, optimizing the workstation to work while standing. The fourth layout was the same as the first but enabled experimentation with working while sitting on the added chair.

To position the physical HMI accurately, relatively to the virtual model, a tripod was used, and an additively manufactured adapter was developed, as shown in Figure 13, to attach the monitor to it, and place it securely where desired.

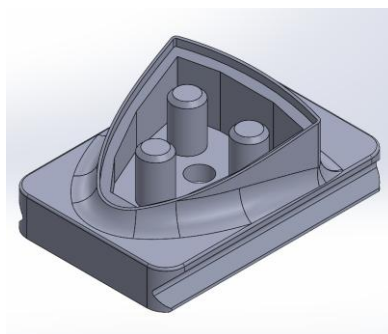


Figure 13 - HMI/tripod adapter

With this part, it was possible to recreate the workstation in the factory, by creating a AR environment in the shopfloor, with the human-interacting parts physically present and correctly positioned relatively to the virtual prototype via a QR code placed on top of the receptor module, as shown in Figure 14. This allowed users to have the perception of using the complete prototype and enabled the engineering team to analyse the user's perspective and feedback, and the ergonomic challenges of the task.



Figure 14 - Shop-floor setup for AR training

The session began with a brief presentation of the AR technology, for the 3 expected users to get familiar with the new technology, without explaining the task extensively, to simulate remote training conditions and understand its potential. During the training session, the 3 participants learned how to interact with the prototype for the task of data gathering, different prototype layouts were presented to the users, and an ergonomic evaluation of each one was performed, using the Rapid Upper Limb Assessment (RULA) ergonomic assessment tool. After completing the AR training, each user answered a questionnaire, developed to understand the perceived advantages of both AR training in general, and of the particular session, to evaluate the prototype design, and to compare opinions on the layout options. The questionnaire is presented in Appendix C.

### **Ergonomic Analysis**

During the AR training session, it was possible to address workstation ergonomic issues by evaluating the three expected users' body position during their interaction with the virtual system. It is relevant to note that the performed ergonomic assessment requires the workstation to already follow the relevant ergonomic standards, and the goal for this assessment was to tune the details to the users' liking, without compromising the workstation's ergonomic standards compliance. The used method was the RULA worksheet, presented in

Figure 15, which consists of a standard worksheet for upper body ergonomic assessment, requiring external task observation for measurement.

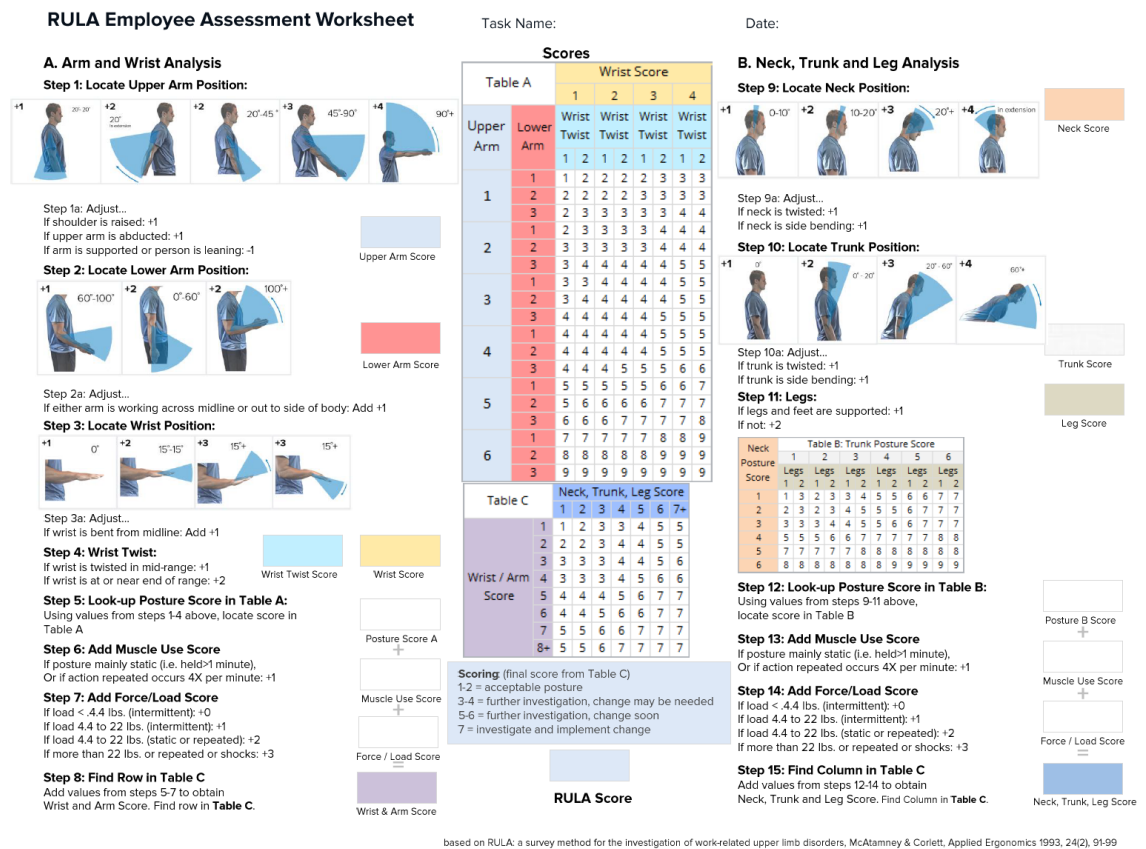


Figure 15 - RULA worksheet (Mcatamney & Corlett, 1993)

When complete, the worksheet result is a number that describes the workstation ergonomic score, and indicates whether it requires immediate change, further investigation, or no action. The goal for this approach was to optimize the position for the dish receptor, the HMI, the prototype relatively to the production line, and the standing or seating position for the user. As the prototype is meant to be used for limited time, for data gathering only, and there are only three expected users, the prototype could be finely tuned for their preferences and capabilities.

### 3.4. User-Product Interaction methodological approach

#### 3.4.1. Qualitative methods

In this case study, the employed qualitative method was a user questionnaire. The developed questions gave users the opportunity to interact with the product and share their self-assessed emotional response, first impressions and product requirements in a structured format for posterior statistical analysis. Beyond this purpose, the questionnaire was designed to provide written guidance for the user testing session, which included eye tracking of the user interaction with the product, for quantitative data analysis.

### **User Questionnaire**

A questionnaire was developed to capture users' emotional response to interacting with the product for the first time. This questionnaire approach has the goal of standardizing the user interaction with the product, for the collected data to be structured, while each user still had the opportunity to extensively comment their unique opinion on most of the questions. Moreover, this questionnaire was designed to test and promote simultaneous data gathering by a wearable eye tracking device throughout the session. The goal is to combine the answers on each section with the respective eye tracking data from each user to enhance the results and underline the potential of eye tracking technology in the development of HCD products.

The questionnaire, presented in Appendix D, guides users through an experimental eye tracking session. Each user was instructed to interact on progressively higher levels while describing their emotions and feelings through the questionnaire. The questionnaire structure follows a structured sequence of steps.

Firstly, demographic and personal data was collected. The goal was to use the information to characterize each user and allow the statistical correlation of user opinions, impressions or choices with the personal data, ranging from age to job position, or brand recognition.

Secondly, after presenting the second-life package, the questionnaire included a set of questions about users' first impressions about the product. The answers followed a 1 to 5 Likert scale format, with an optional comment. These questions evaluated common user requirements, such as aesthetics, weight, or brand connection.

Thirdly, the questionnaire guided the user through a deeper interaction with the product and captured the users' emotions accordingly. Each user was guided through observation, followed by touch and disassembly phases of interaction with the box. In each phase, users were asked to select 1 to 3 emotions that could describe what they were feeling at that moment, and 1 to 3 emotions that never could describe what they were feeling.

Fourthly, the first impressions questionnaire section was repeated, now that users had full knowledge of each component and functionality of the product, with the goal of evaluating the impression evolution.

Lastly, users had the opportunity to select features or parts that they would prefer to be changed, to make the product more personally appealing for them. If users suggested any change, they should comment what and why they suggested it.

## **3.4.2. Quantitative methods**

### **Eye tracking**

To quantitatively measure user-product interaction, an eye tracking device was used, collecting data while users interacted with the product and the questionnaire. This experimental method was proposed to gain comprehension of the relationship between user response while interacting with a product and the product features that may cause it. The case study

encompasses two evaluation sessions for user-product interaction, one for analysing emotional response, and the second for gathering product requirements.

The goal for the first session was to test the technology and find correlations between the eye tracking metrics and user questionnaire responses regarding their opinions and feelings towards the product. These correlations and further findings can serve as a basis for eye tracking tools to be adopted in future product acceptance studies on similar conditions.

The eye tracking device used for this test was the Pupil Labs Neon, presented in Figure 16 along with an included smartphone that stores the software and data. The device allows recording a video that corresponds to the user's field of view during the session, along with extensive data for posterior analysis. The most notable variables are described in Table 7.

Table 7 - Eye tracking notable variables

	<b>Description</b>	<b>Application</b>
<b>Gaze Point</b>	The gaze point is superimposed on the recording to continuously visualize the user's point of interest.	Provides understanding of which product areas attract attention at each stage and how users explore the product over time.
<b>Fixations</b>	The duration of fixed gaze on a point indicates attention level towards a specific area.	Used to assess which product features effectively capture attention, to inform optimization.
<b>Saccades</b>	Rapid eye movements between fixations, reflecting exploration and attention shifts.	Differentiating reading-like behavior vs. scanning can highlight product engagement or confusion, reflecting design intuitiveness.
<b>Blink Detection</b>	Frequency of eye blinks during product interaction.	Can indicate cognitive workload or emotional engagement. Fewer blinks may correlate with high concentration or stress, while more blinks with relaxed attention.
<b>Pupil Size</b>	Changes in pupil diameter during interaction.	Reflects emotional response; larger pupils often signal interest, excitement, or cognitive load, providing information on user engagement or stress.
<b>Eye Recording</b>	Video recording of eyes for analyzing blinks and facial expressions.	Supports data interpretation, validating user reactions alongside other physiological metrics.



Figure 16 - Eye tracking device

After recording, the data from the 9 participants was analysed using the iMotions software, enabling the segmentation of the recorded data, and the detailed analysis of the user's interaction with the product. The area of the video that corresponds to the box was selected in each recording, to isolate the data relating to the product, as shown in Figure 17.

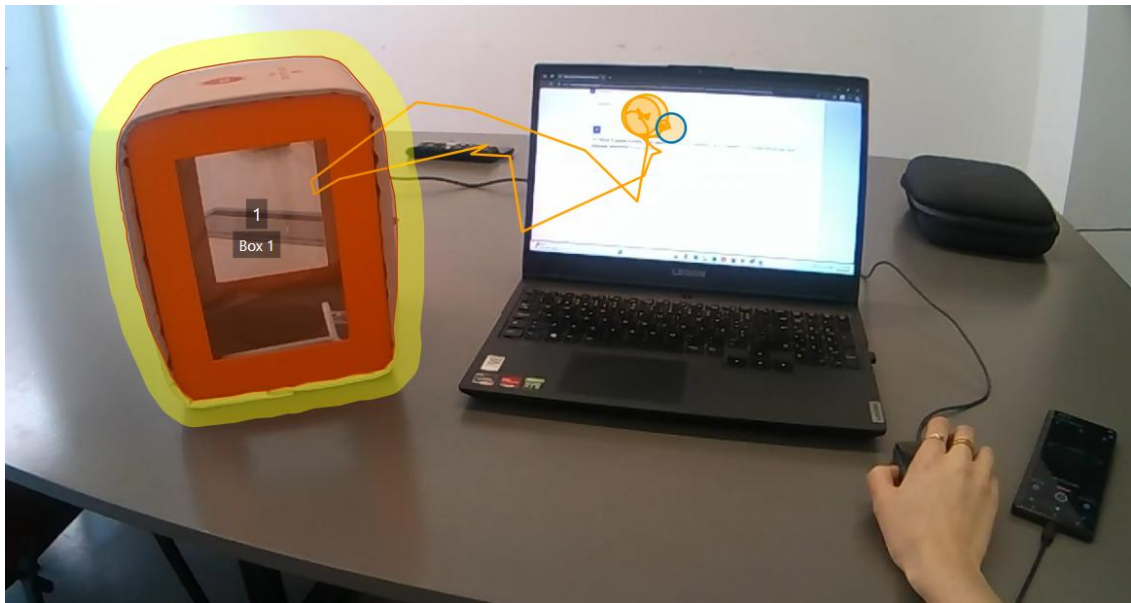


Figure 17 – AOI in eye tracking recording

By discriminating the product area in the recording, designated by Area of Interest (AOI), the iMotions software allowed the extraction of a dataset that isolates the user's interaction with the product, excluding all the surrounding interactions during the session. This dataset is extensive, allowing further research on the existing data from this case study. However, for the first session, the goal was to correlate User-Product Interaction with user emotional response. To that end, the eye tracking metrics in Table 8 were selected as the most relevant for analysis. These were selected for data and correlation analysis as they reflect distinct user behaviours, that could potentially influence users' emotional response, as described in the application column.

