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USING A RESEARCH DOMAIN ONTOLOGY AS A DRIVER FOR TECHNOLOGY COMMERCIALIZATION

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Abstract

The Operator 4.0 concept plays a key role in the kind of industry we find ourselves in today, Industry 4.0. In the course of the literature review, it became evident that there was an absence of a reference model to support the development of innovative concepts for Operator 4.0. Therefore, this research will focus on its development, in partnership with Fraunhofer Portugal Research Center for Assistive Information and Communication Solutions - Fraunhofer AICOS. As a result, an ontology was created, and Design Science Approach was used to help its development, followed by a first validation by Fraunhofer Portugal experts. A Focus Group session was held with experts from Fraunhofer Portugal, who participated in the validation of the ontology as well as the evaluation of the competency questions, as a final validation.

This study contributed to a better understanding of how knowledge organization (Frishammar, Lichtenthaler, & Rundquist, 2012) in a given technological domain might assist in decision making when a new research project is proposed that may result in future intellectual property. This intellectual property would be licensed or exploited in some way in the future. Following the ontology validation, a workshop was held to demonstrate the second contribution of this dissertation, a proposal on how to use the ontology as a driver to start the technology process in the context of identifying opportunities for future commercialization of the technology.

In the end, this study answered the research question and related competency questions. Therefore, it can be said that with this research, a reference model has been effectively developed to support the construction of Operator 4.0 solutions for industry.

Keywords: Operator 4.0, Reference Model, Technology Push, Domain Ontology.

Resumo

O conceito Operator 4.0 desempenha um papel fundamental no tipo de indústria em que nos encontramos hoje, a Indústria 4.0. Durante a revisão da literatura, tornou-se evidente que não existia um modelo de referência para apoiar o desenvolvimento de conceitos inovadores para o Operador 4.0. Por conseguinte, esta investigação centrar-se-á no seu desenvolvimento, em parceria com o Fraunhofer Portugal Research Center for Assistive Information and Communication Solutions - Fraunhofer AICOS. Como resultado, foi criada uma ontologia, e utilizada a abordagem de *Design Science Approach* para auxiliar no seu desenvolvimento, seguida de uma primeira validação por especialistas da Fraunhofer Portugal. Posteriormente, foi realizada uma sessão de *Focus Group*, também com especialistas da Fraunhofer Portugal, que participaram numa segunda e última validação da ontologia, bem como na avaliação das questões de competência.

Este estudo contribuiu para uma melhor compreensão de como a organização do conhecimento (Frishammar, Lichtenthaler, & Rundquist, 2012) num determinado domínio tecnológico pode ajudar na tomada de decisões quando é proposto um novo projeto de investigação que pode resultar em propriedade intelectual futura. Esta propriedade intelectual seria licenciada ou explorada de alguma forma no futuro. Após a validação da ontologia, foi realizado um *workshop* para demonstrar a segunda contribuição desta dissertação, uma proposta sobre como utilizar a ontologia como motor para iniciar o processo tecnológico no contexto da identificação de oportunidades de comercialização futura da tecnologia.

No final, este estudo respondeu à pergunta de investigação colocada e às questões de competência relacionadas. Consequentemente, pode-se dizer que com esta investigação, foi eficazmente desenvolvido um modelo de referência para apoiar a construção de soluções Operador 4.0 para a indústria.

Palavras-chave: Operador 4.0, Modelo de Referência, Impulso Tecnológico, Ontologia de Domínio.

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1. Introduction

Manufacturing businesses are beginning to integrate robotics, automation, and other data-driven technology into their workflows as part of Industry 4.0, or the Fourth Industrial Revolution, as many authors refer to it. As new technologies are introduced, new types of human-machine interaction emerge, altering operational level workers and their job nature. This new generation of laborers is known as "Operator 4.0" (Kadir & Broberg, 2020).

Robots and operators will henceforth support each other in work tasks. This symbiosis will give this new type of operator all kinds of technical support, with the addition of enhanced skills like endurance and safety, while maintaining a constant and controlled link with the robots.

The transition to Industry 4.0 and the rise of cyber-physical systems introduces technical, organizational, and human changes in the various organizational layers of industrial companies (Roblek, Meško, & Krapez, 2016, as cited in Kadir & Broberg, 2020). As new technologies are introduced, new modes of interaction between humans and machines emerge, altering operators and the nature of their employment.

Several papers argue that new human-centered design and engineering philosophies that account for operators' physical, cognitive, and sensory capacities would be required to overcome such problems and assure a successful transition to Industry 4.0 (Pacaux-Lemoine, 2017, as cited in Kadir & Broberg, 2020).

Although the scientific community has already thoroughly investigated the topic of Industry 4.0, the topic of Operator 4.0, on the other hand, requires additional scientific investigation because it is a relatively new notion in the scientific world.

1.1 - Motivation

The focus of this master thesis is dedicated to technology approaches aimed at supporting Operator 4.0. The approach and research of this issue were motivated by a passion for technology and people. This subject was also chosen so that the maximum potential of this new concept, "the worker of the future," could be explored, being such a relatively new topic in the scientific world.

Because this topic has received minimal study and investigation, the goal would be to provide knowledge to this important scientific field.

Human-Technology collaboration has always been the structure for leaps in humankind's prosperity. As we are presently in Industry 4.0, it is crucial to focus on contemporary work-life challenges and opportunities (Romero, Stahre, & Taisch, 2020).

Industry 4.0 offers new sorts of interactions between machines and operators, which will revolutionize the entire industry workforce and have significant ramifications for work nature (Romero, Bernus, Noran, Stahre, & Fast-Berglund, 2016). It is also a hotly debated concept aimed at computerizing and automating manufacturing.

The aim is to identify novel industrial approaches and bring new system solutions to create the so-called factory of the future.

There is no doubt that Industry 4.0 presents its own set of obstacles, but by confronting those issues, it is evident that we have everything to gain.

1.2 – Scope of work

The objective of this research was to know how the organization of knowledge (Frishammar et al., 2012) in a given technological area could contribute to improve the decision-making process, at the moment when it is intended to start a new research project, that may lead to future intellectual property. This intellectual property would be eventually licensed or commercialized in some way. With that in mind, in the scope of this research we will:

- Build an artifact, bringing together and combining the different points of view, identified in the literature review, to support the construction of Operator 4.0 solutions for industry;
- Apply the Design Science Approach in order to drive the research process and assist in the development of the ontology;
- Present the ontology to different experts in order to gather comments and contributions; unfortunately, despite the efforts made, it was not possible to involve industry;
- For the final validation, a meeting was organized with Fraunhofer Portugal experts, divided in a first moment focused on the final validation of the ontology and a second moment aiming at a creative TPM (Technology-Product-Market) process, leading to the selection of Product-Market pairs.

The above process started with a given the literature review, where the following research question emerged:

How is Operator 4.0 structured or modeled by the literature?

- Is there a reference model or do independent models exist to support the construction of Operator 4.0 solutions for industry? Are there any model describing the technological infrastructure?
- If not, would it be feasible to build one and propose a Domain Ontology?
- Can we use this Domain Ontology to drive an early Technology Commercialization opportunity assessment process?

Design Science was used to create an artifact (ontology) to assist the researcher in developing a reference model to support Operator 4.0 in order to answer the research question. Following that, UML (Unified Modeling Language) was critical since it served as a framework to develop the required ontology based on the literature review. As previously stated, Fraunhofer Portugal experts contributed to the model's initial iterations and evolution, as well as to its final validation.

1.3 - Document Structure

This dissertation is organized as follows:

- Chapter 1 provides an overview of the topic of Industry 4.0 and, by extension, Operator 4.0. The motivation, as well as the scope of the work, are also discussed in this chapter;
- Chapter 2 includes a critical examination of the literature review that served as the foundation for the formulation of the research question;
- The complete approach utilized to solve the research topic is outlined in Chapter 3. Also provided is the Design Science Approach, which explains the development and validation of the ontology;
- Chapter 4 introduces the researcher's proposed model, as well as its validation and discussion with Fraunhofer Portugal experts. The Ontology is used to frame the creative process, and a critical analysis of the researcher's findings and limitations are presented;
- Finally, in Chapter 5, the global research results are discussed.

2. Literature review

2.1. Introduction

Rowley and Slack (2004) noted:

> A literature review is a summary of a subject field that supports the identification of specific research questions. A literature review needs to draw on and evaluate a range of different types of sources including academic and professional journal articles, books, and web-based resources. (p. 31)

A literature review "is a means of demonstrating an author's knowledge about a particular field of study, including vocabulary, theories, key variables and phenomena, and its methods and history" (Randolph, 2009, p. 2).

In this chapter, a synthesis of the literature review will be presented, along with an explanation of the complete selection process of the articles that comprise it. Articles selected for review will be organized in a table, with each paper's contribution highlighted. Follows a critical analysis of the papers analyzed in order to form a conclusion and identify the research gap.

2.2 - Synthesis

Only three operator types were deemed significant for this study (Healthy, Smarter and Virtual Operator)[1]. In order to obtain results more in line with what was intended from the model, the researcher cross-referenced the types of operators under study with the industry. For that reason, on November 10, 2020, he looked for articles published in Scopus (a large database of abstracts and citations for works published in academic journals or magazines). The oldest publications investigated on the issue and included in the literature review were published in 2018. The most current articles were published in the year 2020. The search was based on the following keywords:

- '(healthy AND operator) AND industry' (3 document results);
- '(smart* AND operator) AND industry' (107 document results);
- '(virtual AND operator) AND industry' (102 document results);

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[1] This decision was suggested by a group linked to the institution where this dissertation was carried out, which operates in those domains.

- ‘operator 4.0’ (44 document results).

A total of 256 documents were obtained from the search and organized in alphabetical order. The title of 256 papers were read to rank these papers depending on their significance to the topic of research. In that process, 20 duplication papers were eliminated. Of the 236 papers that remained, 144 were excluded due to the weak relationship that the abstract showed in relation to the core subject, being left with a total of 112 papers.

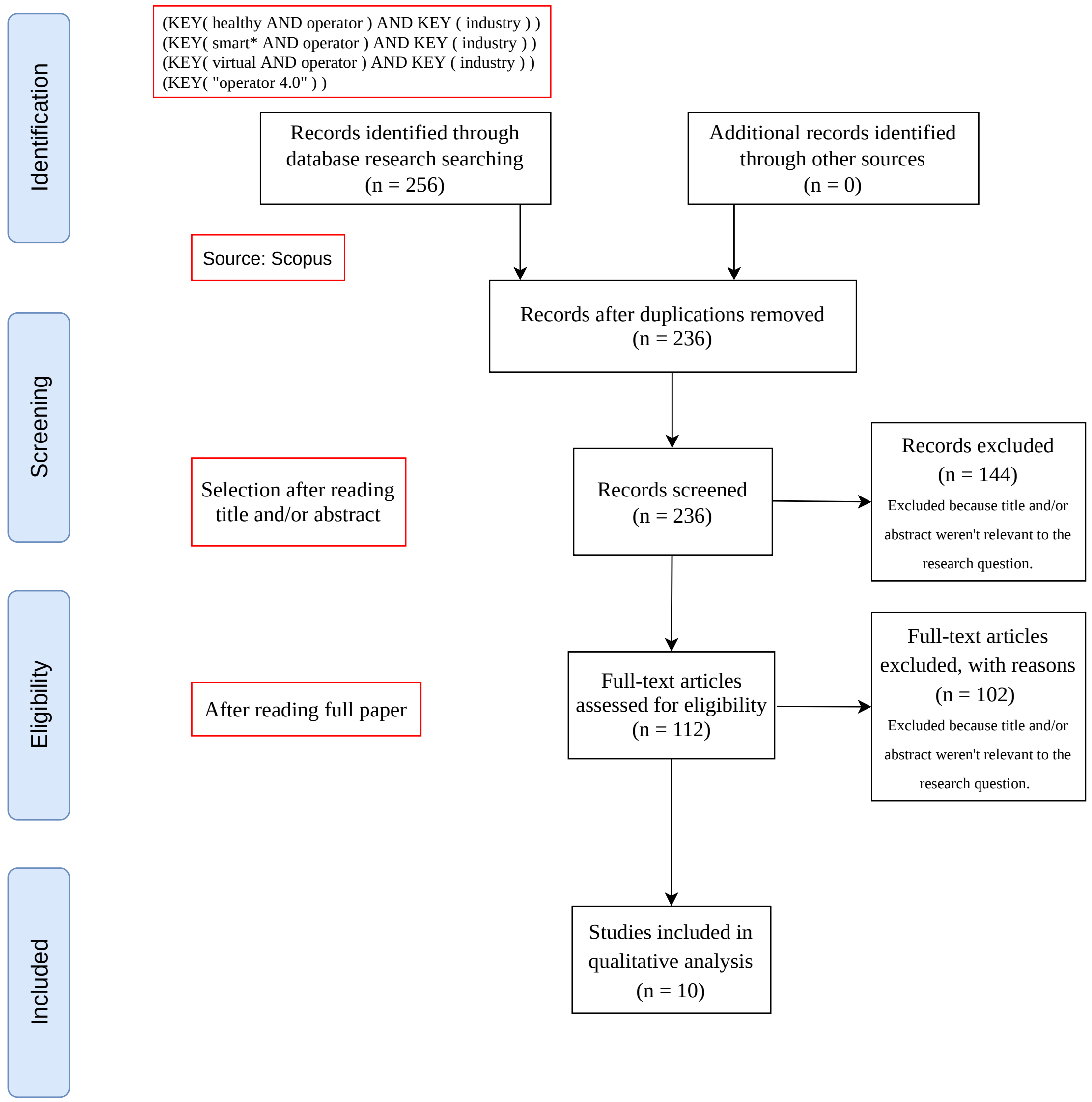

Figure 1 - PRISMA Diagram Flow – Adapted from Moher, Liberati, Tetzlaff, Altman, & Prisma Group (2009; p.3)

To proceed to the final exclusion, all remaining papers were examined in their entirety with the goal of ensuring that only studies that would constitute a relevant contribution to the literature review were included, resulting in a total of 10 papers.

The articles read were subsequently organized in the following Table 1. This table highlights the contribution of each paper, aligned with the focus of this research.

