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Helix Trilogy: the Triple, Quadruple, and Quintuple Innovation Helices from a Theory, Policy, and Practice Set of Perspectives

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Abstract

For an understanding of the concept of the Quadruple and Quintuple Helix Innovation Systems, it is essential to realize that the Quadruple and Quintuple Helices are based on democracy and ecology. This has two implications: (1) the further advancement and evolution of knowledge and innovation are requiring a co-evolution with democracy or knowledge democracy, and (2) ecology, ecological sensitivity, and environmental protection are a necessity for the survival of humanity, but they should also be regarded as drivers for further knowledge production and innovation development. This implies that for an innovation system to be a Quadruple and Quintuple Helix Innovation System, the government and the political system, addressing the innovation system, must be democratic in substance, and not only in form. This indicates how a Quadruple and Quintuple Helix differs from Triple Helix approaches to innovation. Furthermore, within the framework of Quadruple and Quintuple Helix, the "Democracy of Climate" for innovation and the "Democracy of Knowledge" are combined together in creating a nexus. Implications for strategy, policy, and practice are manifold, also incorporating aspects of Industry 5.0 and Society 5.0.

Keywords Anthropocene · Democracy · Democracy as innovation enabler · Democracy 5.0 · Digital transformation · Helix trilogy · Industry 4.0 · Industry 5.0 · Mode 3 knowledge production · Quadruple and Quintuple Helix Innovation Systems · Society 5.0 · Triple Helix

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Introduction: a Comparison of the Different Helix Approaches

> "Democracy and the Environment are Endangered Species"
> Elias G. Carayannis, Interview to Riconfigure EU Project, November 2019 (Carayannis, 2020a).

This analysis refers to the so-called 'Triple Trilogy' in terms of reviewing the Triple, Quadruple, and Quintuple Innovation Helices from a theory, policy, and practice set of perspectives.

Back in 1962, Thomas S. Kuhn published his famous book, "The Structure of Scientific Revolution," in which he refers to the understanding that there is an evolution of thoughts, with several cross-influences, different ideational stages, and also with an option of learning in the world of thoughts. We see this as a background for the approach here, as we are interested to compare more systematically the Triple Helix, Quadruple Helix and Quintuple Helix Innovation Systems. The focus of analysis is clearly on the Quadruple and Quintuple Helix.

The analysis is structured into the following sections: the "Triple Helix, and the Quadruple and Quintuple Helix Innovation Systems: Their History in a Short Overview" section provides a short historical overview, while the "Different Advanced Conceptual Building Blocks of the Quadruple and Quintuple Helix Innovation Systems: Industry 4.0, Industry 5.0, and Society 5.0" section focuses on Industry 4.0, Industry 5.0, and Society 5.0. In the "Conclusion and Outlook" section it is validated why the concept of the Quadruple and Quintuple Helix Innovation Systems depends on democracy and ecology, and is furthermore based on democracy and ecology.

Triple Helix and the Quadruple and Quintuple Helix Innovation Systems: Their History in a Short Overview

> "Should the public perhaps be considered as a fourth strand to be added to the Triple Helix model? In our opinion, the conceptualization of the public as merely a fourth helix narrows the public into another private sphere, rather than seeing civil society as the foundation of the enterprise of innovation" (Leydesdorff & Etzkowitz, 2003, p. 57).
> "Several contributors raised the issue of a fourth or fifth helix and one author provocatively suggested that we could perhaps also develop a Triple Felix model …" (Leydesdorff & Etzkowitz, 2003, p. 59).
> "Three helices are sufficiently complex to understand the social reproduction of the dynamics of innovation" (Leydesdorff & Etzkowitz, 1998; Etzkowitz & Leydesdorff, 2000); "the three institutional spheres can be identified in our type of society as industry, academia, and government" (Leydesdorff & Etzkowitz, 2003, p. 60).

In their assessment, Yuzhuo Cai and Annina Lattu (2020) indicate as early publications, where the Triple Helix was introduced and explained systematically, Etzkowitz and Leydesdorff (1995) (for the introduction) and (2000) (for the comprehensive explanation). The possible adding of a fourth helix was discussed by Leydesdorff and Etzkowitz in (2003) (p. 57; see also Leydesdorff and Etzkowitz, 1998 or Leydesdorff & Smith, 2021). Somewhat later, in the year 2012, Leyesdorff also introduced his concept of "N-Tuple of Helices" in an article in a special issue released by the *Journal of the Knowledge Economy*, which is lead-edited by Elias G. Carayannis (Leydersdorff, 2012). Summarized in a short note, it could be said and argued that the Triple Helix is representing a core model for knowledge production and innovation, but where the emphasis is placed on the economy (knowledge economy), in relation with the higher education system and the state (government), but where the status of a political system, particularly whether it is democratic or non-democratic, does not really matter.

First forms of pre-early work on the Quadruple Helix already date as far back as the early 1990, and continued from there on (Carayannis & Maldifassi, 1992; Carayannis, 1994a, b; Carayannis, 1998, 2001; Carayannis & Gonzalez, 2003a, b). It is generally acknowledged and widely accepted that Elias G. Carayannis and David F. J. Campbell are the two co-creators of the "Quadruple and Quintuple Helix Innovation Systems," based on their article publications in journals "Quadruple Helix" (Carayannis & Campbell, 2009) and "Quintuple Helix" (Carayannis & Campbell, 2010). These articles were released in peer-reviewed journals that are also represented in standard citation journal data bases. In a secondary open-access article publication shortly afterward, Carayannis et al. (2012) provided a further reasoning for the Quadruple and Quintuple Helix. "The conceptual and theoretical work on the Quadruple and Quintuple Helix innovation systems is original work, which, from the beginning, is work that was or is being designed as a four-helix or five-helix model, and this is something very different from being a fourth (or fifth) helix to a Triple Helix model" (Carayannis & Campbell, 2021, p. 3).

The Quadruple and Quintuple Helix Innovation System, as a concept (perhaps also as a theory), has not emerged in an "intellectual vacuum but was motivated by other intellectual narratives and furthermore refers to international discourses. The Quadruple and Quintuple Helix models provide a substantially broader contextualization of the "Triple Helix" (as described by Etzkowitz & Leydesdorff, 2000), the "Quattro Helix" (Danilda et al., 2009), and the "mode 2 of knowledge production" (Gibbons et al., 1994). It is important to emphasize that the Quadruple Helix (Carayannis & Campbell, 2009) not only has led to the somewhat later development of the Quintuple Helix (Carayannis & Campbell, 2010), but also directly associates with the already earlier conceptual development of the so-called 'mode 3' knowledge production (Carayannis & Campbell, 2006). The full title of the article released in 2009 (Carayannis and Campbell), therefore, is also "'Mode 3' and 'Quadruple Helix': Toward a 21st Century Fractal Innovation Ecosystem." Consequently, the first academic mentioning of "mode 3" as a mode and type of knowledge production was in a book chapter, published in 2006 (Carayannis & Campbell, 2006). The book in 2012, which provided a further-going summary of the Quadruple and Quintuple Helix, displays these conceptual cross-connections: "Mode 3 Knowledge Production in Quadruple Helix Innovation Systems. 21st Century Democracy, Innovation, and Entrepreneurship for Development" (Carayannis & Campbell, 2012; on this, follow also the following link: http://www.

springer.com/cda/content/document/cda_downloaddocument/9781461420613-c1.pdf?SGWID=0-0-45-1263639-p174250662).

