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Occupational Safety and Health 5.0—A Model for Multilevel Strategic Deployment Aligned with the Sustainable Development Goals of Agenda 2030

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Abstract: The concept of Industry 4.0 (I4.0) is evolving towards Industry 5.0 (I5.0), where the human factor is the central axis for the formation of smart cyber-physical socio-technical systems that are integrated into their physical and cultural host environment. This situation generates a new work ecosystem with a radical change in the methods, processes and development scenarios and, therefore, in the occupational risks to which safety science must respond. In this paper, a historical review of the evolution of work as a complex socio-technical system formalised through Vygostky's theory of Activity and the contributions of safety science is carried out, for its projection in the analysis of the future of complex systems as an opportunity for safety research linked to the current labour context in transformation. Next, the Horizon 2020 strategies for Occupational Safety and Health (OSH) at the European level are analysed to extract the lessons learned and extrapolate them towards the proposed model, and subsequently the conceptual frameworks that are transforming work and Occupational Risk Prevention (ORP) in the transition to Industry 4.0 are identified and reviewed. Finally, a model is formulated that formalises the deployment of public policies and multi-level and multi-scale OSH 5.0 strategies within the framework of the Sustainable Development Goals (SDGs) of the United Nations (UN) for Horizon 2030.

Keywords: digitalisation of OSH; OSH 4.0; OSH 4.0 policy and strategy; OSH 5.0 model; socio-technical systems safety science

Citation: Ávila-Gutiérrez, M.J.; Suarez-Fernandez de Miranda, S.; Aguayo-González, F. Occupational Safety and Health 5.0—A Model for Multilevel Strategic Deployment Aligned with the Sustainable Development Goals of Agenda 2030. *Sustainability* **2022**, *14*, 6741. https://doi.org/10.3390/su14116741

Academic Editor: Lucian-Ionel Cioca

Received: 7 April 2022
Accepted: 30 May 2022
Published: 31 May 2022

1. Introduction

Horizon 2020 programmes and the set of research lines proposed internationally in the context of the Fourth Industrial Revolution (Industry 4.0) have reflected the interest and need to expand the scope of Occupational Safety and Health (OSH) policies and strategies in production and service systems [1,2]. This is a consequence of the new and emerging risks arising from digitalisation processes and aims to achieve comprehensive worker protection, efficiency in prevention management, and the establishment of safety and health policies and strategies integrated with other areas of management [3].

Significant contributions and implementations in the field of corporate safety science have been made as the result of Horizon 2020 programmes and strategies for safety and health at the European level [4–6]. Such contributions include the digitalisation of OSH, the incorporation of new and emerging scientific and technical knowledge, the implementation of preventive culture, and the integration of OSH under excellence concepts which are broader than the classic idea of quality, such as sustainability, and community health due to the great impact that the community health has on productive activity [7]. In addition, the implementation and development of OSH strategies and processes, in terms of incorporating Key Enabling Technologies (KETs) and the conceptual and working frameworks of complexity science into OSH, have a significant impact with the way in which these are incorporated into other processes and departments at the company level [8].

Recently, the UN, in their Agenda 2030 for sustainable development [9,10], established 17 Sustainable Development Goals (SDGs) and 169 targets [10], of which several are related to safety and health at work: SDG 3 "Ensure healthy lives and promote well-being for all at all ages"; SDG 8 "Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all"; and SDG 16 "Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable, and inclusive institutions at all levels". These targets, together with the public health goals, must be considered in the deployment of policies and incentive strategies on occupational safety and health at different levels and geographical scales in this timeframe.

Under current and future boundary conditions, it is necessary to consider the emergence of new risks as a result of digitisation, connectivity, and implementation of cyber-physical systems in the design and development of future work systems, which constitute one of the processes of deep transformation and innovation not only of the industrial sector (Industry 4.0 to 5.0) [11], but also of all sectors, such as [12–14] construction, agriculture, or services, with an extension to the domestic sphere through teleworking, shaping the essential elements of the future of work. This situation of change leads to new and emerging risks [6], as well as a potential transformation of the OSH, giving rise to a new model called OSH 5.0, in which innovation, digitalisation, and cultural transformations of the OSH constitute sources of value in work and in its development contexts [15]. This is particularly important at a time when OSH programmes and strategies in Horizon 2020 are closed or nearing their end, and which allows us to analyse the degree to which digital, organisational, and technological enablers have been integrated to mitigate occupational safety and health risks under a more holistic conception of sustainability in line with the Agenda 2030.

Among the areas to be explored by OSH 4.0 to 5.0 are those corresponding to the change in terms of not thinking about people to replace or substitute as a consequence of the digital transformation, but how to redesign organisations under the digital transformation to optimise, enhance, and maintain the talent available in companies, conceiving operational areas and intergenerational, cross-cultural activity systems that are not hostile to people and protected from human error, rejection, and conflict [11]. It this context, the OSH 4.0 and its projection towards OSH 5.0, through its digital transformation incorporated with the concept of cyber–physical systems, cognitive computing, virtualisation, connectivity, affective interfaces and KETs, have the potential to respond to the important challenges addressed in the new OSH planning horizons of the 2030 programmes from the principles of security science.

In the context of OSH 4.0 to 5.0 of socio-technical production systems, another aspect to consider is the understanding of work and technology or industrial capital as a generator not only of labour risks, but also of wider risks to society and the environment derived from the metabolic rift in terms of the separation between natural and social capital due to productive activity [16]. This extensive conception of risks enables the potential of KETs to mitigate damage under the models of the integration of the three business management systems—environmental (ecology), health and safety (social), and economic (quality)—which is considered in companies as integrated management systems. These scenarios of integrated management should be given similar consideration in the multi-level and multi-scale deployment of policies and strategies on safety and health for Horizon 2030.

This paper aims to provide answers to the following research questions (RQs): (RQ I) Is it possible that digital transformation and smartisation can facilitate the transition from OSH 4.0 to 5.0 and its integrated deployment? (RQ II) Can new forms of work organisation and cultural change from OSH 4.0 to 5.0 to be developed in VUCA (Volatility, Uncertainty, Complexity and Ambiguity) environments? and (RQ III) How can an alignment of the OSH 4.0 to 5.0 transition with the SDGs be established through excellence and innovation?

Along these lines emerges the opportunity to develop a framework that allows us to facilitate the transition from OSH 4.0 to OSH 5.0 through the deployment of multilevel policies, strategies, and incentives by the EU for their projection at the levels of companies, projects, business and service operations under the sustainable development goals of the Agenda 2030 from the science of safety and from the perspective of complex systems.

The manuscript has been structured based on the following four sections. (1) Introduction: what is the problem being studied and why is it being studied? (2) Background: this section presents the background according to three points to respond to RQs: first, a review of the evolution of occupational health and safety systems organised according to the different industrial revolutions and characterised from the elements that constitute them from Vygostky's Activity Theory is developed; second, an analysis of the current state of the European strategies of Horizon 2020 and and the inclusion of KETs in them as driver of future work and the new responses that they incorporate from the science of security to establish the conclusions and opportunities of improvement for their projection in Horizon 2030; and third, the review of key areas in occupational risk prevention and OSH. (3) Conceptual framework: How and with what materials was the problem studied? This section describes the research procedures employed. (4) Conclusion: it is here that the contribution of this research is reaffirmed, and new lines of research to encourage future collaboration are proposed.