Table 1 - Literature Review (listed by search order)

Reference	#Cited	Contributions	Limitations/Future Research
(Sun, Zheng, Gong, Paredes and Ordieres-Meré, 2020)	9	The article deals with a series of Operator 4.0 support technologies. A unified architecture to support the integration of different enabling technologies was built, supporting recent concepts, such as Indoor Positioning System, Wearable technology, and Ambient environment monitoring. Also, an implementation model to facilitate the practical application of this concept in the industry was designed.	The prototype in question was applied in one company possessing a wide range of operator profiles. Safety regulations can limit specific sensors' application. It will be extended by integrating weight measurement through smart insoles, giving the loads to be carried by operators in their work time.
(Zawadzki, Żywicki, Buń & Górski, 2020).	1	The article deals with research about a viable technology. A possible model to build would be a virtual reality in the effectiveness of workers who perform production tasks. This model would start with the laboratory's digitalization through logical programming and the connection of peripheral devices and would end in a training scenario in a virtual environment.	Virtual reality training improved identification tasks but did not improve assembly operation's speed. The scope of stimulating the production of any designed product configurations is limited—more user behavior analyses, such as head and eye-tracking.
(Rabelo, Romero, & Zambiasi, 2018)	19	The article deals with the research model of the usage of softbots to support Operator 4.0. The study is applied in smart factory environments, helping in the interfacing between intelligent machines and computer information systems to support different support tasks on the shop floor. To develop a proof-of-concept for the Smarter Operator type as an implementation of a softbot, a framework was created called "ARISA." It was chosen due to its main intrinsic properties, giving support for implementing	There is a lack of security, semantic interoperability, advanced voice processing, advanced usability techniques, and adaptive softbot's behavior. The next main steps comprise improvements in voice and natural language recognition, evaluation of softbots in other types of the Operator 4.0 typology, a more in-depth analysis of integration approaches between the softbot and real smart industrial

Reference	#Cited	Contributions	Limitations/Future Research
		the core design principles of Industry 4.0 architectures at different levels of depth.	equipment, including wrappers and controllers.
(Segura et al., 2020)	42	This paper deals with how visual computing technologies can play a significant role in the empowering process, being vital in the perception of the operator 4.0 vision. The application of these technologies can empower operators in the context of Industry 4.0 scenarios. Technologies such as Virtual Reality, Augmented Reality, Visual Analytics, Collaborative Robotics Interaction, HMI (Human-Machine Interfaces), and Media/Social Network.	Technologies shown do not act in isolation. They work in connection with other digital and physical parts of the plant environment. Deploying that kind of solution in a manufacturing environment can raise safety concerns due to the user being primarily isolated from its near surroundings. Future work includes measuring and analyzing the actual impact of these different examples in the factory, including both productivity/efficiency and social/psychological aspects.
(Serras, García-Sardiña, Simões, Álvarez & Arambarri, 2020)	2	The research intends to explore dialogue-based XR (Extended Reality) enhancement usability to facilitate the cognitive burden associated with manufacturing tasks by augmentation of connected multi-modal information to assist operators. Describes an architecture to develop natural and hands-free human-machine interaction systems for industrial environments, combining more classical human augmentation technologies (such as virtual, augmented, and mixed reality) with dialogue-based interaction for process solving tasks.	Future research will be essential to validate the proposed Interactive XR architecture with participants to ensure the evaluation's significance. It is testing different systems in new industrial scenarios that require the combination of additional XR interfaces. Future work also includes finding ways to quickly adapt the language-specific modules (STT (Speech To Text) in the interpretation layer and TTS (Text To Text) in the response generation layer) to multiple languages to overcome possible linguistic barriers for multinational companies.

Reference	#Cited	Contributions	Limitations/Future Research
(Golan, Cohen & Singer, 2019)	18	The paper describes a proposal of a framework for future operators. Talks about its capabilities that permit an ongoing interaction that improves operator, performance, safety, well-being, and the factory's production measures. The paper describes those elements and shows them using an example.	It raises some ethical concerns. Confidential information concerning the operator's personality, mental and physical state is stored and analyzed. Operators will undoubtedly be reluctant to share this information with other people, in particular with supervisors. Future research can present a case study on the implementation and validation of an OWI (Operator – Workstation Interaction) system in a specific production system or build on the suggested framework to describe how it can be designed and implemented on the future production floor. Another line of future direction is the vast research area on the development of artificial social capabilities, which has enormous potential for making a valuable contribution to OWI 4.0 and the field of human-machine interfaces.
(Pierdicca et al., 2020)	1	This article deals with a case study of a "security and safety" application through AR (Augmented Reality) smart glasses. The goal is to develop an augmented reality application that will allow the operator support during the working process for safety and security purposes. In particular, it acts as a guiding system for the operator who wears glasses, offers remote support, and sends real-time alerts in threatening situations from a security point of view. It also performs other tasks like alert and training.	The developed system can be seen as a proof of concept, which can be a baseline for future experiments. Despite the system being designed together with an expert in safety and security, the requirements of a multimedia approach to this issue are not still widespread. Both experts and non-experts can test the application to update the current version in the upcoming future. By performing more tests with real users, it'll probably be possible to draw guidelines and protocols for developing AR applications for safety and security.

Reference	#Cited	Contributions	Limitations/Future Research
(Kaasinen, Aromaa, Heikkilä & Liinasuo, 2019)	4	Industry 4.0 factories require skilled and smarter operators, so in this paper were evaluated three Operator 4.0 solutions (Worker Feedback Dashboard, Contextual Knowledge Sharing, and Participatory Design with a Virtual Factory) that aim to engage and empower workers so that they can develop and understand their competences and can take an active role in the development of the manufacturing environment. The study described in this paper was conducted with a relatively large, homogenous group of participants, as all of them were shop stewards in factories.	The solutions were presented to the participants quite briefly, and they could not try out the answers themselves. After the group discussion, the participants filled in the questionnaire, so it is possible to empower and engage Operator 4.0. Hence, it is possible that the debate affected their opinion. The assessment results will help develop the solutions and design how to introduce them on the factory floor. Although the answer was seen as exciting and valuable, there were some doubts regarding privacy. Contextual knowledge sharing was felt necessary, but workers were skeptical as many previous knowledge sharing attempts had failed.
(Besnea et al., 2019)	1	This article deals with developing an application for the operator's training within the manufacturing lines, aiming to experiment, in a virtual environment, the simulation and the orderly assembly of objects as a stack form. It was also necessary to develop a glove prototype that can manipulate and control objects in a virtual environment. This paper also demonstrates how VRCG (Virtual Reality Control Glove) can quickly help companies in the automotive industry approach operators training through specialized equipment, making them more efficient and productive by improving skills and implying long-term economic growth.	For the future, it is planned that the authors will develop an immersive environment using a 3D projecting system and an active-reactive system for a gauntlet that will generate the force simulating the weight and contact with training tools for the workers. Also, the learning process can be monitored for each operator, keeping track of his progress. That will estimate the completion time of the training to express an overflow on future work activities.

Reference	#Cited	Contributions	Limitations/Future Research
(Peruzzini, Grandi & Pelliciari, 2020)	33	This paper aims at a framework based on data collection about the operator's performance, reactions, and actions, with the final goal to improve the overall factory performance. It is based on adopting an Operator 4.0 monitoring system, a wearable biosensor, and an eye tracking device, combined with a proper protocol analysis to explain data and create a firm knowledge. The paper's most crucial benefaction is the definition of a procedure to carry out a pragmatic assessment of the relation between physical and cognitive measurable human factors and workplace design.	Future work will focus on further developments in two main areas: the definition of a more detailed protocol for mental/cognitive workload and emotion assessment, and industrialization of the proposed set-up for real monitoring at the shop floor, considering certified devices for industrial use. The current experimental study's main limitations refer to three main points: the lack of assessment of the emotional response based on humans, the applicability of the proposed set-up, and the lack of extensive empirical data.

Following the completion of the synthesis, the results were critically examined in order to discover additional study prospects. This entire procedure resulted in the identification of a knowledge gap, which was addressed in the research.

2.3 - Analysis

While literature is reviewed, it is vital to identify where the excess research exists and where the new study is needed (Levy & Ellis, 2006).

After reviewing the ten articles, it became evident that some authors wrote about possible frameworks that are developed to improve Operator 4.0 attributes, such as: performance, safety, well-being, and satisfaction, whereas others chose to refer to possible technologies to assist the tasks of the Operator 4.0. The critical papers for this research were grouped under the following themes, discussed in the next paragraphs:

- Understanding the frameworks to increase Operator 4.0 attributes;
- Different technologies for Operator 4.0 work support.

2.3.1 - Understanding the frameworks to increase Operator 4.0 attributes

Rabelo, Romero, and Zambiasi (2018), presented a framework called ARISA, which allows the derivation of softbots for given domains to investigate how they can help the Operator 4.0 in smart factory environments, supporting with the interfacing between computer information systems and intelligent machines.

While Golan, Singer, and Cohen (2019) introduced another framework composed of three subsystems:

- The observation subsystem notices all the processes that occur in the workstation, as well as the operator;
- The analysis subsystem generates both understanding and also implications of the output of the observation;
- The reaction subsystem determines if and how to.

In addition to these articles, Peruzzini, Grandi, and Pellicciari (2020) elaborates a defining a human-centered framework for Operator 4.0, and testing its feasibility on companies, thanks to merging human factors in 4.0 cybernetic industrial contexts.

For new research opportunities, authors planned to develop a more detailed protocol for mental workload and emotion assessment and the industrialization of the proposed set-up for real monitoring at the shop floor.

2.3.2 - Different technologies for Operator 4.0 work support

Some advanced enabling technologies to guarantee a successful implementation of the Healthy Operator architecture are presented. Technologies like wearable technology are divided into four major groups:

- Environmental sensors;
- Biosensors;
- Location tracking sensors;
- Other sensors (camera sensors, communication sensors).

According to the authors, future research opportunities will be the extension of the prototype by integrating weight measurement, giving the information of the loads to be carried along their working time (Sun et al., 2020).

A proposed solution, using VR techniques such as virtual environments and virtual goggles, seems to be one of the best solutions for conducting employee training because it can be fully integrated with an entire production system (Zawadzki et al., 2020).

It is clarified that the application of different visual computing technologies can contribute decisively to the enhancement of operator ability to perform traditional tasks and to the definition of new jobs and scenarios. Authors also defend that they improve productivity and efficiency but are essential to tackle the social, inclusion, and interaction aspects central to new socio-technical systems (Segura et al., 2020).

An interactive XR architecture using the spoken dialogue system was tested in two use case scenarios.

Authors confirmed a high user acceptance rate with efficient knowledge communication even for operators without prior experience in both cases. New research opportunities would be the validation of the proposed Interactive XR architecture with a broader sample of participants to ensure the significance of the evaluation (Serras et al., 2020).

A case study is presented approaching a "security and safety" application through the usage of AR smart glasses that were tested in a real scenario. The writers described this technology, saying that it will be acting as a guide system for the operator and the possibility of providing remote support. In a safe way, it would send real-time alerts in dangerous situations, despite performing other tasks. For future research opportunities, authors want both experts and non-experts to test the application to update the current version to draw guidelines and protocols for developing AR applications for safety and security (Pierdicca et al., 2020).

Kaasinen, Aromaa, Heikkilä, and Liinasuo (2019) evaluated three Operator 4.0 solutions that aim to captivate and qualify workers in the manufacturing environment. They concluded that there are high expectations towards the virtual factory-based participatory design solution.

Besnea, Resceanu, Cismaru, Ganea, Pistritu, and Bizdoacastated (2019) stated that "The operator will acquire skills faster, which normally require long practice and a high level of dexterity" (p. 1). Thus, an application for the operators training in a virtual environment to the assembly of objects as a stack form was proposed. For future new research opportunities, authors intend to develop an immersive environment using a 3D projecting system for a gauntlet to generate the force simulating the weight.

2.4 - Conclusion

The literature revealed that there was a lack of a reference model or independent models to support building Operator 4.0 solutions for industry. The literature showed some partial models focused on specific perspectives, thus leaving room for further research in trying to bring these different points of view into a common model.

3. Methodology

3.1. Introduction

This chapter presents the research question and outlines the approach selected in order to answer this question. The research design section will present the design science approach used to assist in the development of the ontology. Follows the description of the process to build the ontology and use it as a way to support the construction of Operator 4.0 solutions for industry.

3.2 Research Question

After reviewing the literature, it became apparent to the researcher that there was an absence of a reference model for supporting the development of innovative concepts for the Operator 4.0.

From this conclusion, the following research question was formulated:

How is Operator 4.0 structured or modeled by the literature?

a) Is there a reference model or do independent models exist to support the construction of Operator 4.0 solutions for industry? Are there any model describing the technological infrastructure?
b) If not, would it be feasible to build one and propose a Domain Ontology?
c) Can we use this Domain Ontology to drive an early Technology Commercialization opportunity assessment process?

3.3 Research Design

Regarding item a) of the research question, the literature showed that it was not possible to identify any type of model that would cover either the Operator 4.0 or the supporting infrastructure.

Since such a model does not exist, we have the opportunity to build it. To guide the execution of this process we will use design science approach, as the primary goal will be to develop an artifact., consisting of a Model of the Knowledge Domain of Operator 4.0, focusing on the Healthy, Smarter and Virtual Operator, as recommended by the institution hosting this project.

3.3.1 Design Science Approach

Design Science in areas like information systems and IT, aims at creating novel artifacts in the form of models, methods and systems that support people in developing, using, and maintaining IT solutions (Johannesson & Perjons, 2014). "The design-science paradigm seeks to extend the boundaries of human and organizational capabilities by creating new and innovative artifacts" (Hevner, March, Park, & Ram, 2004, p. 75).

This approach is fundamentally constructed based on two design procedures: build and evaluate. Also, is composed of four design artifacts: constructs, methods, models, and instantiations (Hevner et al., 2004). Figure 2 below, aims at, illustrating of the design science approach.

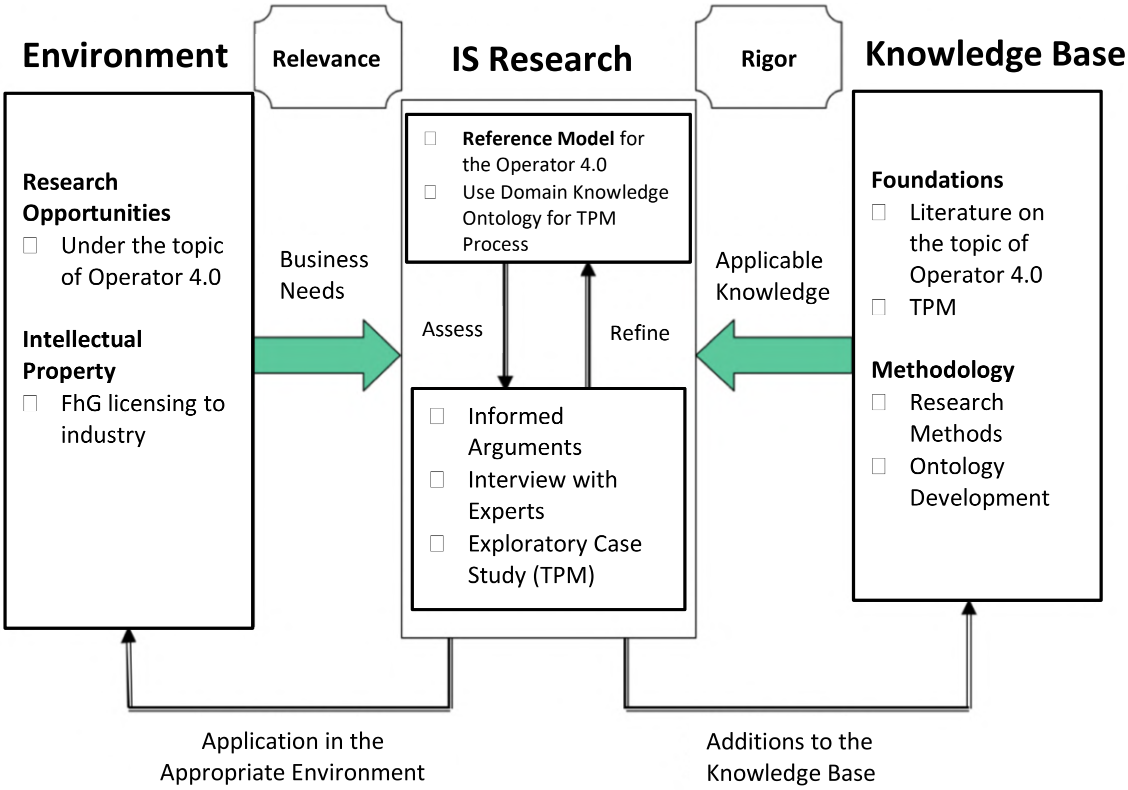

Figure 2 - Framework for Understanding Design Science Approach – Adapted from Hevner, March, Jinsoo, & Sudha (2004; p. 80)

Peffers, Tuunanen, Rothenberg, and Chatterjee (2014) stated, "The development of the artifact should be a search process that draws from existing theories and knowledge to come up with a solution to a defined problem" (p. 49).