It is important to recognize that from the beginning, the concept of the Quadruple and Quintuple Helix Innovation System also had a sensitivity for the encouragement of the arts and their importance for knowledge and innovation. As Carayannis and Campbell (2021, p. 4) are stating here (see also Fig. 1 for a graphical visualization):

> "In general, universities and higher education institutions have three main functions: teaching and education, research (research and experimental development, R&D) as well as what is called 'third mission' or 'third party' activities or outreach actions and initiatives, for example, innovation, democracy, and civic education (Campbell & Carayannis, 2013b, p. 5). One question arising is as to whether, as to what degree and how the art universities are differing from the scientific universities (in the world of the sciences). Certainly, art universities emphasize the arts, and the arts are different from the sciences. Yet, even art universities themselves frequently refer to the sciences. Thus, art universities can help co-create and co-develop further skills and competences for the teaching of the sciences and the conducting of research in the sciences. The other major challenge for art universities is to undertake 'artistic research' and 'arts-based innovation.' In doing so, art universities and higher education institutions are also closely linked with national innovation systems and multi-level innovation systems. This widens the interdisciplinary and transdisciplinary spectrum of higher education institutions. Artistic research complements art teaching in art universities (see also the analysis in Bast, 2013). Universities of the arts and universities of sciences can join forces, and these associations can suggest new organizational structures to encourage creativity (Campbell & Carayannis, 2013a). When asking what the purpose of the arts is, the traditional answer is inclined to refer to 'aesthetics'. However, the arts may also be considered to represent a manifestation of knowledge" (see also Carayannis & Campbell, 2015).

Traditionally understood, academic research (of universities of the sciences) focuses on basic research, commonly in reference to academic disciplines, and without a particular interest in the practical use of knowledge or innovation. This model of knowledge creation of the universities also has been called "mode 1" of knowledge production (Gibbons et al., 1994). Mode 1 is compatible with the so-called linear model of innovation, which is usually being attributed to Vannevar Bush (1945). This linear mode states that there is first a basic research in a university context, which gradually diffuses out into economy and the society. Economy and society (sometimes also politics) refer to these basic research activities and outcomes of universities, and transform them into applications and innovations, often with an economic interest to collect revenues or profit. The one final rationale here is to create economic and commercial successes and success stories in markets, more precisely in markets outside of (or beyond) the higher education system. In this framework of a linear innovation approach, we are facing a "sequential cause-effect relationship," where there is first basic research (knowledge production) within the universities (the higher education system), and then

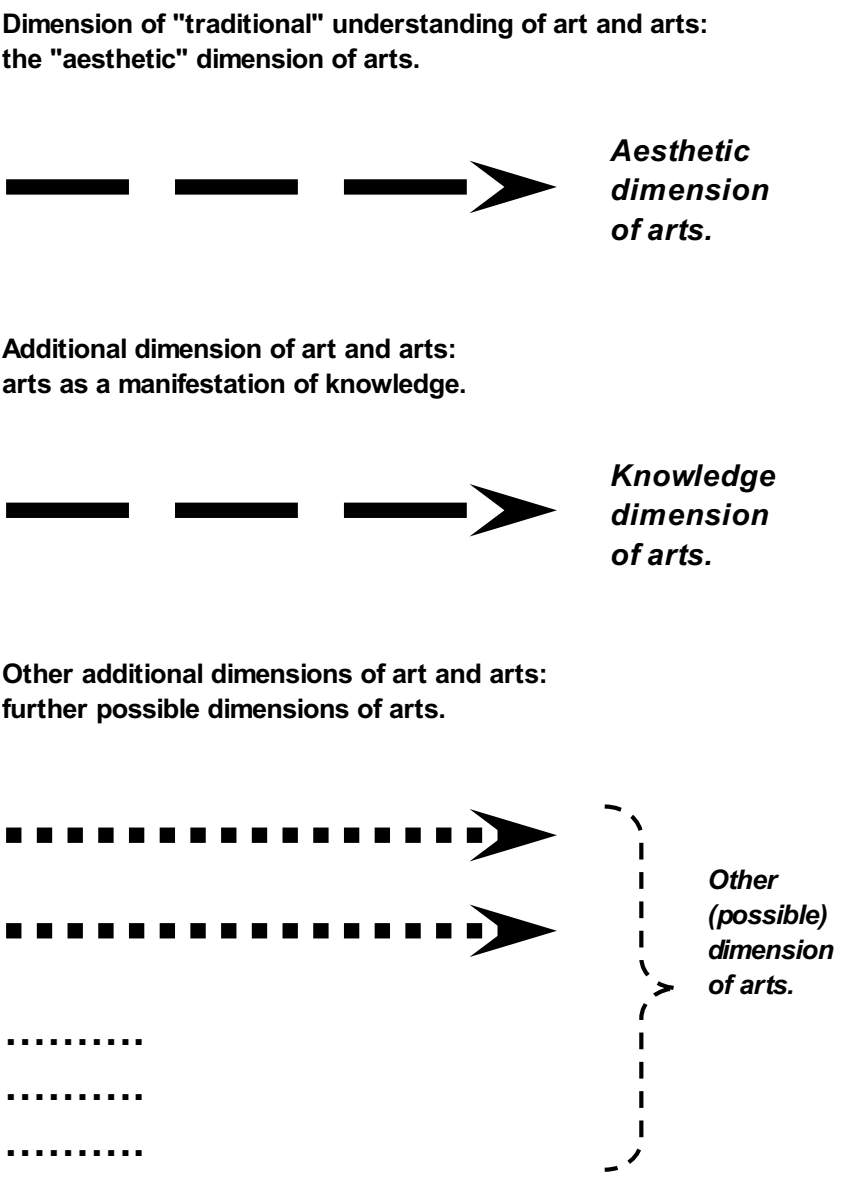

Fig. 1 Conceptualization of art and arts. Source: authors' own conceptualization and adopted from Carayannis and Campbell (2009)

innovation (knowledge application) outside of the universities, but where application and innovation are taking place clearly after the university-based basic research.

Knowledge production, in terms of a "mode 2" format, is emphasizing a knowledge production that is designed for the purpose of a problem solving, and refers to the following principles: "knowledge production in an application context,"

"transdisciplinarity," "heterogeneity and organizational diversity," "social responsibility and reflexivity," and "quality control" (see Nowotny et al., 2001, 2003, 2006; see furthermore Carayannis et al., 2017). The priority here is to focus on a knowledge production with the implication of practical purposes. Mode 2 acknowledges and promotes innovation and innovation activities. In contrast to the "linear model of innovation," the "models of non-linear innovation" are interested to link knowledge production more directly with knowledge application (innovation), by particularly and directly coupling basic research and innovation, which are then not seen as successive steps, but as steps in a parallel advancement. Mode 2 appears to be prepared to support models of non-linear innovation, with all their ramifications.

Henry Etzkowitz and Loet Leydesdorff (2000, pp. 111–112) introduced the so-called Triple Helix model of knowledge and innovation that is focusing more specifically on the relationship and interactions of academia, industry, and government. These three helices, through their interconnectedness and mutual shaping and co-shaping, are creating national innovation systems with their dynamical flows and spins. The helices represent the following three systems and sectors, which are academia (universities or higher education institutes), industry (business), and the state (government).

Furthermore, Etzkowitz and Leydesdorff are inclined to emphasize "trilateral networks and hybrid organizations," promoting relationships and networks between university, industry, and government and creating a hybrid interconnection between the different helices. In the words of Etzkowitz and Leydesdorff (2000, p. 118), the Triple Helix is a model that interprets the mode 2 as a shift (or transformation) in the ways of scientific knowledge production, while the Triple Helix itself may be regarded as a superstructure in societal terms, which places on "top" of those processes of knowledge production and the transformations of knowledge production: "[The] Triple Helix overlay provides a model at the level of social structure for the explanation of Mode 2 as an historically emerging structure for the production of scientific knowledge, and its relation to Mode 1." Later, Leydesdorff (2012) also introduced the "N-Tuple Helix" model (Park, 2014).

Mode 1 and mode 2 qualify to be interpreted as "knowledge paradigms" (or at least have the potential for this), which explain how knowledge production and knowledge application are operating within universities and other higher education institutions. Based on mode 1, a definition for quality and success is "academic excellence, which is a comprehensive explanation of the world (and of society) on the basis of 'basic principles' or 'first principles', as is being judged by knowledge producer communities (academic communities structured according to a disciplinary framed peer review system)." Based on mode 2, quality and success can be defined as "problem-solving, which is a useful (efficient, effective) problem-solving for the world (and for society), as is being judged by knowledge producer and knowledge user communities" (Campbell & Carayannis, 2013b, p. 32; furthermore, see also Campbell & Carayannis, 2013a, c, 2016a, b).