Table 8 - Selected eye tracking metrics

	Definition (adapted from iMotions)	Application
<b>Gaze time (%)</b>	How much time the respondent spent gazing at the AOI in relation to the time during which the area of interest was visible.	Identifies the user's interest in observing the product at a given time frame.
<b>Fixation time (%)</b>	How much time the respondent spent fixating at some point in the AOI in relation to the time during which the area of interest was visible.	Reveals how effectively the product captures and retains user attention during an interaction.
<b>Fixation duration (ms)</b>	Average duration of all the respondent's fixations detected inside the AOI.	Evaluates how intuitive and easy to use a product is during user interaction.
<b>Peak velocity (deg/s)</b>	Average peak velocity of all the respondent's saccades detected inside the AOI (i.e. the maximum speed of the eyes during this saccade).	Assesses user visual effort and cognitive load while interacting with the product.

The results are analysed in the Section 4, merging the qualitative and quantitative methods in a correlation analysis between user's emotional response answers from the questionnaire, with the mentioned eye tracking data.

A second eye tracking session took advantage of the findings from the first one, and some changes were applied to the testing method. This session aimed to improve the data gathering technique and to extract product requirements from the eye tracking data. For this session, participants answered an online questionnaire instead of paper, as some question visibility issues were found in the recordings, due to paper reflecting the lighting in the room. As a solution, online questionnaires enabled bigger text size and adjustable brightness. The test regarded a single box instead of two, to isolate the area of interest for data analysis. In this second session, after a briefing, the box was uncovered suddenly, instead of slowly entering the participants' field of view, allowing to gain an insight of:

- **First point of fixation:** The point in which participants first focus their attention on can reveal the area of the product that better captures the participants' attention, either for positive or negative reasons.
- **Time to first fixation:** A low time interval until the first fixation can be associated with a positive UX.

The goal of the second session was to explore other potentials of the eye tracking device regarding the discovery of new product requirements. In this session there were 14 new participants, resulting in data from 23 different users to be analysed. The main challenge was to quantify the importance of user requirements for the product according to the real users' priorities and personal preferences, based on eye tracking data. For this assessment, different

questionnaire sections were analysed, in which participants described their ideas for optimizing each product component, and the product in general. The eye tracking data was also analysed differently, between the 23 participants from the two sessions. The first, second and third fixations, along with the two longest fixations, were extracted from each participant's dataset, identifying the product component that was fixated on. With this knowledge, it is possible to better understand which component captures the participants' attention the most, and which component provides the better UX. Furthermore, by correlating this information with the answers from the questionnaire, it is possible to complement these findings, identifying which component captures attention for positive or negative reasons. With that information, it is possible to prioritize the optimization of specific components. This process is described thoroughly along with the results from each step, in section 4.

A known limitation for this method is the controlled environment in which users interacted with the product. The findings from the eye tracking data should be more accurate as the interaction is closer to the one intended for the product. In other words, if it was possible to recreate a store environment, with other products to compare, and invite real potential buyers to interact with the prototype, the eye tracking data would be richer. However, it is relevant to note that the applied methodology consists of a baseline and technology exploration process to a large-scale study in the future.

## 4. Results and Discussion

### 4.1. Human-Machine Interaction

This section describes and discusses the results regarding the Human-Machine Interaction methodological approach presented in chapter 3. It starts with the user acceptance assessment to collect information regarding the macro dimensions identified by the UTAUT-for-Industry methodology and follows through the usability assessment allowing to collect user requirements that will improve the acceptance of the machine

#### User acceptance assessment

The user acceptance study results were analysed, and the obtained scores are presented in Table 9. The percentages show the average result for (n) users to each set of questions.

Table 9 – User acceptance results

Colour scheme: 50% 100%

Macro dimension	Shop floor workers (n=4)	Supervisors (n=5)	Quality Controllers (n=2)	Acceptance score (n=11)
Intention to use	88%	92%	100%	93%
Satisfaction with current system	73%	78%	89%	80%
Perceived usefulness	76%	88%	92%	85%
Perceived ease of use	78%	83%	80%	80%
Perceived safety of use	80%	96%	90%	89%
Organizational support	86%	88%	93%	89%
Implementation process	84%	66%	100%	83%
Long-term consequences	66%	75%	N/A	71%
Social influence	75%	77%	90%	81%

The results highlight that users are motivated to use a new system, with an intention to use of 93 %, but they seem to have doubts about the long-term consequences of using it, with the lowest acceptance score of 71 %. The highest deviation between job roles emerged in the

implementation process scores, suggesting different communication approaches to different job roles. It can be concluded that the acceptance would potentially improve if the company invested in their communication about the new system, sharing more of the long-term benefits, and with a more structured approach among job roles.

The UTAUT-for-industry questionnaire method resulted in clear and segmented data, to inform future decisions that could impact specific factors or job roles. By developing this opportunity for users to express their concerns in a structured way this early in the product development, and by statistically analysing the results to take conclusions, it is possible to reshape the next implementation steps. This allows the creation of meaningful changes that fulfil users’ desires and address their doubts through approach adjustments. These adjustments can vary from simple verbal communication improvements to an iteration on the product concept. In this case study, as the results were positive and encouraging, communication improvements were applied, as well as a higher emphasis on the product’s ease of use for the next development stages, due to the lower-than-average score.

### Usability assessment

Concerning the second user testing session, the results of the usability questionnaire are expressed in Table 10. The percentages show the average result for (n) users to each set of questions. The results show that users consider this prototype highly usable, with an overall score of 95 %, considering that the two modules have similar influence on the system’s usability. However, having the lowest average score of 92 %, the HMI module could benefit more from optimization than the receptor module. Therefore, the HMI will be the focus for optimization. The lowest scores for both modules are related to the usefulness, seemingly because users cannot see immediate benefits of using this data gathering prototype daily. In fact, users will only benefit immediately from the use of the final machine. The current prototype and the data gathering tasks will consume some of their time and will not help them with quality control with immediate effect. To avoid a consequent lack of motivation, it can be concluded that the interface usability can benefit from compensating users with a more engaging experience.

After statistical data analysis, the usability questionnaire enlightened the product development team about which component would benefit more from optimization, identifying priorities for the remainder of the prototyping stage. This information is the result of focusing individually on each component and assessing the different factors that compose its usability.

Table 10 - Usability questionnaire results

Colour scheme: 50% 100%

		Quality Controllers (n=2)	Supervisor (n=1)	Combined (n=3)	Average (n=3)
<b>HMI Module</b>	Ease of Use	95%	91%	94%	92%
	Usefulness	87%	93%	89%	
	Satisfaction	90%	97%	92%	
<b>Receptor Module</b>	Ease of Use	98%	100%	99%	97%
	Usefulness	93%	100%	96%	
	Satisfaction	95%	100%	97%	

Along with the overall scores, the most deviating answers and the user verbal and written comments were analysed. More requirements were identified, and the most relevant examples are:

- i) The yellow colour should be removed from the buttons, because users are already familiar with another colour scheme;
- ii) The system's status should be more visible;
- iii) The task complexity, intuitiveness and duration should be improved.

Facing the newly discovered usability issues, some requirements can be addressed with future features, such as:

- a) Live video of the dish inside the enclosure to promote task engagement, understanding of system status and intuitiveness;
- b) Dish position sensors on the receptor to remove one click per sequence, reduce duration and positioning errors;
- c) Integrated dish counter to promote engagement by reducing repetitiveness sensation, possibly providing a daily target;
- d) Larger text size to highlight the system status;
- e) New colour scheme for defect classes to increase intuitiveness.

These requirements were translated into product features, and integrated on the first physical prototype for enhanced usability and user satisfaction.

### **Augmented Reality testing**

The AR testing results were collected through three different methods: questionnaire, comments and ergonomic analysis. In this section, findings are exposed and discussed firstly and separately, and the resulting design iteration is presented in the end.

Conducting an AR testing session, as proposed, required an experimental set up at the factory, with accurate positioning of the modules and virtual prototype, requiring attention to detail and knowledge of both the prototype and the AR system. An AR set up was prepared, positioning the virtual prototype relatively to the surroundings, which proved to be difficult for shop floor-workers, unfamiliar with the technology. The set up process is, thereby, identified as a limitation for the remote application of AR testing sessions in shop-floor context, requiring technical preparation, guidance and supervision throughout the session, as presented in Figure 18.



Figure 18 - AR technical support

In contrast, the learning curve for shop-floor workers interacting with the AR system was steep, and all the users understood the virtual instructions. They successfully completed the designated task, both interacting with the physical and virtual component, as presented in Figure 19.



Figure 19 - AR interaction

The individual questionnaire resulted in the scores presented in Table 11.

Table 11 - AR test questionnaire results

#	Question	Answer (%)
1	I believe that after this training session I'll be able to use the prototype without supervision.	87
2	The virtual instructions and warnings were indispensable for learning the task correctly.	80
3	I didn't make any mistakes using the virtual prototype.	87
4	I feel that I am completely familiar with how the prototype works.	73
5	I think the training helped me avoid mistakes in the future when I use the physical prototype.	87
6	Using the augmented reality glasses didn't cause me any discomfort.	87
7	I found it easy to understand the virtual instructions.	80
8	I found it easy to select the virtual buttons.	80
9	After this session I can envisage what it will be like to work with the real prototype.	80
10	I find the position comfortable enough to repeat the task throughout the day.	67
11	I feel that the design of the prototype gives me the confidence to fulfil the proposed task.	80
12	The monitor on the right side is the most comfortable layout.	87
13	The monitor on the left side is the most comfortable layout.	33
14	The height of the monitor is ideal.	87
15	The size of the monitor is sufficient.	87
16	The height of the receptor is comfortable.	93

From the questionnaire results, the following conclusions were extracted:

- The users learned how to use the prototype and found the session and learnings valuable. After repeating the task twice, every user understood the assignment and could repeat the process autonomously. Yet, users value the contact with the physical prototype, to feel completely secure in their ability.
- The technology showed to be comfortable for users in general. The main difficulties were related to the incompatibility of the AR headset with prescription glasses, and the learning curve of interacting with the virtual environment.
- Users value instructions and guidance from a specialist.

- The monitor position requires optimization to make the task more comfortable for repetition throughout the day.
- Users prefer the monitor on their right side.
- The receptor height and the monitor dimensions are comfortable for the users.

User opinions are fundamental to HCD, particularly when these opinions do not conform to predefined questions. Therefore, the following informal comments made throughout the session were noted and considered as important requirements for the product:

- Users prefer working while sitting for most of the day. Nevertheless, they value the comfort for working while standing up as well.
- For users to work sitting, adding a chair to the workstation, with wheels and adjustable height, will allow to maximize the satisfaction of the individual requirements.
- The workstation lighting is not enough for users to perform defect detection.
- Users value the reduction of task cycle time.

An ergonomic analysis was performed for four different workstation layouts, with all the users involved. Each user simulated the task while the analysis was conducted, using the RULA worksheet.



Figure 20 - AR task simulation

The ergonomic analysis allowed extracting the following conclusions from the four layouts:

- A monitor height of about 100 cm allows maximum comfort for users to work either standing or sitting.

- Some of the less ergonomic positions derive from individual preferences for completing the defect detection task, such as neck inclination and wrist flexion. These positions are arbitrary and not influenced by the workstation.
- For the remaining task, workstation layout affects the ergonomic score, namely concerning neck and trunk twisting, leg support and arm inclination.
- According to the RULA worksheet, the analysis generated scores between 3 and 5 for all layouts and users. Therefore, a deeper workstation analysis is required to develop alternative workstation layouts, as changes might be necessary soon.

Facing the discoveries made throughout the session, a new layout proposal was created, presented in Figure 21.