2. Background

In this section, a review will be carried out with the aim to answer the research questions (RQ I–III). The review is based on the proposal of Mayer [17], and is called Status Quo due to the fact that it corresponds to a description of the most current research on the emerging OSH 4.0 to 5.0 study concept. In this sense, Squires [18] calls this type of review descriptive, the purpose of which is to update useful concepts in evolving areas of knowledge. The research organisation in the present is showed in Figure 1.

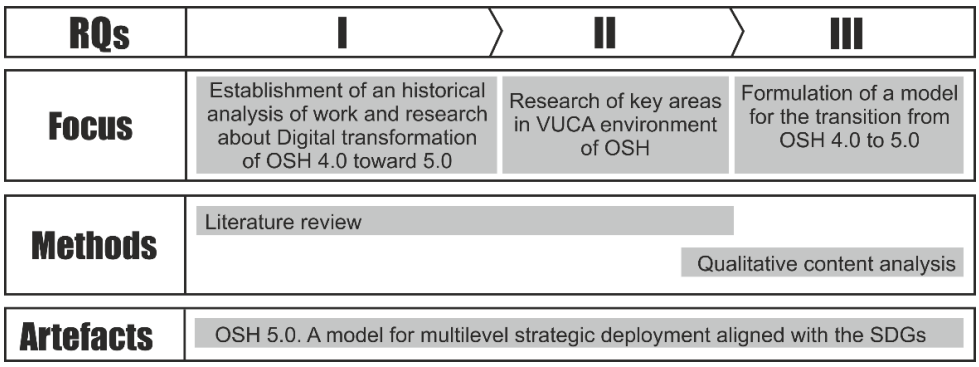

Figure 1. Research organisation. Source: own elaboration.

In order to answer the research questions proposed, a historical review is carried out about the evolution of work and the different elements that characterise it as a complex system, from Vygotsky's Activity Theory [19,20] to its analysis as an element that generates the metabolic rift [16], one of the consequences of which are the risks derived from work and its affectation to public health. Moreover, a historical overview includes the policies and incentives developed in the Horizon 2020 and an analysis of key areas about OSH to establish the lessons learned from their development in the different countries of the European Commission. The purpose is its projection into a new concept of OSH 4.0 to 5.0 from the science of the safety of complex systems that can be articulated under sustainability criteria, where quality, circular economy (CE) and health and safety constitute a triple source of value creation for work and the mitigation of the metabolic rift, being the Triple Button Line or 3E (Ecology, Economy and, Equity) a complementary analysis tool.

This section is divided into three main subsections that show, firstly, the evolution of prevention systems from Industry 1.0 (I1.0) to Industry 4.0 (I4.0) and its transition towards Industry 5.0 (I5.0), secondly, the analysis of OSH strategies based on Horizon 2020 to stablish the lessons learned and project them into a new model, and thirdly, the characterisation of key areas of ORP and OSH in the transition to Industry 4.0 to 5.0, whose model represents the way in which future work is developing.

2.1. Evolution of Work and OSH from I1.0 to I4.0 and towards I5.0

Health and safety and occupational risks is a preventive activity associated with the development of productive activity to obtain products or services under safe and healthy conditions for workers. Regarding knowledge of OSH and its mechanisms and processes for the identification and control of risk, it is necessary to consider the multidimensionality of work activity at a historical moment. For this purpose, and given its socio-technical character, the Activity Theory by Vygotsky in its version developed by Engeström [21–24] is adopted for the analysis of OSH, as shown in Figure 2.

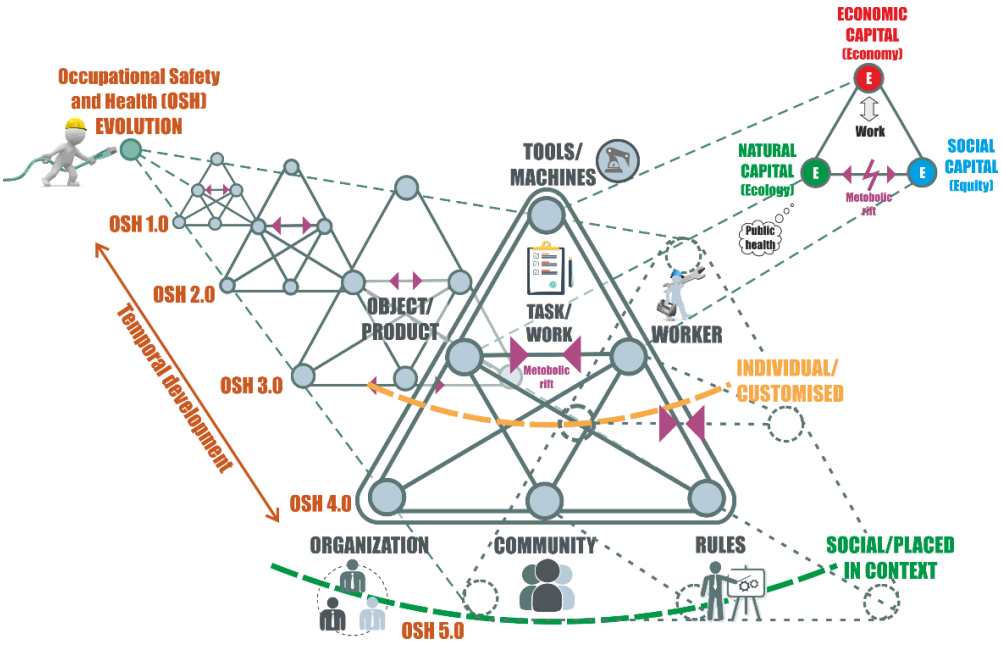

Figure 2. Evolution of labourial activity model. Source: own elaboration.

In order to examine the work, or the way in which industrial capital has given rise to the metabolic rift in its specification of occupational risks, the analysis of historical–cultural work activity based on Vygostky's Activity Theory is used in Figure 2. This will serve as an analytical tool to establish the evolution of OSH as a result of the major social transformations brought about by technological and work-related advances resulting from important discoveries in the scientific development of mankind.

Figure 2 shows the key elements in the Activity Theory such as: the worker or social capital that constitutes the technical system; the object or natural capital; and the tools or economic capital. The human actions transform natural capital with the use of tools. The separation of the natural and social capital through the work was named metabolic rift, a concept introduced by Marx and continued by Foster [16]. Organisation, community, and rules constitute the artifacts used in the activities to stablish the context.

The First Industrial Revolution [25–27], which dates its beginnings to the end of the 18th century (1750–1780), is a period in which hydraulic energy and the steam engine played decisive roles both for their contributions to industry and transport (the start of the mechanisation of production processes using water and steam) and for being the driving force for the invention of other devices such as the mechanical loom, which was developed

in the textile industry. There were also other revolutionary inventions of the time, such as gas heating and the sewing machine. During this period, the raw material used for energy was coal. The characterisation according to the Activity Theory for the OSH 1.0 is shown in Table 1.