The "mode 3" university and the "mode 3" higher education institution, represents a type of organization, institution, or even a system, which are interested in connecting, integrating, and combining different modes or principles of knowledge production (research) and knowledge application (innovation), by this fully enabling

and promoting a diversity and heterogeneity of and in knowledge and innovation. This encourages to create creative contexts for research and innovation within organizations. Consequently, mode 3 is in line with the promotion of "creative knowledge environments" (Hemlin et al., 2004).

"Mode 3" type universities, higher education institutions, and higher education systems are based on designs that are encouraging a "basic research in the context of application" (Campbell & Carayannis, 2013b, p. 34). This should also unfold the qualities of non-linear innovation. Governance decisions require an understanding according to which mode of knowledge production and knowledge application (innovation) an organization operates, for example, whether the organization follows the rationales of mode 1, mode 2, or mode 3 (or variations thereof). Here, the concept of "epistemic governance" is explicit, implying that the underlying knowledge concepts of knowledge and innovation are being directly addressed, since this is necessary to promote quality and a continuous quality improvement as a result of strategies, policies and measures (Campbell & Carayannis, 2013b, c). "Epistemic governance is referring explicitly to the 'underlying understandings' that are underlying the structures and processes of an organization" (Carayannis & Campbell, 2021, p. 7). There are even further implications in reference with the Fractal Education, Innovation, and Entrepreneurship (FREIE) proposition (Carayannis & Campbell, 2011).

"The competitiveness and superiority of a knowledge system or the degree of development of a knowledge system are particularly determined by their adaptive capability and capacity to combine and integrate several and different modes of knowledge and innovation through co-evolution, co-specialization and 'co-opetition' (cooperation and competition), also of stock-and-flow dynamics" (Carayannis & Campbell, 2009, p. 201; Carayannis, 2008; in reference to "Co-Opetition" see also Brandenburger & Nalebuff, 1997). There is the proposition (and assumption) of a co-development and co-evolution of a knowledge diversity and heterogeneity in advanced knowledge society and knowledge economy and the political pluralism and quality of democracy in an advanced democracy (knowledge democracy) (Campbell, 2019). The "Democracy of Knowledge" also is cross-referencing to such processes of co-development.

Accordingly, "The Democracy of Knowledge, as a concept and metaphor, highlights and underscores parallel processes between political pluralism in advanced democracy, and knowledge and innovation heterogeneity and diversity in advanced economy and society. Here, we may observe a hybrid overlapping between the knowledge economy, knowledge society and knowledge democracy" (Carayannis & Campbell, 2012, p. 55). The idea of a "Knowledge Democracy" clearly is further reaching than the original and earlier "Republic of Science" (Polanyi, 1962) and indicates also mutual linkages with a "Democratization of Innovation" (von Hippel, 1995, 2005).

As is indicated by Carayannis and Campbell (2021, pp. 7–8):

> "The Triple Helix model emphasizes the relationship between academia, industry, and government (Etzkowitz & Leydesdorff, 2000). In this regard, it is a basic or a core model for explaining knowledge production and knowledge application. Contrary to this, the models of innovation systems based on the

> Quadruple Helix and the Quintuple Helix are designed in such a way that they already understand and refer to a wider complexity and context of knowledge production and knowledge application (innovation). In this way, they are organically and proactively including and engaging civil society and environmental considerations. The analytical architecture of these models is therefore conceptualized on a broader basis. We can say metaphorically that the Quadruple Helix integrates and contextualizes the Triple Helix, while the Quintuple Helix integrates and contextualizes the Quadruple Helix (and the Triple Helix) …. The Quadruple Helix adds as a fourth helix citizens influenced by the media and culture ('media-based and culture-based public'), 'civil society,' as well as 'art, arts, artistic research and arts-based innovation' but also democracy and knowledge democracy, all in all creators, inventors, innovators, and entrepreneurs. The Quadruple Helix innovation model can be seen as a model that integrates the dimension of democracy or the context of democracy in order to promote knowledge, knowledge production, and innovation (Carayannis & Campbell, 2009, 2012, p. 14; Carayannis & Pirzadeh, 2014; Campbell & Carayannis, 2016b; see also: Bast et al., 2015; Danilda et al., 2009; Eigelsreiter, 2017; Mitterlehner, 2014; Schallmo et al., 2017). The innovation model of the Quintuple Helix is more complete in terms of its analytical and explanatory scope as well as in its design by adding additionally a fifth helix and perspective, which is 'the natural environment of society' ('natural environments of society')." (Carayannis & Campbell, 2010, p. 62; Carayannis et al., 2012; Carayannis et al., 2018a, b).

Reflecting further, perhaps it can be said that Triple Helix is explicit in underscoring the importance of higher education for innovation. However, the main emphasis of Triple Helix is on the economy or better the knowledge economy. In this regard, the Quadruple Helix already is broader, by additionally emphasizing the importance of society (knowledge society), and of democracy (knowledge democracy), for knowledge production and innovation. The Quadruple Helix recognizes not only scientific universities (or other higher education institutions in the sciences), but also the art universities (or other higher education institutions in the arts), concerning the contributions of arts and arts universities for knowledge and innovation, which often are being created and generated in interdisciplinary and transdisciplinary frameworks and networks, possibly connecting the spheres of the sciences and that of the arts. "Social ecology," as a concept, refers to the interaction between society and nature ("society-nature interactions"), i.e., between "human society" and the "material world" (for example, see Fischer-Kowalski & Haberl, 2007). The European Commission (2009) identified and specified the need of a "socio-ecological transition" as a crucial challenge for economy and society. Therefore, the Quintuple Helix is explicit in referring to this socio-ecological transition of economy, society, and democracy. This explains why the innovation systems of the Quintuple Helix are designed in such ways, so to be ecologically sensitive. What matters for the further progressing of knowledge and innovation are respective co-evolutions of knowledge economy, knowledge society, and knowledge democracy, but coupled with an

ecological approach. Environmental sensitivity has all the capability and capacity to act as a "driver of innovation" and as a "driver for innovation" (Carayannis et al., 2012).

The Quintuple Helix Innovation System intends to relate knowledge production (research) and knowledge application (innovation) to considerations of "social ecology." Environmental problems, for example, climate problems such as global warming, represent themes and topics in relation to the survival of human civilization or humanity as a whole. But at the same time, the Quintuple Helix regards environmental or ecological challenges also as possible drivers for further and new knowledge and innovation, by this future knowledge and future innovation, which may have the potential to also finally advance society, economy and democracy (Carayannis et al., 2012). This should encourage major learning processes for the knowledge economy: "The Quintuple Helix supports here the formation of a win–win situation between ecology, knowledge and innovation, creating synergies between economy, society and democracy" (Carayannis et al., 2012, p. 1).

Different Advanced Conceptual Building Blocks of the Quadruple and Quintuple Helix Innovation Systems: Industry 4.0, Industry 5.0, and Society 5.0

Clearly, the identified five dimensions of the Quintuple (Quadruple) helix are relating to Industry 5.0 and Society 5.0 as expressions for advanced developments in society, economy, and democracy (see Carayannis et al., 2021a, b; see furthermore also Carayannis et al., 2020). With a focus on Industry 4.0 and 5.0 and Society 5.0, different conceptual building blocks are reviewed, demonstrating how modern economies are working, based on knowledge, and driven by innovation.