The artifact generated in this research was the Operator 4.0 ontology. At the basis of this construct are, in order:

- The literature review on the topic of Operator 4.0;

- The methodology and research methods used for the purpose of developing the ontology;
- The validation of the created ontology, through interviews with Fraunhofer Portugal experts;
- The use of the domain knowledge ontology to create a TPM (Technology-Product-Market) process;
- Finally, the intellectual property and research opportunities under the topic of Operator 4.0, that could be conducted by a new research project.

3.3.2 Description of the Ontology Building Process

An ontology is a formal explicit description of concepts in a domain of discourse, properties of each concept describing various features and attributes of the concept. (Noy & McGuinness, 2001, p. 3).

Developing an ontology is beneficial because it creates a shared common understanding of the structure of information among people, allowing reuse of the knowledge domain to introduce standards (Noy & McGuinness, 2001, p. 2). Table 2 represents the definition of requirements for the ontology.

Table 2 - Ontology Requirements Specification (ORS)

Ontology Requirements Specification (ORS)	
Identify purpose	To assess and analyze of Operator 4.0 solutions.
Identify Scope	Operator 4.0 solutions for industry focusing on the Healthy Operator, Smarter Operator and Virtual Operator.
Identify Implementation Language	The Unified Modelling Language (UML) is an ontology modeling tool to facilitate the mapping from knowledge model (Wang & Chan, 2001).
Identify intended end-users	User 1: Operator 4.0 solution developers. User 2: R&D and Innovation teams in the scope of Operator 4.0 solutions.
Identify intended uses	Use 1: Use as a Reference Model for Operator 4.0 solutions, check innovation and integration opportunities. Use 2: Use as Operator 4.0 Domain knowledge reference in the technology(-push) commercialization process. Use 3: Use a Domain Knowledge reference in an innovation process (Frishammar et al., 2012).
Identify requirements	Non-functional Requirements Whenever possible, reuse of existing ontologies or models from the literature.

	The concepts in the ontology should be supported by the literature. The focus of the Ontology, for the sake of limiting the scope, should be on the Healthy Operator, Smarter Operator and Virtual Operator.
	<u>Functional Requirements</u> CQ1: What is the Operator 4.0? CQ2: Is the ontology providing different perspectives on how to assist the Operator 4.0? CQ3: Which types of operators does the ontology identify? CQ4: The Operator 4.0 Operating Framework is composed of which blocks? CQ5: Which components build the Observation Stage of the Operating Framework? CQ6: How does the Operator-&-Workstation joint observation works? CQ7: What is the difference between Passive and Active operator observation? CQ8: Are all technology and/or knowledge domains for the Operator 4.0 represented?

Source: Adapted from Suárez-Figueroa, Gómez-Pérez, & Villazón-Terrazas (2009;p. 970)

Ontology Development: The first steps towards the construction of the ontology were the gathering of both constructs and models proposed in the literature. The addition of new concepts involved several iterations, namely for concept validation and comparison between authors. The UML (Unified Modelling Language) was used as the "standard mechanisms for defining extensions for specific application contexts such as ontology modeling" (Kogut et al., 2002, p. 3). The development of the ontology was performed, from the very beginning, using UML class diagrams.

Ontology Refinement: The ontology was initially built from the literature and was later adapted. The validation of the proposed model involved interaction with experts in the topic of Operator 4.0 at Fraunhofer Portugal. The feedback gathered was used to improve the ontology.

Ontology Validation: The ontology was finally validated through a Focus Group session with Fraunhofer Portugal experts, who then evaluated each of the sub-ontologies and the competency questions. All answers for the proposed evaluation criteria were analyzed according to the Attribute Agreement Method, which consists of a quantitative approach with the objective of evaluating and organizing all the experts' answers (Pereira, 2017). For the Operator 4.0 Ontology, the results consisted of the averaged sum of all participants' evaluations, for each criterion, as shown in the Equation 1 below.

$$\text{Approval} = \frac{100}{n}\sum_{i=1}^{n} x_i$$

Equation 1 - Attribute Agreement Equation

A workshop was held following the first session to validate the use of the ontology in the Technology Push process. Additional details will be provided in a later chapter.

3.3.3 Using Ontology to Create Innovation Opportunity

In this section, the researcher proposes an approach to answer point c) of the research question. To this end, a test was made to assess how the ontology could be used to initiate a technology commercialization process. The objective is to define where should a research team focus their research effort, namely in the execution of a research project having in mind the production of intellectual property. This intellectual property would ultimately be licensed or commercialized in some way.

When the researcher incorporates the domain ontology into the process, the explicitness of the many items that comprise that knowledge domain is enhanced. We are building on the idea that domain-specific knowledge is critical to improve both efficiency and effectiveness of new product development (Frishammar et al., 2012). As argued by the same author, this domain-specific knowledge can also blind team members and stifle innovativeness. Making knowledge explicit with a domain ontology will help overcome this issue, by ensuring that all members grasp the full scope of the problem domain.

In this context, the research team can then determine which parts of the model they want to use for the creative process, in order to produce research opportunities for developing new technologies. Figure 3 illustrates how this ontology is used prior to the Technology push process, the so-called TPM.

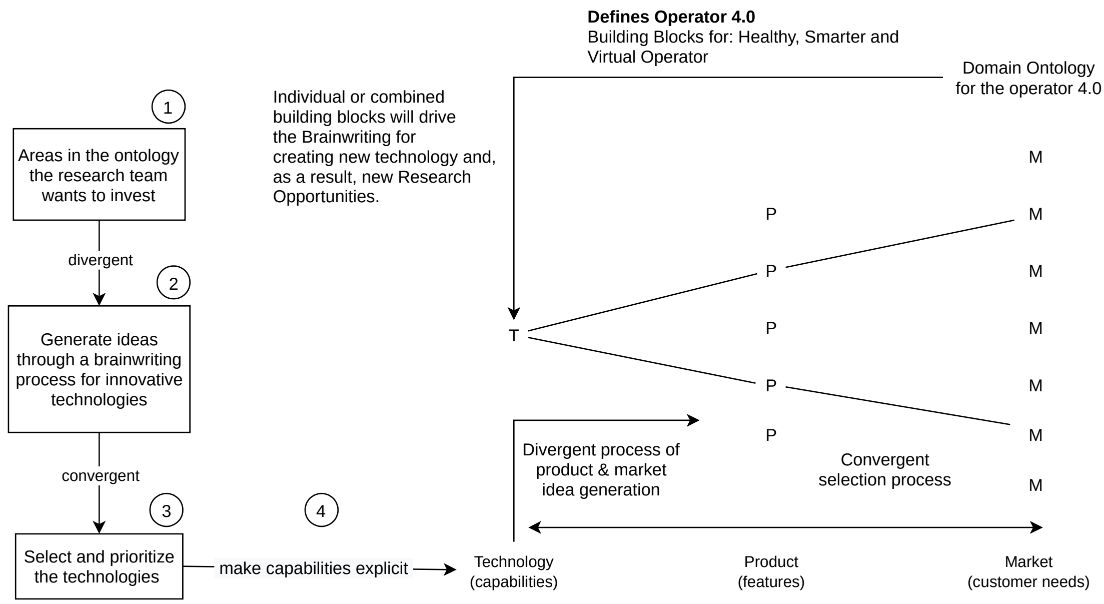

Figure 3 - Adapted TPM model – Source: Adapted from Markham & Kingon (2004; p. 73)

Upon the TPM presentation, Markham and Kingon (2004) noted that the technology-push process:

> "begins by finding technologies with unique advantages that can be recognized as new capabilities. Those capabilities in turn can be manifested as product features. The product concepts are then presented to experts in the field, and potential lead customers within specific potential market segments" (p. 72).

In the proposed process we foresee a step prior to starting the TPM, that unfolds as follows:

1. Using the ontology to first define which areas in the ontology the research team wants to invest;
2. Through a divergent process, generate ideas through a brainwriting process for innovative technologies in the selected areas;
3. Select and prioritize the technologies resulting from the brainwriting session;
4. Take the technology selected in the 1st place or an architecture combining more than one technology. Clearly identify and describe the technology or technology architecture and its capabilities;
5. Using these capabilities start the TPM process (Markham & Kingon, 2004).

The validation of this extended TPM Process (using the Domain Ontology), will be done in the scope of an Exploratory Case Study by testing the whole concept in a real setting at Fraunhofer Portugal.

3.4 Conclusion

This chapter described the methodology used in this research, as well as the answers to the research question. Firstly, a framework was used for better understanding of the design science approach. Secondly, the Ontology Requirements Specification table was provided to explain why the ontology was built. Finally, a TPM model was created in order to come up with innovation opportunities.

4. Ontology development and use in the TPM context

4.1 Introduction

In this chapter, the ontology constructed by the researcher is presented and explained, aiming to answer the research question. As referenced earlier, considering the literature, a model has not yet been developed to assist in building solutions to support Operator 4.0 in industry. Based on this scientific gap, the researcher developed an ontology that incorporated all areas of knowledge offered in the literature as well as experts' feedback. The forthcoming paragraphs will present the proposed model for the Operator 4.0 Ontology, namely:

- Top-Level Ontology: Operator 4.0;
- Sub-Ontology: Operating Framework;
- Sub-Ontology: Observation Stage;
- Sub-Ontology: Workstation Observation;
- Sub-Ontology: Virtual Operator;
- Sub-Ontology: Smarter Operator.

Follows the description of a workshop held with experts from Fraunhofer Portugal, who validated the ontology and its competency questions after their presentations. In a second step, with the validated ontology, we proceeded to generate a creative process for the technology idea and consequently the description of its capabilities. Based on the technology capability, a creative TPM process was conducted, leading to the selection of Product-Market pairs. Finally, the feedback provided by the experts on the added value of the process is presented, along with the recommendation for managers.

4.2 Model Proposal

4.2.1 Top-Level Ontology: Operator 4.0

Tables 13-22 in the ANNEX A3.1 section, define all the terms used in this ontology, as well as their interactions. Figure 4 below, illustrates the core ontology, for the proposed model to support the construction of Operator 4.0 solutions for the industry.

Starting from this ontology, five sub-ontologies will emerge where the connection point between them is established by the concept. A background color is used to ease the mapping across diagrams.

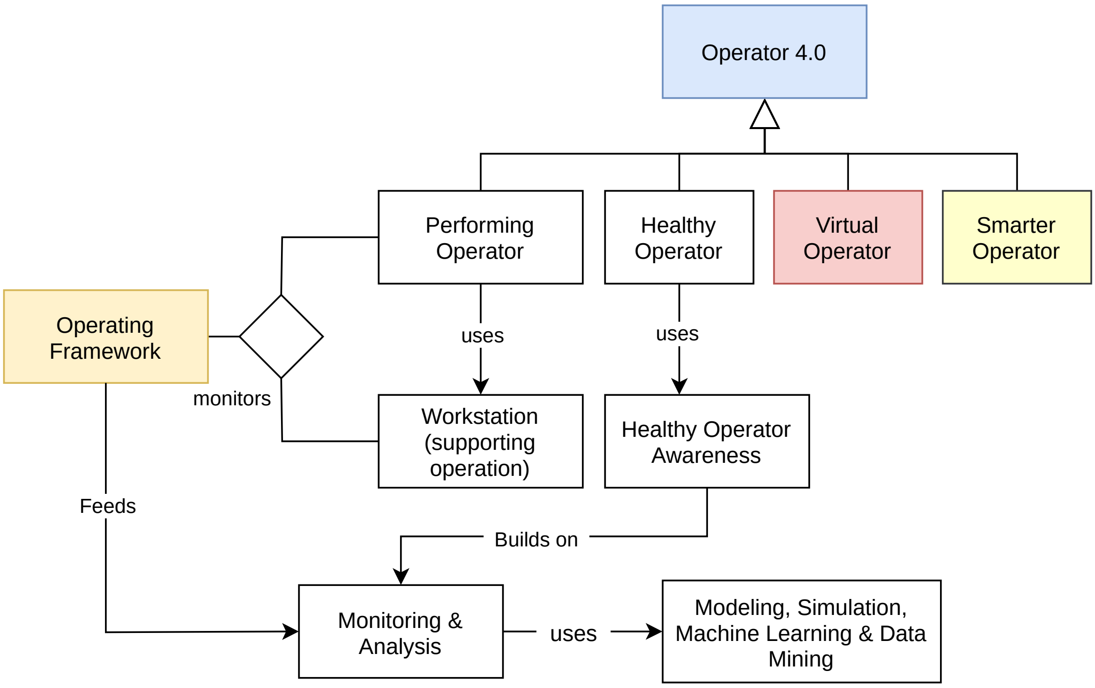

Figure 4 – Top-Level Ontology: Operator 4.0

First, a ternary association is established that encompasses the monitoring of the OPERATING FRAMEWORK[2], the PERFORMING OPERATOR[3] that will use the WORKSTATION (Golan et al., 2020), which serves to support the entire operation. Like the PERFORMING OPERATOR, the HEALTHY OPERATOR (Sun et al., 2020), the VIRTUAL OPERATOR (Zawadzki et al., 2020) and the SMARTER OPERATOR (Rabelo et al., 2018) have an inheritance relationship with the OPERATOR 4.0. In this way, the HEALTHY OPERATOR uses the HEALTHY OPERATOR AWARENESS (Sun et al., 2020), which relies on ANALYSIS & MONITORING (Peruzzini et al., 2020) for preventive decisions by the operators. This process is fed by the OPERATING FRAMEWORK and uses MODELING, SIMULATION, MACHINE LEARNING & DATA MINING ALGORITHMS (Sun et al., 2020).