Table 1. Work elements characterisation according to Activity Theory in the First Industrial Revolution (I1.0) and the OSH 1.0.

Tasks/Work	Tools/Machines/Environment	Worker	Object/Product	Organisation/Community/Rules
- Primitive. - Manual. - Non-standardised. - Beginning of their mechanisation.	- Not adapted to the worker. - No safety measures. - Steam engine and hydraulics. - Hydraulic power. - Unhealthy environment.	- No formal training for the task and its risks. - Does not receive risk and task information.	- Not secure. - Not optimised. - Not hygienic. - Not ergonomic.	- Transformation from craft to industrial or repetitive work. - Transition from workshop to factory work. - Incipient and informal organisation. - Tacit rules of the game. - No preventive culture in the community.
Risks	- Physical and hygienic risks. - Ergonomic.			
OSH 1.0 (Security Science)	- No systematic or prescriptive action on safety at work. - No prevention model in factories, or in other sectors such as mining, agriculture. - Lack of specific regulations. - Work as a source of metabolic rifts, its origins.			

The Second Industrial Revolution [27,28] dates from the end of the 19th century (1870) to the beginning of the 20th century and is characterised by advances in the form of energy used (electricity, gas, and oil) and its application to industry, mining, transport and domestic life. The use of steel in the construction of machinery, in domestic life, telephones and household appliances stands out. All this gives rise to mass production and the assembly line. Table 2 shows the characterisation of the work elements in Vygostky's Activity Theory and in OSH 2.0.

Table 2. Work elements characterisation according to Activity Theory in the Second Industrial Revolution (I2.0) and the OSH 2.0.

Tasks/Work	Tools/Machines/Environment	Worker	Object/Product	Organisation/Community/Rules
- Taylorism adapts the work to the worker. - Fordism or mass production. - Assembly line	- User customisation. - Electric automatisms with wired logic. - Unsafe and unhygienic. - Taylorism. - Electrical machines.	- Primary or basic training. - Basic health and safety training.	- Physical security aspects taken into account. - Rationalisation of the product. - Rationalisation of product and process.	- Scientific organisation of work (Taylor). - Administrative organisation, hierarchical structures (Fayol) - Division of labour and specialisation. - Incipient preventive culture. - From the waistline to the flexible line of work.
Risks	- Physical risk. - Ergonomic risk. - Hygienic risk.			
OSH 2.0 (Security Science)	- Prevention model focused on the safety and hygiene of production processes and the product. - Prescriptive models of occupational safety and industrial hygiene. - Accident insurance law in Spain and prescriptive framework in other countries. - Work intensifies the generation of metabolic rift.			

The Third Industrial Revolution [29] dates from the 20th century (1964) and is characterised by the incorporation of atomic energy into production processes and the rise of electronics and cybernetics. The automatisation and incorporation of information and communication technologies (ICT) into the processes. The move from the shop floor to in-line manufacturing or Flexible Manufacturing. It is also an era where the deployment of the aeronautical and astronautical industries shows a great peak, as well as the development of communication media (television, video, cinema, computers) and various means of transport. In addition, a digitalisation of processes and products is beginning to be observed, as shown in Table 3.

The latest revolution is referred to as the "Fourth Industrial Revolution" (since 2012) [30–33] and its transition to Industry 5. 0 (until today) is characterised by the digital transformation of organisations through machine-to-machine (M2M) connectivity, digital enablers such as IoT/IoS, Big Data, intelligent systems, Cloud Computing, virtualisation and simulation, collaborative robotics, intelligent human–robots, machine–machine collaborative work, incorporation of technological innovations, new work organisation, globalisation, inclusion of work and personal life, volatility of change and skills and knowledge, etc. The I4.0 to I5.0 transition, as shown in Table 4, should be considered as one of the three major economic and social transitions from linear to circular, from material to intangible and from analogue to digital.

Table 3. Work elements characterisation according to Activity Theory in the Third Industrial Revolution (I3.0) and the OSH 3.0.

Tasks/Work	Tools/Machines/Environment	Worker	Object/Product	Organisation/Community/Rules
- Task digitisation. - Formalisation of the task. - Quality. - Mandatory and real work. - Automation and flexibility.	- Process computerisation - Informatisation and automation of tasks - Digitalisation of tools. - Health and safety and environmental hygiene measures.	- Vocational training for workers - Health and safety training in vocational training studies. - Training and information in the workplace.	- Product safety. - Product ergonomics - Product optimisation	- Hierarchical, heterhierarchical and systemic organisational systems. - Socio-technical occupational system. - Macroergonomics. - Formalised rules of the game - Preventive culture in companies - Incorporation of ICT - Teamwork.
Risks	- Specific risks of new electrical and nuclear technologies. - Classic risks.			
OSH 3.0 (Security Science)	- Prevention model focused on process and product safety. - Law on the prevention of occupational hazards. - Prevention management model, prevention services as an organisational unit. Specialities of safety at work, hygiene, ergonomics and psychosociology. - Prevention management model from occupational risk prevention system. OHAS 18001. - Globalisation of productive activity and transnationalisation of the metabolic rift. Awareness of the loss of value and damage to the environment.			

Table 4. Work elements characterisation according to Activity Theory in the Fourth Industrial Revolution (I4.0) and the OSH 4.0 to 5.0.

Tasks/Work	Tools/Machines/Environment	Worker	Object/Product	Organisation/Community/Rules
- Virtual. - Cognitive. - Affective. - Emotional intelligence. - Teleworking. - Collaborative. - Creative. - Digital Taylorism. - Ecological. - Sustainable.	- Operational interfaces. - Simulation. - Cyberphysical twin. - Connected and intelligent safety, hygiene, and ergonomics. - Digital platforms. - Interactions with the environment.	- Operator 4.0. - Cyber-physical system. - Sensory and motor exoskeletons. - OSH training. - Co-robots. - Ecological awareness.	- Virtual. - CPS Product. - Ergo-ecological. - Connected and intelligent. - Sustainable, environmentally friendly.	- Virtual, connected and intelligent organisation. - Virtual and distributed organisation. - Multicultural rules of the game. - Cyber-physical system and digital transformation. - Disruptive innovations. - Preventive and sustainability culture. - VUCA (Volatility, Uncertainty, Complexity and Ambiguity) environments. - Digital Taylorism. - New modes of contracting. - From linear to circular. - From the tangible to the intangible. - From analogue to digital. - Sharing economy. - Decontextualisation of the workplace. Work in the family environment.
Risks	- Concept of risks as social, environmental, and economic loss of value and as an emergent property of complex systems. - New and emerging risks arising from new edge process technologies. - Radical Innovations. - New and emerging risks arising from new technologies, Industry 4.0 digital enablers, technology platforms and ways of executing future work. - Workforce characteristics in terms of training, motivation, and culture. - Risk and hazard as an emerging property of complex systems of cyber–physical socio-technical systems. Proactive conception of the risk of technologies in research.			
OSH 4.0 to 5.0 (Security Science)	- Conception of the science of safety from the science of complexity, in an integrated multi-scale, multi-level, and multi-aspect economic, environmental, and social way, under principles of minimum complexity with fractal organisational and management structure. - Prevention model focusing on ergonomics, applied psychosociology and ecology, integrated into Public Health policies and strategies as the organisation and direction of efforts to protect and repair health, by public authorities. - OSH model in the context of social sustainability as one of the three pillars of sustainability (economic, environmental and social). - Model of management based on cyber-physical systems, integrated multi-level and multi-scale, eco-ecological and the potential of KETs. - Connected and intelligent occupational risk prevention model in intelligent environments for connected and intelligent products, processes, embedded as part of the operational competence. - Integrated European, national and regional OSH strategies. - Continuous improvement of OSH by integration of advanced (edge) knowledge of preventive specialities and digital enablers. Articulation of techniques of anthropotechnology and other techniques of technology design for community health and safety—ethnotechnology. - Monitoring and control of health and safety in real time by intelligent connected systems and dashboards through indicators managed with systemic thinking. - Development of cyber-physical socio-technical systems aligned with the sustainable goals of the UN Horizon Agenda 2030. - Possibility of reversing the metabolic rift with the digitisation strategy of Industry 4.0 and the new developments in production and service models based on the circular economy.			