Conceptual Building Block of Digital Transformation

Digital transformation (DT) created a growing attention in recent years (Morakanyane et al., 2017). DT requires the involvement of interdisciplinary approaches, since also the "human" component is fundamental (Hauseberg et al., 2019). Partially, the technology is driving "radical change" (Nambisan et al., 2019), whereas others prefer to see technology as an enabler for a new "organizational shift" (Morakanyane et al., 2017; Nambisan et al., 2019), with impacts on knowledge management, society, and people (Braganza et al., 2017; Urbinati et al., 2018). The society nexus of technology is being referred to in:

- Society and communication (Gano, 2015; Madsen et al., 2016; Carolan, 2017)
- Policy and international (Chandler, 2015; Rothe, 2017)
- Philosophy and ethics (Lake, 2017)

This also expresses a multi-disciplinary approach that is taking several social perspectives of DT into account. Furthermore, this should indicate the opportunities and risks of big data and digital technologies.

Conceptual Building Block of Industry 4.0

Digitalization has changed the world of the economies, and originally was referred to as "Industry 4.0." First, it was used explicitly in a high-tech program of a German strategic initiative in 2011 and was defined by Kagermann et al. (2013, pp. 5) as a "new type of industrialization." The drivers of the first three industrial revolutions were mechanization, electricity, and IT; the fourth industrial revolution was started and amplified by incorporating the Internet of things and services into manufacturing environments. This should lead to the development of (completely) new products and services.

In the current literature, we cannot identify a consensus definition about the proper meaning of Industry 4.0 (Piccarozzi et al., 2018; Hofmann & Rüsch, 2017). In the mentioned German "High-Tech Strategy 2020," the focus was on the development of innovative technologies for production. Other governments also included the adoption of Industry 4.0 technologies for firms (Liao et al., 2017). Examples here are the Advanced Manufacturing Partnership (AMP) of the US government in 2011, the "Nouvelle France Industrielle" in 2013, the "Future of Manufacturing" of the UK government, and the "Piano Industria 4.0" initiative in Italy for Italian firms interested in technological transformation (see also Carayannis, 2019a, b, c; Carayannis & Campbell, 2020).

The attempt to define Industry 4.0 is facing several challenges, if not, even ambiguities (Carayannis & Campbell, 2021, p 11; see also see Carayannis, 2019a, b, c; Carayannis & Campbell, 2020):

> "One of the main difficulties in defining Industry 4.0 derives from the different labels (industrial Internet, Internet of things, smart factories, human–machine-cooperation, smart manufacturing) used to indicate the same phenomenon: the application of digital and interconnected technologies to the manufacturing sector. As Burrit and Christ (2016) claimed, Industry 4.0 is an umbrella term used to describe a group of connected technological advances that provide a foundation for increased digitization of the business. Hermann et al. (2015) identify four components of Industry 4.0: cyber-physical systems (CPS), Internet of things (IoT), Internet of services (IoS), and smart factory. CPS are systems that integrate computation, networking and physical processes (Bag et al., 2018); they actually bring the physical and the virtual world together (Hofmann & Rüsch, 2017). In the manufacturing environment, CPS comprise smart machines, storage systems, and production facilities able to autonomously exchange information, trigger actions, and control each other independently (Kagermann et al., 2013). The fact that machines and devices of production lines and cells are transformed into a network, allow to collect data in real-time and use them to make decisions such as prioritization of production orders, optimization of tasks, maintenance requirements, etc. (Lee & Lee, 2015). Their

application to manufacturing process allows for a whole new degree of control, transparency, efficiency, and flexibility of production processes. The IoT, or the Internet of everything (Lee & Lee, 2015), was first described by Ashton (2009) as the phenomenon of adding new technologies (RFID) to everyday objects (Ashton, 2009). Today, the term has evolved in a much broader meaning, which includes a network of entities—which are called 'Internet-connected constituent'—coupled to each other by any form of wireless sensors, actuators, mobile phones (Giusto et al., 2010). They allow the objects to provide information about their environment, context, and location (Ng & Wakenshaw, 2017). According to this meaning, even physical objects can now become 'intelligent objects' with which it is possible to dialogue thanks to the Internet (Haller et al., 2008). Similar to IoT, the IoS allows service vendors to offer their services via the Internet and consequently to add value to their offer. New Web technologies, such as services-oriented architecture (SOA), software as a service (SaaS),or business process outsourcing (BPO), enabled the rise of new business models where 'one party grants temporary access to the resources of another party in order to perform a prescribed function and a related benefit. Resources may be human workforce and skills, technical systems, information, consumables, land and others' (Hofmann & Rüsch, 2017). As a result of application of IoT and IoS technologies in manufacturing, firms are shifting from offering products to offering integrated product–service bundles, a phenomenon that in literature is called 'servitization'."

Smart factories can be taken as another example for innovations. There, CPS (cyber-physical systems) are communicating via IoT (Internet of things) and IoS (Internet of services), so to assist people and machines in the performance of tasks (Hermann et al., 2015). In smart factories, the communication between human beings, machines and resources resembles a "social network" (Kagermann et al., 2013). By embedding sensors, actuators, and autonomous systems within the manufacturing, this finally will help, in Industry 4.0, to make factories more dynamic, flexible, and also intelligent (Kamble et al., 2018). Other examples for Industry 4.0 may be big data, augmented reality applications, wireless networks, cloud computing (Bag et al., 2018), and smart cities. Smart cities emphasize the following approach: offering or supporting added-value services to citizens, by combining social and business infrastructures with the physical IT, so to support the intelligence of communities in cities (Hollands, 2008). IoT also matters for social care and well-being. Furthermore, this should provide also opportunities for firms by referring to technologies in relation to IoT and CPS (Bresciani et al., 2018).

Interdisciplinarity represents another aspect of the complexity of Industry 4.0. For example, engineering and computer sciences are cross-connecting with human resources, behavior of consumers, and the environmental sciences. Piccarozzi et al. (2018, pp.16) formulate this in the following way: "… the first insight that appear clear […] is that Industry 4.0 is a cross-cutting theme of many disciplines that influence each other […] It is very difficult to find a research paper purely dedicated to the managerial and business aspects of Industry 4.0 because in every aspects the business aspect blend

with those pertaining to technical engineering, ICT or sustainability" (compare additionally with Carayannis, 2019a, b, c; Carayannis & Campbell, 2020).

The application of these new technologies provides several opportunities and benefits for firms as well as societies, such as improvements in enduring competitiveness, faster adaptations to changes of customer behavior and environmental requirements, optimizations in decision-making, increased productivity and efficiency in the use of resources, and also opportunities for value creation with new services. Different factors can either promote or constrain Industry 4.0 in the different organizational contexts. In this regard, Müller et al. (2018) qualifies three groups of "opportunities" as decisive: "strategic opportunities (new business models, new value offers for enhanced competitiveness), operational opportunities (increased efficiency, decreasing costs, higher quality, increased speed and flexibility, load balancing and stock reduction), and environment and people opportunities (reduction of monotonous work, age-appropriate workplaces, reduction of environmental impact)." At the same time, also common barrier factors are being identified: "competitiveness and future viability (existing business models endangered, loss of flexibility, standardization, transparency), organizational and production fit (high implementation efforts regarding costs and standardization), and employee qualification and acceptance (employee fear and concerns, lack of expertise)."

So what is the role of human resources for the digital revolution in Industry 4.0 (see on this Horváth & Szabó, 2019)? On the one hand, this may imply that firms and organizations focus on allocating human resources into the direction higher value-added areas, and to reduce other forms of labor. On the other hand, the disruptive paradigm effects of the digital revolution are requiring not only dynamic capabilities, but also the access, incorporation, and integration of technology and other knowledge from the outside of the organization (Alavi & Leidner, 2001; Carayannis et al., 2018b furthermore, see Bast et al., 2019, pp. 245–246; Carayannis, 2019a, b, c; Carayannis & Campbell, 2020). In addition, technologies of Industry 4.0 are becoming also therefore more important, because they enable a faster development of "green manufacturing processes," "green manufacturing supply chain management," and "green products" (de Sousa Jabbar et al., 2018).

Conceptual Building Block of Industry 5.0 and Society 5.0: a Parallel Path

While Industry 4.0 is impacting all of society, society can be understood also as a "broader ecosystem." Digitalization allows for an optimization of processes of industrial production, but the digital transformation is more radically connected with a re-organization of "socio-cultural paradigms," interlinking with a diversity of technology-based and technology-driven innovations (Nambisan et al., 2019).