4.2.2 Sub-Ontology: Operating Framework

Tables 23-33 in the ANNEX A3.2 section, define all the terms used in this sub-ontology, as well as their interactions.

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[2] Own elaboration.

[3] Own elaboration.

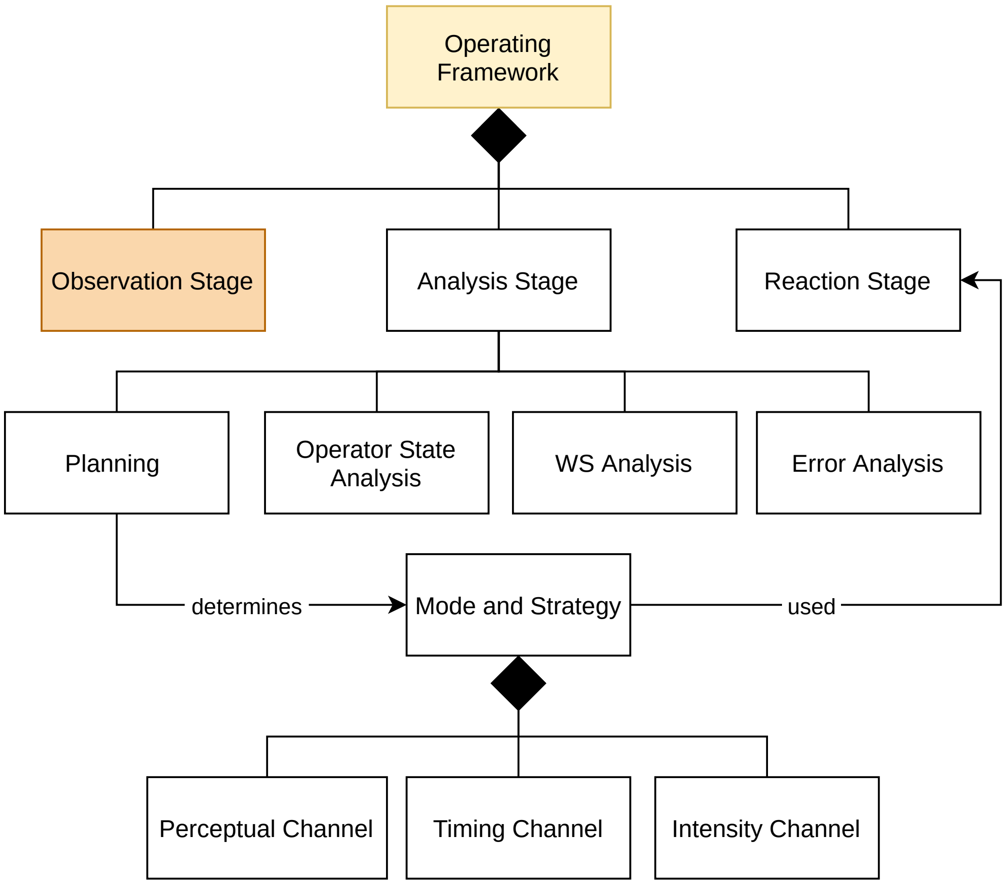

Figure 5 - Sub-Ontology: Operating Framework

The OPERATING FRAMEWORK is a composition of three components (Golan et al., 2020):

- OBSERVATION STAGE, which acquires the function of observing the operator and the processes that occur in the WORKSTATION;
- ANALYSIS STAGE, which is based on the generation of understanding and implications of the observations output;
- REACTION STAGE, where the MODE AND STRATEGY of a particular reaction will be used.

The ANALYSIS STAGE, in turn, is made up of several units, such as the (Golan et al., 2020):

- PLANNING, responsible for opting for a particular MODE AND STRATEGY to be used in the REACTION STAGE;
- OPERATOR STATE ANALYSIS, useful for diagnosing both the physiological and cognitive state of the operator;

- WORKSTATION ANALYSIS, which will diagnose the overall state of the workstation;
- ERROR ANALYSIS, which will interpret OBSERVATION STAGE data depending on whether an error has been made or is likely to occur.

Regarding the MODE AND STRATEGY used in the REACTION STAGE, there are three channels, each responsible for different types and characteristics of the messages. We have (Golan et al., 2020):

- PERCEPTUAL CHANNEL, which determines the type of message to be sent (audio, a visual, or a tactile message);
- TIMING CHANNEL, which enables the message frequency, timing and length regulation;
- ITENSITY CHANNEL, which relates to the loudness, brightness, or strength of the message.

4.2.3 Sub-Ontology: Observation Stage

Tables 34-50 in the ANNEX A3.3 section, define all the terms used in this sub-ontology, as well as their interactions.

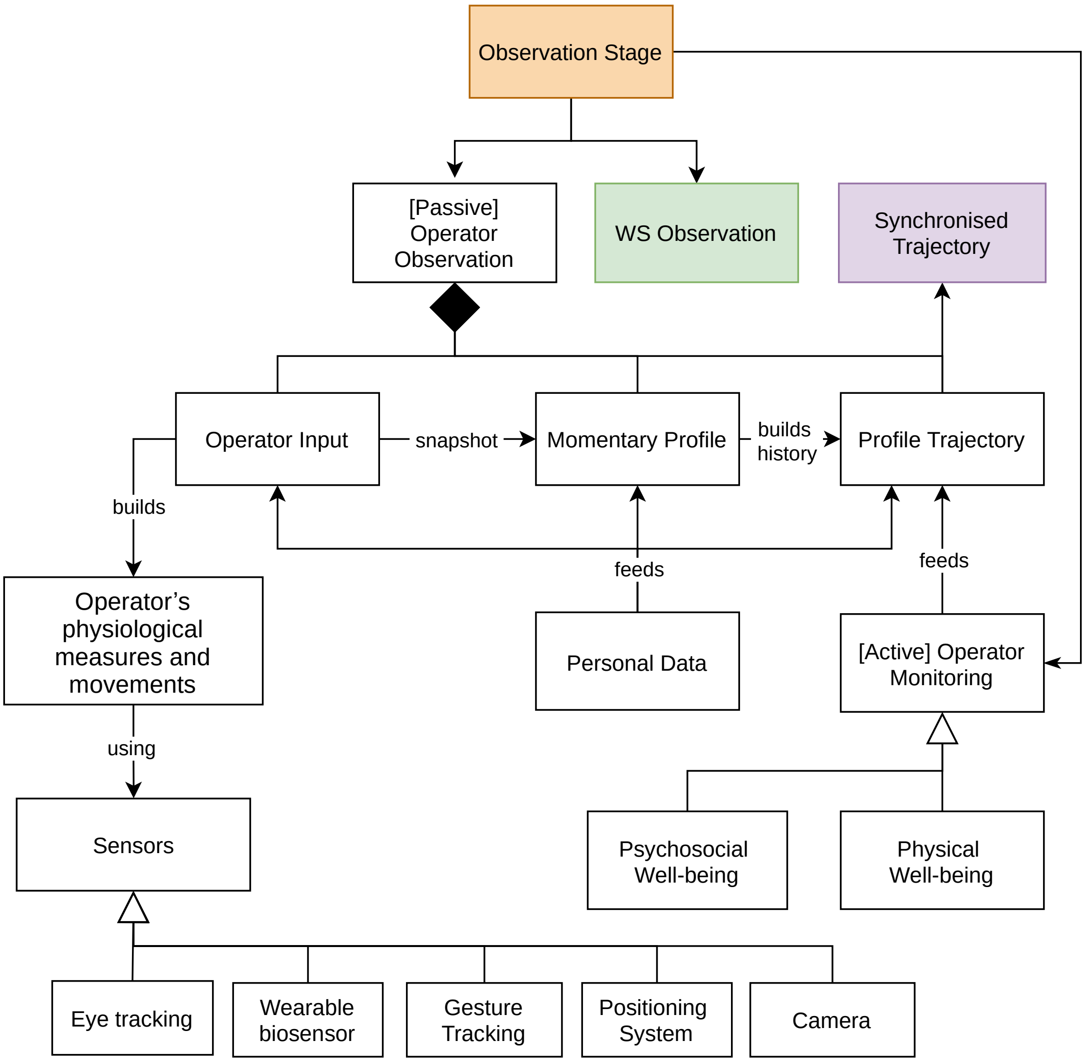

Figure 6 - Sub-Ontology: Observation Stage

Figure 6 illustrates the sub-ontology for the Observation Stage. We have:

- WS OBSERVATION (Workstation Observation), which will be refined by another sub-ontology (Golan et al., 2020);
- [PASSIVE] OPERATOR OBSERVATION[4].

[4] Concept resulted of the experts' input.

The latter is in the passive state, due to the transmission of its observation being made indirectly, that is, there is no self-report. Thus, it is possible to compose the OPERATOR OBSERVATION into three components (Golan et al., 2020):

- OPERATOR INPUT, which serves as a way to receive inputs through external SENSORS (Peruzzini et al., 2020 ; Sun et al., 2020) thus determining what the OPERATOR'S PHYSIOLOGICAL MEASUREMENTS AND MOVEMENTS are;
- MOMENARY PROFILE, which will consist in the use of a snapshot of the OPERATOR INPUT, in order to periodically save its state;
- PROFILE TRAJECTORY, receives information, grouping the MOMENTARY PROFILE history and also receives inputs from [ACTIVE] OPERATOR MONITORING[5]. The [ACTIVE] OPERATOR MONITORING is an intentional action of the operator that inputs information about its PSYCHOSOCIAL WELL-BEING[6] and PHYSICAL WELL-BEING[7].

OPERATOR INPUT, MOMENTARY PROFILE and PROFILE TRAJECTORY all use PERSONAL DATA, in order to be able to perform the functions assigned to each one of them.

This last process is directly linked to the workstation's PROFILE TRAJECTORY through the SYNCHRONIZED TRAJECTORY, so that, the trajectory of the workstation and the trajectory of what is recorded for the operator may be synchronized and related for analysis.

[5] Concept resulted of the experts' input.

[6] Concept resulted of the experts' input.

[7] Concept resulted of the experts' input.

4.2.4 Sub-Ontology: Workstation Observation

Tables 48-54 in the ANNEX A3.4 section, define all the terms used in this sub-ontology, as well as their interactions.

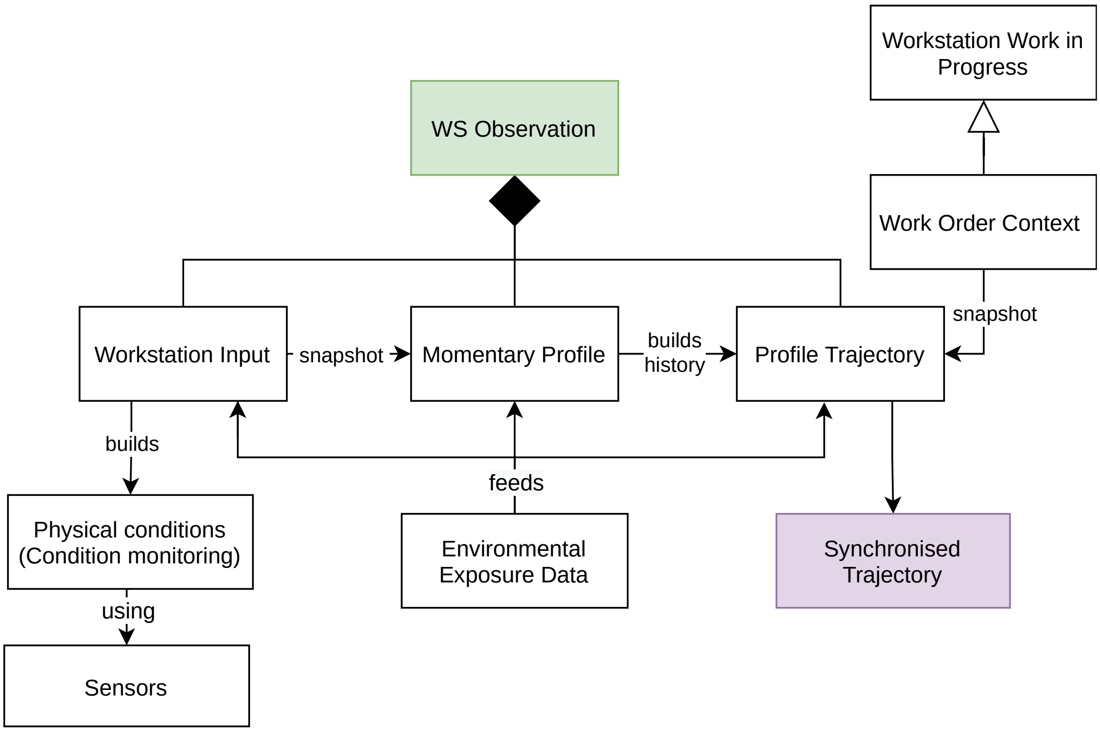

Figure 7 - Sub-Ontology: Workstation Observation

In this figure, it can be seen that WS OBSERVATION is composed of (Golan et al., 2020):

- WORKSTATION INPUT, which is a component that allows the provision of an online representation of the workstation in terms of technical measurements, obtained through the information collected by the SENSORS about the PHYSICAL CONDITIONS (CONDITION MONITORING);
- MOMENTARY PROFILE, which will consist in the use of a snapshot of the WORKSTATION INPUT, in order to periodically save its state;
- PROFILE TRAJECTORY, receives information, grouping the MOMENTARY PROFILE history.

All elements above, are fed by the ENVIRONMENTAL EXPOSURE DATA (Golan et al., 2020), which is where all the static information is gathered and integrated, such as noise, temperature, light, and humidity.

In this sub-ontology, the information reaches the PROFILE TRAJECTORY component through the operation performed at that moment in the workstation, having to get the snapshot of the operator's state and of the operation he is going to perform (WORK ORDER CONTEXT[8]), allowing to know what the operator was doing, as well as to record feedback from the operator himself (WORK IN PROGRESS[9]).

4.2.5 Sub-Ontology: Virtual Operator

Tables 55-65 in the ANNEX A3.5 section, define all the terms used in this sub-ontology, as well as their interactions.