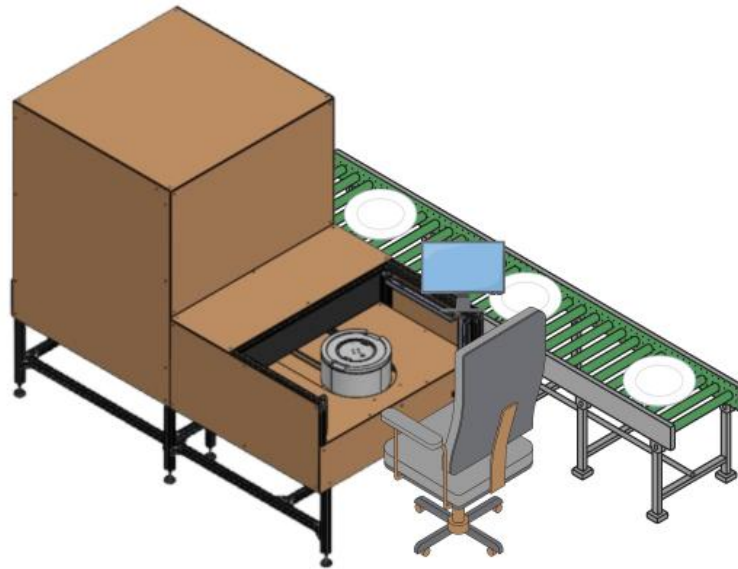


Figure 21 - New layout proposal

This newfound solution aims to avoid some of the inefficiencies that were found during the session, namely:

- The new prototype position relatively to the production line takes advantage of the existing illumination in the shopfloor, now positioned directly above the user.
- This new prototype orientation also allows:
  - Reducing users' range of action from 150° to 90°;
  - Reducing the amount of movement needed to complete the task, which is expected to reduce the cycle time;
  - Reducing user neck and trunk twisting, which constitute the main ergonomic optimization opportunities found in the analysis;
  - Facilitating visibility of incoming dishes from the production line.
- The use of a chair with wheels and adjustable height allows the user fatigue reduction by supporting their legs, reducing neck and trunk twisting, and improving comfort and workstation customization.

- The defined height for the monitor allows users to choose between working standing or sitting, without compromising comfort too much. The monitor fixation is also adjustable in slope, to further customize the workstation for each user.

The presented layout was submitted to the host company, defining the workstation layout for implementation of the prototype. When the prototype is installed and production begins, a new ergonomic evaluation should be performed to validate the result of the HCD approach.

## 4.2. User-product interaction

This section describes and discusses the results following the application of the user-product interaction methodological approach.

### Emotional response assessment

In the first session, to discover and measure user's emotional response, individual users interacted with the product, with progressively more freedom to explore it while answering the questionnaire. Each questionnaire had the duration of 30 minutes, and the participants explored two different sized prototypes. The whole process was recorded via eye tracking, to correlate the qualitative answers about emotions and first impressions about the product, with the quantitative data that could be extracted from eye tracking. The exploration process is represented in Figure 22, being the three freedom degrees: a) observation, b) touch, and c) disassembly.



Figure 22 - Product exploration stages: a) observation, b) touch, and c) disassembly

After disassembling the box, users further explored the product, to find out the second purpose of the box, a picture frame. Along with the exploration process, users would register their emotions and impressions in the corresponding stages of the questionnaire. The emotions were registered in each exploration stage, with each user selecting a maximum of three emotions they felt and three they felt the least at that moment, from an assortment of basic emotions. For the statistical analysis presented next, the felt emotions were counted as +1, while the least felt emotions counted as -1, and a sum was calculated for each emotion and stage. The results, shown in Figure 23 show the average emotional evolution through the session among the 9 participants.

## Results and Discussion

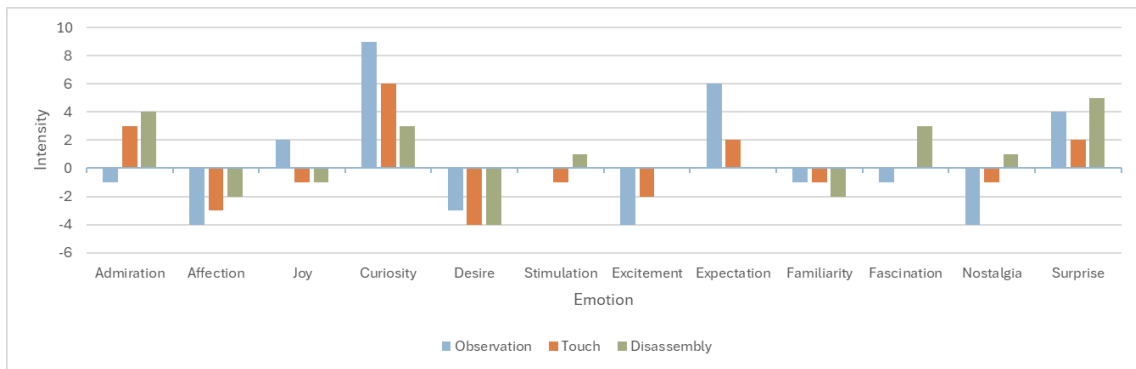


Figure 23 - Emotional response evolution

It is possible to observe, for example, a notable decrease in curiosity throughout the session, which is understandable as exploring the product with more freedom allowed users to satisfy their curiosity progressively. In contrast, admiration improved as users discovered more about the product.

In parallel, the eye-tracking average metrics also evolved through the session. The evolution is represented in Figure 24, Figure 25, Figure 26 and Figure 27.

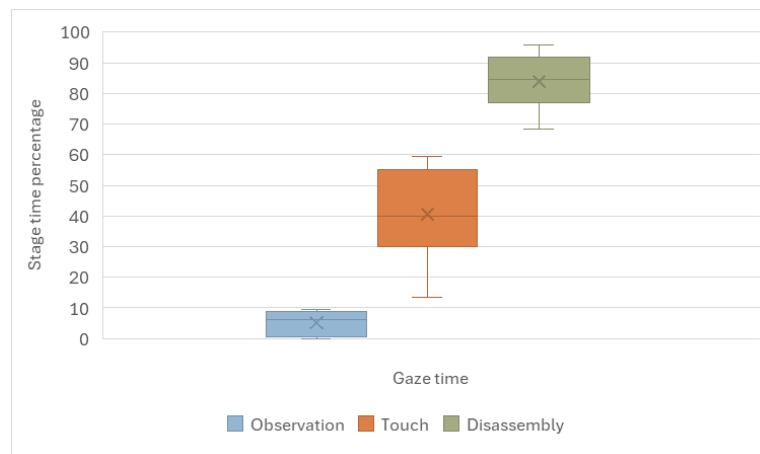


Figure 24 – Gaze time evolution

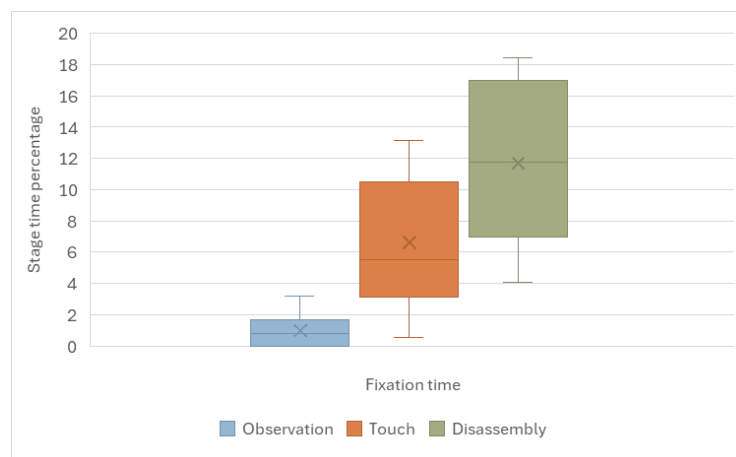


Figure 25 - Fixation time evolution

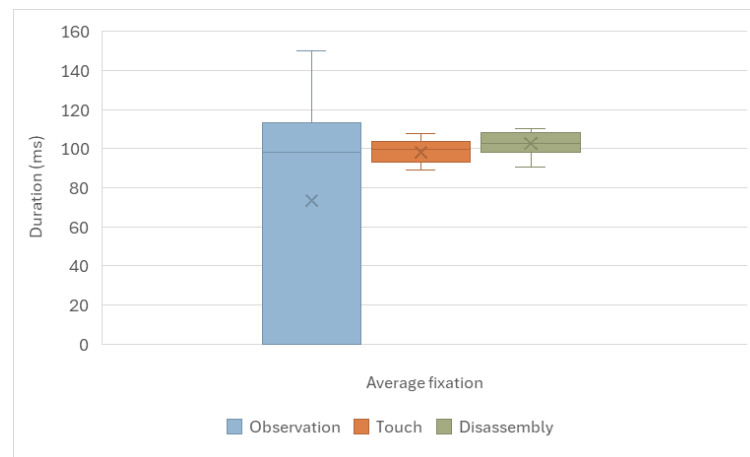


Figure 26 - Average fixation evolution

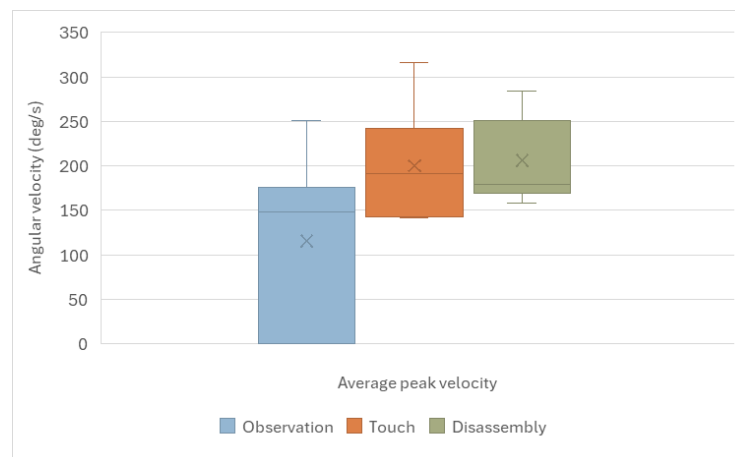


Figure 27 - Average peak velocity evolution

The figures show a development in eye tracking metrics, most notably the rise in gaze time on the AOI as the session evolved, as the users looked progressively more time at the product. This correspondence between gaze time and interaction level highlights how this eye tracking variable is able to reflect user-product interaction. The gaze and fixation time data also shows a clear and approximately linear increase in percentage through the session. From that data, it is possible to understand that users observed the product for a larger portion of time as their degree of interaction increased. The average fixation duration and average peak velocity also increased through the session, most suddenly between the observation and touch sections. This increase may reflect an emotional change when users are authorized to interact physically with the product, compared with the observation stage.

To analyse possible correlations between the emotional response answers and the corresponding eye tracking data, a Pearson's correlation analysis was developed between each emotion and eye tracking metric. This method allows the statistical analysis of relationships between two variables, by addressing the direction and the strength of the relationship. The result of this analysis is the Pearson's correlation coefficient ( $r$ ), which reveals both relationship direction and strength. The absolute value of this coefficient reveals the intensity of the correlation, while the signal indicates the direction, thus being 1 and -1 the perfect positive and

negative correlations, respectively, while a value of 0 indicates no relationship (Cohen et al., 2009). The Pearson's correlation coefficients ( $r$ ) between emotional response and eye tracking variables are visible in Table 12.

Table 12 - Correlation analysis

	Gaze time (%)	Fixation time (%)	Average fixation (ms)	Peak velocity (deg/s)
Admiration	0.3538	0.1169	-0.0140	0.2276
Affection	0.2090	0.1007	0.2238	0.3125
Joy	-0.2884	-0.0640	-0.2857	-0.5051
Curiosity	-0.5022	-0.1369	-0.1255	-0.4985
Desire	-0.1728	-0.1053	-0.2677	-0.4634
Stimulation	0.1790	0.4055	0.0736	-0.2646
Excitement	0.2797	0.1604	-0.0875	0.1601
Expectation	-0.3264	-0.1205	-0.1537	-0.3202
Familiarity	0.0343	0.0833	-0.0571	-0.0810
Fascination	0.4037	0.3823	0.2597	0.1871
Nostalgia	0.2136	0.0735	0.3365	0.4433
Surprise	0.2055	0.1900	0.0063	-0.0947

Moderate correlations are found in the context of these user testing sessions, namely between:

- Curiosity and Gaze time (%): Moderate negative correlation of  $r=-0.5022$ . This result could mean users analyze the product quicker when they feel more curious.
- Curiosity and Peak velocity (deg/s): Moderate negative correlation of  $r=-0.4985$ . This result suggests lower saccade speeds when users are curious about the product.
- Joy and Peak velocity (deg/s): Moderate negative correlation of  $r=-0.5051$ . This result could indicate lower saccade speeds when users are enjoying the product.
- Fascination and Peak velocity (deg/s): Moderate positive correlation of  $r=0.4433$ . This result could indicate higher saccade speeds when users feel fascinated by the product.
- Stimulation and Fixation Time (%): Moderate positive correlation of  $r=0.4055$ . This result could indicate higher fixation time when users are being stimulated by the product.
- Nostalgia and Average Fixation (ms): Moderate positive correlation of  $r=0.3365$ . This result could indicate higher average fixation when users are feeling nostalgic about the product.