In reference to the concept of "Society 5.0," Carayannis et al. (2020, pp. 3–4) formulate the following positions:

> "At the basis of this broadening, the idea of Society 5.0 (or "Super Smart Society") is defined. This prototypical philosophy originated in Japan and was presented as a core concept in the "Fifth Science and Technology Basic Plan" by

the Japanese "Council for Science, Technology and Innovation", and approved by Cabinet decision in January 2016 (Ferreira & Serpa, 2018; Salgues, 2018). It was identified as an overall growth strategy for Japan, and was reiterated in "The Investment for the Future Strategy 2017: Reform for Achieving Society 5.0". In essence, Society 5.0 tries to provide a common societal infrastructure for prosperity based on an advanced service platform. Industry 4.0 follows society 5.0 to a certain extent, but while Industry 4.0 focuses on production, Society 5.0 aims to put human beings at the center of innovation, taking advantage of the impact of technology and the results of industry 4.0 with the deepening of technological integration in improving quality of life, social responsibility and sustainability (Onday, 2019). This innovative perspective is not restricted to Japan, as it has points in common with those of the UNDP SDGs ("United Nations Development Program" "Sustainable Development Goals" (www.undp.org). ….. Furthermore, unlike the concept of Industry 4.0, Society 5.0 is not constrained only to the manufacturing industry, but it solves social problems with the help of integration of physical and virtual spaces. In fact, Society 5.0 is the society where the advanced IT technologies already discussed (IoT, robots, artificial intelligence, augmented reality, etc.) are actively used in people common life, in the industry, health care and other spheres of activity not for the progress, but for the benefit and convenience of each person." (Fukuyama, 2018).

In a future era of Society 5.0, an emerging "post-nonclassical science of intersubjective management processes" may come together cybernetically with "Evergetics." Evergetics in Greek (Ευεργέτης) has the meaning of a "benefactor," and, concerning its etymological origin, we already recognize a focus on "good actions" in processes of management and decision making (Vittikh, 2014; Yousefikhah, 2017). Complementary to Society 5.0, there also should be a reference made to Industry 5.0, which could and should be framed in no less terms than a renewed "human centered/human centric industrial paradigm," which pushes for a re-organization of processes of production in industry (see further Lorenz et al., 2015).

In Carayannis et al. (2020, p. 3), it is being stated:

> This is why the "… discussions on Industry 4.0 and Society have tended to focus on either a dystopian fearful future shaped by the IoT where robots ("CoBots") with AI replace humans, or a future that will invariably be benevolent and prosperous for all with the introduction of the Industry 4.0. Both visions subscribe, however, to technological determinism (evolution in organizational behavior, acceptance of robots in the workplace, evolution in organizational structures and workflows, evolution in work ethics, discrimination against robots or people, privacy and trust in a human–robot collaborative work environment, education and training, redesign of workplaces for robots), and as if the emergence of Industry 4.0 and its societal shaping and impacts are preordained and inevitable they do not yet acknowledge the need to broaden the understanding of Industry 4.0 outcomes and its multiple possible futures in society (Pashek et al., 2019; Pereira et al., 2020)."

"How can people and society benefit from Industry 4.0?" (Buhr, 2017). There are several elaborations in this regard, and several authors are providing further details on the dynamics and development patterns and trends of Industry 4.0 (Aslam et al., 2020; Buchanan, 1992; Dorst, 2011; Elim & Zahi, 2020; Ellitan & Anatan, 2019; Fauquex et al., 2015; Gehrke et al., 2015; Lorenz et al., 2015; Nahavandi, 2019; OECD, 2005; Ozdemir & Hekim, 2018; Pasisi et al., 2014; Riesener et al., 2019; Stacey et al., 2000; Skobelev & Borovik, 2017; Taratukhin et al., 2018; Vitali et al., 2017; Walch & Karagiannis, 2019; Zahara & George, 2002). Some authors are underscoring the crucial role of "design thinking" for the adaptation of the frameworks for innovation management and for the creation of ecosystem for IoT, but even more so an Industry 5.0, which is expected to express a greater "human/user centeredness" (Fauquex et al., 2015; Nahavandi, 2019; Taratukhin et al., 2018; Vitali et al., 2017; Walch & Karagiannis, 2019). In that line of thinking, it is said that Industry 5.0 has all the opportunities to be more "human-centered" than Industry 4.0. Again, also here design thinking should come into play in favor of Industry 5.0 (Ozdemir & Hekim, 2018; Skobelev & Borovik, 2017). Design thinking is in a position to contribute to processes of creation and development of enduring environments and ecosystems for IoT and Industry 5.0, so to support here cross-interlinkages between firm strategies and innovation and technology policies.

As has been referred to by Carayannis and Campbell (2021, pp. 16–17; also see Carayannis & Campbell, 2019; Carayannis, 2019a, b, c; Carayannis & Campbell, 2020):

> "Definitively, there is a need for new interdisciplinary research between science and engineering with the aim of developing the perfect human-technology collaboration in Industry 5.0. In addition to this, it is necessary to develop and conduct a multilevel analysis, which takes into account three levels of framework: macro, meso, and micro. A smart industry must understand and update the situation inside and outside its boundaries, with a broad perspective of intraorganizational and interorganizational cooperation. In a business firm perspective, a micro level would concern the optimization of production processes and structure, with reference to the dynamics relating to worker-machine interaction and the implementation of new products and services closer to the needs expressed by customers (and stakeholders in general). At a meso level, we can assume an analysis of the industry in which the firm is located, also including the territorial peculiarities within which to develop cooperative synergies. Lastly, a macro analysis (completely external agents, such as political, economic, demographic, sociocultural conditions, legal aspects, technology, etc.) can be implemented to support joint growth based on the new routes of an industry fully declined in terms of 5.0 version. This multi-level path is still very relevant to the condition of Industry 4.0 toward Industry 5.0/Society 5.0. Starting with a clear vision and mission statement, then translated into strategies and operational plans, it can ensure the sustainability of the firm and, in a synecdotal relationship, that one of its broader ecosystem, by

taking into account all the Ethical, Legal, and Social Implications (ELSI) involved. Again, given the importance of the social aspects related to the concept of Industry 5.0, proposed a paradigm shift from cyber-physical systems (CPS) to cyber-physical-social systems (CPSS). The application of the (eco)logics that orbit around the Quintuple Helix innovation model (Carayannis & Campbell, 2009, 2010) can ensure the continuous interaction of the five dimensions involved: (1) industry, (2) government, (3) university, (4) society, and (5) natural environment, going toward an innovation eco-system design centered on a truly human-centered, 'evergetical,' 5.0 paradigm (furthermore, see also Carayannis & Campbell, 2019)".

Conclusion and Outlook

"Over the medium to long term, our fundamental belief and premise is that true and transparent democracy constitutes a sine qua non for smart, sustainable and inclusive growth and this constitutes our main motivation and guide for our focus on ways and means that concepts such as the Quadruple and Quintuple Innovation Helix, can better serve architect a better tomorrow for the peoples of the world." (Carayannis & Campbell in Park, 2014, p. 5).

"The two endangered species of today: Democracy and Environment need a Quadruple and Quintuple Innovation Helix framework approach. The Triple Helix ennobles, empowers and enables autocratic policies and practices." (Carayannis, 2020, p. 4: http://riconfigure.eu/wp-content/uploads/2020/01/Interview-with-Elias-Carayannis_2020_Final.pdf).

"We need to change the way we envision both business and society. The old ways have worn themselves out. We are having both a crisis of democracy and a climate crisis. They are both the result of a limited way of thinking." (Carayannis, 2020, p. 3: http://riconfigure.eu/wp-content/uploads/2020/01/Interview-with-Elias-Carayannis_2020_Final.pdf).