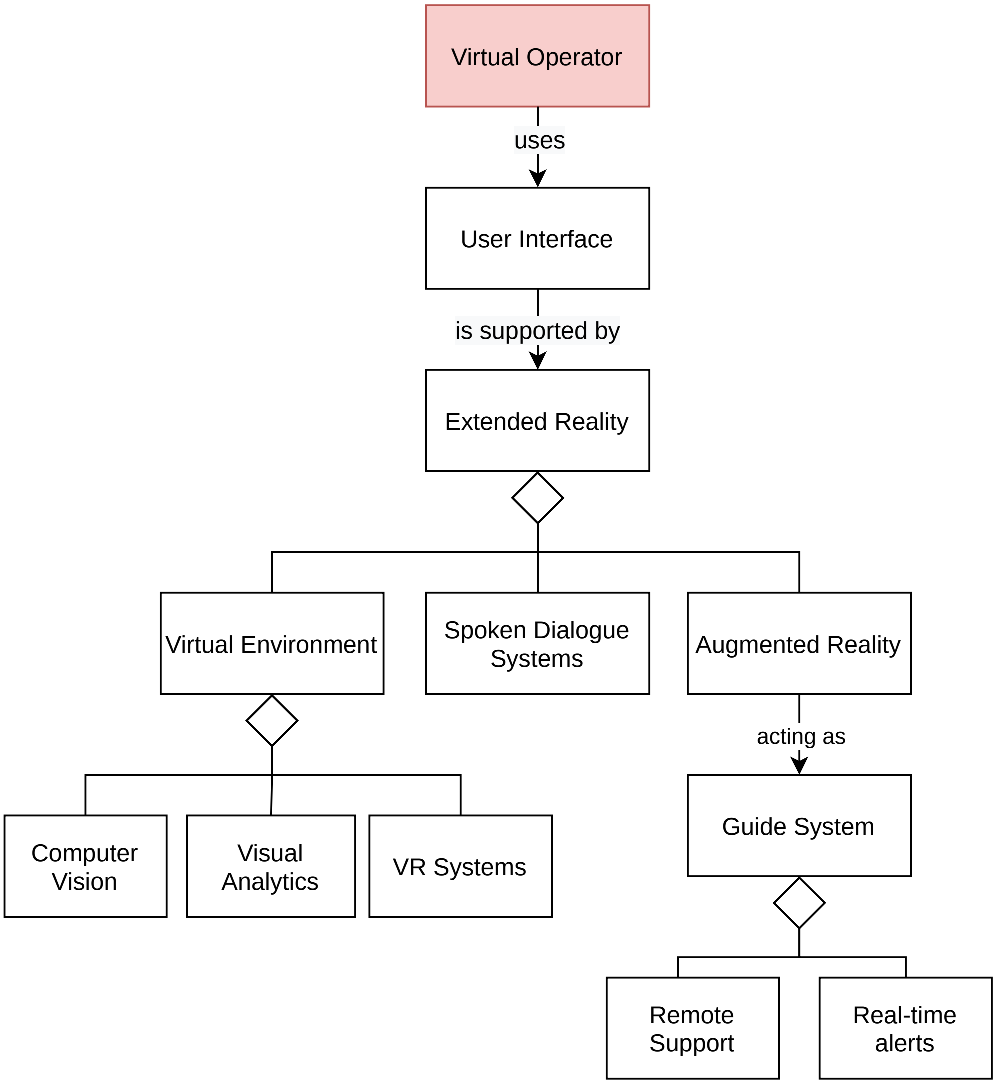

Figure 8 - Sub-Ontology: Virtual Operator

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[8] Own elaboration.

[9] Own elaboration.

As far as this sub-ontology is concerned, we can initially define that the VIRTUAL OPERATOR uses a USER INTERFACE (Rabelo et al., 2018), with the purpose of allowing interaction and communication between the human and the device. In turn, this interface comes from the EXTENDED REALITY[10] support, which aggregates three groups:

- VIRTUAL ENVIRONMENT, which is defined as an environment that allows user interaction with the computing environment (Besnea et al., 2019);
- SPOKEN DIALOGUE SYSTEMS, which are voice-enable machine interfaces to communicate with computers and other devices (Serras et al., 2020);
- Finally, AUGMENTED REALITY, which in this case acts as a GUIDE SYSTEM providing REMOTE SUPPORT and sending REAL-TIME ALERTS in dangerous situations (Pierdicca et al., 2020).

It is important to note that also the VIRTUAL ENVIRONMENT, in this sub-ontology, can be broken down into:

- COMPUTER VISION, allowing to obtain information from images or any multidimensional data (Segura et al., 2020);
- VISUAL ANALYTICS, for effective decision making based on very large and complex data sets (Segura et al., 2020);
- VR SYSTEMS (Virtual Reality Systems), allowing the user to interact directly with virtual components, thus increasing the sense of immersion (Zawadzki et al., 2020).

[10] Own elaboration.

4.2.6 Sub-Ontology: Smarter Operator

Tables 66-74 in the ANNEX A3.6 section, define all the terms used in this sub-ontology, as well as their interactions.

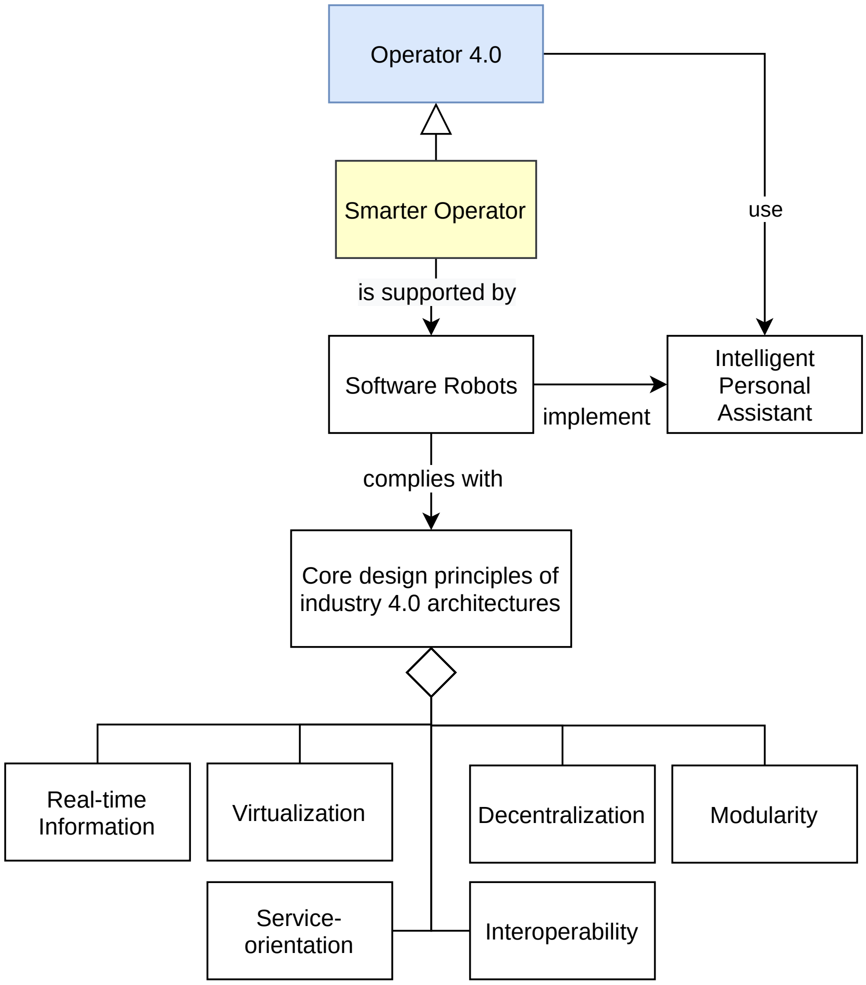

Figure 9 - Sub-Ontology: Smarter Operator

The sub-ontology illustrated in Figure 9, refers to the SMARTER OPERATOR, a category of OPERATOR 4.0, which in this sub-ontology, is supported by SOFTWARE ROBOTS (Rabelo et al., 2018), which are defined by an automated virtual system that assists the human being in the execution of certain tasks with varying levels of intelligence and autonomy. However, in this example, they are implemented in such a way as to have the characteristics of an INTELLIGENT PERSONAL ASSISTANT (Rabelo et al., 2018), which, in turn, will be used in the functions of the OPERATOR 4.0. These SOFTWARE ROBOTS are in accordance with the CORE DESIGN PRINCIPLES OF INDUSTRY 4.0 ARCHITECTURES which are composed of (Rabelo et al., 2018):

- REAL-TIME INFORMATION, allowing Softbots to perform multiple tasks simultaneously;
- VIRTUALIZATION, which will allow the derivation of instances of ‘softbots' for different domain applications;
- SERVICE-ORIENTATION, which means that a given softbot is internally composed of a set of embedded software services;
- DECENTRALIZATION, which refers to the behavior of the softbot, which can be variable and implemented for different scenarios;
- INTEROPERABILITY, which is based on open IT standards, facilitating interoperability with human end users and other softbots;
- Finally, MODULARITY, which means that new services can be added to or deleted from the softbot, never damaging its internal structure.

4.3. Ontology Validation

4.3.1 The Validation Process

The validation process was performed in the scope of the workshop with experts. This validation had a total duration of 30 minutes. A total of seven experts were invited, but only five of them participated. The session took place on May 20, 2021, starting at 4:00 pm in a videoconference format. The role within the company of each of the participants and their background are described below.

Table 3 - Focus Group Participants Overview

Gender	Position	Background
M	R&D Group Leader	Electrical and Computers Engineering
F	New Business Development Manager	English Studies
F	Head of Department in Human Centred Design Group	Industrial Design
M	Scientist in Human Centred Design Group	Materials Engineering
M	New Business Development Coordinator	Chemistry

The agenda for the session was as follows:

- A presentation of the final version of the ontology and sub-ontologies was made:
  - Top-Level Ontology: Operator 4.0;
  - Sub-Ontology: Operating Framework;
  - Sub-Ontology: Observation Stage;
  - Sub-Ontology: Workstation Observation;
  - Sub-Ontology: Virtual Operator;
  - Sub-Ontology: Smarter Operator.
- After the presentation, a form was distributed for each sub-ontology presented, asking the experts to fill them in, regarding four criteria, which were: Completeness, Utility, Consistency and Understandability (Pereira, 2017). Within each criterion, the participant had five options, numbered from 1 to 5, where 1 meant that the participant strongly agreed with the presence of that criterion in the model, 2 if the expert agreed, 3 if neither agree or disagree, 4 if disagreed and 5, if the participant strongly disagreed. Furthermore, in the stated method, the experts' results were changed from a Likert Scale to a Binary Scale (Joshi, Kale, Chandel, & Pal, 2015). Scores were obtained for each of the adopted criteria, as well as for each sub-ontology. The higher the score, the more reliable is the validation of the parameters for each sub-ontology. Furthermore, the sub-ontology was considered validated if it reached a score higher than 70%.

Table 4 - Ontology Evaluation Coding

Likert Scale	Binary Scale
1 Strongly Agree 2 Agree	1
3 Neither agree nor disagree 4 Disagree 5 Strongly Disagree	0

Source: Adapted from Joshi, Kale, Chandel, & Pal (2015;p. 400)

- Finally, a last form was distributed, with the purpose of having the participants give their opinion on whether the ontology would answer the competency questions formulated, thus finalizing the Focus Group session.

4.3.2 Validation Results of the Operator 4.0 ontology

The following table shows the global evaluation. The calculation performed was the average of the overall evaluation of all sub-ontologies, which are represented in the ANNEX A1 section.

Table 5 - Global Evaluation of Operator 4.0 Ontology

Sub-Ontology	**Score**
Top-Level Ontology: Operator 4.0	85%
Sub-Ontology: Operating Framework	≈ 77%
Sub-Ontology: Observation Stage	95%
Sub-Ontology: Workstation Observation	≈ 78%
Sub-Ontology: Virtual Operator	≈ 72%
Sub-Ontology: Smarter Operator	≈ 87%
Global Evaluation	≈ 82%

In conclusion, from the data showed in Table 5, we can state that the Operator Ontology 4.0 has been successfully validated with a validation rate of about 82% being above the reference value (70%).

To conclude the Focus Group session, participants were instructed to fill out a form indicating if they considered the ontology could answer the competency questions. Table 6 summarizes the findings.

Table 6 - Answers regarding Competency Questions

Competency Questions	Yes Responses	No Responses
1. What is the Operator 4.0?	2	3
2. Is the ontology providing different perspectives on how to assist the Operator 4.0?	4	1
3. Which types of operators does the ontology identify?	5	0
4. The Operator 4.0 Operating Framework is composed of which blocks?	5	0
5. Which components build the Observation Stage of the Operating Framework?	5	0
6. How does the Operator-&-Workstation joint observation works?	4	1
7. What is the difference between Passive and Active operator observation?	4	1
8. Are all technology and/or knowledge domains for the Operator 4.0 represented?	3	2

The answers given by the participants, allowed the evaluation of the Competency Questions during the session. No changes were made, ensuring homogeneity of treatment for all data. The results show that three competency questions (CQ3, CQ4 and CQ5) received full support, thus concluding that they were answered by the ontology. Follows, CQ2, CQ6, and CQ7 all received one negative response, with CQ8 receiving two. Finally, the most lagging competency question was CQ1 with three negative responses. Based on the overall average of the participants' answers, it is concluded that the ontology has the ability to answer the competency questions.

4.3.3 Limitations

Although the average global score is quite high and above 70%, in some cases, namely the Completeness, Understandability and Consistency criteria, individual values are below 70% (see ANNEX A1). The rationale for this is discussed for each case, in the same annex. For the sake of this research, and as the global values were indeed high, we considered that the ontology was validated. However, we would have wished to have a focus group where all participants would be experts in the topic, this feeling comfortable in the validation of Completeness. Moreover, we would have liked to have had more validation by the industry, with experts involved. However, this was not possible because the companies addressed did not respond to the request, despite Fraunhofer Portugal's efforts.

4.4 Using the Ontology to drive the TPM process

This simulation was performed immediately after the validation focus group. This workshop lasted about 1h30 hours.

The agenda for this workshop with 5 researchers from Fraunhofer Portugal's was as follows:

- By looking at the ontology, we started with a brainwriting session to identify and decide which areas of research the team intended to work on, with the option of selecting just one or a mixture of them. Given the number of areas identified, three votes were distributed to each participant so that in the end one area was defined. For this, a Shared Google Docs was distributed to the participants so that everyone could collaborate all the iterations and vote in the end.
- Afterwards, another brainwriting session was conducted, which consisted of selecting a technology inside the prior phase's chosen area. The same Google Docs Shared was utilized. Considering the number of technologies identified, this time, four votes were distributed to each participant to determine which technology was selected by the majority.
- The following stage was to provide a full description of the technology described in the preceding section, including its components and capabilities. Another Shared Google Docs, as shown in ANNEX A2, was distributed for this purpose. The highlight of this step was the clear definition of the technology capabilities.
- A final Shared Google Docs was provided, this time with the goal of performing another brainwriting session. The objective was to start the TPM process by producing ideas for products where this technology could be incorporated. The starting point for each product is the already identified technology capability. Given the large number of potential products found, five votes were distributed per expert. This allowed the identification of the top three most preferred products.
- As a final step, and in the same Shared Google Docs. For each of the three products, a brainwriting session was performed in order to generate market ideas where these products might be commercialized. Given the number of markets identified, four votes were allocated among the participants, resulting in two markets for a given product, thus providing the criteria for selecting product-market pairs.