The transition process from Industry 4.0 to Industry 5.0 has its origin in 2011 in Germany as a strategy to become a leading provider of advanced manufacturing solutions and high-quality customised products. It was explicitly defined by the German government in Angela Merkel's speech in the European Parliament [34], in which she defined Industry 4.0 as: "The digital transformation of the entire sphere of industrial production through the fusion of digital technology and the internet with conventional industry". The risks associated with the transition from I4.0 to I5.0 constitute an opportunity for proactive safety science research and development based on complex systems science thinking and addressing a triple bottom line or 3E approach in economic, social, and environmental terms.

2.2. Analysis of OSH Strategies Based on the European Horizon 2020 and Lessons Learned

The European 2020 strategy is published in [35]. The strategic framework identifies three major challenges (CH): CH1—improve the implementation of existing health and safety standards, in particular by strengthening the capacity of micro and small enterprises to implement effective and efficient risk-prevention strategies; CH2—improve the prevention of work-related diseases by addressing new and emerging risks, without neglecting those that already exist; and CH3—take into account the aging of the EU workforce. In addition, there are seven objectives (Ob) with their actions on occupational health and safety: Ob1—further consolidate national strategies; Ob2—facilitate compliance

with occupational health and safety legislation, particularly by micro- and small enterprises; Ob3—improve the enforcement of occupational health and safety legislation by Member States; Ob4—simplify existing legislation; Ob5—manage the aging workforce and new emerging risks, and prevent occupational diseases and work-related illnesses; Ob6—improve statistical data collection and develop the information base; Ob7—better coordinate international and EU efforts to manage occupational health and safety at work and collaborate with international organisations.

From the analysis of the Challenges–Objectives–Actions contained in the European 2020 Strategy, it is possible to establish lessons learned in order to constitute a body of preventive knowledge for the transformation of future work. The 2020 Strategy quantifies the objectives to be achieved, as well as the indicators to measure and verify the degree of fulfilment, which allows economic authorities to acquire a level of commitment with society that did not exist before. This strategy does not focus exclusively on the achievement of economic objectives, but tries to combine them with environmental and other social objectives. Finally, the strategy has laid the foundations for the EU to consider longer-term goals, which will be essential for the future development of its economy and society. On the other hand, it is important to note that the envisaged objectives are oriented exclusively towards the EU countries as a whole, which is a delay, given that we live in the era of globalisation and, therefore, of the interconnection of economies [36]. Furthermore, it should be noted from the above analysis that there is no specification of the driving forces determining the transformation of work, such as: digitalisation and new technologies (Eff.1), virtualisation and dematerialisation (Eff.2), and sustainability and efficiency (Eff.3). Together with the above aspects, it is necessary to consider the absence of a holistic perspective of safety and health that integrates environmental deterioration and its influence on public health from a more general point of view of sustainability, equality, and community health (Eff.4). This must be framed by the principles of safety science and complex thinking [37,38].

The findings of the deployment of European health and safety policies and strategies are published in the report [39]. According to the seven key objectives defined at the beginning of this section (Ob.1, Ob.2, Ob.3, Ob.4, Ob.5, Ob.6, and Ob.7) the following countries can be classified as shown in Table 5. In addition, this table analyses the extent to which the strategies deployed by the different countries are oriented towards the driving forces of the future of work for the implementation of Industry 4.0 and its transition to Industry 5.0, as well as its driving forces such as digitalisation and new technologies (Eff.1), virtualisation and dematerialisation (Eff.2), sustainability and efficiency (Eff.3), and Public Health connection (Eff.4). Finally, there is also the contribution towards the Circular Economy (CE).

From the analysis of the reports made by the different countries for the deployment of the OSH strategy, the following can be concluded: (1) the seven objectives are mostly satisfied; (2) the OSH strategies of Horizon 2020 and the reports that the different countries have carried out in their implementation have been totally alien to the prospective, proactive, and resilient character, as they do not contain systematic strategic analyses such as the SWOT analysis (Strengths, Weaknesses, Opportunities, and Threats) from which the strategies are derived, which should have accompanied the preventive action to identify new and emerging risks arising from the implementation of I4.0 to I5.0; (3) in very few cases do the objectives of the strategies contemplate environmental aspects such as digitalisation, dematerialisation, and cyclicality and efficiency, and nor was OSH considered as an element of value creation for both companies and public health; (4) one aspect to consider due to the potential of digitalisation, connectivity, and cyber–physical systems is the triple bottom-line perspective of sustainability where the I4.0 to I5.0 transition involves the possibility of making products of higher personalised quality (economic value), with lower environmental impact (environmental value), and mitigating social impact (social value), including the safety, health, and well-being of workers; and (5) the incorporation of new technologies in the workplace beyond the labour consequences, which are mandatory, can be extended, given the indices derived from different studies [40].

Table 5. Achieving national objectives and efforts.

