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Quintuple Helix Innovation Model for the European Union Defense Industry—An Empirical Research

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Abstract: The European defense industry is undergoing profound upheavals, and traditional innovation models may no longer be adequate. For this reason, further investigation is needed to know if the triple helix (TH) is suitable for one of the most influential industries in the world. If not suitable, it is necessary to identify which type of n-helices are appropriate. This article follows an embedded case study research strategy that uses several sources of data collection such as interviews with active-duty military personnel, scholars, the defense industry, and interagency professionals. Field notes and official documentation were also collected for corroboration and triangulation purposes. The results showed that the defense industry is increasingly globalized, leaving the national sphere and weakening the action and participation of European Union governments. This research resulted in the design of a quintuple helix innovation model for the defense industry, which was based on a TH combined with technology and the natural environment. We concluded that the traditional TH may not be adequate for the entry of new supranational players and that political contributions are subject to a further response by the European states. Scientific research is also needed, especially in Asian and American countries, which have national defense policies different from those of Europe.

Keywords: defense industry; triple helix; N-helix; technology; environment; governments

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1. Introduction

The defense industry is a central instrument of national sovereignty and foreign policy [1–3]. Its importance is highlighted in the Treaty of Lisbon, in which European Union (EU) heads of state and governments held a debate on common defense [4]. From this debate, they identified a series of cooperation actions within the scope of the Common Security and Defense Policy (CSDP) [5], stressing the need for an integrated, sustainable, innovative, and competitive EU Defense Technological and Industrial Base (EDTIB) [6]. With the 2022 Russia–Ukraine war, the European defense industry has gained greater importance.

In this article, we emphasize innovation, considered a central engine of economic development, growth, and competitiveness of companies and nations [7]. In this regard, open innovation has become one of the hottest topics in several disciplines [8]. After Chesbrough's [9] notable publication a decade ago, many companies applied its conceptual guidelines, and many academic and practitioner journals have organized special issues inspired by that book [8,10,11]. Therefore, in recent years we have been witnessing a paradigm shift—moving from a "closed innovation" approach, where companies must "generate their own ideas and then develop, build, market, distribute, service, finance and support them on their own" [12], to "open innovation". According to Chesbrough [9], open innovation requires companies to use external and internal ideas and paths to market as firms seek to advance their technology. The model of open innovations (OI) can be compared with the triple helix (TH), which is composed of three institutional spheres (university–industry–government) as the primary actors [13,14]. The basic view is that the TH model is universal [15], but almost as soon as it was proposed, observers tried to add additional propellers to address issues beyond innovation [14]. Thus, our intention is to not vitiate the original purpose and go beyond the logic of simple additionality. In fact, there are several interpretations of helical models, sometimes deviating from their original intent, which confuses newcomers to the field concerning which helix model to apply in their empirical research [16]. At first glance, given the definition of OI, we might think that the concept does not tend to fit well with the characteristics of the defense industry. This is because OI incorporates many other different aspects than those of the TH, and these concepts simply cannot be leveled. An example of the above argument is that in the defense industry there are tensions between openness and secrecy [17]. However, in this regard, Langlois et al. [18] conducted a recent investigation within a company that operates in the defense and military industry, implementing an OI strategy. The authors found that adopting OI in such a secret environment opens up new possibilities for analyzing how companies can pursue openness and secrecy. Therefore, to keep pace with innovation, defense companies have recently launched a series of OI initiatives to seek out and integrate external knowledge into their internal development process. Thus, our research aims to use the universal TH model within the context of OI in the defense industry, such as similar research conducted in Portugal [2].

As we initially did not know how many helixes we would find, we defined the following research question (RQ): How does the European defense industry operate in the N-Helix model? Addressing this RQ allows for fulfilling a gap in the literature regarding the appropriate innovation model for the defense industry. In the Dutch context, Sezal and Giumelli [3] found that the triple helix model is suitable for the defense and security industry, feeding the needs of both the military defense establishment and the national economy. However, researchers such as Fernández Lorenzo et al. [19] and Reis et al. [20] highlighted that the development of the defense industry in an unknown n-helix model is a possibility. As far as we know, the literature has evolved from a triple helix, to quadruple, quintuple, . . . , and an N-Tuple of helixes [21], gravitating around stakeholders, internationalization, specialization, and ecological conservation, which offers various implications and interpretations [22]. Due to the numerous interpretations of the set of existing helices, the term N-Helix seemed to be the most appropriate at an early stage of this investigation, avoiding initial bias.

Our findings suggest a quintuple helix model for the defense industry, focused on technology and the natural environment. In this regard, within the scope of the TH model, the relationship between industry and universities was strengthened, while the relationship with the government weakened due to the entry of international players. Additionally, in the context of the quadruple helix, we show that there has been an increasing use of technologies, highlighting the need to automate the tactical level of warfare. Regarding the quintuple helix, although the results related to the natural environment seem a little disappointing, we identified a growing interest in environmental issues throughout the technological production chain from development to testing and implementation.

This article is organized according to the following sections: Section 2 discusses each of the helixes providing a holistic perspective; Section 3 discusses the research design and respective data analysis; Section 4 aims at presenting an empirical model for the defense industry; Section 5 presents the political, theoretical and managerial contributions, as well as limitations and recommendations for further research.