At last, before closing the meeting, followed a period of in-depth discussion of the entire process. The participants were invited to provide feedback on the process added value. The benefits and drawbacks of using the ontology, as well as its utility.

4.4.1 Discussion of the Workshop results

In this workshop we performed a simulation of the real process. This means that we compressed the times of several activities to ensure that the overall workshop would not go beyond 1h30. Several insights emerged from the workshop:

- It would be interesting to begin the process by working our way down the ontology hierarchy one level at a time. This means that, after reviewing the high-level ontology, we should choose one of the items on which we want to zoom in and explore. This would have allowed for a more systematic approach in determining which areas of ontology should be chosen as the technological area to begin the first brainwriting session;
- It was suggested that it could be interesting to perform the exercise in the opposite way. Starting with the market and mapping it within the ontology, we would generate products that would help us in finding different types of technologies;
- The sharing of different points of view during the brainwriting session, proved beneficial. Various interpretations were gathered and presented based on the experts' backgrounds. As a core development process, these can help supplement the final solution.

4.5 Recommendation for Managers

The Operator 4.0 Ontology provides a framework from which technological areas and ideas for technologies can be generated. The technology push innovation process builds therefore an early structured approach to identify the technology scope based on the ontology before starting the actual TPM process.

Below are the multiple benefits that the developed ontology possesses for managers:

- The entire process can be initiated by looking at the high-level ontology and selecting one of the items on which it is desired to zoom in and explore, allowing for a more systematic approach to selecting areas of the ontology. The first brainwriting will be performed, based on the selected technology area;

- It is possible to perform the exercise in the opposite way. Starting from the market, through its mapping, within the ontology, generate products that will be of help in the discovery of technology development opportunities;
- It provides, depending on the experts' backgrounds, the sharing of different perspectives in the brainwriting session. It also allows for different forms of interpretation that may help complement the final solution, enriching it.

4.6 Conclusion

The process developed in this section was intended to present the proposed model composed of six sub-ontologies. As a way of validating the Operator 4.0 ontology, two stages were carried out for this purpose. The first stage consisted of a Focus Group session in which the ontology was presented to the participants in its global form, followed by its validation. In the second and final stage, a workshop was held with the goal of developing a creative TPM process that would lead to the selection of Product-Market pairs. This chapter concludes with the discussion of the results.

5. Conclusions

Through the understanding brought by the scientific reading on the subject of Operator 4.0, it was safe to say that there was a lack of a reference model that spanned several technological areas in order to support the construction of Operator 4.0 solutions for industry. The first step was to organize the most relevant articles from the scientific literature in a table, along with the contribution and future research of each article. This was followed by a critical discussion of these articles, concluding with the identification of the research gap. The Literature Review chapter has presented these points.

With the identified gap, the second step was to elaborate a research question and select the adequate approach in order to answer this question. As chapter 3 introduced the design science approach used to assist in the development of the ontology. The ontology building process described in the literature was followed, encompassing its development, refinement and first validation by Fraunhofer experts.

The contribution of this research was built on article "Identifying Technology Commercialization Opportunities: The Importance of Product Development Knowledge Integration" in the *Journal of Product Innovation Management*. The point was, can we use an ontology, that provides a way organize concepts and relations within a knowledge domain, to support the process of initiating new research, in order to produce future intellectual property. Chapter 4 presents the result of this effort. The first contribution of this research, the ontology, is presented. Follows the presentation of the result of the Focus Group session with experts from Fraunhofer Portugal, who participated in the ontology validation, including the assessment of the competency questions. After the ontology validation, a workshop was held to demonstrate the researcher second contribution, a proposal of how to use the ontology as a driver to start the technology process in the context of identifying opportunities for future technology commercialization. Followed a fruitful discussion with the experts on the workshops results, and opportunities for improvement.

As future work, the next step in preparing a proposal for a research project would be to take each of the selected markets and refine the product. Then formulate a value proposition of the product for the respective market and in a short time do a brief validation of the market feasibility. The goal would be to arrive at the end of a given period with an understanding of the future commercial value of each of the possibilities, allowing one to choose between developing a specific technology or restarting the brainstorming exercise, identifying another technology, and exploring it.

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Annex A1

Ontology Validation – Results of the Focus Group Session

The outcomes about Top-Level Ontology: Operator will be presented.

Table 7 - Evaluation of the Top-Level Ontology: Operator 4.0

Criteria	P1	P2	P3	P4	P5	Validation
Completeness	N/D	N/D	1	1	1	100%
Utility	1	1	1	1	1	100%
Consistency	1	0	1	1	1	80%
Understandability	1	0	0	1	1	60%
Top-Level Ontology: Operator 4.0 overall evaluation						85%

First, in this case, it is important to note the meaning of the acronym Not Defined (N/D), present in Table 7. The term indicates that both Participants 1 and 2 chose not to comment on the Completeness criterion, as they are not experts in the field and could not assess whether the model was incomplete. It is also important to mention that both of these participants' evaluations regarding this criterion were not part of the final average of the sub-ontology. Interpreting the table, it is easy to see that the top-rated criteria were Completeness and Utility, with a maximum approval score of 100%. Consistency received an approval rating of 80%. The combined validation of the four criteria yields an acceptance percentage of 85%. The percentage expressed for Understandability of 60%, may have as a reason, the fact that it clusters other sub-ontologies that were presented afterwards, thus making it harder to grasp the whole meaning.

Next, the results about Sub-Ontology: Operating Framework are as follows.

Table 8 - Evaluation of the Sub-Ontology: Operating Framework

Criteria	P1	P2	P3	P4	P5	Validation
Completeness	N/D	N/D	0	1	1	≈ 67%
Utility	1	1	0	1	1	80%
Consistency	1	1	1	1	1	100%
Understandability	1	1	0	0	1	60%
Sub-Ontology: Operating Framework overall evaluation						≈ 77%

In this evaluation, the criterion with the highest approval rate was Consistency, standing out from the others with 100% approval – the highest score. Next, the Utility criterion settled at 80% approval. Both the Completeness and Understandability criteria have values below the reference value for validation, which may indicate a lack of clarity in the meaning of the concepts upon first contact. Still, in the end, the sub-ontology was validated, achieving an overall evaluation of 77%.

Next, the results about Sub-Ontology: Observation Stage are shown below, in Table 9.

Table 9 - Evaluation of the Sub-Ontology: Observation Stage

Criteria	P1	P2	P3	P4	P5	Validation
Completeness	N/D	N/D	1	1	1	100%
Utility	1	1	0	1	1	80%
Consistency	1	1	1	1	1	100%
Understandability	1	1	1	1	1	100%
Sub-Ontology: Observation Stage overall evaluation						95%

The sub-ontology: Observation Stage has an overall approval of 95%, the highest of all the ontologies. This is due to an approval percentage of 100% in three criteria (Completeness, Consistency and Understandability). The remaining one, although they did not reach the maximum validation percentage, reached 80% which is still a high level of approval.

Next, the scores about Sub-Ontology: Workstation Observation are as follows.

Table 10 - Evaluation of the Sub-Ontology: Workstation Observation

Criteria	P1	P2	P3	P4	P5	Validation
Completeness	N/D	N/D	0	1	0	≈ 33%
Utility	1	1	0	1	1	80%
Consistency	1	1	1	1	1	100%
Understandability	1	1	1	1	1	100%
Sub-Ontology: Workstation Observation overall evaluation						≈ 78%

Regarding this sub-ontology, we can immediately see the low percentage of validation of the criterion Completeness, which stands at only 33%. The reason for this value may be that the Workstation is a subject with which the participants would be less familiar, thus the possibility of conveying a sense of incompleteness. However, as in the validation of the previous sub-ontology, the Consistency and Understandability criteria also reached the maximum percentage. Together with the Utility criterion, they helped to raise the overall evaluation above 70%, with a total of 78%, thus allowing the sub-ontology to be validated.

Next, the results about Sub-Ontology: Virtual Operator will be presented.

Table 11 - Evaluation of the Sub-Ontology: Virtual Operator

Criteria	P1	P2	P3	P4	P5	Validation
Completeness	N/D	N/D	0	1	1	≈ 67%
Utility	1	1	0	1	1	80%
Consistency	0	1	0	1	1	60%
Understandability	1	1	0	1	1	80%
Sub-Ontology: Virtual Operator overall evaluation						≈ 72%

The overall evaluation of this sub-ontology is 72%, the lowest of all, making it almost impossible to validate. The highlights of this evaluation were the Utility and Understandability criteria, with a score of 80%. The lowest values were for the Completeness and Consistency criteria, which may come from the simplicity of the sub-ontology construction and its concepts. P3 zeros, in fact, correspond to the rating of 3, meaning neither agreement nor disagreement.

Below, in Table 12 are shown the scores about Sub-Ontology: Smarter Operator.

Table 12 - Evaluation of the Sub-Ontology: Smarter Operator

Criteria	**P1**	**P2**	**P3**	**P4**	**P5**	**Validation**
Completeness	N/D	N/D	0	1	1	≈ 67%
Utility	1	1	0	1	1	80%
Consistency	1	1	1	1	1	100%
Understandability	1	1	1	1	1	100%
Sub-Ontology: Smarter Operator overall evaluation						≈ 87%

Finally, the last sub-ontology to be evaluated will be the Smarter Operator. Its strongest criteria were Consistency and Understandability, reaching the maximum percentage of 100%. Next is the Utility criterion with 80%. Regarding the criterion of Completeness, its low value may indicate the possibility of inserting additional factors in this category, besides the ones mentioned.

The overall evaluation of this sub-ontology reached 87%, thus allowing us to conclude that it is validated. In conclusion, we can say that all six sub-ontologies were validated by Fraunhofer Portugal's experts.

Annex A2

Template for Technology Description

In this paper, one of the participants is asked to answer the following questions, regarding the chosen technology.

1. **Name** the technology.
2. Identify technology **components**.
3. Identify the main **capabilities**.
4. In non-technical terms, describe the potential **applications** this technology presents. List potential products based upon the technology.
5. Explain how this technology or product is unique from other technologies or products. What **advantage** does it represent for a product, or for manufacturing a new product (what are its unique capabilities?)
6. Does the technology represent a **platform for the creation of multiple new products**?
7. Describe what **must be done** to this technology **before** it can be commercialized in the form of products/services (i.e. what is the stage of technical development)
8. Describe the **legal and practical protection status** of the technology or product or the potential for protection; i.e., patent applied for (where), patent granted (how old, where), trademark, copyrights, trade secret?

Annex A3

A3.1 Definition of concepts used in the Top-Level Ontology: Operator 4.0

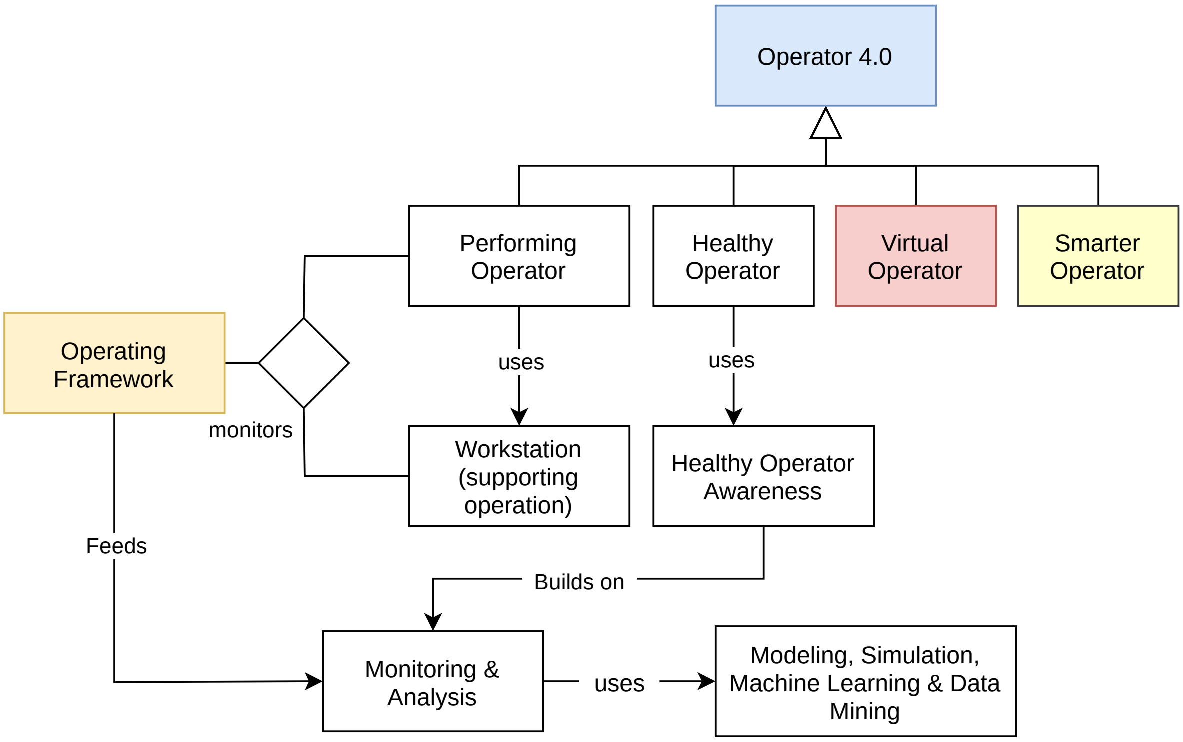

Table 13 - Operator 4.0

Name of Element	**Operator 4.0**
Definition	"The Operator 4.0 generation represents the 'operator of the future', a smart and skilled operator who performs 'work aided' by machines if and as needed "(Romero, Bernus, Noran, Stahre, & Fast-Berglund, 2016, p. 1).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Romero, Bernus, Noran, Stahre, & Fast-Berglund, 2016)

Table 14 – Performing Operator

Name of Element	**Performing Operator**
Definition	Operator who performs tasks using the workstation for operation support.
Part of	Top-Level Ontology: Operator 4.0
Reference	Own elaboration

Table 15 – Operating Framework

Name of Element	**Operating Framework**
Definition	Framework that monitors both performing Operator and the workstation.
Part of	Top-Level Ontology: Operator 4.0
Reference	Own elaboration

Table 16 - Healthy Operator

Name of Element	**Healthy Operator**
Definition	The Healthy operator "aims to address the concerns regarding increasing workforce stress levels, the state of psycho-social health, and the new potential physical risks in the cyber–physical production environments" (Sun, Zheng, Gong, Paredes and Ordieres-Meré, 2020, p. 2).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Sun, Zheng, Gong, Paredes, & Ordieres-Meré, 2020)

Table 17 - Smarter Operator

Name of Element	**Smarter Operator**
Definition	Smarter Operator "is helped by softbots as Intelligent Personal Assistants (IPAs) to interface with smart machines and robots, computers, databases and other information systems" (Rabelo, Romero, & Zambiasi, 2018, p. 2).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Rabelo, Romero, Zambiasi, 2018)