		Objectives from European Strategies							Efforts towards I4.0 to 5.0				CE Strategies
Country	**Time Frame**	**Ob.1**	**Ob.2**	**Ob.3**	**Ob.4**	**Ob.5**	**Ob.6**	**Ob.7**	**Eff.1**	**Eff.2**	**Eff.3**	**Eff.4**	
Austria	2013–2020	✓	✓	✓	✓	✓	×	✓	✓	×	×	×	×
Belgium	2016–2020	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	×
Bulgaria	2018–2020	✓	✓	✓	×	✓	✓	✓	×	×	×	×	×
Cyprus	2013–2020	✓	✓	✓	×	✓	✓	✓	×	×	×	×	×
Czech Rep.	2019–2020	✓	✓	✓	✓	✓	✓	✓	×	×	×	✓	×
Denmark	2011–2020	✓	✓	×	✓	✓	×	×	✓	×	×	×	×
Estonia	2019–2020	✓	✓	✓	✓	✓	×	×	×	×	×	×	×
Finland	Until 2030	✓	✓	✓	✓	✓	×	✓	✓	×	✓	×	×
France	2016–2020	✓	✓	✓	✓	✓	✓	×	✓	×	×	✓	×
Germany	2019–2024	✓	✓	✓	✓	✓	×	×	✓	×	×	×	×
Greece	2016–2020	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×
Hungary	2016–2022	✓	✓	✓	✓	✓	✓	×	✓	×	×	×	×
Italy	2014–2018	✓	✓	✓	✓	✓	✓	×	✓	×	✓	✓	×
Ireland	2019–2021	✓	✓	✓	✓	✓	✓	✓	×	×	✓	×	×
Latvia	2016–2020	✓	×	✓	×	✓	✓	×	✓	×	×	✓	×
Lithunia	2017–2021	✓	✓	✓	×	✓	✓	✓	✓	×	×	×	×
Malta	2014–2020	✓	✓	✓	✓	✓	✓	×	×	×	×	×	×
Netherland	No time	✓	✓	✓	✓	✓	✓	✓	✓	×	✓	×	×
Poland	2014–2019	✓	✓	✓	×	✓	×	✓	✓	✓	×	×	×
Portugal	2015–2020	✓	✓	✓	×	✓	✓	✓	✓	×	×	×	×
Romania	2018–2020	✓	✓	✓	✓	✓	✓	✓	×	×	✓	✓	×
Slovaquia	2016–2020	✓	✓	✓	✓	✓		✓	✓	×	✓	✓	×
Slovenia	2018–2027	✓	✓	✓	✓	✓	✓	✓	✓	×	×	✓	×
Spain	2015–2020	✓	✓	✓	×	✓	×	×	✓	×	✓	×	×
Sweden	2016–2020	✓	✓	✓	×	✓	×	×	✓	×	✓	×	×
United Kingdom	2010 and beyond	✓	✓	✓	✓	✓	✓	×	✓	×	✓	×	×

Due to the scope and diversity of strategies and the number of public resources they mobilise, it is necessary to have a unified framework that allows for an integrated deployment under a triple bottom-line approach in the three areas of sustainability based on the objectives of the Agenda 2030 for Sustainable Development of the UN. To this end, the conceptual frameworks of the driving forces of work transformation are reviewed below, which, together with the lessons learned, allow for the development of an OHS 5.0 framework aligned with the Sustainable Development Goals of the Agenda 2030.

2.3. Review of the Key Areas of Occupational Risk Prevention and OSH 4.0 to 5.0

The review of the key areas focuses on works referring to the Occupational Safety and Health (OSH) model associated with the production paradigm of Industry 4.0 to 5.0, known as "OSH 4.0 to 5.0". To this end, the search has been limited to the following areas that constitute the most significant features of OSH 4.0 to 5.0 as shown in Figure 3: (1) digital transformation and innovation of OSH 4.0 to 5.0; (2) preventive culture and OSH integration and simplicity; and (3) OSH 4.0 to 5.0 policies and strategies.

In Figure 3, the review areas [41–43] are structured as drivers of change and innovation that will determine the future of work in the context of the transition from I4.0 to I5.0 and the digital transformation of other production and service sectors through the disruptive action of digitisation, dematerialisation, circularity and efficiency.

The identification, characterisation and control of new and emerging risks in the context of the transition from Industry 4.0 to 5.0 is the subject of research by interdisciplinary teams given their complexity. The establishment of measures for prevention, monitoring and management requires new models, given that the existing ones are inadequate because they are built around traditional risks [41–45].

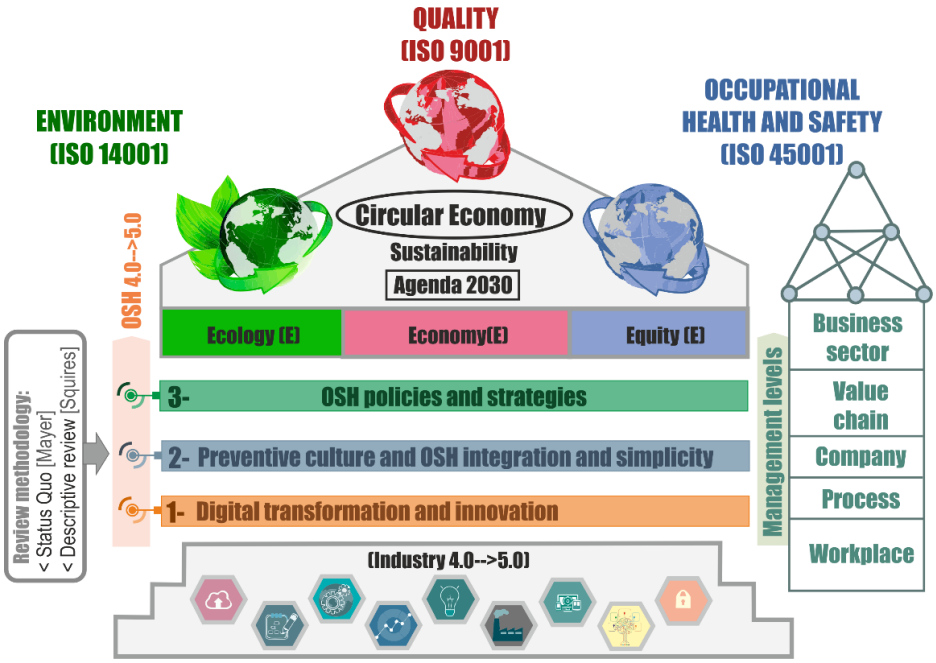

Figure 3. Bibliographic review areas of Industry 4.0 for its projection in the occupational health and safety. Source: own elaboration.

Based on the above-mentioned three key aspects to be analysed, there are the following:

(1) "Digital transformation and innovation" should not only be understood from the point of view of productive transformation through the incorporation of digital enablers (IoT, Big Data, Cloud Computing, co-robots, drones, 3D printing, cybersecurity, virtual and augmented reality, blockchain and 5G, virtual and augmented reality, blockchain and 5G) [46,47], but also in the context of the emergence of new professional roles, continuous learning and the interactivity of the human factor with technology in VUCA (Volatile, Uncertain, Complex, Ambiguous) environments through virtuality and connectivity [48]. All of this is framed in the context of hybridisation between the real and digital worlds supported with smart connected processes, where physical resources collaborate with virtual resources through connectivity [49]. The incorporation of digitalisation in I4.0 to I5.0 offers new possibilities for innovation, improvement and dealing with new and emerging risks in the field of occupational risk prevention, by incorporating emerging knowledge and neurocognitive computing technologies as well as safety and health aspects in smart environments with artificial intelligence (AI) [15,50], supporting operators in online problem solving, and learning through connectivist instructional techniques [51]. A complementary issue of digitalisation is the impact [52,53] on OSH management and its integration with other quality, environmental, and prevention management systems as an organisational unit and its relationship with other departments, with special emphasis on connectivity, sensorisation of data, the establishment of intelligent dashboards for OSH integrated with those of other management systems and the concept of cyber–physical systems of the different elements that make up the prevention service.