2. Conceptual Background

This section provides the basic concepts for discussion while describing the N-helix concepts, i.e., the triple helix model, devised by Etzkowitz and Leydesdorff [23,24], the quadruple and quintuple helix by Carayannis et al. [25,26], and the N-tuple of helices by Leydesdorff [21]. We end the section with a preliminary discussion of whether the traditional quintuple helix model is suitable for the defense industry.

2.1. Triple Helix, Quadruple Helix, Quintuple Helix and N-Tuple of Helices

Triple helix is widely recognized as a conceptual tool that promotes innovation and entrepreneurship through better understanding, cooperation, and interaction between university, industry, and government institutions, and supports economic growth and innovation policy design [16,27]. Thus, there is somehow a consensus that TH represents a central model for the production of knowledge and innovation [28]. Meanwhile, the relationship between university–industry–government (UIG) and its indicators has evolved over the last few years, giving rise to new paradigms [21]. Evolution went through the quadruple helix that contextualizes TH by adding "media and cultural audiences" and "civil society" [25]. The quintuple helix innovation model is more comprehensive, as it incorporates the "natural environments of society" [26] (Figure 1).

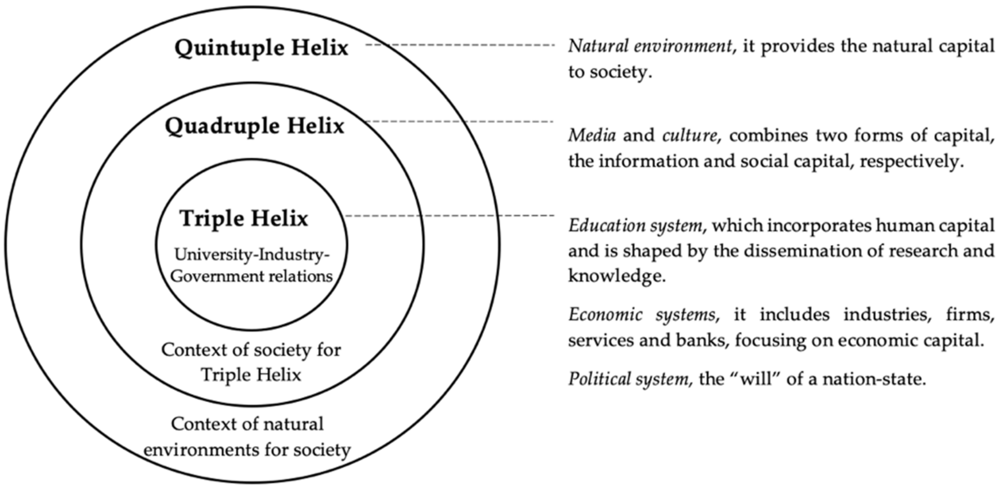

Figure 1. Triple, quadruple, and quintuple helix models. Adapted from the authors Carayannis and Campbell [28,29].

Later, Leydesdorff [30] also presented his model of "N-Tuple of Helices", which can be interpreted in different ways. It can be seen as a meta-reflection and comparison of different approaches to helices to allow for creative designs and redesigns, and, at the same time, it also expresses an "abstract" question [28]. However, while it is impossible to operationalize and show the development in the relatively simple case of three dimensions, Leydesdorff [30] recommends that scholars be cautious when generalizing beyond the TH model to an N-tuple of helices.

The complexity of the topic is closely related to the knowledge-based economy, as opposed to a political economy. In other words, the emphasis is on society being continually disturbed by the transformations that originate from the technosciences [31]. Leydesdorff [30] refers to the complexity of national innovation systems theory and presents a series of national systems case studies. In this regard, the Netherlands can be considered a national example of innovation. It became a tomato exporting country, although tomatoes do not grow naturally in that country—in a knowledge-based system, nothing is taken for granted that cannot be deconstructed and constructed innovatively. This case of a knowledge-based economy made universities more salient in the system, with less need for state action. In Germany, on the other hand, synergies must be made at the level of federal states, and in the case of Hungary, regional innovation has replaced the national–central system. For example, Budapest remained in a regional metropolitan and an independent innovation system, while the western part remained in a state-led innovation system; and the western part of the country was integrated into European innovation systems due to foreign/foreign investments. Leydesdorff [21,30] also mentions that innovation systems can be technology-specific or sector-based. Leydesdorff took the example of Japan, where the UIG relationship has declined despite policies in this direction. This is because academics increasingly co-author with foreign colleagues, favoring internationalization over industrial relevance. Therefore, in Japan, internationalization appeared as a fourth dimension in the design, requiring the addition of a fourth propeller to the model. In this regard, Leydesdorff [21,30] imagines an N-tuple or an alphabet of 20+ helices that can be envisioned.

2.2. Defense Industry—Is the Traditional Quintuple Helix Model Enough?

An analysis of the literature led us to identify two interesting issues. First, we found that high-tech defense industries focus more on tactical ground military capabilities [32–35]. Therefore, there is greater focus on technological growth at the tactical level of warfare. Second, it was possible to ascertain a growing concern with ecological sustainability in military operations [20,36]. These two preliminary insights were red flags for identifying two helices that are expected to be relevant: the technological and the environmental. However, some authors [20,32] present preliminary studies and suggest further research to obtain more solid evidence, which is what we intend to do with this article.