These findings from the first session indicate that certain emotional states manifest in distinct eye movement patterns, although the relationships are moderate and context dependent. This overall results underscore the potential of eye tracking as a complementary tool - rather than a standalone method - for assessing emotional engagement during product interactions. The methodology must be repeated to compare results for stronger correlations and conclusions to be taken. To this end, a large-scale study is proposed for future work, aiming to extract statistically significant conclusions on the correlation between eye tracking metrics and emotional response.

### User requirements assessment

In parallel with emotional response assessment, the questionnaire also enabled the gathering of individual suggestions and opinions for new product requirements. Each user suggested changes for each component that would make the product more appealing. This questionnaire data was analysed after the second session, with the goal of informing future design iterations. The merged results from the two sessions enabled the development of a QFD matrix for each component of the product, quantifying the interaction between user requirements and product features. The different product sections are shown in Figure 28, with the assembled box at the left side, and the disassembled components at the right side.

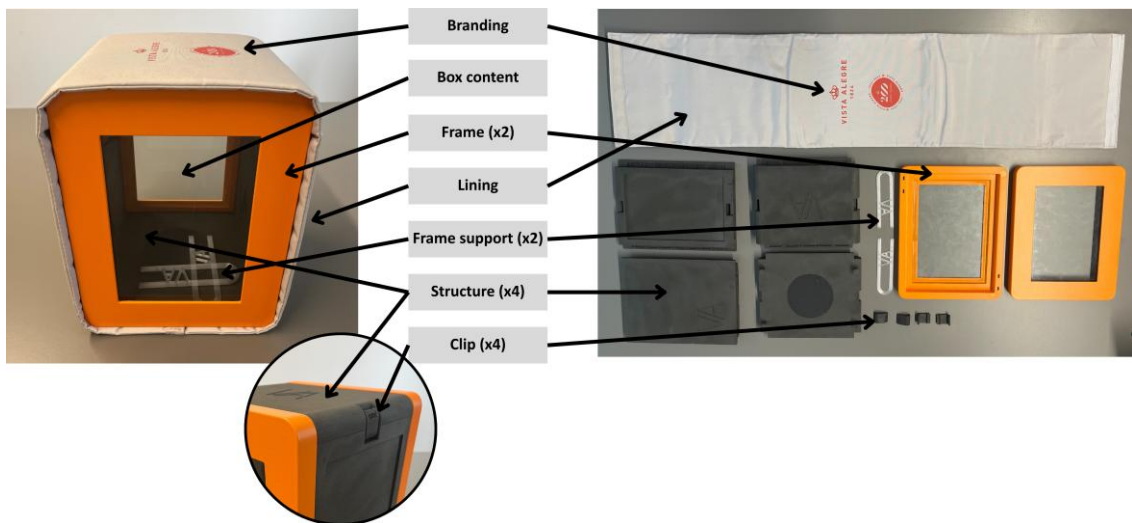


Figure 28 - Box components

The QFD matrices for each product component are based on the questionnaire data and include the Kano model user requirement classification. All QFD matrices are presented in Appendix E, for each individual component. For illustration, the QFD matrix for the box lining is presented in Figure 29.

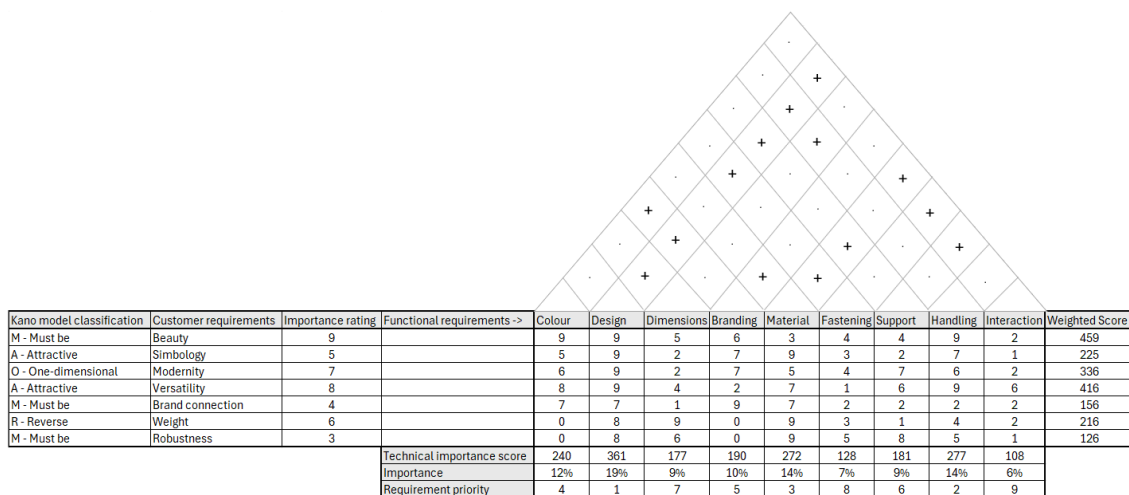


Figure 29 - Box lining QFD

At this stage, it is important to link these results to other opinions captured in the questionnaire, to create a priority ranking that can reflect the participants' preferences, based on the collected eye tracking data. The eye tracking findings regarding component attractiveness and user attention added relevant information for decision making on product optimisation, by quantitatively comparing the UX provided by each component. With this complementary information presented in Table 13 and Table 14, respectively, it is possible to quantify the priority of user requirements with data-based attractiveness and attention indexes, and include these factors in the decision-making process for new product requirements.

The attractiveness index in Table 13 consists of the percentage of fixations on each component within the three first fixations on the product for the 23 participants. The relevance column shows the importance of optimizing the attractiveness of each component, and the priority column indicates the subsequent priority ranking for component attractiveness optimisation by following the users' requirements. The box content relevance and priority values in the second row were removed from further data processing. Although it may reveal UX issues, this value does not apply to a product component that could be optimized.

Table 13 - Attractiveness index

Attractiveness Index		Relevance	Priority
Branding	19%	15%	4
Box Content	30%	-	-
Frame	28%	12%	6
Structure	7%	18%	3
Lining	16%	15%	4
Clip	0%	20%	1
Frame Support	0%	20%	1

The attention index in Table 14 consists of the percentage of fixations on each component within the two longest fixations for all participants. As the captured attention can derive from positive or negative reasons, the chosen indicator, to distinguish between positive and negative attention, was the percentage of changes suggested by participants for each component, relatively to all the suggestions among the participants. Therefore, a high suggested changes percentage indicates a less appealing component to users, independently of how much attention it captured. By combining attention with suggested changes, it is possible to comprehend the users' perspective on the necessity to improve the component. Therefore, by multiplying the two indexes, as shown in the following equation (1), the relevance of optimizing the component is reflected in the result.

$$Relevance(x) = \frac{Attention\ Index(x) \times Suggested\ Changes(x)}{\sum(Attention\ Index \times Suggested\ Changes)} \times 100 \quad (1)$$

Table 14 - Attention index and suggested changes

Attention Index		Suggested Changes	Relevance	Priority
Branding	9%	4%	2%	6
Box Content	4%	-	-	-
Frame	20%	23%	26%	2
Structure	33%	25%	46%	1
Lining	7%	26%	10%	3
Clip	17%	8%	7%	5
Frame Support	11%	15%	9%	4

The two presented tables indicate distinct human-centred factors that will influence the development of the product. The results can be analysed separately, and the product development team may choose to improve mainly the attractiveness or attention capturing of the product, by prioritizing optimization accordingly to the respective table. However, for this context, attractiveness and attention were considered equally important for optimization, as shown in the 50% factor affecting both variables in the combined importance equation. To apply more emphasis in optimizing components that capture attention, or on components that lack attractiveness, the factors should be adjusted towards the desired priority. The combined optimization importance is calculated using equation (2), which represents a weighted average of attractiveness relevance and attention relevance and it is presented in Table 15.

$$\text{Combined importance}(x) = 0.5 \times \text{Attractiveness}(x) + 0.5 \times \text{Attention}(x) \quad (2)$$

Table 15 - Optimization importance

	Relevance (Attractiveness)	Relevance (Attention)	Combined Importance
Branding	15%	2%	8%
Frame	12%	26%	19%
Structure	18%	46%	32%
Lining	15%	10%	13%
Clip	20%	7%	14%
Frame Support	20%	9%	14%

From these results, considering equal importance between attractiveness and attention as component evaluation factors, the product development team is guided to begin by optimizing the structure. From that, within this component's QFD matrix, the team can find that the design is the most important functional user requirement, and understand that improving aesthetics, modernity, and versatility would be effective ways to improve customer satisfaction. To develop the product in that direction, a table is presented in Appendix F, in which the user suggestions for the product are organized. Following this process, the product development team can choose to apply the customer suggestions following clear eye tracking data-based guidelines to improve HCD in this product.

Furthermore, to set a baseline for evaluating the optimisation, the time took for opening and disassembling the box and to discover how to assemble the frame were also noted from eye

tracking recording and presented in Appendix G, averaging 102 seconds for disassembly and 106 seconds from disassembly until frame assembly.

Along with the presented results, the participants' interaction with the product highlighted some important usability concerns. Regarding the inner structure fastening mechanism, 4 clips were broken during the product exploration process. Due to the low intuitiveness of the mechanism, users applied force in the wrong direction while trying to open the box for the first time, unintentionally breaking the clips. Other concern is the fitment of some frames in the structure being too loose, causing the frame to fall off the box while handling the product in some positions. These problems should be addressed to ensure the correct product functioning ahead of optimization.

### **4.3. Lessons learned from the case studies**

In this section, the main scalable takeaways from the case studies will be presented, with the goal of guiding product development teams in integrating HCD into product development.

The first takeaway, and arguably the most important, relates to both case studies. It is the necessity of involving real product users, who are not involved in its development, to learn more about the current state of a product from the user point of view. Both case studies involved samples of either trained professionals or general public in the evaluation of a product, and both approaches resulted in valuable and unexpected insights that refocused product development on the meaningful issues for the real users. This involvement and human connection truly centred the design process on the human factor, originating some of the best solutions presented throughout the case studies, sometimes deriving from the informal conversations behind the scenes of user testing. Considering this information adds value to systematically applying HCD user testing methods in product development, independently of the chosen method.

The second takeaway is that questionnaires, interviews, and surveys are very efficient data gathering methods to complement any user testing session, from acceptance until user training. One advantage of having a structured set of questions is that the product development team can enforce that the most important questions will be answered, while having more freedom to explore details and harness unique perspectives. In parallel, the structured answers, particularly multiple choice or Likert scale, enable statistical processing, which can be useful at large scale studies. A disadvantage of using structured questions is that these may influence the user's impressions and excessively guide the session, missing the point of letting users freely discover and formulate unique opinions. However, this user testing method proved to be essential across the case studies, providing easily accessible data on product feedback.

The previous considerations regard any approach to HCD on any product. In the two next sections, the distinct guidelines for applying HCD to human-machine interaction and user-product interaction are discussed, respectively.

### 4.3.1. Human-machine interaction

The implementation of the HCD approach in an industrial context is extremely relevant to provide an effective response to the challenges identified in the context of Industry 4.0. Problems related to the low level of technology acceptance by the workers in the shop-floor due to the difficulty in using complex systems and the lack of understanding of new technologies and how useful they are for them, highlight the need for the implementation of HCD strategies. Through the implementation of combined methods, it is possible to enhance usability, improve worker engagement, and support more successful integration of advanced technologies.

Due to the specific challenges of developing a human-machine interaction product, the selected user testing sessions for this product focused on acceptance, usability and ergonomics. These three assessments are central to the development of industrial products. As a complementary technology, utilising AR in this context also shows potential for systematic application in the future.

In this work, assessing user acceptance highlights the opportunity to improve the adoption process and reduce the resistance to change in users. Discovering what concerns them since the early development stages and addressing the issues makes users feel as the machine is made for them, instead of feeling forced to use it. For this assessment, the present research allowed to validate the UTAUT-for-industry model as an effective discovery tool for product acceptance. As mentioned before, a questionnaire based on the UTAUT-for-industry model allows accessible understanding of the factors that compose user acceptance and facilitates statistical processing.

Usability assessment allows early optimisation of the most relevant components of the machine in terms of use, the ones that directly interact with the workers. This strategy avoids costly redesigns by allowing user interaction with the system before implementation, providing an opportunity for users to input their perspective and influence on detail design of components. Standard questionnaires were utilised and presented advantages for assessing general usability. The SUS, SUMI, and NASA-TLX provided a baseline set of questions that applies to the average product. However, it is recommended to adapt the questionnaire to the product characteristics, namely step by step or component by component questions. For this stage, although it was not tested in industrial context, eye tracking technology showed potential in evaluating user interaction with the prototype system, namely regarding emotional response and first impressions. Therefore, eye tracking may prove to be a useful technology for usability testing in human-machine interaction applications in the future.