(2) "Preventive culture and Integration and simplicity of OSH 4.0 to 5.0", a key element of the future of work is a consequence of the adaptive response of companies to VUCA environments, through the creation of complex and intelligent socio-technical cyber-physical systems that evolve through the continuous innovation of processes and operations, which determines the incorporation of new technologies, knowledge and volatility of professional skills, with the re-engineering of the knowledge and competences of the worker and the organisation [54,55]. These VUCA work environment traits, together with the situation of performing work in isolation in

the home environment, represent new occupational risks inherent to the I4.0 to I5.0 company. The preventive culture as a construct formed by knowledge, affections, and behaviours located in an operational context, must be understood as the fundamental part of the organisational culture with an impact on the level of safety and health of the organisation [56,57]. Among the five modes of preventive culture listed in the so-called preventive ladder (pathological, reactive, calculating, proactive and generative) [58], only the proactive, generative, and resilient modes can be understood for the preventive culture of the I4.0 to I5.0 transition. Regarding the organisation of prevention services and external prevention services, different organisational models have been proposed, highlighting the fractal organisational model [59] as a model of minimum complexity [60,61], characterised by its self-similarity, scalar innovation, and growth through recursive processes, of special consideration in delocalised projects and activities of the inter-company value chain.

(3) "Policies and strategies of OSH 4.0 to 5.0 aligned with sustainability of Agenda 2030", it is necessary to consider that the current situation determines as inadequate OSH policy and legislation in the face of the changes arising from the implementation of I4.0 to I5.0 and the future of work in the different sectors induced by the force of change of digitalisation, virtualisation, and circularity and efficiency [2,15,62,63]. Thus, it is necessary to make a criticism of the different institutions for having a reactive attitude regarding the incorporation of digitalisation into OSH Policies, strategies, management and regulations; it is also necessary to highlight the work of the British Standards Institute (BSI), which can be mentioned as a pioneering institution thanks to its BS611 Official Ethical Guidance on Robots [64].

In conclusion, it is necessary to remember that individual nations must take the initiative to establish a European policy and legislative framework at their frontiers. It is the responsibility of each country to ensure compliance with European laws and to enrich them in order to achieve advocacy and enforcement of OHS 4.0 to 5.0 from their different levels.

3. Conceptual Framework for Setting Integrated Policies and Strategies on Occupational Safety and Health 4.0 (OSH 4.0 to 5.0)

The context of studies of the future of work regarding the establishment and deployment of Horizon 2020 strategies and its expected evolution can be found in different publications [10,39,62,65–67].

From the review of the 2020 strategy, its lesson learned and the challenges and opportunities arising from the key areas of Occupational Risk Prevention and OSH 4.0 to 5.0 frameworks, it emerges that the characteristics of work and risk that need to be considered in the strategies and incentives to support the transition from OSH 4.0 to 5.0 and the development of a framework for its integrated multilevel deployment are [62,68]:

- The existence of new and emerging professional profiles based on the management of KETs. As a result, there is a need to highlight in job skills those characteristics that make us more human, such as imagination, criticism, empathy, leadership, creativity, social skills, and affective behavior.
- Reduction of manual labor. The work of humans is focused on tasks that are proper to their thinking, creating social relationships with a collaborative approach. Work requires attention to the public with tasks whose work rhythm is determined by the client's part or by an algorithm; privacy and monitoring of work execution through technology; isolation or invisibility of the employee, loss of social contact. Incorporation of cobots [69].
- Precariousness, unpredictability and uncertainty in work and incomes; hiring on demand, by hours, without a stable contract. The existence of algorithms or Artificial Intelligence as the manager and director of work, with cession of control from the worker to the clients through evaluation. These working conditions may result from the relationship between Industry 4.0 and the sharing economy, since, if demand decreases, one of the ways to stay in the market, in addition to reducing costs, is to

increase productivity, and this is precisely the link between the sharing economy and Industry 4.0.

- Results transparency with loss of worker's privacy through the accessibility of work data. This is materialised through intelligent management with algorithms on data provided by the sensors implanted in the workers' wearables.
- Increased collaborative work, shared vision and mental models between humans and between humans and cobots, as well as between machines and intelligent robots. It is possible that this will lead us to work for algorithms. For example, writing offers for our digital twins in the cloud to make decisions.
- New ways of work organisation, as a consequence of the incorporation of KETs such as supplying power to an artificial intelligence system, powering ERPs, and so on. A distinction is made between ICT-based collaborative work, which can be done anywhere in the world, teaching AI, web recognition, feeding AI, etc.
- Proliferation of self-employed workers who have their own means, must manage their learning and required skills and OSH means. With a permanent connection waiting to receive orders without predictability, with intelligent management and supervision of the development of their activity through IA and social isolation in the development of the task. Dispossessing workers of the application of protective labour standards.
- Crowdsourcing or distributed collaboration or open outsourcing of tasks, which consists of externalising tasks that were traditionally performed by employees or suppliers, leaving them in charge of a large group of processes that are not strategic for the product or service presented by the company and that is carried out in a delocalised way through digital platforms.
- Transferring technologies, digitised work systems, and technological solutions to different countries in the third world that are not compatible with the cultural characteristics, the context, and auxiliary support technologies.
- Need for ubiquitous, virtual OSH systems embedded in organisational and industry value chain information systems with management techniques related to sustainable production and service operations.
- Innovation of OSH systems of service-oriented manufacturing (servitisation), whose operations are network-based with industrial platforms under shared economy, or Blockchain, among others.
- The digitisation and smartisation of OSH observatories so that they can carry out the overall mission that World Health Organisation (WHO) attributes to public health observatories to provide preventive and health intelligence so that actions aimed at different populations are evidence-based.
- Use of cloud, IOT, big data, cognitive computing, open data, and other KETs to obtain epidemiological data, share experience and improve occupational health and safety under a holistic model of public and community health.
- Variety of professional profiles in terms of demographic, transcultural and immigration variety that must be contemplated in the analysis of risks and preventive techniques in the delocalised work model.
- Training of technicians in occupational risk prevention at the levels of vocational training. Bachelor's, Master's and Doctorate degrees in the same condition as other regulated professions such as medicine, engineering, agriculture or health psychology with special emphasis on the characteristics of VUCA environments and the driving factors of work change and dynamic and complex preventive conditions.
- OSH approach beyond the prevention of occupational risks and diseases in the workplace, such as those derived from the effects of the natural environment modified by preventive impacts and, in general, a broader vision of OSH in the context of sustainability.

In view of this very complex transformation process in which the future work finds itself, the OIT [70,71] prepares reports in which the modes of action to address and resolve the challenges and opportunities of the new scenarios of the digitalisation of productive

and service activities are seen, which in general lines have a prospective, proactive and resilient anticipation character in the face of the VUCA characteristics of the future of Work.

Under these perspectives, a set of strategies is developed at European and national level to encourage the OSH, in Horizon 2020, based on the conclusions that constitute learned lessons on establishing a model for the deployment of integrated multilevel and multiscale strategies, policies and incentives for Horizon 2030 under the Sustainable Development Goals of the UN.