Table 18 - Virtual Operator

Name of Element	**Virtual Operator**
Definition	Consists in mixed reality technology (virtual and augmented reality), thus allowing training and orientation to be adapted to constantly changing circumstances (Zawadzki et al., 2020).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Zawadzki et al., 2020)

Table 19 - Workstation (supporting operation)

Name of Element	**Workstation (supporting operation)**
Definition	The workstation "permit an adaptive, ongoing interaction that aims to improve operator safety, performance, well-being, and satisfaction as well as the factory's production measures" (Golan, Cohen, & Singer, 2019, p. 2421).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Golan, Cohen, & Singer, 2019)

Table 20 - Healthy Operator Awareness

Name of Element	**Healthy Operator Awareness**
Definition	The HO (Healthy Operator) awareness is used to "provide hints and insights from cyber space to physical space and acts as a monitoring system for the preventive decisions from operators, machines, or ambient environments" (Sun, Zheng, Gong, Paredes and Ordieres-Meré, 2020, p. 5).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Sun, Zheng, Gong, Paredes and Ordieres-Meré, 2020)

Table 21 - Monitoring and Analysis

Name of Element	**Monitoring and Analysis**
Definition	The monitoring and analysis are a way of measure workers' performances to provide useful data in order to improve the human-machine interaction (Peruzzini, Grandi, & Pellicciari, 2020).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Peruzzini, Grandi, & Pellicciari, 2020)

Table 22 - Modeling, Simulation, Machine Learning and Data Mining

Name of Element	**Modeling, Simulation, Machine Learning and Data Mining**
Definition	It is a way to support the useful knowledge extraction, such as risk alerts, improved advice, and rules (Sun, Zheng, Gong, Paredes and Ordieres-Meré, 2020).
Part of	Top-Level Ontology: Operator 4.0
Reference	(Sun, Zheng, Gong, Paredes and Ordieres-Meré, 2020)

A3.2 Definition of concepts used in the Sub-Ontology: Operating Framework

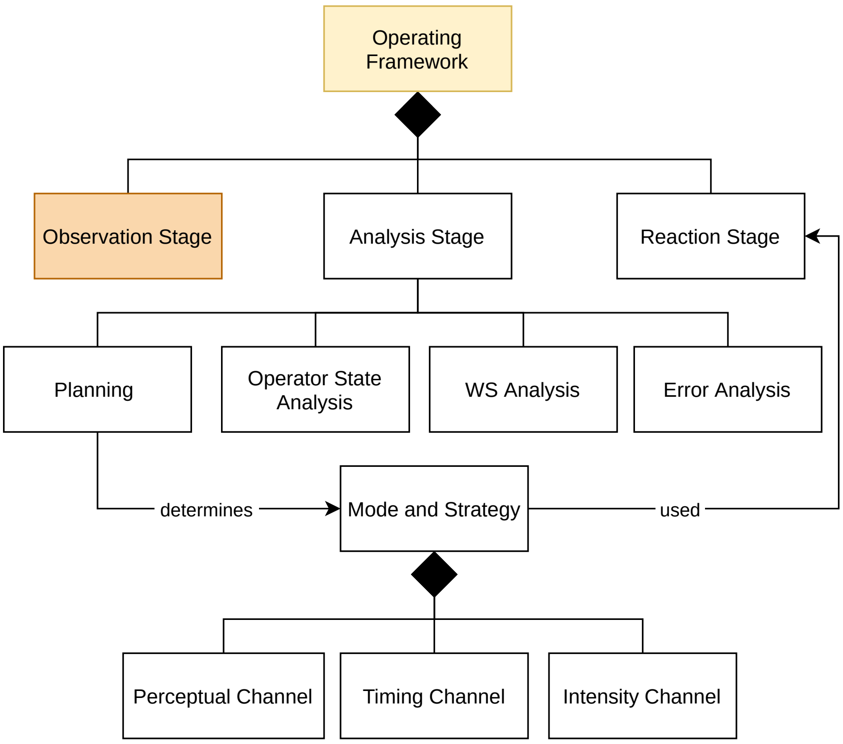

Table 23 - Observation Stage

Name of Element	**Observation Stage**
Definition	The Observations stage is what "observes the operator and the processes occurring in the workstation" (Golan, Cohen, & Singer, 2019, p. 2421).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 24 - Analysis Stage

Name of Element	**Analysis Stage**
Definition	The Analysis stage is what "generates understanding and implications of the observations output" (Golan, Cohen, & Singer, 2019, p. 2421).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 25 - Planning

Name of Element	**Planning**
Definition	"Is responsible for selecting the most appropriate mode and strategy in the Reaction stage" (Golan, Cohen, & Singer, 2019, p. 2426).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 26 - Reaction Stage

Name of Element	**Reaction Stage**
Definition	The Reaction stage is what expresses the mode and strategy established in the Planning unit in a particular reaction (Golan, Cohen, & Singer, 2019).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 27 - Operator State Analysis

Name of Element	**Operator State Analysis**
Definition	Integrates the static, momentary and trajectory information from the Operator Observation sub-component in order to diagnose his/her physiological and cognitive state (Golan, Cohen, & Singer, 2019).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 28 - Error Analysis

Name of Element	**Error Analysis**
Definition	It is a unit responsible to interpret and classify "data collected during the Observation stage according to whether or not an error has been committed or is likely to be committed based on a sequence of actions" (Golan, Cohen, & Singer, 2019, p. 2426).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 29 - Mode and Strategy

Name of Element	**Mode and Strategy**
Definition	Specifies the characteristics of the sent messages
Part of	Sub-Ontology: Operating Framework
Reference	Own elaboration

Table 30 - Workstation Analysis

Name of Element	**Workstation Analysis**
Definition	It integrates the static, momentary, and trajectory information from the Workstation Observation sub-component in order to diagnose the workstation's overall state (Golan, Cohen, & Singer, 2019).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 31 - Perceptual Channel

Name of Element	**Perceptual Channel**
Definition	It is what "determines whether to use an audio, a visual, or a tactile message" in the Reaction sub-component (Golan, Cohen, & Singer, 2019, p. 2426).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 32 - Intensity Channel

Name of Element	**Intensity Channel**
Definition	It is what "relates to the loudness, brightness, or strength of the message" in the Reaction sub-component (Golan, Cohen, & Singer, 2019, p. 2426).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

Table 33 - Timing Channel

Name of Element	**Timing Channel**
Definition	It is what "determines the frequency, timing, and length of the message" in the Reaction sub-component (Golan, Cohen, & Singer, 2019, p. 2426).
Part of	Sub-Ontology: Operating Framework
Reference	(Golan, Cohen, & Singer, 2019)

A3.3 Definition of concepts used in the Sub-Ontology: Observation Stage

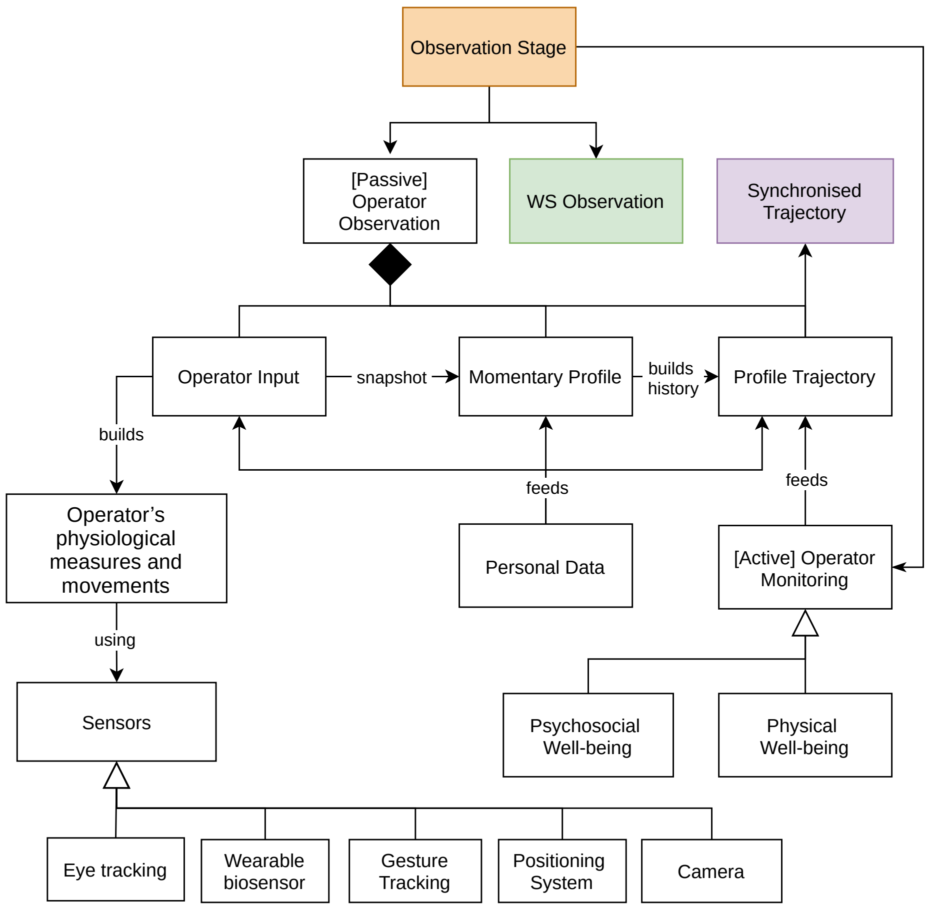

Table 34 - Workstation Observation

Name of Element	**Workstation Observation**
Definition	It consists of three units: "the Workstation Input, Momentary Profile and Profile Trajectory, which are accompanied by a fourth, parallel unit that provides environmental data (e.g. noise, temperature, light, humidity)" (Golan, Cohen, & Singer, 2019, p. 2425).
Part of	Sub-Ontology: Observation Stage
Reference	(Golan, Cohen, & Singer, 2019)

Table 35 - [Passive] Operator Observation

Name of Element	**[Passive] Operator Observation**
Definition	Observation by the operator is done indirectly, with no self-reporting.
Part of	Sub-Ontology: Observation Stage
Reference	Concept resulted of the experts' input

Table 36 - Synchronized Trajectory

Name of Element	**Synchronized Trajectory**
Definition	Synchronized path between operator observation and workstation observation.
Part of	Sub-Ontology: Observation Stage
Reference	Own elaboration

Table 37 - Operator's physiological measures and movements

Name of Element	**Operator's physiological measures and movements**
Definition	Physical movements produced by the operator acquired through sensors.
Part of	Sub-Ontology: Observation Stage
Reference	Own elaboration

Table 38 - [Active] Operator Monitoring

Name of Element	**[Active] Operator Monitoring**
Definition	The operator self-reports his physical and mental state.
Part of	Sub-Ontology: Observation Stage
Reference	Concept resulted of the experts' input

Table 39 - Psychosocial Well-being

Name of Element	**Psychosocial Well-being**
Definition	"Psychosocial well-being is a multidimensional construct consisting of psychological, social, and subjective components which influence the overall functionality of individuals in achieving their true potentials as members of the society" (Taimur, 2020, p. 676).
Part of	Sub-Ontology: Observation Stage
Reference	Concept resulted of the experts' input

Table 40 - Physical Well-being

Name of Element	**Physical Well-being**
Definition	Actions and choices made to ensure physical health, leading to better mental health.
Part of	Sub-Ontology: Observation Stage
Reference	Concept resulted of the experts' input

Table 41 - Eye tracking

Name of Element	**Eye tracking**
Definition	Technique that allows measuring the position and behavior of eye movement.
Part of	Sub-Ontology: Observation Stage
Reference	(Peruzzini, Grandi & Pellicciari, 2020)

Table 42 - Wearable biosensor

Name of Element	**Wearable biosensor**
Definition	Instruments that provide monitoring of the user's vital signs.
Part of	Sub-Ontology: Observation Stage
Reference	(Peruzzini, Grandi & Pellicciari, 2020)

Table 43 – Gesture Tracking

Name of Element	**Gesture Tracking**
Definition	Set of techniques to make the computer recognize certain types of gestures.
Part of	Sub-Ontology: Observation Stage
Reference	Own elaboration

Table 44 - Positioning System

Name of Element	**Positioning System**
Definition	Mechanism with the purpose of determining the position of an object in space.
Part of	Sub-Ontology: Observation Stage
Reference	(Sun et al., 2020)

Table 45 - Camera

Name of Element	**Camera**
Definition	Optical instrument for capturing images in the form of photographs.
Part of	Sub-Ontology: Observation Stage
Reference	Own elaboration

Table 46 - Personal Data

Name of Element	**Personal Data**
Definition	Is what "includes personal data such as age, gender, health condition, and the history and background of the operator, as well as information that is recorded by the operator concerning his or her personal feedback preferences" (Golan, Cohen, & Singer, 2019, p. 2425).
Part of	Sub-Ontology: Observation Stage
Reference	(Golan, Cohen, & Singer, 2019)

Table 47 - Operator Input

Name of Element	**Operator Input**
Definition	Is what "receives inputs from external sensors and cameras that monitor the operator and integrates them in order to create a multi-dimensional representation of the operator's physiological measures and movements" (Golan, Cohen, & Singer, 2019, p. 2425).
Part of	Sub-Ontology: Observation Stage
Reference	(Golan, Cohen, & Singer, 2019)

Table 48 - Momentary Profile

Name of Element	**Momentary Profile**
Definition	Is what "uses the representation created by the Operator Input in order to periodically determine the operator's granular status during the previous few seconds" (Golan, Cohen, & Singer, 2019, p. 2425).
Part of	Sub-Ontology: Observation Stage and Sub-Ontology: Workstation Observation
Reference	(Golan, Cohen, & Singer, 2019)

Table 49 - Profile Trajectory

Name of Element	**Profile Trajectory**
Definition	It is a "a sequence of profiles that represent a longer time frame than the momentary profile, thereby enabling the detection of granular changes and trends" (Golan, Cohen, & Singer, 2019, p. 2425).
Part of	Sub-Ontology: Observation Stage and Sub-Ontology: Workstation Observation
Reference	(Golan, Cohen, & Singer, 2019)

Table 50 - Sensors

Name of Element	**Sensors**
Definition	They are external devices used to collect data (e.g., number of blinks per time, type and range of movement or gesture, heart rate, blood pressure, and so on) (Golan, Cohen, & Singer, 2019).
Part of	Sub-Ontology: Observation Stage and Sub-Ontology: Workstation Observation
Reference	(Golan, Cohen, & Singer, 2019)