The article by Reis et al. [20] suggests that industrial activity is operating in a quintuple helix, with the deep involvement of universities and governments in innovation. Additionally, military innovations are being transferred to civil society, with increasing attention to the environment. Several notable authors [37,38] have focused on innovative military materials, which in some cases have been tested in operational environments (i.e., Besmayah, Iraq) [20]. Such materials included textile technologies that currently equip the Portuguese Army and have been instrumental to military missions abroad. As some of these articles are exploratory [20], we intend to deepen their results. At the same time, we argue that a specific quintuple helix is present for the defense industry based on TH, technology, and the environment.

3. Methodology

This article follows a qualitative embedded case study research strategy. The methodological orientation of the embedded case study research followed the guidelines of Yin [39]. Thus, embedded case studies contain more than one subunit of analysis, allowing a higher level of detail when compared to single case studies. This choice is justified by the need to conduct in-depth research on the defense industry, where the subunits allow for the presentation of particular details and a description of the phenomenon in greater depth. The selected unit of analysis is the Portuguese defense industry (idD Portugal Defense), with embedded cases presented below.

Thus, this article integrates three distinct cases (subunits): the first describes the use of TAKEVER's unmanned aerial vehicles (UAVs); the second focuses on the projects AuxDefense (advanced materials for defense), ACU (advanced combat uniform), and SCS (soldier's combat system); the third refers to the warfare ecology managed by idD Portugal. The subunits were selected by convenience sampling, a type of non-probabilistic sampling involving the sample being drawn from a conveniently available group of respondents [40,41]. In other words, acquiring data in the military context is sometimes tricky, provided that it is a very closed community and, in certain circumstances, requires some security clearance. In this regard, the first author was in a privileged position enabling access to data, both in Portugal and in the theaters of operation, where the materials were tested. Moreover, the idD Portugal Defense was selected as a unit of analysis due to its recent creation (2020) and for having projected international visibility to the Portuguese Defense Technological and Industrial Base (DTIB) [20]. DTIB currently comprises more than 380 organizations [42].

It is a set of public and private institutions, companies, and national scientific and technological centers. idD Portugal has been representing DTIB in the value chain with some global defense players (e.g., EU, NATO). We also highlight the mission of idD-Portugal in promoting the cooperation between the armed forces, companies, universities, and research centers (i.e., TH).

Following recently published articles [43], we defined the methodological process in three distinct phases: exploratory, analytical, and conclusive. The exploratory phase began with the search for scientific articles indexed in Scopus on technology and ecology in the defense industry. The preliminary search with the words "defense industry" and "technology" and "ecology" in title–abstract–keyword was conducted on 19 January 2022. The search yielded 31 articles that were read in full to obtain a holistic understanding of the existing literature.

The exploratory phase also included planning and preparing data collection from various sources. Specifically, it involved: (1) an initial contact by a research assistant with respondents (i.e., military personnel, researchers, and experts); (2) the elaboration of interview protocols [44,45] that were based on information previously collected from the literature [16,46,47], reports, and seminars organized by idD-Portugal; and (3) the data collection from the selected sources, which are presented below (Table 1).

Table 1. Sources of data collection.

Military/Rank	Quantity	Position (Place)	Interview Date
Lieutenant Colonel (OF-5)	2	NATO HQ Staff (Middle East)	April–May 2022
Major (OF-4)	3	NATO HQ Staff (Middle East)	March–April 2022
Lieutenant (OF-2)	2	Command, Training Role (Middle East)	February 2022
Sergeant First Class (OR-6)	2	Command, Training Role (Middle East)	February 2022
Sergeant First Class (OR-6)	2	UAV Operator (Central Africa)	July 2022
Experts/Job Title	**Quantity**	**Duty (Place)**	**Interview Date**
Academic/Researcher	1	Full Professor (University, Portugal/EU)	March 2022
Academic/Researcher	1	Assistant Professor (University, Portugal/EU)	March 2022
Manager/Expert	2	NATO Air Defense Systems Support and Supply (NSPA, Luxemburg/EU)	July 2022
Director/Expert	1	Executive Director (Private company, Portugal/EU)	March 2022
Manager/Expert	2	Project Manager (Private company, Portugal/EU)	March–April 2022
Activity	**Quantity**	**Type (Place)**	**Direct observation date**
Round Table	1	First study on Defense Economy in Portugal (National Defense Institute, Portugal/EU)	December 2021
Seminar	1	European Defense Fund (Webinar)	February 2022
Seminar	1	NATO 360°: Business and development opportunities (Webinar)	April 2022
Seminar	1	European Defense Fund: Challenges and Opportunities (Portuguese Military Academy, Portugal/EU)	April 2022
Type	**Quantity**	**Title**	**Official Documents (Publication Date)**
Report, NATO HQ Staff	3	End of tour and mission reports	2017–2022
Report, idD Portugal	1	*Defense Industrial Capabilities in Portugal/EU*	July 2022
Report, idD Portugal	1	*Demilitarization and Deactivation of Energy Materials*	July 2022