Before implementing a product or prototype into the shop-floor, an ergonomic analysis should take place, to get to know the real users' preferences and difficulties in operating the system. The ergonomic analysis session should serve also as a presentation and training session for operators to learn how to use the system. AR prototyping proved to be an exceptional solution in this regard, for early presentation and user training. The use of this technology allows remote training by introducing the necessary virtual guidance for users throughout the task. Combining the virtual prototype with the physical environment can still provide relevant information for

ergonomic evaluation, while avoiding the efforts of transporting a physical prototype to the workspace, without previous ergonomic optimization or user training. Moreover, the ergonomic analysis session should imply that users perform the task repetitively, already providing some training, so when the optimized product is implemented, user training should be facilitated.

Throughout the implementation process, a clear communication between workers and the company management team is important, in order to integrate the people that will directly work with the technologies and products into the concept definition or into the integration processes. Upon implementation, all the previous improvements should be validated, and at this stage users should already be familiar with the product and task. Therefore, users should be presented with the details of operating the physical product, such as safety procedures and error management, with more emphasis than the task itself, ensuring that all the relevant information is progressively explained and understood across the different user testing sessions.

The described case study approach resulted in a structured product development in the direction of user requirements and human factors. However, some improvements can be made to this approach. The main improvement to the presented method refers to the inclusion of an AR or VR session as soon as the detailed product design is translated to a CAD model. For this session, the virtual prototype should be presented to the users in an AR or VR environment, to allow prototype and task exploration, to gather user feedback towards product design and develop ergonomic considerations. The goal of this session is to anticipate steps that were conducted in the AR session in the previous case study, namely ergonomic optimization and prototype presentation, to allow earlier improvements to the prototype. At this stage, interaction with the virtual prototype should be limited, as the user interacting module prototypes are not yet available. However, the session allows an easier task for users that may not be familiar with AR or VR technology, facilitating learning for the second session, which requires users to perform the complete task in an AR prototype. Moreover, the earlier findings from user interaction can be introduced to the first physical prototypes, being a more time and resource effective approach.

### **4.3.2. User-product interaction**

For user-product interaction, the case study also enables the proposal of guidelines to integrate HCD on similar product development stages. This case study comprised a shorter period, and the user testing sessions did not yet have an influence on the product. Therefore, the main findings from this case study are focused on the iterative design process, in particular to gather user requirements to develop upon the first prototype. The selected assessments are emotional response, usability and UX, which should ensure that the product development process remains aligned with human values and user expectations. As soon as a prototype is available, user testing should take place, and eye tracking has proven to be a promising technology in this field, for collecting large amounts of quantitative data from user testing, which combined with questionnaires, allowed to obtain relevant data that can be processed and integrated into the

product's design phase. Emotional response assessment provides insights into users' feelings while interacting with a product, which can be a strong indicator for adoption and satisfaction. The understanding of users' emotional response to a product

The findings can be hints of poor UX or usability that need to be addressed before launching the product. Usability and UX needs are crucial to improve the design to fulfil user needs, beyond the functional requirements. The findings from testing these factors should be restructured into clear product requirements. To correlate product features with user feelings or experience, eye tracking technology presents a unique perspective that shows potential for systematic application. This opportunity should be explored, and the relevant eye tracking metrics should be considered to complement emotional response, UX, and usability assessments.

Beyond the positive findings from the applied methodology, it is relevant to describe the shortcomings and improvements to be made on the method. The case study approach thoroughly discusses the prototyping stage, and the results lead to extensive changes in the product. Such findings force the product development team to step back and redefine user requirements, with a possible impact on the product concept. To avoid this added iteration, product development teams should be following the HCD approach since the concept development.

In the product concept stage, most user requirements and acceptance data can be gathered by using questionnaires, interviews or surveys to collect feedback on the existing product drafts, ensuring the alignment between the functional requirements and user needs. To organize user requirements systematically and inform detail design, a QFD matrix is useful at this stage. As soon as a virtual prototype is available, at the end of detail design, AR or VR technology can be useful to make preliminary assessments on user-product interaction. In this phase, user acceptance and new product requirements can be discovered through a questionnaire and implemented on prototype development. As physical prototypes become available, detailed feedback should be collected, namely on user-interacting components, to refine user-product interaction until a satisfactory prototype is complete. At this stage, an eye tracking session should take place, simulating real world use of the product, in which the product development team can analyse emotional response, usability and UX through realistic scenario eye tracking data and a questionnaire. This approach ensures user feedback is central to product development since early stages and takes advantage of emerging technology to enhance the results.



## 5. Conclusion

The presented dissertation reflects the work on HCD integration on product development that took place over the internship at INEGI, and its merits and limitations are going to be discussed in this section.

### 5.1. General conclusions

This dissertation proposes a structured methodology to implement HCD into the product design and development process. It follows a practical approach that can be easily integrated by the engineering team, avoiding the need for specialized knowledge related to health and psychology. A theoretical approach into the problem included a review into the state-of-the-art practices in product development and HCD, to provide an understanding of the existing challenges and solutions. The proposed methodology, applied to two case studies, offers valuable insights into the importance of HCD in product development, demonstrating its applicability across various industrial sectors and product types. The human-machine interaction case study provides an example solution to improve technology acceptance among shop-floor workers, utilising state-of-the-art technology, in this case AR, and methodologies that are coherent with the literature review. In parallel, the user-product interaction approach aims more towards enhancing user satisfaction with new market released products, also taking advantage of the reviewed methods and emerging technology in the form of a wearable eye tracking device. Both case studies allowed to inform product development and its integration management, considering the human factor by actively seeking user feedback throughout the product development process.

To answer the proposed research question “How can structured Human-Centred Design methodologies improve technology acceptance among shop-floor workers and enhance user satisfaction with new market released products?”, this dissertation proposes a structured HCD approach that aligns product development with real user needs, behaviours, and emotional responses. To improve technology acceptance of an industrial product, the UTAUT-for-industry model, usability testing and ergonomic assessment allowed to align both implementation approach and prototype development with workers’ real needs, behaviours and capabilities. AR technology was crucial to assess user interaction and ergonomics in a virtual environment before a physical prototype was developed, ensuring less physical and cognitive effort for workers, and leading to greater acceptance since the first use of the product. To enhance user satisfaction with new market released products, emotional response and user requirements assessments allowed the specification of user requirements. The eye tracking technology

## Conclusion

enabled a quantifiable understanding of real users' emotional response and their priorities for product iterations. The application of this knowledge into product development leads to a product that reflects user feedback with new attractive and meaningful features that increase satisfaction since the release into the market.

To answer the research question in broader terms, structured HCD methodologies allow user requirements and concerns to be systematically obtained, analysed and translated into enhanced product features, as early as possible in the development process. This approach aims to avoid the release of unattractive or flawed products into the market or shop-floor by proactively improving product usability, appropriateness and quality accordingly to the users' perspective, ultimately leading to their increased satisfaction and acceptance from the moment the product is released.

## 5.2. Future work

The augmented reality test session, and the subsequent workplace ergonomic analysis resulted in new recommendations for the workstation layout and in the implementation of changes to the prototype. As production has not yet started in the dish models that will use the prototype, a validation of the new workplace layout is still required. As soon as production starts, the ergonomic analysis should be repeated to validate and quantify the improvement that derived from the workplace layout optimization. Moreover, at that stage, user feedback should continue to be considered for future improvements.

The eye tracking sessions resulted in the collection of extensive amounts of data that can be explored much further. This dataset can be valuable for future work, for correlating several factors that were not explored. Furthermore, the subsequent phases to the DfER methodology are going to be addressed, in a parallel study that will utilize the presented results.

Eye tracking presents high potential for systematic use in HCD. However, the required data treatment can discourage the deep investigation into insightful details. This also presents a limitation of the current work, as the collected dataset has potential for further exploration, that was not conducted in the presented case study due to the available time frame. Although the eye tracking research is valuable for product development and HCD practice, the resulting product requirements were not translated into a new design iteration, therefore the methodology has not yet been validated. In the future, a new version of the prototype should integrate the new product requirements, and a similar approach should be followed in order to validate the methodology and quantify its impact by comparing questionnaire results. Repeating the approach as described can also be relevant to consolidate the eye tracking analysis takeaways.

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## **Declaration of Integrity**

I declare that I conducted this academic work with integrity. I did not plagiarize or apply any form of misuse of information or falsification of results throughout the process that led to its preparation. I declare that the work presented in this document is original and my own and has not previously been used for any other purpose. I further declare that I am fully aware of the Code of Ethical Conduct of P.PORTO, ISEP.

NAME: José Pedro Cardoso de Almeida

Porto, June 14, 2025

## Declaration of integrity

## **Appendix A – Acceptance questionnaire**

## Appendix A

## Informações Pessoais / Profissionais

As questões aqui apresentadas tem como objetivo recolher os dados pessoais do trabalhador, para a sua caracterização sociodemográfica. A equipa de investigação garante a confidencialidade dos dados.

### 1. Informações pessoais

1.1. Nº Colaborador: \_\_\_\_\_ 1.2. Turno: \_\_\_\_\_

1.3. Data de nascimento: \_\_\_\_/\_\_\_\_/\_\_\_\_ 1.4. Sexo: Masculino  Feminino  Prefere não indicar

1.5. Escolaridade: Básico  Secundário incompleto  Secundário completo  Superior  Prefere não indicar

1.6. Nacionalidade: \_\_\_\_\_

### 2. Situação Profissional Atual

2.1. Profissão / ocupação principal: \_\_\_\_\_

2.2. Há quantos anos se encontra afeto à empresa? \_\_\_\_\_

2.3. Há quanto tempo ocupa este cargo ou função? \_\_\_\_\_

*Este questionário tem o intuito de medir os fatores que influenciam a aceitação de novas tecnologias/sistemas por parte dos colaboradores, utilizando uma escala de 1 a 5 para medir o grau de concordância com as 57 afirmações a seguir.*

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.	1	2	3	4	5
---------------------------------------------------------------------------------------------------------------------	---	---	---	---	---

*As próximas 8 perguntas têm como intuito avaliar a **utilidade percebida** pelo colaborador, perante a implementação do novo sistema nas suas tarefas.*

1	Considero que a utilização da máquina permitirá que eu realize as minhas tarefas mais rapidamente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	----------------------------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

2	Considero que a utilização da máquina irá aumentar a qualidade do meu trabalho.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	---------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

3	Considero que a utilização da máquina irá tornar o meu trabalho mais fácil.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	-----------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

4	Considero que a utilização da máquina irá permitir-me focar em outras tarefas que considero mais importantes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	---------------------------------------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