In order to formulate a model for the deployment of OSH 4.0 to 5.0 in Horizon 2030 from the security science of sustainable socio-technical cyber–physical systems, a starting point is taken from the lessons learned from the way in which the European OSH strategies [39] of Horizon 2020 have been deployed in the different countries, which have been structured for analysis in Table 5, containing the most substantive elements of the strategies of the different countries that make up the EU.

The proposed framework has three fundamental purposes: (1) aligning OSH integrally with broader goals such as the 17 Sustainable Development Goals of Agenda 2030; (2) realising this purpose under a conception of a triple-value reservoir in the three domains of sustainability by generating economic capital and reversing the damage of metabolic rift from the creation of social and environmental value; and (3) articulating the principles of security science from the framework of complexity science and complex thinking with integrated multi-level, multi-aspect analysis and top-down and bottom-up causality.

The conceptual framework can be sumarised as shown in Figure 4. This figure shows the value areas conceptualised from the triple bottom line—environmental, social, and economic—in which safety science abandons the hitherto existing conception in which the creation of economic value from work determined the loss of environmental and social value, giving rise to the metabolic rift. The central axis is the theory of activity that marks the level of activity of the OSH from an economic or labour point of view. This activity has a fractal character and can be deployed at several levels and scales of implementation, such as national, sectorial, value chain, or company, among others. From the interaction between natural and social capital comes the knowledge associated with the sustainable development goals of Agenda 2030. The new organisation of future work accompanied by a transition from OSH 4.0 to 5.0 must be considered as another element of value creation contributing to industrial, social, and environmental capital directly and indirectly to public health, and integrated through the mitigation of the metabolic rift that work has been developing since the first industrial revolution and that, with the 3E analysis, it is possible to obtain a triple bottom line of positive results. The metabolic rift has had a high impact on environmental damage and public health through occupational diseases, medical leave, job dissatisfaction, environmental deterioration through accidents, and emissions that affect community health, these relationships are reflected in the holistic conception proposed on the OSH 4.0 to 5.0.

The proposal is based on the conceptualisation of work in the context of sustainability from the 3E triple bottom line as a tool for exploring the triple value reservoir, which mitigates or reverses the metabolic rift as a global goal, and which can be fractalised at different scales and levels of intervention by public authorities and companies. All this constitutes a holistic framework that allows for the integration of strategies and incentives on operational excellence, the circular economy or other ecological and equity transition strategies, together with public and community health under the sustainability goals of the Agenda 2030 of the UN.

Figure 5 develops an integrated approach that supports the driving elements that constitute the design of work under digital transformation and 3E, articulated from security science, in order to enable the design of sustainable and adaptive cyber-physical socio-technical systems. This proposal is structured as a Strategy and Policy Deployment Matrix and supports its implementation. In this case, it is implemented at the company level.

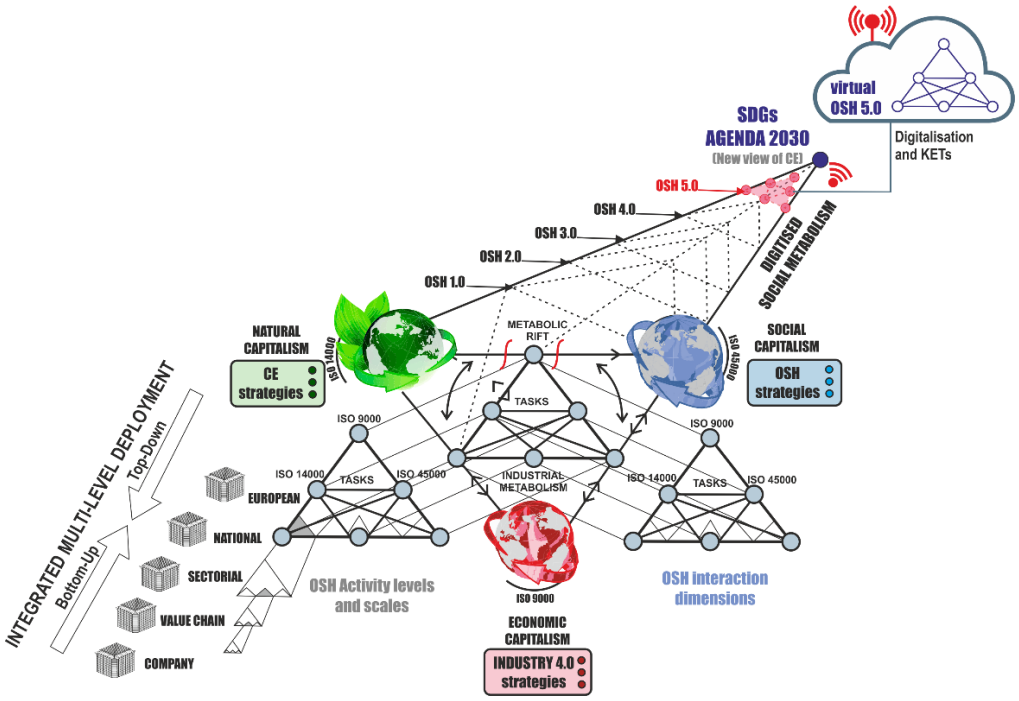

Figure 4. Conceptual framework for the deployment of OSH 4.0 policies and strategies from sustainability in the context of the metabolic rift of labour.

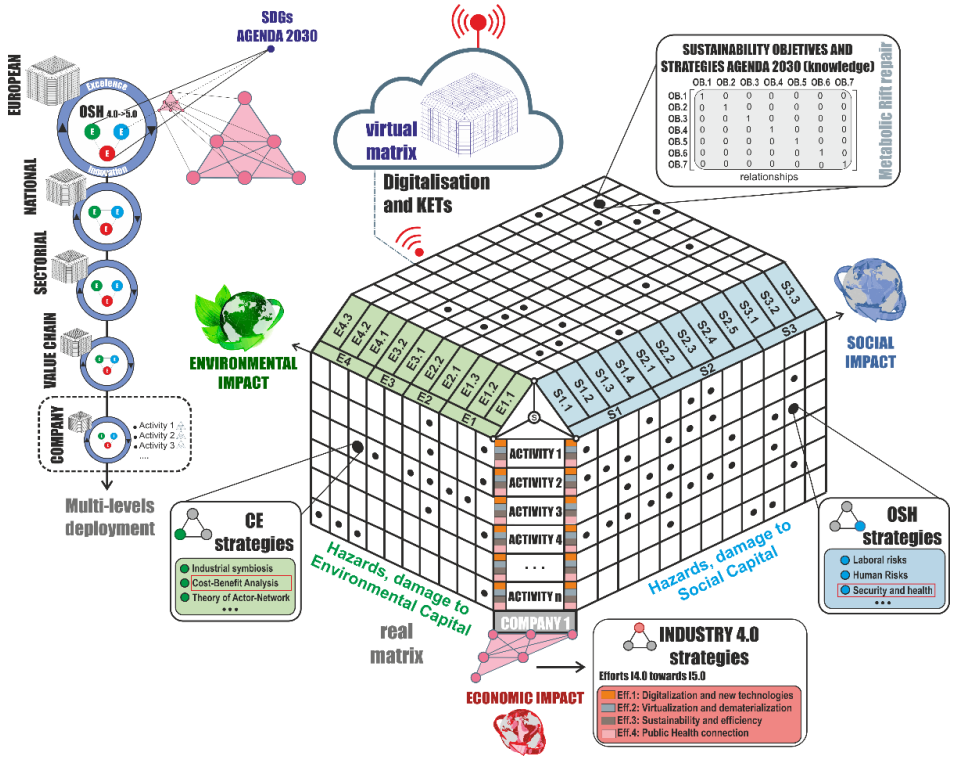

Figure 5. Matrix of integrated policy, strategy, and program deployment specific to the company level.