A3.4 Definition of concepts used in the Sub-Ontology: Workstation Observation

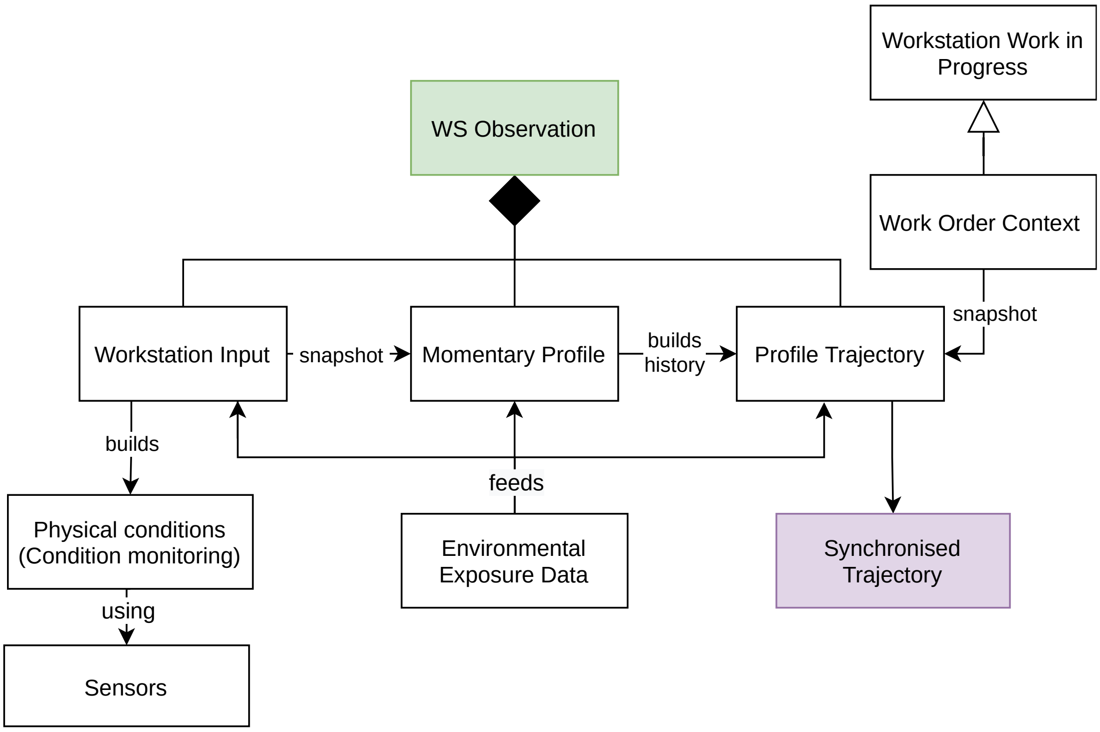

Table 51 - Environmental Exposure Data

Name of Element	**Environmental Exposure Data**
Definition	It is what integrates the static information (e.g., noise, temperature, light, humidity) from the Workstation Observation sub-component (Golan, Cohen, & Singer, 2019).
Part of	Sub-Ontology: Workstation Observation
Reference	(Golan, Cohen, & Singer, 2019)

Table 52 - Work Order Context

Name of Element	**Work Order Context**
Definition	Indication to the machine operator what to do.
Part of	Sub-Ontology: Workstation Observation
Reference	Own elaboration

Table 53 - Workstation Work in Progress

Name of Element	**Workstation Work in Progress**
Definition	Corresponds to the description of all work orders.
Part of	Sub-Ontology: Workstation Observation
Reference	Own elaboration

Table 54 - Workstation Input

Name of Element	**Workstation Input**
Definition	It is what "provides an online representation of the workstation in terms of technical measures, obtained by receiving continuous data signals from sensors with regard to physical conditions" (Golan, Cohen, & Singer, 2019, p. 2425).
Part of	Sub-Ontology: Workstation Observation
Reference	(Golan, Cohen, & Singer, 2019)

A3.5 Definition of concepts used in the Sub-Ontology: Virtual Operator

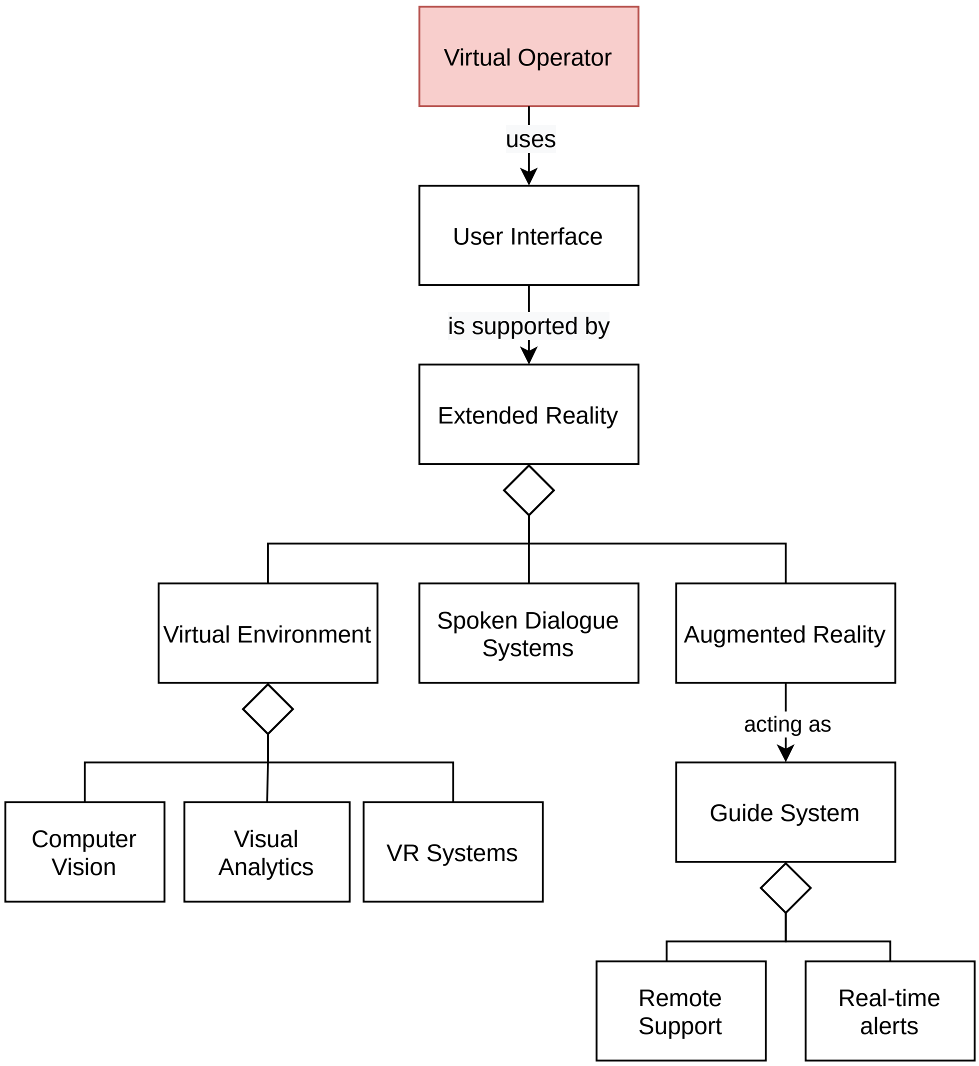

Table 55 - User Interface

Name of Element	**User Interface**
Definition	Device that allows both interaction and communication between man and machine.
Part of	Sub-Ontology: Virtual Operator
Reference	(Rabelo et al., 2018)

Table 56 - Extended Reality

Name of Element	**Extended Reality**
Definition	Designation that covers all forms of immersion and human-machine interaction, be it Virtual Reality, Mixed Reality or Augmented Reality.
Part of	Sub-Ontology: Virtual Operator
Reference	Own elaboration

Table 57 - Virtual Environment

Name of Element	**Virtual Environment**
Definition	A network application that enables a user interaction with the computing environment.
Part of	Sub-Ontology: Virtual Operator
Reference	Own elaboration

Table 58 - Spoken Dialogue Systems

Name of Element	**Spoken Dialogue Systems**
Definition	"Spoken Dialogue Systems (SDSs) are voice-enabled Human–Machine Interfaces for natural communication with a computer, robot, and other devices" (Serras, García-Sardiña, Simões, Álvarez, & Arambarri, 2020, p. 3).
Part of	Sub-Ontology: Virtual Operator
Reference	(Serras, García-Sardiña, Simões, Álvarez, & Arambarri, 2020)

Table 59 - Augmented Reality

Name of Element	**Augmented Reality**
Definition	Is an "immersive" technology, which aims to make the boundary between the real and the virtual world less clear, creating a feeling of immersion between elements.
Part of	Sub-Ontology: Virtual Operator
Reference	(Pierdicca et al., 2020)

Table 60 - Computer Vision

Name of Element	Computer Vision
Definition	Technology for building artificial systems that get information from images or any multidimensional data.
Part of	Sub-Ontology: Virtual Operator
Reference	(Segura et al., 2020)

Table 61 - Visual Analytics

Name of Element	Visual Analytics
Definition	Combines automated analysis techniques with interactive visualization for effective understanding, reasoning, and decision making based on very large and complex data sets.
Part of	Sub-Ontology: Virtual Operator
Reference	(Keim et al., 2008)

Table 62 - VR Systems

Name of Element	VR Systems
Definition	"VR Systems are IT solutions supporting more and more areas of the economy (medicine, entertainment) but also used often in various production processes" (Zawadzki, Żywicki, Buń & Górski, 2020, p. 1).
Part of	Sub-Ontology: Virtual Operator
Reference	(Zawadzki, Żywicki, Buń & Górski, 2020)

Table 63 - Guide System

Name of Element	Guide System
Definition	Provides remote support and sends real-time alerts in dangerous situations.
Part of	Sub-Ontology: Virtual Operator
Reference	(Pierdicca et al., 2020)

Table 64 - Remote Support

Name of Element	**Remote Support**
Definition	Support activity that enables remote connection to a computer via the Internet.
Part of	Sub-Ontology: Virtual Operator
Reference	(Pierdicca et al., 2020)

Table 65 - Real-time alerts

Name of Element	**Real-time alerts**
Definition	Alerts that are programmed to be triggered at the precise moment when something they were programmed to do happens.
Part of	Sub-Ontology: Virtual Operator
Reference	(Pierdicca et al., 2020)

A3.6 Definition of concepts used in the Sub-Ontology: Smarter Operator

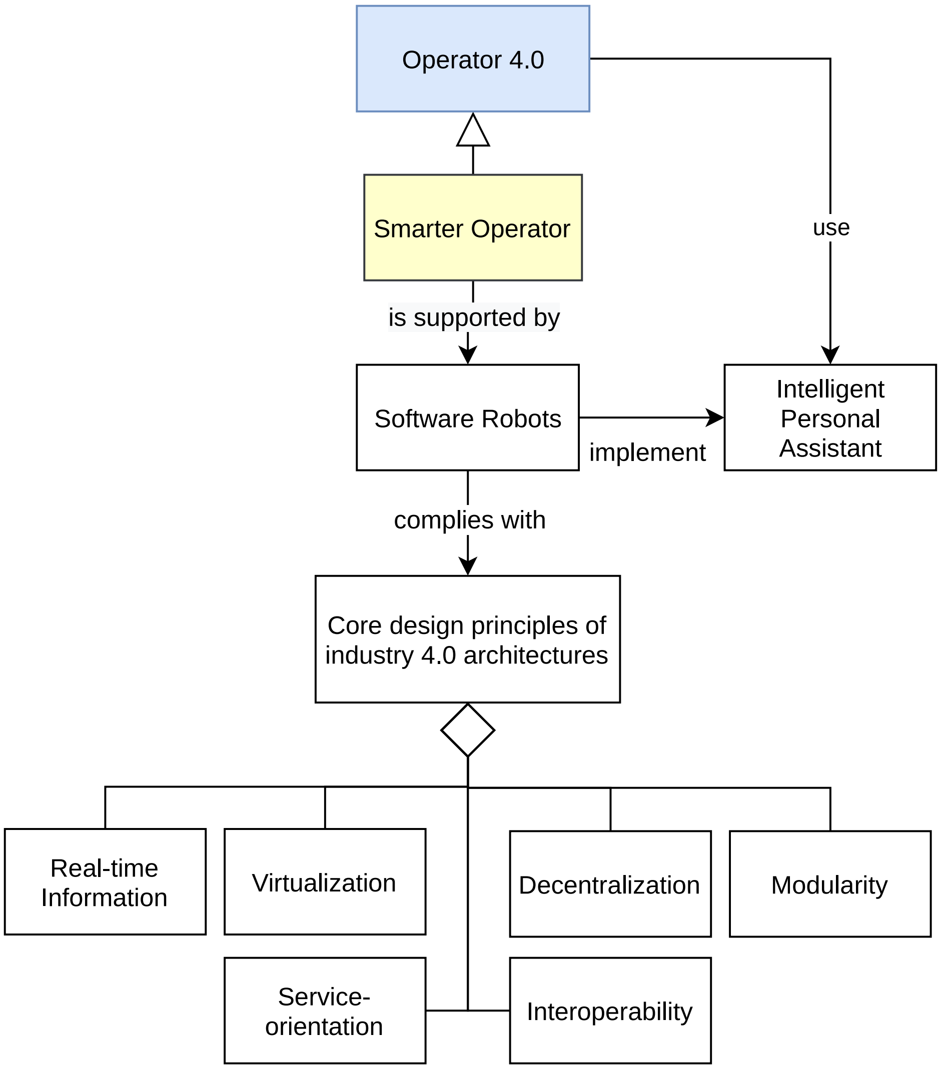

Table 66 - Software Robots

Name of Element	**Software Robots**
Definition	They are a "virtual system deployed in a given computing environment that automates and helps humans in the execution of some tasks with variable levels of intelligence and autonomy" (Rabelo, Romero, & Zambiasi, 2018, p. 2).
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 67 - Intelligent Personal Assistant

Name of Element	**Intelligent Personal Assistant**
Definition	Software agent, designed to assist people, by performing tasks or services based on commands or questions in natural languages.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 68 - Core design principles of industry 4.0 architectures

Name of Element	**Core design principles of industry 4.0 architectures**
Definition	Set of principles that support the Softbots Reference Framework.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 69 - Real-time Information

Name of Element	**Real-time Information**
Definition	The ability to perform multiple functions simultaneously and asynchronously.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 70 - Virtualization

Name of Element	**Virtualization**
Definition	Process of creating a software based or virtual version of something.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 71 - Service-orientation

Name of Element	**Service-orientation**
Definition	It means that "a given softbot is internally composed of a set of built-in (distributed) software services, such as communication ways" (Rabelo, Romero, & Zambiasi, 2018, p. 5).
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 72 - Decentralization

Name of Element	**Decentralization**
Definition	The autonomy that a system has so that its behavior can be variable and implemented in different scenarios.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 73 - Modularity

Name of Element	**Modularity**
Definition	Defines how the models of a system are replaceable, linking and combining them to form a complete system.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)

Table 74 - Interoperability

Name of Element	**Interoperability**
Definition	It is the way a system communicates effectively and transparently with another system.
Part of	Sub-Ontology: Smarter Operator
Reference	(Rabelo, Romero, & Zambiasi, 2018)