"… finally, as a last note and thought: perhaps the economic successes of non-democracies or autocracies (authoritarian and semi-authoritarian regimes) are being overestimated anyway, because autocracies are also benefitting from the knowledge production and innovation systems of democracies and semi-democracies, so in that sense autocracy is depending on democracy and the knowledge and innovation of democracy in a global system." (Campbell, 2019, pp. 338–339: https://link.springer.com/chapter/10.1007/978-3-319-72529-1_7).

The focus of our analysis has concentrated on the "Helix Trilogy," driven from the perspective to compare the different concepts of the Triple Helix and the Quadruple and Quintuple Helix Innovation Systems, and to elaborate on connections to theory, practice, and policy. In the following, we provide a summary of our reasoning, where it will be demonstrated again how the Quadruple

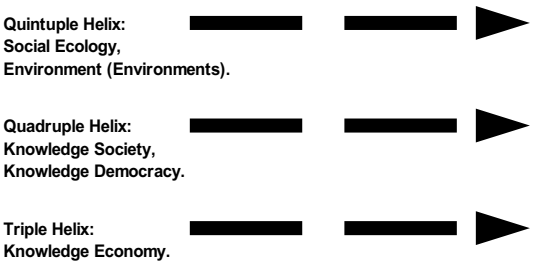

Fig. 2 The multi-level helix innovation systems. Source: authors' own conceptualization; see also Carayannis and Campbell (2009, p. 207; 2010, p. 62; 2014), Carayannis et al. (2012, p. 4), Etzkowitz and Leydesdorff (2000, p. 112), and Danilda et al. (2009)

and Quintuple Helix are emphasizing democracy and ecology for the advancement of knowledge and innovation (see Fig. 2).

Mode 3 Knowledge Production in Summary

A focused conceptual definition of mode 3 knowledge production can be designed in the following way (Carayannis & Campbell, 2012, p. 49):

> Mode 3 "… allows and emphasizes the co-existence and co-evolution of different knowledge and innovation paradigms. In fact, a key hypothesis is: The competitiveness and superiority of a knowledge system or the degree of advanced development of a knowledge system are highly determined by their adaptive capacity to combine and integrate different knowledge and innovation modes via co-evolution, co-specialization and co-opetition knowledge stock and flow dynamics" (see Carayannis & Campbell, 2009; on "Co-Opetition", see Brandenburger & Nalebuff, 1997). Analogies are being drawn and a co-evolution is being suggested between diversity and heterogeneity in advanced knowledge society and knowledge economy, and political pluralism in democracy (knowledge democracy), and the quality of a democracy or knowledge democracy. The "Democracy of Knowledge" refers explicitly to this overlapping relationship. As is being asserted: "The Democracy of Knowledge, as a concept and metaphor, highlights and underscores parallel processes between political pluralism in advanced democracy, and knowledge and innovation heterogeneity and diversity in advanced economy and society. Here, we may observe a hybrid overlapping between the knowledge economy, knowledge society and knowledge democracy" (Carayannis & Campbell, 2012, p. 55).

"Learning" also can be approached in different ways (for example, see Carayannis (2001) is drawing here distinctions by distinguishing between (1) learning, (2) "learning to learn," and (3) "learning how to learn learning."

Quadruple and Quintuple Helix Innovation Systems in Summary

The approaches of the Quadruple Helix and Quintuple Helix Innovation Systems are referring to broader conceptualizations of knowledge production and knowledge application in greater complexity. The Quadruple Helix contextualizes the Triple

Helix, while the Quadruple Helix is being contextualized by the Quintuple Helix. The Quadruple Helix emphasizes not only the "media-based and culture-based public," "civil society," "arts, artistic research and arts-based innovation," but also "democracy and knowledge democracy" (Carayannis & Campbell, 2009, 2012, p. 14; Caraynnis et al., 2012; Carayannis et al., 2018a, b; see furthermore: Bast et al., 2015, 2019; Danilda et al., 2009; Park, 2014). The Quadruple Helix emphasizes the perspective of the dimension of a democracy, thus of a knowledge democracy, for further progressing of knowledge, knowledge production, and knowledge application and innovation (Campbell, 2019, pp. 61, 343). The Quintuple Helix also integrates the "natural environments of society" (Carayannis & Campbell, 2010, p. 62) into knowledge production and innovation architectures (see Figs. 3 and 4).

The interaction and cooperation of higher education systems with firms (companies) is of importance for Quadruple and Quintuple Helix Innovation Systems. Knowledge and innovation gain in importance for the economy, also basic research ("basic research in the context of application," Campbell & Carayannis, 2013b, p. 34), so to support the co-evolution of higher education institutions and of firms, also by creating cross-connecting networks, so to combine the world of academia with the world of business, by integrating the good qualities of academia with the good qualities of business. The concept of the "academic firm" is focusing on such developments (Campbell & Carayannis, 2016b). The academic firm can be designed as a "whole firm" or as a "subunit of a firm." The academic firm focuses on knowledge, knowledge creation, and knowledge production and innovation (knowledge application) as the main drivers and regards an "academic atmosphere" and "internal academic environments" within firms (companies) as being crucial for knowledge and innovation. Therefore, the academic firms qualify cross-linkages and networks, also networks with higher education institutions and other academic institutions and organization, as opportunities and as essential for progressing knowledge and innovation all together (see Figs. 5 and 6).

Outlook: the Importance of Democracy and Ecology for Quadruple and Quintuple Helix Innovation Systems

From a recent interview, Carayannis (2020) refers to the following metaphor "Democracy and the Environment are Endangered Species." The current world, as it is, may be understood as a competition or race between "Developed Democracies versus Emerging Autocracies" (Carayannis & Campbell, 2014). Here, the Quadruple and Quintuple Helix Innovation Systems place themselves clearly, by emphasizing the importance of democracy and ecology (for example, the climate and a constraint of global warming). In his book "Democracy as Innovation Enabler," Campbell (2019) demonstrated the co-development and co-evolution of democracy (knowledge democracy) with society (knowledge society) and economy (knowledge economy), in which knowledge and innovation are acting as crucial drivers (Campbell et al., 2015).

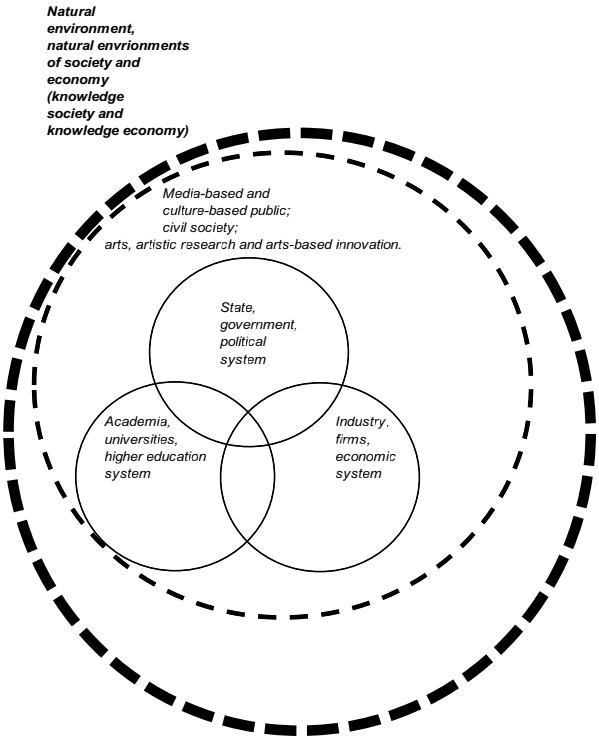

Fig. 3 The Quintuple Helix Innovation System. Source: authors' own conceptualization adapted from Carayannis and Campbell (2010, p. 62; 2013)

To understand the basic approaches of the Quadruple and Quintuple Helix Innovation Systems, the following must be taken into account (Carayannis & Campbell, 2021, p. 22):

> "The approach of Quadruple and Quintuple Helix Innovation Systems provokes with the following two propositions: (1) Without a democracy or knowledge democracy, the further advancement of knowledge and innovation are seriously constrained. In this sense, knowledge and innovation evolution depend on democracy and knowledge democracy. (2) Ecology and environmental protection represent a necessity and challenge for humanity, but they also act as drivers for further knowledge and innovation (this should lead to a win–win situation for ecology and innovation). For the Quadruple and Quintuple Helix Innovation Systems, democracy and ecology (environmental protection) are constituting categories, without these a Quadruple and Quintuple Helix Innovation System not possible is."