We selected highly recognized respondents who could describe the phenomenon from different perspectives. Based on the TH UIG, we selected respondents through convenience [40,48] and snowball sampling [49] from academic/scientific, industrial, and governmental areas. Specifically, we interviewed: (1) eleven military personnel of different ranks and levels of responsibility who had the opportunity to test military equipment in the Middle East and Central Africa; (2) two academic experts with a strong connection to industry and who developed intellectual property; (3) two managers from NATO Support and Procurement Agency (NSPA); and (4) three specialists from a private company (part of DTIB) who were responsible for producing military technologies. The interviews lasted 30–60 min, were transcribed in full, and sent to the interviewees to avoid misinterpretations. The research was conducted under the Declaration of Helsinki, i.e., respondents gave their permission and signed an informed consent form before participating in the study. In some exceptional cases, we observed that the discussion addressed topics about sensitive military activities, so the interviewees remained anonymous and none of this information was included in the transcripts.

For data corroboration and triangulation, we also carried out participant observation activities, mainly conducted by collecting information through informal conversations and discussions in seminars. In the scope of direct observation, we used a research diary [50] to record field notes, such as direct quotes and respondents' behaviors.

Lastly, we analyzed official documents (e.g., reports) from idD Portugal and military personnel to obtain greater rigor. To avoid presenting an excessive list in Table 1, we have included only a sample of the official documentation.

The analytical phase consisted of processing a significant amount of data (i.e., 6152 pages). To do so, we used inductive content analysis, a widely known technique from the social sciences [51]. We started by reading all the existing content: interview transcripts, field notes, and official documents. We then coded the phrases into categories and subcategories [52]. That is, we had to find patterns in the codes, identifying the most relevant ideas [53], allowing us to generate a map that gave us an overview of the data. Moreover, we used computer-based qualitative data analysis software (QDAS) NVIVO 12 (https://www.qsrinternational.com, accessed on 27 July 2022). NVIVO 12 enables a high quantity of qualitative data handling, reduces the time required for manual handling tasks, increases flexibility and depth in data handling, and provides more rigorous data analysis [54]. Regarding the validity and reliability of the results, the first author performed the content analysis process, while the last author performed an independent analysis to identify discrepancies, correct them and make the process more rigorous.

The conclusion phase aims to interpret, evaluate, describe, and discuss the evidence from the data analysis. In this context, we sought to identify opportunities and contributions related to the nexus between technology and ecology within the defense industry. Finally, we describe the limitations and recommendations of this research to broaden the discussion from a future research perspective.

Table 2, shown above, summarizes the methodological approach used in this article. It was intended to make the methodological process clearer, more objective, and easier to understand. Thus, in the table we can see the hierarchical relationship between the nature and strategy of the research, the (sub)units of analysis, sources of data collection, data analysis technique, and coding approach, as explained in this section but in an organized way.

Table 2. Summary of the methodological approach (adapted from Reis et al. [20]).

Methodological Process	Approach	
Research nature:	Qualitative research	
Research strategy:	Literature review	Embedded case study research
(Sub)unit of analysis:	Not applicable	TEKEVER Projects AuxDefense, ACU and SCS Warfare ecology
Sources of data collection:	Scopus database	Semi-structured interview Direct observation Official documents
Data analysis technique:	Full article reading for a holistic understanding	Content analysis
Coding approach:	Not applicable	Inductive

4. Results and Discussion

The results showed the Portuguese DTIB was relevant for designing a new empirical model of quintuple helix suitable for the defense industry. The next section presents a description and discussion of the research results.

4.1. The Portuguese DTIB

The Portuguese DTIB is currently formed by more than 380 companies, mainly small and medium-sized companies (SMEs) with dual function, organized in clusters [42] (Figure 2). But, DTIB is made up of more than only private companies, as it includes public institutions, and scientific and technological centers, making a total of 911 organizations [55]. These organizations can cooperate with each other and intervene in one or more phases of the equipment production cycle in defense and other domains, such as security, aeronautics, space, and sea. In other words, cooperation between organizations is usually very close throughout the project for developing military equipment, resorting to working groups or consortia.

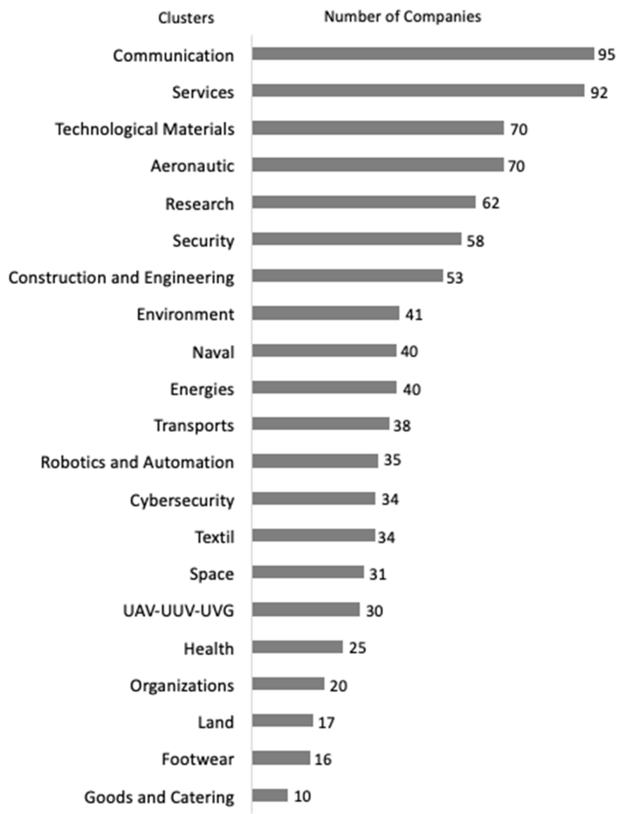

Figure 2. Portuguese Defense Technological and Industrial Base [55].