Figure 5 is characterised by a fractal deployment of multilevel and multiscale health and safety policies at European, national, regional, local and company levels, with the same scheme of analysis, design, implementation, monitoring, and establishment of learned lessons. Based on the science of complexity, it integrates the elements of social, economic and environmental sustainability as a reference for conceiving the socio-technical systems.

The matrix has three main parts. First, the central axis corresponds to the industrial capital which is constituted by the activities carried out at the company level and organised according to Vigotsky's activity theory as an instrument for the work organisation. Second, on the right axis is the social capital, which is organised according to the following levels: S1—preventive specialisation; S1.1—occupational medicine; S1.2—occupational safety; S1.3—ergonomic; and S1.4—hygiene. S2—laboral conditions; S2.1—laboral risks; S2.2—security and health; S2.3—innovative social projects (diversity); S2.4—human right; and S2.5—continuous improvement. S3—Material health; S3.1—nutrient type (metabolism); S3.2—material characteristics; and S3.3—VOC emissions. Third, on the left, is the environmental capital axis structured as: E1—production; E1.1—self-sufficiency for raw materials; E1.2—green public procurement and, E1.3—waste generation. E2—waste management; E2.1—recycling rates; and E2.2—recycling recovery for specific waste. E3—secondary raw material; E3.1—contribution of recycled materials to raw material demand; and, E3.2—trade in recyclable raw materials. E4—competitiveness and innovation; E4.1—private investment, jobs and gross value; E4.2—number of patents; and E4.3—number of patents related to secondary raw materials.

The central axis or economic capital interacts with social and environmental capital through the use of strategies, which allows the full potential of risks and hazards to be explored in an integrated manner by multidisciplinary teams and the value reservoirs available to security science from the driving forces available to security science under the paradigm of complexity and digital transformation, virtuality, and connectivity. Moreover, in the upper part of the matrix are interactions that establish the key hazard and risk indicators to form a scorecard based on the principles of security science to ensure the integrated deployment of integrated policies, strategies, and programmes to design and incorporate value into sustainable socio-technical systems to reverse the metabolic rift.

The matrix is a cyber–physical element and supports the full potential of the KETs or technological enablers that make up the transformative elements of work. Moreover, it contains all the driving elements of the transition from OSH 4.0 to 5.0, which were characterised in the section of review areas of drivers of Prevention of Occupational Risks and OSH 4.0 to 5.0, for multi-level and multi-scale deployment of safety and health policies and strategies.

4. Conclusions

The contributions of this paper correspond to the following areas of occupational risk prevention: (1) establishment of an analysis of work as a socio-technical system and characterisation of OSH through the elements that structure it from the Activity Theory of Work by Vygotsky and Engeström, for its projection in the smart and connected OSH, which is developed in Section 2.1; (2) establishment of the state-of-the-art of research aimed at organising the new and emerging model of work in VUCA environment aligned with the Sustainable Development Goals of Agenda 2030 and characterised through Industry 4.0 to 5.0 described and developed in Sections 2.2 and 2.3; and finally (3) formulation of a model for the transition from OSH 4.0 to 5.0 that supports the strategic deployment of integrated, multi-level, and multi-scale OSH public incentives, under the model of the fractal (self-similar) organizational enabler for Industry 4.0 of minimum complexity and generator of the variety required by the different host contexts, which is discussed in Section 3.

Activity theory focuses on the analysis of human activities and especially on complex work environments, because the factors that characterise a workplace can be open to change. From this point of view, the study of the evolution of work under this theory focuses on the design and characterisation of the different nodes in order to analyse the information collected in them for their projection towards the transition from OSH 4.0 to 5.0. The review of historical evolution of the work, makes special mention to the future of work which are characterised by: new technologies, use of new materials or substances, transculturality, globalisation of operations, changes in forms of work and organisation, the increasing

ageing of the working population, the gender and inclusive perspective, the incorporation of migrant workers, and psychosocial factors as emerging risks. These are all issues that should occupy the system of information, research and transfer of results in OSH to help companies, regions, countries and the EU in their process of permanent change.

With regard to the possible articulation under the proposed triple bottom line, the most characteristic elements for the transition from I4.0 to I5.0 are digital technologies, dematerialisation, cyclicality, and efficiency as factors of change, which will allow an OSH accompaniment in the design and development of future work. Among the potentials or sources of value of the elements of transformation are sensors, data, and artificial intelligence for their processing, which make it possible to know the elements of work, their conditions of execution, risk situations and the possibility of acting on them. Virtualisation and smart cyber–physical systems for simulation, forecasting, and problem-solving assistance to operators. The inclusion of wearables and exoskeletons as an extension of smart connected operating and personal protective equipment (PPE) is the first sign of digitalisation and its connection to the smart environment of ORP [72]. The achievement of a safe, healthy, and affective work future comes from the possibility to incorporate sensor devices into the work environment, allowing data to be obtained, which can be processed by artificial intelligence techniques. Big Data and Thick Data, for preventive purposes, together with connectivity, allow data and information to be collected and processed continuously, monitoring and controlling the OSH in real time. The use of simulation and virtual models is used for decision making in order to assess risk, establish safety and control measures and mitigate them through proactive management, being able to determine dangerous situations before they occur or become critical by analysing data and transforming it into information for prevention services through subrogated models, in the context of cyber-physical systems, extending all these possibilities to environmental and economic damage from the integrated management of hazards and risks. In addition, real-time dashboards of risk status and OSH measures for KPI-based management of the three dimensions of sustainability and the SDGs of Agenda 2030, in this case, the creation of historical records will be much more reliable and the detection process will be enriched. In this context of an intelligent environment, the development of PPE capable of self-management, as intelligent elements and not as mere sensors and transmitters of signals for interpretation by the prevention service, will be the next step in the digitalisation of the OSH. All the aspects indicated above determine that the transformation from I4.0 to I5.0 constitutes the method of representation of future work for its object of analysis, due to the great impact that technologies have on it and the conclusions can be extrapolated to the primary sector and the tertiary or service sector, under an integrated approach of the SDGs of the UN aimed at mitigating the metabolic rift. Future work will focus on the development of a multi-level and multi-scale information system architecture for compliance with OSH incentive policies and their alignment with the SDGs of the Agenda 2030.

Author Contributions: Conceptualization, M.J.Á.-G. and F.A.-G.; investigation, M.J.Á.-G. and S.S.-F.d.M.; methodology, M.J.Á.-G. and F.A.-G.; writing—original draft M.J.Á.-G. and S.S.-F.d.M.; writing—review and editing, M.J.Á.-G. and F.A.-G. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

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