Is the Triple Helix sensitive (sensitive enough) about democracy and ecology? A word count of two pivotal publications of Etzkowitz and Leydesdorff (2000, 2003) is somewhat revealing, because in Etkowitz and Leydesdorff (2000), the two words of

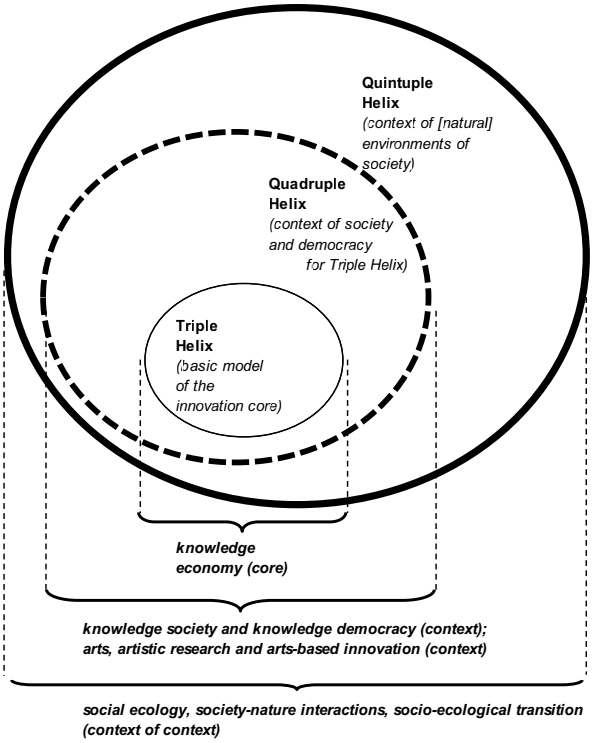

Fig. 4 The Quadruple and Quintuple Helix Innovation Systems in relation to society, democracy, and social ecology. Source: authors' own conceptualization based on Carayannis and Campbell (2014, p. 15) and adapted from Carayannis and Campbell (2009, p. 207). See also Etzkowitz and Leydesdorff (2000)

ecology and democracy are never ever mentioned, and in Leydesdorff and Etzkowitz (2003), ecology is never mentioned, and the word democracy only once, but in a technical sense by referring to the quote of "technology democracy" by citing Latour and Weibel (2002). To quote on this directly Leydesdorff and Etzkowitz (2003, p. 57), "The axis governance/citizenship is in need of new forms of representation in a 'technological democracy' (Latour & Weibel, 2002)." In addition, in Etzkowitz and Leydesdorff (2000, 2003), also the words "Quadruple" and "Quintuple" are never mentioned. Leydesdorff (2012) introduced his model of "N-Tuple of Helices." Of course, there are different ways how these N-tuple helices may be interpreted. It could be seen as a meta-reflection and comparison of different helices approaches, so to allow here creative designs and re-designs. At the same time, N-tuple helices also have and express an "abstract" question. So, from a Quadruple and Quintuple Helix perspective, the critical question raised is whether the Triple Helix is really sufficiently sensitive about the importance of democracy and ecology.

Back in their well-known article, Leydesdorff and Etzkowitz (2003) are using an interesting title "Can 'The Public' be considered as a Fourth Helix in University–Industry–Government Relations?" This title is indeed interesting, but, at the same time, Leydesdorff and Etzkowitz decided to not develop or to add such a fourth helix in combination with their Triple Helix model: "Three helices are sufficiently complex to understand the social reproduction of the dynamics of innovation … the

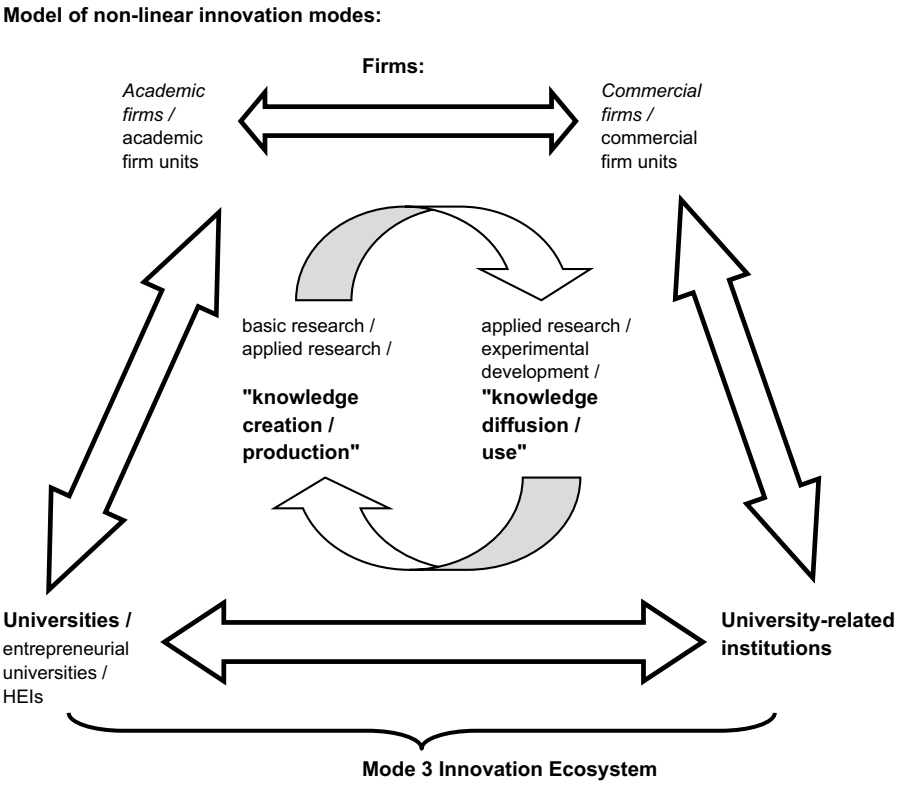

Fig. 5 Non-linear innovation modes (with commercial and academic firms or firm units). Source: authors' own conceptualization adapted from Carayannis and Campbell (2009)

three institutional spheres can be identified in our type of society as industry, academia, and government." (Leydesdorff & Etzkowitz, 2003, p. 60).

Therefore, we again can quote Carayannis and Campbell (2021, p. 25):

> "Referring back to the approach of Kuhn (1962), the structure of scientific revolutions, could the history of ideas about innovation have developed differently, if back in 2003, in their published article, Leydesdorff and Etzkowitz (2003) had decided to add the development of a fourth helix to Triple Helix? Our answer is: yes, for sure."
>
> In his later writings, Leydesdorff has attempted to argue that any helix order higher than Triple Helix could be interpreted as a variation of his N-tuple helices forward-moving approach. For example, the following quote may be conclusive here:
>
> "Carayannis and Campbell (e.g., 2009; 2010) have argued for using Quadruple and Quintuple Helices as models encompassing and generalizing Triple-Helix dynamics. In the meantime, Quadruple and Quintuple Helices have been adopted by the European Committee for the Regions and the European Commission as metaphors for further strategy development ….. Here we argue that