The Portuguese DTIB comprises a small number of organizations and thus has a flexible structure and is very innovative. The human capital is highly qualified, with knowledge and skills in technological areas and capabilities to develop products and provide services in all military domains. The Portuguese defense industry is also very segmented, being divided into 21 clusters. A series of consortia have been promoted to promote synergies between companies, as we will see later in this article (see case study 2).

4.1.1. Case Study 1—TEKEVER (Unmanned Aerial Vehicles)

The widespread use of technology in military operations has highlighted several opportunities. This research discloses the contributions of highly technological defense industries, namely mini-UAS (unmanned aerial system) and textile technology designed for military and commercial applications.

The first mini-UAV (unmanned aerial vehicle) used in a real-life situation was the fixed-wing mini-UAV AR4 Light Ray (Figure 3). The manufacturing company, TEKEVER, stresses that the equipment is ideal for intelligence, surveillance, target acquisition, and reconnaissance (ISTAR) missions [56], but it is not limited to these (e.g., perimeter security, battle damage assessment). TEKEVER is a startup born in the context of a university business incubator (UBI), and it started its activity by developing the first UAV in partnership with the Portuguese Army and the University of Aveiro. The company decided to start working within the scope of TH, since it could test the materials in real-life situations before entry into operations. The UAV was used in 2014, as part of a Portuguese mission within NATO in Kosovo. The AR4 Light Ray was used in Kosovo for reconnaissance and surveillance of large-scale events. In 2022, the Portuguese Army used UAVs in Central Africa for small tactical military use, i.e., reconnaissance, surveillance, and target acquisition (RSTA).

Figure 3. TAKEVER AR4 [56].

RSTA operations are mainly performed by a mini-UAV system. It is operated by two military personnel (i.e., a mission operator and an air vehicle operator) and requires an aircraft (UAV) and a ground control station (GCS) [56]. The short-range system is launched manually and does not require specific installation, only a vertical adjustment area. The RAVEN is a modern mini-UAV with a flight autonomy of between 60 to 90 min, covering distances from 48 to 72 km at a cruising speed of 26 knots (approx. 48 km/h) [57]. The RAVEN UAVs were acquired under a contract with the NATO Support and Procurement Agency (NSPA), having been awarded to the US company AeroVironment, to supply 12 Raven B Digital Data-Link systems (comprising three UAVs each) to the Portuguese Army [58].

As NATO's main logistics and procurement agency, the NSPA has been changing the TH paradigm in the EU, particularly in relation to the theory of national innovation systems (NIS). NIS are understood as "set of institutions that (jointly and individually) contribute to the development and diffusion of new technologies. These institutions provide the framework within which governments form and implement policies to influence the innovation process. As such, it is a system of interconnected institutions to create, store, and transfer the knowledge, skills, and artifacts which define new technologies" [59]. In this regard, the Portuguese DTIB has continued to collaborate with the State and its Armed Forces because they can test and certify military materials in real-life situations (e.g., the Middle East and Central Africa). After the military prototypes are tested and approved, the natural path in the industry is to contract military equipment with the State. However, the national defense industry (DTIB), which operates within the scope of TH, may prefer contracts with the local government. In the context of European public procurement, states are committed to contracting at the most competitive market value. The NSPA gains a competitive advantage in this context, as it aggregates requests from European states and can negotiate with European defense industries. Smaller EDTIBs find it more difficult to access large European contracts in this circumstance. Therefore, one of the original conclusions of this article highlights that the defense industry is increasingly globalized, leaving the national sphere and weakening the action and participation of EU governments as actors. The EU governments continue to be a player in the testing and certification of material in the theater of operations, but not as direct investors. In this context, idD Portugal has provided information on the NSPA to the Portuguese DTIB. The objective is to increase the turnover of Portuguese defense companies, enhancing their participation in NSPA contracts.

According to the respondents, there are three more issues that deserve due attention. First, the UAVs, initially designated for military purposes, are currently dual-use, providing support for forest surveillance and fire detection within the scope of operations to support the special device used for fighting rural fires in Portugal. Thus, UAVs are acquired for civil protection purposes, although the technology developed originates from the DTIB and the military. Second, RAVEN aircrafts operating in Central Africa allow military units to access hard-to-reach areas, reduce movement and optimize resources in military operations (e.g., energy, fuel), affording strength to the concept of warfare ecology. However, this is not the first priority of military use. An excerpt from the interviews clearly demonstrates this issue:

"In the Central African Republic, the quality of the data transmitted by RAVEN allowed to know whether certain military patrols were worth carrying out. In some cases, the surveillance of these aircrafts prevented the entire displacement of a motorized force. The RAVEN is electric and, although generators produce the energy, the environmental impact is minimal compared to a military patrol".