5	Considero que a utilização da máquina atenderá às minhas necessidades relacionadas com o trabalho.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	----------------------------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
6	Acredito que a adoção da máquina será vantajosa para o meu desempenho profissional.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
7	Considero que a utilização da máquina irá melhorar a eficiência da tarefa de seleção de pratos.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
8	Considero que a utilização da máquina atenderá as necessidades atuais da empresa.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 6 perguntas têm como intuito avaliar a <b>percepção de conforto</b> do colaborador, perante a utilização de novas tecnologias.</i>						
9	Considero que tenho facilidade em aprender a utilizar novas tecnologias/sistemas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
10	Seria simples para mim, integrar novos sistemas com as minhas tarefas diárias.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
11	Procuo me manter atualizado quanto ao lançamento de novas tecnologias.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
12	Gosto de experimentar novas tecnologias antes que a maioria das pessoas o faça.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
13	Sinto-me confortável em explorar e testar novos sistemas por conta própria.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
14	Estou sempre à procura de maneiras inovadoras de melhorar o meu trabalho utilizando novas tecnologias.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a percepção do colaborador, perante o <b>processo de implementação</b> da nova tecnologia.</i>						
15	Considero que será simples aprender a integrar a máquina às minhas tarefas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
16	Acredito que irá levar pouco tempo para aprender a integrar a máquina nas minhas tarefas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
17	Fui informado previamente quanto à adoção da máquina na empresa.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
18	Participei ativamente na ideia de utilizar a máquina para a classificação de defeitos nos pratos.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
<i>As próximas 4 perguntas têm como intuito avaliar o <b>suporte esperado</b> pelos colaboradores, por parte da organização, ao utilizar o novo sistema.</i>						
19	Considero que o meu supervisor é favorável à utilização da máquina de classificação de defeitos.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
20	Considero que os meus superiores hierárquicos irão me auxiliar na integração da máquina com as minhas tarefas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
21	Considero que a alta gestão da empresa irá me dar todo o suporte para aprender a integrar a máquina às minhas atividades.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
22	Acredito que será disponibilizada informação necessária sobre como integrar a máquina nas minhas atividades.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a <b>influência social</b> percebida pelos colaboradores quanto à implementação do novo sistema.</i>						
23	Considero que os meus colegas de trabalho serão favoráveis à implementação da máquina.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
24	Considero que os meus colegas de trabalho procuram maneiras inovadoras de melhorar o trabalho.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
25	Considero que os meus colegas de trabalho irão adotar a máquina com naturalidade.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
26	Acredito que a utilização da máquina irá aumentar a minha reputação perante os meus colegas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a <b>percepção de segurança</b> dos colaboradores quanto à implementação dos novos sistemas.</i>						
27	Considero que a utilização da máquina não representa riscos significativos para a minha segurança física.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
28	Considero que a utilização da máquina não representa riscos significativos para a minha saúde.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
29	Considero que terei confiança nos sistemas de segurança implementados na máquina.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
30	Acredito que me sentirei confortável trabalhando próximo da máquina.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a percepção dos colaboradores quanto à <b>facilidade esperada</b> para a adoção do novo sistema.</i>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
31	Prevejo que a minha interação com a máquina será clara e intuitiva.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
32	Considero que será mais simples utilizar a máquina do que o sistema atual.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
33	Sinto-me confiante com a utilização da máquina.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
34	Prevejo que conseguirei aprender facilmente a integrar a máquina à minha rotina de trabalho.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a percepção dos colaboradores quanto aos <b>impactos a longo prazo</b> que a utilização do novo sistema promoverá.</i>						
35	Considero que a utilização da máquina irá contribuir para o meu desenvolvimento profissional.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
36	Considero que a máquina não representa riscos ao meu futuro na empresa.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
37	Considero que a utilização da máquina irá aumentar a minha oportunidade de crescer dentro da empresa.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
38	Considero que a máquina é compatível com as minhas demais tarefas.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a <b>intenção de uso</b> dos colaboradores quanto a utilização do novo sistema.</i>						
39	Considero uma boa ideia a utilização da máquina para a tarefa de classificação de defeitos nos pratos.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
40	Pretendo aprender a utilizar a máquina assim que for implementada.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
41	Estou disposto/a a investir tempo para aprender a utilizar a nova máquina de forma eficaz.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
42	Pretendo utilizar a máquina regularmente nas minhas tarefas diárias.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
<i>As próximas 15 perguntas têm como intuito avaliar a <b>satisfação</b> dos colaboradores com a forma como a tarefa é realizada atualmente.</i>						
43	A minha estação de trabalho é apropriada para realizar a tarefa de classificação de pratos.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
44	A bancada de trabalho é adequada para a minha altura.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
45	Realizo a tarefa com normalidade, sem sentir desconforto físico (por exemplo, dor nas costas, pescoço, ombros, mãos, cansaço ocular ou dores de cabeça, entre outros).	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Se sente dor, indicar o local:</b>						
46	Disponho de todas as ferramentas e equipamentos necessários para realizar esta tarefa de maneira confortável e prática.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
47	Recebi formação sobre como realizar esta tarefa com segurança.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
48	Sinto-me mentalmente estimulado com as minhas tarefas diárias.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
49	Sinto-me satisfeito com a variedade de tarefas relacionadas com a minha função.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
50	Realizo a tarefa sem sentir níveis de stress relevantes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
51	Realizo a tarefa sem sentir níveis de ansiedade relevantes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Se sente ansiedade na tarefa, indique o motivo:</b>						
52	Acredito que a tarefa de seleção de pratos é equilibrada em termos de demandas físicas e mentais.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
53	Considero que o processo de seleção de pratos é feito de maneira eficiente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
54	Foram-me fornecidas todas as informações e recursos necessários para realizar a tarefa de forma eficaz.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
55	É-me fornecido tempo suficiente para selecionar os pratos de maneira confortável.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
56	Acredito que a tarefa contribui para o meu desenvolvimento profissional.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
57	Acredito que a tarefa contribui para o meu desenvolvimento pessoal.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

## **Appendix B – Usability questionnaire**

## Appendix B

## Informações Pessoais / Profissionais

As questões aqui apresentadas tem como objetivo recolher os dados pessoais do trabalhador, para a sua caracterização sociodemográfica. A equipa de investigação garante a confidencialidade dos dados. Duração estimada: 30min

### 1. Informações pessoais

1.1. Nº Colaborador: \_\_\_\_\_ 1.2. Turno: \_\_\_\_\_

1.3. Data de nascimento: \_\_\_\_/\_\_\_\_/\_\_\_\_ 1.4. Sexo: Masculino  Feminino  Prefere não indicar

1.5. Escolaridade: Básico  Secundário incompleto  Secundário completo  Superior  Prefere não indicar

1.6. Nacionalidade: \_\_\_\_\_

### 2. Situação Profissional Atual

2.1. Profissão / ocupação principal: \_\_\_\_\_

2.2. Há quantos anos se encontra afeto à empresa? \_\_\_\_\_

2.3. Há quanto tempo ocupa este cargo ou função? \_\_\_\_\_

*Este questionário tem o intuito de medir os fatores que influenciam a usabilidade do protótipo por parte dos colaboradores, utilizando uma escala de 1 a 5 para medir o grau de concordância com as 49 afirmações a seguir.*

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.	1	2	3	4	5
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*As próximas 17 perguntas têm como intuito avaliar a percepção do colaborador relativamente à **facilidade de utilização** do monitor do protótipo.*

1	Acredito que consigo utilizar a interface sem qualquer supervisão de um especialista.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
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**Comentários:**

2	Conseguí compreender todos os passos apresentados pela interface ao longo do teste.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
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**Comentários:**

3	Acredito que as características da interface me ajudaram a evitar erros.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
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**Comentários:**

4	Considero que a interface responde suficientemente rápido às minhas ações.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
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**Comentários:**

5	Compreendi claramente a função de todos os botões apresentados na interface.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
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**Comentários:**

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
6	Compreendi claramente todo o texto apresentado na interface.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
7	Acredito que qualquer pessoa é capaz de utilizar esta interface com facilidade.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
8	Considero que as funcionalidades do sistema foram fáceis de encontrar na interface.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
9	<b>Não</b> identifiquei na interface nenhuma característica ou funcionalidade que considere desnecessária. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
10	Considero que todo o texto apresentado na interface é indispensável.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
11	Considero que todas as imagens e símbolos apresentados na interface são indispensáveis.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
12	Considero que a utilização desta interface <b>não</b> é psicologicamente desgastante. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
13	Considero que a utilização desta interface <b>não</b> é fisicamente desgastante. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
14	Considero que as funcionalidades apresentadas na interface são <b>fáceis</b> de memorizar.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
15	Considero que é <b>difícil</b> cometer erros na interação com a interface. Se não, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
16	Considero que é <b>fácil</b> de identificar erros cometidos na interação com a interface.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
17	Considero que é <b>fácil</b> de corrigir erros cometidos na interação com a interface.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
<i>As próximas 3 perguntas têm como intuito avaliar a percepção da <b>utilidade</b> do monitor do protótipo, por parte do utilizador.</i>						
18	Considero que a interface apresenta todas as informações importantes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
19	Usar esta interface nas minhas tarefas laborais diárias é viável para mim.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
20	<b>Não</b> encontrei qualquer problema de funcionamento durante minha interação com o monitor. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 6 perguntas têm como intuito avaliar a <b>Satisfação</b> do colaborador, em relação à utilização da interface do protótipo.</i>						
21	Gostei de todos os aspetos da minha interação com a interface.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
22	Considero que as imagens e o texto apresentados na interface são claros e intuitivos.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
23	As cores, o brilho, o contraste e a nitidez da imagem são ideais.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
24	Estou familiarizado/a com todas as terminologias utilizadas pelo sistema.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
25	<b>Não</b> precisei de praticar até conseguir usar a interface corretamente. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
26	A sequência de passos apresentada na interface adequa-se perfeitamente à tarefa.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
<i>As próximas 16 perguntas têm como intuito avaliar a percepção do colaborador relativamente à <b>facilidade de utilização</b> do recetáculo do protótipo.</i>						
27	Acredito que consigo utilizar o recetáculo sem qualquer supervisão.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
28	Conseguí perceber sempre se cada prato estava bem posicionado no recetáculo.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
29	Acredito que as características do recetáculo me ajudaram a evitar erros.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
30	Considero que este recetáculo permite posicionar cada prato suficientemente rápido.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
31	Compreendi claramente a posição em que deveria colocar cada prato.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
32	Acredito que qualquer pessoa é capaz de utilizar este recetáculo com facilidade.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
33	Considero que é <b>fácil</b> de encontrar a posição correta de cada prato. Se não, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
34	<b>Não</b> identifiquei no recetáculo nenhuma característica ou funcionalidade que considere desnecessária. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
35	Considero que as operações a desempenhar no recetáculo são simples.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
36	Considero que todas as características do recetáculo são indispensáveis.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
37	Considero que a utilização deste recetáculo <b>não</b> é psicologicamente desgastante. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
38	Considero que a utilização deste recetáculo <b>não</b> é fisicamente desgastante. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
39	Considero que é <b>fácil</b> de memorizar a posição correta do prato. Se não, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
40	Considero que é <b>difícil</b> cometer erros ao utilizar o recetáculo.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
41	Considero que é <b>fácil</b> identificar os meus erros ao utilizar o recetáculo. Se não, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
42	Considero que é <b>fácil</b> corrigir os meus erros ao utilizar o recetáculo. Se não, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 3 perguntas têm como intuito avaliar a <b>percepção da utilidade</b> do recetáculo do protótipo, por parte do utilizador.</i>						
43	Considero que todas as características do recetáculo são importantes.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
44	Consigo imaginar-me a utilizar um recetáculo como este nas minhas tarefas laborais diárias.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
45	<b>Não</b> encontrei qualquer problema de funcionamento durante minha interação com o recetáculo. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 4 perguntas têm como intuito avaliar a <b>Satisfação</b> do colaborador, em relação à utilização do recetáculo do protótipo.</i>						
46	Gostei de todos os aspetos da minha interação com o recetáculo.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
47	Acredito que o recetáculo é suficientemente sólido.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
48	<b>Não</b> precisei de praticar até conseguir usar o recetáculo corretamente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
49	As características do recetáculo adequam-se perfeitamente à tarefa.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

## **Appendix C – AR questionnaire**

## Appendix C

## Informações Pessoais / Profissionais

As questões aqui apresentadas tem como objetivo recolher os dados pessoais do trabalhador, para a sua caracterização sociodemográfica. A equipa de investigação garante a confidencialidade dos dados. Duração estimada: 30min

### 1. Informações pessoais

1.1. Nº Colaborador: \_\_\_\_\_ 1.2. Turno: \_\_\_\_\_

1.3. Data de nascimento: \_\_\_\_/\_\_\_\_/\_\_\_\_ 1.4. Sexo: Masculino  Feminino  Prefere não indicar

1.5. Escolaridade: Básico  Secundário incompleto  Secundário completo  Superior  Prefere não indicar

1.6. Nacionalidade: \_\_\_\_\_

1.7. Altura: \_\_\_\_\_

1.8. Problemas de visão: \_\_\_\_\_

1.9. Mão dominante: Direita  Esquerda

### 2. Situação Profissional Atual

2.1. Profissão / ocupação principal: \_\_\_\_\_

2.2. Há quantos anos se encontra afeto à empresa? \_\_\_\_\_

2.3. Há quanto tempo ocupa este cargo ou função? \_\_\_\_\_

*Este questionário tem o intuito de avaliar a sessão de testes assistidos por realidade virtual, por parte dos colaboradores, utilizando uma escala de 1 a 5 para medir o grau de concordância com as 16 afirmações a seguir.*

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.	1	2	3	4	5
---------------------------------------------------------------------------------------------------------------------	---	---	---	---	---

*As próximas 5 perguntas têm como intuito avaliar a percepção do colaborador relativamente ao **treino** assistido por realidade aumentada.*

1	Acredito que, após esta sessão de treino com o protótipo virtual, vou conseguir utilizar o protótipo real sem qualquer supervisão.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	------------------------------------------------------------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

2	As instruções e avisos virtuais foram indispensáveis para aprender a tarefa corretamente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	-------------------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

3	<b>Não</b> cometi erros ao usar o protótipo virtual. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	-----------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

4	Sinto que estou completamente familiarizado com o funcionamento do protótipo.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	-------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