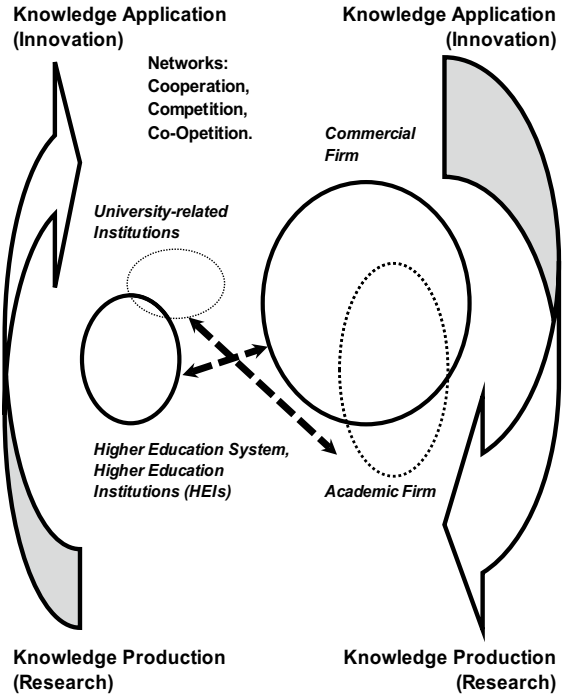

Fig. 6 Knowledge production and linear and non-linear innovation interaction between academic firms, commercial firms, and universities (higher education institutions). Source: authors' own conceptualization based on Carayannis and Campbell (2009, p. 211; 212 p. 25) and Campbell and Carayannis (2013b, p. 29) and adapted from Campbell and Carayannis (2016b)

the transition from a Double Helix to a Triple Helix can change the dynamic from a trajectory to a regime. However, next-order transitions (e.g., to Quadruple, Quintuple, or N-tuple Helices) can be decomposed and recombined into interacting Triple Helices. For example, in the case of four helices A, B, C, and D, one can distinguish ABC, ABD, ACD, and BCD; each triplet can generate synergy. The Triple-Helix synergy indicator can thus be elaborated for more than three dimensions. However, whether innovation systems are national, regional, sectorial, Triple-Helix, Quadruple-Helix, etc., can inform policies with evidence when one proceeds to measurement" (Leydesdorff and Smith, 2021, p. 1).

Almost self-explanatory, Leydesdorff and Smith (2021) also title their text as "Triple, Quadruple, and Higher-Order Helices: Historical Phenomena and (Neo-) Evolutionary Models" (Leydesdorff & Smith, 2021, p. 1).

However, from the perspective of Quadruple and Quintuple Helix Innovation Systems, the implication of such an arguing, in reference to N-tuple helices, is to not acknowledge what matters in the self-perception of Quadruple and Quintuple Helix Innovation Systems, because democracy (Quadruple Helix) and ecology (Quintuple Helix) represent essentials and fundamental principles for Quadruple and Quintuple Helix Innovation Systems and cannot be reduced to abstract games of Helix reconfigurations, without neglecting the essence and meaning of democracy and ecology. "Democracy of Climate" and "Climate for Democracy" (Carayannis & Campbell, 2021) express even the emphasis of exploring and networking connections between

democracy and ecology, enabled and promoted by innovation and innovation systems. "Democracy *of* Climate" and "Climate *for* Democracy" certainly represent approaches more radical than variations of "democracy and climate" or "climate and democracy" (on the latter, for example see Deese, 2019, and Hanusch, 2018). The "Anthropocene" as a term and concept is reflecting on the impact and influence of humanity on the natural environments on Earth. As is being said on Wikipedia about the Anthropocene: "The Anthropocene ….. is a proposed geological epoch dating from the commencement of significant human impact on Earth's geology and ecosystems, including, but not limited to, anthropogenic climate change" (https://en.wikipedia.org/wiki/Anthropocene) (accessed on April 9, 2021). By this, governance of climate and democracy of climate are not utopian categories, but in fact necessities for a further development and progress of humanity. Therefore, it could be said that the concept of Quadruple and Quintuple Helix Innovation Systems is in direct reference to the Anthropocene, but demonstrating, how it is the interaction, co-evolution and co-creation of democracy, knowledge and innovation that are actually driving, or even more so enabling the further evolution of humanity.

As already has been stated by Carayannis and Campbell (2021, p. 22):

> "'Democracy of climate' (creating a 'climate for democracy,' desirably a 'positive climate' for democracy), in cocreation with a 'democracy of knowledge' (emphasizing a co-evolution of political pluralism and a diversity of knowledge modes in innovation), are referring to new designs and performances of innovation and innovation systems, being furthermore expressed in the principles, building blocks and design of Quadruple and Quintuple Helix Innovation Systems. Democracy enables and encourages innovation, and the ecology and climate can act as drivers for further innovation."

So, the discourse on Helices is progressing toward its next stage.

Epilogue

In terms of a shortened epilogue, the following quote is reviewing and summarizing some of the future trends, which are unfolding, and which have the potential to further shape society, economy, and democracy:

> "The transformation of Industry 4.0 will destroy labor, and the transformation of Industry 4.0 will create new labor, so finally there even may more (new) labor (Bast et al., 2019). This requires, however, to reorganize labor and education in innovative and progressive approaches, so that then the net gain of new labor has the full potential of even to outpace the losses of old labor. Competences of persons, people and humans must be developed and developed further, to prevent that labor can be replaced by automation effects or by artificial intelligence (at least not in simple ways). Crucial are here multi-facetted competences, where disciplinary professional knowledge is being augmented and recombined with interdisciplinary and transdisciplinary skills and competences (for this also the metaphors of "T-competences" and "M-competences" are being used). Creativity and creativity skills are crucial in driving innovation, which again is

advancing the evolution of knowledge society, knowledge economy and knowledge democracy. Arts and artistic research represent crucial components in an advanced innovation system. Artificial intelligence will not replace human intelligence, but artificial intelligence will complement human intelligence. However, also here the challenge is to organize labor (and the economy, society and democracy) in a way, so that human intelligence is using artificial intelligence for the purpose of supporting (and carrying higher) human intelligence and human labor. Therefore, the idea is to speak more of a co-evolution of artificial intelligence and of human intelligence, but where the humans are in the position of control and sovereign decision-making (also expressed in the metaphor of a "Centaur Intelligence"). Artificial intelligence can provide assumptions and guidance, however, the humans are the ones who are making the decisions or who engage in "making the decision-making". There is this understanding that advanced knowledge manifests itself in a diversity of knowledge modes and innovation modes, and that this pluralism of knowledge also requires a political pluralism, which is a characteristic and component clearly of democracy. Democracy as innovation enabler, or the quality of democracy as an innovation enabler, emphasize the connectedness and interconnectedness of (a) knowledge development and of (b) democracy development and democracy evolution. In reference to the example and metaphor of a society of free women and free men in ancient Greece (the democratic polis in Athens), we can speculate, how in Industry 4.0 the artificial intelligence and other advanced technological means could be used and can be used and utilized to carry out the (boring) standard work, whereas persons, people and humans then are focusing more on the interesting work. This we may phrase and paraphrase as a type of Renaissance of (interesting) labor in the Age of Knowledge and Innovation. So what are then the new (and old) forms of entrepreneurship and of creative innovation in Industry 4.0 (or Industry 5.0 in a later phase), what can artificial-intelligence-based entrepreneurship possibly mean? What Industry 4.0 really needs and requires is a Democracy 5.0. If there is Art and Democracy, we also should think about the Art of Democracy" (Bast et al., 2019, pp. 245–246).

The theory, policy, and practice set of perspectives of the Triple, Quadruple, and Quintuple Innovation Helices is offering references, in the metaphorical sense of a "Helix Trilogy," how knowledge and innovation could and can proceed in co-evolution, in the context of knowledge economy, knowledge society, and knowledge democracy.

Finally, we also would like to refer to the following quote, evoking finally a philosophical metaphor:

"No man is an Iland, intire of it selfe; every man is a peece of the Continent, a part of the maine; if a Clod bee washed away by the Sea, Europe is the lesse, as well as if a Promontorie were, as well as if a Mannor of thy friends or of thine owne were; Any Mans death diminishes me, because I am involved in

Mankinde; And therefore never send to know for whom the bell tolls; It tolls for thee."
MEDITATION XVII
Devotions upon Emergent Occasions.
John Donne, written in 1624.
(https://web.cs.dal.ca/~johnston/poetry/island.html and https://www.ncbi.nlm.nih.gov/pmc/articles/PMC6369629/).

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