Third, it was possible to ascertain that developing new technologies has provided new momentum for the defense industry and military operations, particularly regarding tactical operations, where autonomous and/or unmanned systems are being developed. Thus, in this case, it was possible to empirically validate the results previously published in other literature reviews [32,33] and provide a better understanding of the phenomenon. That is, in the field of tactical military operations, where decisions are structured (i.e., following orders) and require complex analytical–cognitive tasks (e.g., real-life data acquisition/analysis) [32,33], the use of military technologies is confirmed to be rising.

4.1.2. Case Study 2—Projects AuxDefense (Advanced Materials for Defense), ACU (Advanced Combat Uniform) and SCS (Soldier´s Combat System)

As mentioned earlier, the DTIB currently has a representation of more than 380 organizations [42] and is highly segmented (+20 distinct segments) [20]. To mitigate segmentation and enable better coordination, the Portuguese Ministry of Defense opened a call to promote a consortium that became known as "AuxDefense". According to the respondents, the TH partnerships brought together the Portuguese Armed Forces (two of its three branches, namely Army and Air Force), a Portuguese university (University of Minho), technological platforms (Fibrenamics) and centers (Technological Center for Textile and Clothing Industries—CITEVE), as well as several private companies (e.g., LMA—textile) [20].

The organizations involved in AuxDefense started by developing lighter and more resistant military prototypes (e.g., bulletproof vests, helmets, elbow and knee pads) based on scientific research. In parallel, the ACU and SCS worked on developing advanced composite materials from auxetic textile structures. These auxetic fibrous structures reinforce polymeric matrices, allowing the fabrication of fibers in clothing components and military equipment [60]. As Underhill [42] mentioned, despite the vast literature on auxetic materials, the transition to industrial production at the desired commercial scale has been difficult. Therefore, the goal of AuxDefense/AUC/SCS was to develop innovative defense products and put military technologies into drill in different theatres of operation. The technology produced on the basis of advanced auxetic structures aimed for high performance in terms of mechanical protection, i.e., high resistance to cuts. According to the interviews, the battle dress uniform (BDU) and military protection equipment (helmets, bullet-proof vests, knee and elbow pads) developed with technological textile materials were tested in an operational environment (Figure 4).

Figure 4. Battle dress uniform and military protection equipment [61].

In other words, Portuguese soldiers deployed on a NATO mission in the Middle East had the opportunity to test the equipment in adverse conditions of heat and abrasion. Similar to case 1, these materials are just a few examples illustrating the relevance of certain military technologies and how they can protect military forces in light of the TH innovation model.

According to the experts (Table 1), three issues still deserve attention. First, the technology developed by AuxDefense/AUC/SCS was to be used at a tactical level for individual protection. In addition to military use, knowledge transfer is expected to enable commercialization in the civilian market. Civil materials are expected to have similar characteristics to military ones, as the interest in civil commercialization is associated with the same needs for energy absorption, impact resistance, hardness, and tenacity. For example, auxetic composite materials have great potential for applications where energy absorption is crucial in protection, such as sports protective gear and equipment, and others [20]. Second, the products developed by AuxDefense/AUC/SCS incorporated an environmental dimension. There was a weight reduction of about 20% (without loss of performance), greater resistance, greater comfort/ergonomics, improved temperature regulation [62], and material durability. Military personnel interviewed who had the opportunity to test the materials in the theatre of operations corroborated the arguments of academic experts and companies. An interviewee describes the use of BDUs in a theater of operations as follows:

“Conditions in the Iraqi theater of operations were extremely adverse, with very high temperatures. Comparing the current BDU with the previous version, I can tell you that this version is much lighter and has better performance, especially in terms of heat, as it allows for greater comfort and temperature regulation. Additionally, it is more resistant to abrasion, which gives it greater durability".

Third, there was consensus among military respondents, academics, researchers, and managers on the need to combine manufacturing with scientific research. For that reason, credit goes to the organizers of the AuxDefense conference series [38]. Moreover, the respondents also stressed the need for greater involvement of military universities and their respective research centers in defense industry projects.

4.1.3. Case Study 3—Warfare Ecology

We also found a nexus between technological development and the environment in the realm of warfare. Although the environment is not recognized as a core business of the Armed Forces, some steps are taken in that regard. As far as we know, war has always had the potential to alter the biosphere [63]. Note the legitimate concerns about the nuclear issue in the context of Russia's 2022 war with Ukraine. In addition to the destructive effects of nuclear weapons, they have extremely adverse effects on the structure and function of ecosystems, drastically altering the habitat and causing losses almost irreversible in the biosphere. Lawrence et al. [47] argue that due to the challenges associated with carrying out research in areas with military activity (e.g., restricted access), information regarding military impacts on the environment is relatively scarce and is often studied years after the end of military activities. For example, going back to the situation in Ukraine, after successive attacks on the Zaporizhzhia nuclear power plant, the International Atomic Energy Agency (IAEA) has still not been able to investigate the site. As mentioned by Lawrence et al. [47], in some specific circumstances, military activity is beneficial when exclusion zones are defined that result in population increase and/or recovery.