5	Acredito que o treino virtual me ajudou a evitar erros no futuro, quando utilizar o protótipo real.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
---	-----------------------------------------------------------------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
<i>As próximas 4 perguntas têm como intuito avaliar a percepção do colaborador relativamente à experiência da realidade aumentada.</i>						
6	Utilizar os óculos de realidade aumentada <b>não</b> me causou <b>nenhum</b> desconforto. Se sim, comente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
7	Tive facilidade em compreender as instruções virtuais.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
8	Tive facilidade em selecionar os botões virtuais.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
9	Após esta sessão consigo prever como será trabalhar com o protótipo real no meu local de trabalho.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
<i>As próximas 7 perguntas têm como intuito avaliar a percepção do colaborador relativamente ao design e layout do protótipo</i>						
10	Considero que a posição de trabalho é suficientemente confortável para repetir esta tarefa ao longo do dia.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
11	Considero que o design do protótipo me transmite segurança para cumprir a tarefa proposta.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Discordo totalmente; 2 – Discordo parcialmente; 3 – Neutro; 4 – Concordo parcialmente; 5 – Concordo totalmente.		1	2	3	4	5
12	O layout 1 (monitor à direita) é o mais confortável.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
13	O layout 2 (monitor à esquerda) é o mais confortável.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
14	A altura do monitor é ideal. Se não, comente se preferia um ecrã <b>mais elevado</b> ou <b>mais baixo</b> .	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
15	O tamanho do monitor é suficiente.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
16	A altura do recetáculo é confortável. Se não, comente se preferia um recetáculo mais elevado ou mais baixo.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

## **Appendix D – Eye tracking questionnaire**

## Appendix D

### Informações Pessoais / Profissionais

As questões aqui apresentadas tem como objetivo recolher os dados pessoais do participante, para a sua caracterização sociodemográfica. A equipa de investigação garante a confidencialidade dos dados. Duração estimada: 30min

1.1. Data de nascimento: \_\_\_\_/\_\_\_\_/\_\_\_\_

1.2. Sexo: Masculino  Feminino  Prefere não indicar

1.3. Escolaridade: Básico  Secundário incompleto  Secundário completo  Ensino Superior Técnico   
Licenciatura  Mestrado  Doutoramento

1.4. Nacionalidade: \_\_\_\_\_

1.5. Zona de Residência: Açores  Aveiro  Beja  Braga  Bragança  Castelo Branco  Coimbra  Évora   
Faro  Guarda  Leiria  Lisboa  Madeira  Portalegre  Porto  Santarém  Setúbal  Viana do Castelo   
Vila Real  Viseu

1.6. Atividade Profissional: \_\_\_\_\_

1.7. Há quantos anos se encontra afeto à empresa? \_\_\_\_\_

1.8. Há quanto tempo ocupa este cargo ou função? \_\_\_\_\_

1.9. Passatempos/Hobbies: \_\_\_\_\_

1.10. Está familiarizado com a marca Vista Alegre? Sim  Não

1.11. Já comprou produtos da marca Vista Alegre? Sim  Não

*Esta secção do questionário tem o intuito de avaliar as **primeiras impressões** sobre a caixa da Vista Alegre, por parte dos participantes, utilizando uma escala de 1 a 5 para classificar as 10 afirmações a seguir.*

1 – Mau; 2 – Fraco; 3 – Neutro; 4 – Bom; 5 – Excelente.		1	2	3	4	5
1	Como classifica o valor estético da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
2	Como classifica a beleza da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
3	Como classifica o valor simbólico da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
4	Como classifica a modernidade da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
5	Como classifica a versatilidade da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

1 – Mau; 2 – Fraco; 3 – Neutro; 4 – Bom; 5 – Excelente.		1	2	3	4	5
6	Como classifica a ligação da caixa à marca Vista Alegre?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
7	Como classifica a adequação da caixa para a sua finalidade?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
8	Como classifica a preciosidade da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
9	Como classifica o seu interesse pessoal pela caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
10	Como classifica a utilidade da caixa para outras finalidades (reutilização)?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

Nesta secção do questionário, é explorada a caixa da Vista Alegre em estudo. Ao longo da interação com o produto, são abordadas as **emoções sentidas e opinião** sobre o produto.

Para responder às próximas 2 perguntas, deve **apenas observar a caixa, sem tocar na mesma**.

11 Seleccione no mínimo 1 e no máximo 3 emoções/sensações que **possam descrever** a sua reação à interação com a caixa.

Admiração <input type="checkbox"/>	Desejo <input type="checkbox"/>	Familiaridade <input type="checkbox"/>
Afeto <input type="checkbox"/>	Estimulação <input type="checkbox"/>	Fascínio <input type="checkbox"/>
Alegria <input type="checkbox"/>	Excitação <input type="checkbox"/>	Nostalgia <input type="checkbox"/>
Curiosidade <input type="checkbox"/>	Expectativa <input type="checkbox"/>	Surpresa <input type="checkbox"/>

12 Seleccione no mínimo 1 e no máximo 3 emoções/sensações que **nunca poderiam descrever** a sua reação à interação com a caixa.

Admiração <input type="checkbox"/>	Desejo <input type="checkbox"/>	Familiaridade <input type="checkbox"/>
Afeto <input type="checkbox"/>	Estimulação <input type="checkbox"/>	Fascínio <input type="checkbox"/>
Alegria <input type="checkbox"/>	Excitação <input type="checkbox"/>	Nostalgia <input type="checkbox"/>
Curiosidade <input type="checkbox"/>	Expectativa <input type="checkbox"/>	Surpresa <input type="checkbox"/>

Para responder às próximas 2 perguntas, pode **tocar e manusear a caixa, sem abrir a mesma**.

13 Seleccione no mínimo 1 e no máximo 3 emoções/sensações que **possam descrever** a sua reação à interação com a caixa.

Admiração <input type="checkbox"/>	Desejo <input type="checkbox"/>	Familiaridade <input type="checkbox"/>
Afeto <input type="checkbox"/>	Estimulação <input type="checkbox"/>	Fascínio <input type="checkbox"/>
Alegria <input type="checkbox"/>	Excitação <input type="checkbox"/>	Nostalgia <input type="checkbox"/>
Curiosidade <input type="checkbox"/>	Expectativa <input type="checkbox"/>	Surpresa <input type="checkbox"/>

14 Seleccione no mínimo 1 e no máximo 3 emoções/sensações que **nunca poderiam descrever** a sua reação à interação com a caixa.

Admiração <input type="checkbox"/>	Desejo <input type="checkbox"/>	Familiaridade <input type="checkbox"/>
Afeto <input type="checkbox"/>	Estimulação <input type="checkbox"/>	Fascínio <input type="checkbox"/>
Alegria <input type="checkbox"/>	Excitação <input type="checkbox"/>	Nostalgia <input type="checkbox"/>
Curiosidade <input type="checkbox"/>	Expectativa <input type="checkbox"/>	Surpresa <input type="checkbox"/>

<p><i>Para responder às próximas 2 perguntas, pode <b>abrir, desmontar, e explorar</b> a caixa <b>livremente</b>.</i></p>		
15	<p>Selecione no mínimo 1 e no máximo 3 emoções/sensações que <b>possam descrever</b> a sua reação à interação com a caixa.</p>	
	<p>Admiração <input type="checkbox"/></p> <p>Afeto <input type="checkbox"/></p> <p>Alegria <input type="checkbox"/></p> <p>Curiosidade <input type="checkbox"/></p>	<p>Desejo <input type="checkbox"/></p> <p>Estimulação <input type="checkbox"/></p> <p>Excitação <input type="checkbox"/></p> <p>Expectativa <input type="checkbox"/></p>
		<p>Familiaridade <input type="checkbox"/></p> <p>Fascínio <input type="checkbox"/></p> <p>Nostalgia <input type="checkbox"/></p> <p>Surpresa <input type="checkbox"/></p>
16	<p>Selecione no mínimo 1 e no máximo 3 emoções/sensações que <b>nunca poderiam descrever</b> a sua reação à interação com a caixa.</p>	
	<p>Admiração <input type="checkbox"/></p> <p>Afeto <input type="checkbox"/></p> <p>Alegria <input type="checkbox"/></p> <p>Curiosidade <input type="checkbox"/></p>	<p>Desejo <input type="checkbox"/></p> <p>Estimulação <input type="checkbox"/></p> <p>Excitação <input type="checkbox"/></p> <p>Expectativa <input type="checkbox"/></p>
		<p>Familiaridade <input type="checkbox"/></p> <p>Fascínio <input type="checkbox"/></p> <p>Nostalgia <input type="checkbox"/></p> <p>Surpresa <input type="checkbox"/></p>

*Esta secção do questionário tem o intuito de avaliar a opinião final sobre a caixa da Vista Alegre, por parte dos participantes, utilizando uma escala de 1 a 5 para classificar as 10 afirmações a seguir.*

1 – Mau; 2 – Fraco; 3 – Neutro; 4 – Bom; 5 – Excelente.		1	2	3	4	5
---------------------------------------------------------	--	---	---	---	---	---

17	Como classifica o valor estético da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
----	--------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

18	Como classifica a beleza da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
----	------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

19	Como classifica o valor simbólico da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
----	---------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

20	Como classifica a modernidade da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
----	-----------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

21	Como classifica a versatilidade da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
----	-------------------------------------------	-----------------------	-----------------------	-----------------------	-----------------------	-----------------------

**Comentários:**

1 – Mau; 2 – Fraco; 3 – Neutro; 4 – Bom; 5 – Excelente.		1	2	3	4	5
22	Como classifica a ligação da caixa à marca Vista Alegre?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
23	Como classifica a adequação da caixa para a sua finalidade?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
24	Como classifica a preciosidade da caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
25	Como classifica o seu interesse pessoal pela caixa?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						
26	Como classifica a utilidade da caixa para outras finalidades (reutilização)?	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
<b>Comentários:</b>						

*A secção final do questionário avalia as **alterações** que o participante considera que iriam contribuir para a sua classificação da caixa.*

27 | Selecione e descreva as alterações que considera relevantes para melhorar a qualidade deste produto.

VISUAL:

Cor  Alterações: \_\_\_\_\_

Forma  Alterações: \_\_\_\_\_

Tamanho  Alterações: \_\_\_\_\_

Logótipo  Alterações: \_\_\_\_\_

Outras  Alterações: \_\_\_\_\_

DE TATO:

Textura  Alterações: \_\_\_\_\_

Robustez  Alterações: \_\_\_\_\_

Temperatura  Alterações: \_\_\_\_\_

Materiais  Alterações: \_\_\_\_\_

Outras  Alterações: \_\_\_\_\_

FUNCIONAL:

Abertura/Fecho  Alterações: \_\_\_\_\_

Suporte/Pega  Alterações: \_\_\_\_\_

Ajuste  Alterações: \_\_\_\_\_

Outras  Alterações: \_\_\_\_\_

COMPONENTES:

Capa (Cinzenta)  Alterações: \_\_\_\_\_

Estrutura (Laranja)  Alterações: \_\_\_\_\_

Janela  Alterações: \_\_\_\_\_

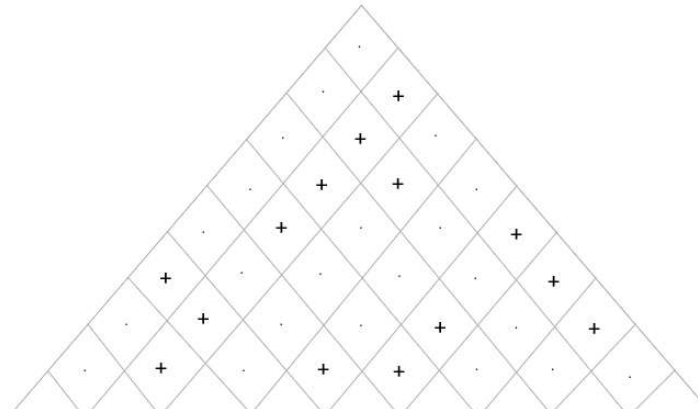
Interior  Alterações: \_\_\_\_\_

Outro  Alterações: \_\_\_\_\_

## Appendix E – Component QFD matrices

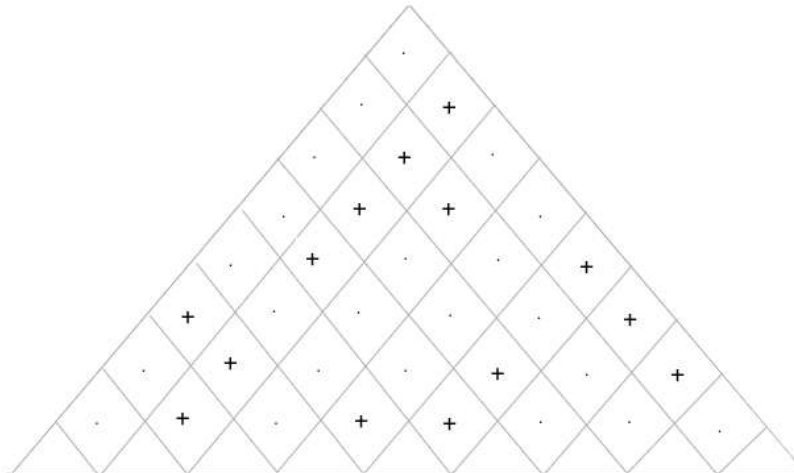
## Appendix E

## QFD for Lining



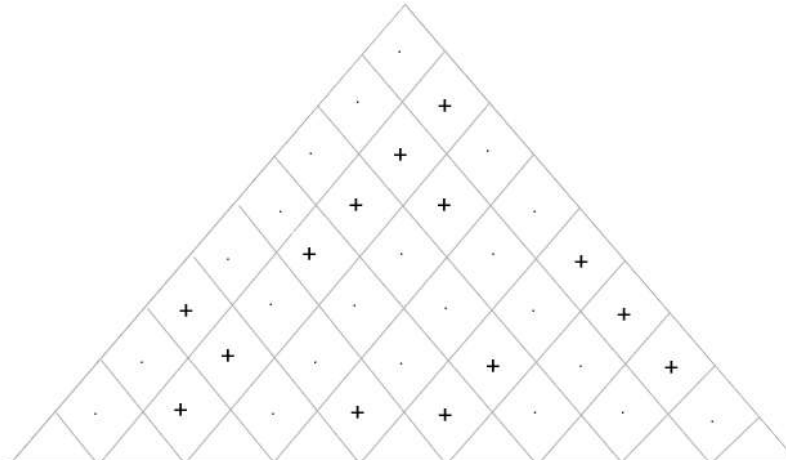
Kano model classification	Customer requirements	Importance rating	Functional requirements ->	Colour	Design	Dimensions	Branding	Material	Fastening	Support	Handling	Interaction	Weighted Score
M - Must be	Beauty	9		9	9	5	6	3	4	4	9	2	459
A - Attractive	Simbology	5		5	9	2	7	9	3	2	7	1	225
O - One-dimensional	Modernity	7		6	9	2	7	5	4	7	6	2	336
A - Attractive	Versatility	8		8	9	4	2	7	1	6	9	6	416
M - Must be	Brand connection	4		7	7	1	9	7	2	2	2	2	156
R - Reverse	Weight	6		0	8	9	0	9	3	1	4	2	216
M - Must be	Robustness	3		0	8	6	0	9	5	8	5	1	126
Technical importance score				240	361	177	190	272	128	181	277	108	
Importance				12%	19%	9%	10%	14%	7%	9%	14%	6%	
Requirement priority				4	1	7	5	3	8	6	2	9	

## QFD for Frame



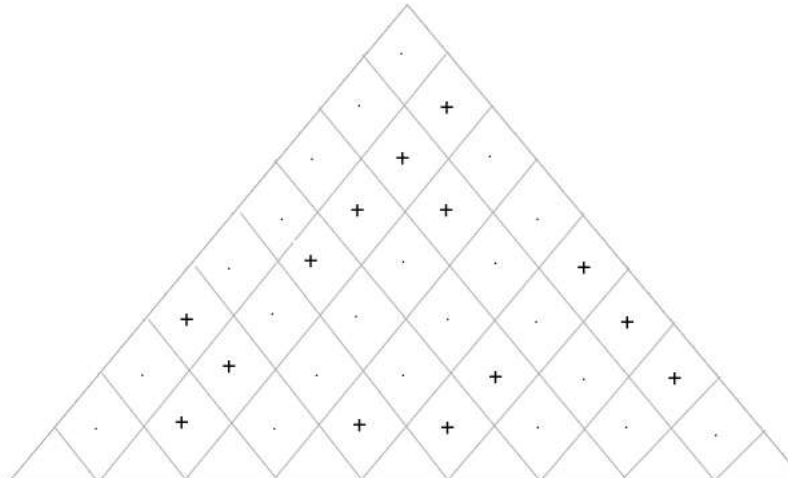
Kano model classification	Customer requirements	Importance rating	Functional requirements ->	Colour	Design	Dimension	Branding	Material	Fastening	Support	Handling	Interaction	Weighted Score
M - Must be	Beauty	9		9	9	6	9	5	1	3	1	1	396
A - Attractive	Simbology	5		7	9	3	4	6	1	3	3	1	185
O - One-dimensional	Modernity	7		7	9	5	8	7	5	3	5	3	364
A - Attractive	Versatility	8		8	8	7	1	3	1	5	2	3	304
M - Must be	Brand connection	4		7	7	1	9	7	1	2	4	1	156
R - Reverse	Weight	6		1	8	9	1	9	3	3	5	2	246
M - Must be	Robustness	3		1	8	6	1	9	7	7	2	7	144
Technical importance score				266	353	236	210	257	100	150	127	96	
Importance				15%	20%	13%	12%	14%	6%	8%	7%	5%	
Requirement priority				2	1	4	5	3	8	6	7	9	

# QFD for Frame Support



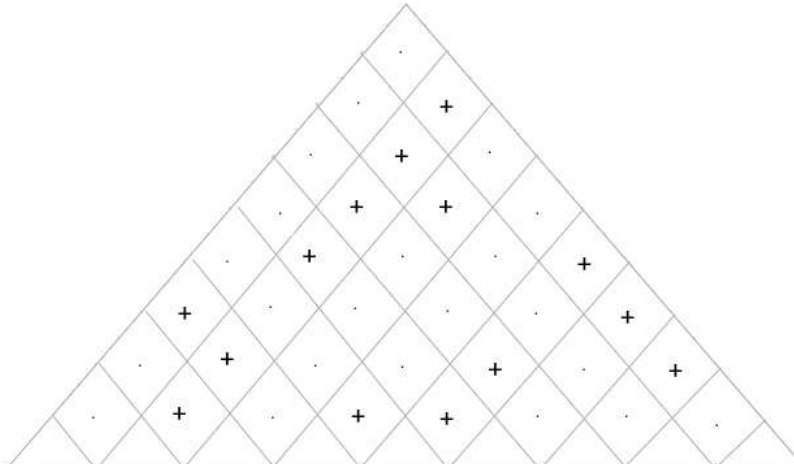
Kano model classification	Customer requirements	Importance rating	Functional requirements ->	Colour	Design	Dimensio	Branding	Material	Fastening	Support	Handling	Interactio	Weighted Score
M - Must be	Beauty	7		9	9	4	7	5	4	1	1	3	301
A - Attractive	Simbology	4		7	9	1	6	5	4	5	1	5	172
O - One-dimensional	Modernity	6		8	9	7	6	5	5	4	1	5	300
A - Attractive	Versatility	3		8	7	3	8	7	1	6	3	9	156
M - Must be	Brand connection	5		7	8	3	9	6	4	1	1	5	220
R - Reverse	Weight	1		1	8	9	4	9	1	1	1	1	35
M - Must be	Robustness	9		1	7	5	1	9	1	8	1	9	378
Technical importance score				208	285	152	191	226	107	147	41	205	
Importance				13%	18%	10%	12%	14%	7%	9%	3%	13%	
Requirement priority				3	1	6	5	2	8	7	9	4	

## QFD for Structure



Kano model classification	Customer requirements	Importance rating	Functional requirements ->	Colour	Design	Dimension	Branding	Material	Fastening	Support	Handling	Interaction	Weighted Score
M - Must be	Beauty	4		8	9	5	6	4	3	1	1	3	160
A - Attractive	Simbology	2		2	8	3	5	6	3	1	1	3	64
O - One-dimensional	Modernity	5		7	9	5	6	7	6	4	1	6	255
A - Attractive	Versatility	9		6	9	3	2	6	3	4	5	9	423
M - Must be	Brand connection	6		8	7	1	9	8	4	1	1	6	270
R - Reverse	Weight	9		1	8	9	1	9	3	1	5	4	369
M - Must be	Robustness	7		1	5	5	1	9	9	5	3	9	329
Technical importance score				189	327	200	152	309	189	112	128	264	
Importance				10%	17%	11%	8%	17%	10%	6%	7%	14%	
Requirement priority				5	1	4	7	2	5	9	8	3	

## QFD for Clip



Kano model classification	Customer requirements	Importance rating	Functional requirements ->	Colour	Design	Dimension	Branding	Material	Fastening	Support	Handling	Interactio	Weighted Score
M - Must be	Beauty	4		9	9	5	7	7	6	4	3	1	204
A - Attractive	Simbology	3		7	8	1	6	9	6	5	3	5	150
O - One-dimensional	Modernity	8		9	9	1	7	8	9	5	1	9	464
A - Attractive	Versatility	6		6	4	2	1	1	4	4	1	9	192
M - Must be	Brand connection	4		9	6	1	9	8	4	4	1	7	196
R - Reverse	Weight	2		1	8	9	1	9	5	2	1	5	82
M - Must be	Robustness	9		1	9	3	1	9	8	7	1	9	432
Technical importance score				212	277	92	155	256	236	178	50	264	
Importance				12%	16%	5%	9%	15%	14%	10%	3%	15%	
Requirement priority				5	1	8	7	3	4	6	9	2	

## Appendix E

## **Appendix F – Product requirements**

## Appendix F

	Lining	Frame	Frame Support	Structure	Clip	General
<b>Colour</b>	Less neutral colours (white, beige, wood or marble effects)	Less strong colour	Use a colour that matches the frame (black)	Lighter colour		Use colours suitable for any home (more neutral colours)
	Greater contrast with branding	Finish reminiscent of ceramics		More eye-catching		Colours suited to the product
		Black, white, wood effect		Brighter		
		Various colour options				
<b>Design</b>	Integrate better with the modern design of the rest of the product	More luxurious shape (straighter lines, textures)	Improve the connection to the frame	Improve design by reducing robustness	Make more intuitive	Develop different formats suitable for different products
	Promote lines that can be more associated with the brand	Less generic	Use the branding itself as the shape of the component	Make more sophisticated		Improve product design for the second purpose
						Less industrial design
<b>Size</b>	Less thickness	Less volume, particularly thickness		Adjust the dimensions to those of the frame to allow it to fit as part of the frame during the product's second life		
	More tailored width					
<b>Branding</b>	Make it more appealing (review format and colour)	Include branding on this component				

	Lining	Frame	Frame Support	Structure	Clip	General
<b>Texture</b>	More delicate and soft to the touch		Make softer	Make softer		
				Make smoother		
<b>Robustness</b>	Visually less robust		Improve robustness	Reduce robustness and weight	Make more robust to prevent breakage	
<b>Materials</b>	More elegant/ premium (leather, natural fibres, wood or marble effects)	Lighter	Do not use plastic or make it less noticeable that it is plastic	More pleasant to the touch and sustainable material (wood)		Materials that are more appealing to the touch, such as cork
		Acrylic on the window	Make it similar to the frame material	Internal acrylic structure to make it more attractive and increase reuse potential		
		More brand-appropriate material				
<b>Fastening</b>						
<b>Handling</b>	Make more stable	Allow the frame to be supported vertically and horizontally				
	Include clear handling method					
	Include a handle or grip					

	Lining	Frame	Frame Support	Structure	Clip	General
<b>Interaction</b>	More practical way of fastening that defines a position instead of velcro		More robust and reliable fitting	Improve the connection between the parts (pins) so that the structure remains solid without the frames	Change the fitting to prevent clips from becoming loose	
<b>Other</b>	Include in the frames assembly	Fit the window instead of gluing it		Disguise the bottle's foam support so that it goes unnoticed, or highlight it with another colour.	Include in the frame assembly	Adapt/customise the box model to the product/collection
				Develop so that the pieces are part of the frame;		Include instructions on the parts to assemble the frame
						Use the structure for the base and back of the frame (to hold a photo), and the fasteners to fix this structure to the frame. With a few slots in the structure of the box to fit the frame. This way you can use all the elements of the box for the second purpose.

## Appendix F

## **Appendix G – Disassembly and assembly times**



Participant	Box disassembly time	Frame assembly time
1	00:01:32	00:00:58
2	00:01:05	00:02:25
3	00:01:20	00:02:55
4	00:01:24	00:00:14
5	00:01:40	00:00:34
6	00:02:32	00:03:12
7	00:01:34	00:01:22
8	00:01:08	00:00:34
9	00:01:32	00:02:25
10	00:02:45	00:03:00
11	00:01:51	00:00:13
12	00:01:16	00:01:31
13	00:00:52	00:00:37
14	00:01:19	00:01:06
15	00:02:29	00:01:05
16	00:02:23	00:04:40
17	00:01:05	00:01:37
18	00:01:41	00:00:50
19	00:01:10	00:01:56
20	00:03:13	00:03:00
21	00:01:49	00:04:18
22	00:01:47	00:00:40
23	00:01:34	00:01:30