One of the most relevant issues identified in the analyzed data was the need for demilitarization, dismantling, and alienation (D3) of military assets. Thus, as a case study, this section focuses on processing end-of-life military systems. Although societies have become increasingly sensitive to environmental issues, the conservation and preservation of natural resources and energy efficiency in the military domain continue to be largely neglected. As identified in cases 1 and 2, the environmental dimension begins to take place in the development and production of military material (albeit limited). However, when it comes to the disposal of military equipment, innovation has fallen far short of expectations.

In Portugal, the D3 is carried out by idD Portugal. According to official sources, the quality and environment management system is certified according to ISO standards (9001:2015; 14001:2015) and NATO AQAP 2110 certification [64]. As of 2017, Portugal joined the NSPA D3. From that moment on, it also began to rely on this supranational institution. This put the Portuguese Armed Forces in better condition to make the most of their end-of-life military equipment. With the adhesion to NSPA D3, the Portuguese Government also started arguing that Portuguese private companies linked to the environmental sector would have better access to all tenders of this partnership [65], including the possibility of developing cooperation actions with industries from the current member-states of the program, thus generating new opportunities for defense industries.

Traditional government options have been donation, sale, and conversion for training or destruction, but other options exist. In this regard, and according to NSPA respondents, this organization has a clear ambition to introduce green initiatives aimed at reducing energy use and increasing recycling. The NSPA respondent's transcript is clear on this issue:

"In addition to the dynamics used by European states (donation, sale, and conversion to training or destruction), greener initiatives are needed, in particular in the context of the circular economy (CE)".

A recent publication in the field of sustainability corroborates the information above, particularly regarding the BDU case for the circular economy. The article by Reis et al. [66] demonstrates that the EU defense industry has been an important player in CE R strategies such as repurpose, remanufacture, repair, reuse, reduce, and rethink military materials. The contribution of new technologies has allowed military equipment, such as the BDU, to incorporate improved characteristics and fundamental circular economy measures for a green transition to be taken.

Yet, more practical dynamics and investment in this regard are needed. While the analysis of this case may seem a little disappointing to the reader, we have identified a clear environmental concern in all data collection sources, from the military on the ground and acting in NATO HQ, to universities, civil companies, and the NSPA. Clearly, this topic deserves further attention from the academic community; therefore, more research is needed at this point.

4.2. Empirical Model for the Defense Industry

Relating our results to the results of earlier research in the same geographic region, the article by Simões et al. [2] also identified a relationship between UIG, leading to a TH approach. Similar results were identified in the Brazilian Army, which in 2016 created the defense, industry and academy system (SisDIA) of innovation, operating in a TH model, to promote the development of innovations by taking advantage of the presence of the army in all regions of the country [67]. In Portugal, due to DTIB's segmentation, the UIG is managed in consortia supported by the government. However, the governments of EU member states are committed to contracting at the most competitive market value. For this reason, supranational agencies such as the NSPA have gained a competitive advantage. In these circumstances, (1) small companies of EU member states (e.g., startups) find it more difficult to access large European contracts; (2) governments have reduced their role as TH actors, as they are no longer direct investors in DTIB, and companies thus seek to establish new relationships with interagency organizations; (3) DTIB companies maintain a close relationship with universities to seek greater competitive advantage through innovation and knowledge transfer. Briefly, within the scope of the TH, the government does have the same influence in relation to the traditional TH innovation model (Figure 5).

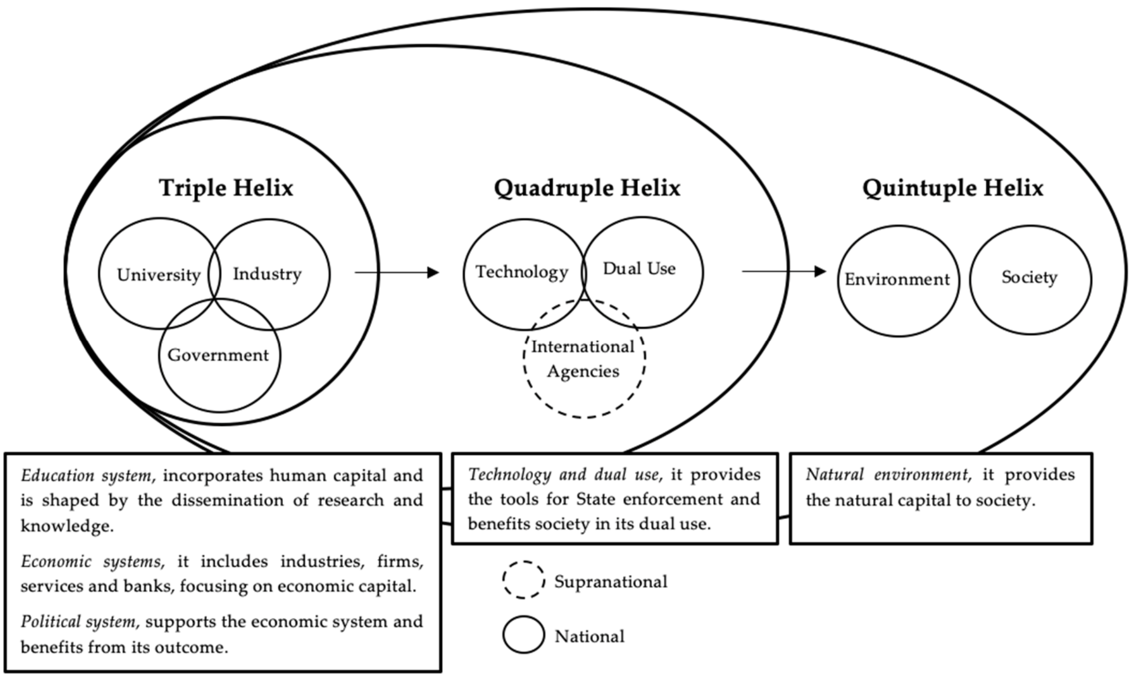

Figure 5. Empirical model for innovation in the European defense industry.

As far as the research question is concerned, the European defense industry operates in a quintuple helix model, although not in terms of the traditional model. Regarding the quadruple helix, the focus is no longer on "media and cultural audiences" and "civil society" but rather technology and dual use. In this regard, military technology seeks to provide the tools for state enforcement overseas. At the same time, these military innovations are being transferred to civil society, with increasing attention to the environment. Society becomes more relevant downstream, along with the environment, which remains one of the most pertinent aspects of the quintuple helix. In short, although the quintuple helix model for the defense industry has been previously proposed in the field of sustainability [66] and defense studies [20], the model is now presented in this article based on several real cases (empirical) and in much more depth than the earlier literature.

5. Conclusions

Following recent research [20], we have divided our conclusions into two subsections. The first focuses on contributions to policy, theory, and management, and the second on research limitations and suggestions for future research.

5.1. Political Contributions

The continued growth of military technologies has contributed to the development of new, high-tech defense products and ecological strategies, disrupting traditional innovation models. By adapting known innovation models to the reality of the defense industry, we realized that there is a long way to go for green transition in this type of industry. Policymakers should follow this path in the context of creating strategies for sustainable development. In this regard, the sustainable development of defense industries should not revolve strictly around the military operations and the strategic needs of EU states, but rather on a sustainable development approach that seeks a balance with the environment. Therefore, as a suggestion for policymakers and practitioners, innovation models should balance economic and defense issues with social needs (dual use) and the natural environment.

5.2. Theoretical and Managerial Contributions

The results of this article present relevant contributions to theory. Firstly, we found that the TH base model is not entirely suitable for the defense industry. If, on the one hand, the industry has sought to obtain greater synergy with universities, in relation to the government, the relationship has weakened. This is because the defense industry is increasingly globalized, leaving the national scope and seeking synergies in the European and international space. Secondly, we presented an empirical innovation model for the European defense industry. Our research resulted in the proposal of a quintuple helix model, mainly focused on technology and the natural environment. From the perspective of the natural environment, the results can be disappointing, but we have seen growing concern regarding the incorporation of the environmental issue into the entire technological production process: development, testing, and implementation. Management contributions relate to the empirical validation of results from previously published studies [32,68]. In this regard, we have shown that there has been increasing use of technologies at the tactical level of war. This result highlights the need to automate the tactical level; thus, defense managers should invest their time and resources in research and development. We also recommend greater involvement of universities and military research centers, synergies that are still underexplored by companies.

5.3. Limitations and Recommendations for Future Research

This article is limited by its methodological approach. Yin [39] refers that case studies do not have ambitions of statistical generalization. Therefore, as the research was carried out in a single EU country, it may not be generalizable to other geographies. Indeed, according to the policy of different regions of the world, there are different approaches to the defense industry [1]. For instance, some countries show an integration approach, such as the EU, which has witnessed many acquisitions and mergers within the European defense industry, as well as the coordination of European defense policy and arms procurement through the European defense industry (EDA). In other cases, countries present a domination approach, where governments promote the defense industry to become actors in the international arena. The most notable case of domination is the People's Republic of China, which seeks regional dominance through military diplomacy, particularly in strengthening military relations with its regional partners to weaken its opponents. Therefore, it is likely that for each approach, different results can be found. However, in our understanding, the results may have some degree of generalization at a European level. This argument finds support in the literature with several academic references to technological [69,70] and environmental [71] issues for different industries in the EU. However, we assume that the empirical model may have to be adapted slightly to spatial and temporal circumstances.

Further empirical research is needed, especially in Asian and American countries, as they have national defense policies significantly different from European ones [1]. Concerning the quintuple helix, we also argue that the results related to the natural environment seem a little disappointing. However, in this regard, the *European Defense Action Plan* (EDAP) is focused on the need to include CE and energy efficiency measures in the EU armed forces. Thus, it seems evident that European militaries, institutions, and defense industries are beginning to show an increasingly strong interest in the environmental domain, as defended by Fiott [72]. The above argument shows that CE strategies in safeguarding the natural environment are a hot topic within the scope of the EU defense industry. To understand whether the scientific production was aligned with the political orientation, on 24 September 2022, we performed a search on Elsevier's Scopus using the terms "circular economy" and "defense industry" without any results, which is surprising. For this reason, we recommend scientific research about CE in the defense industry to improve the natural environment.

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