A CONCEPTUAL AND CASE STUDY REVIEW OF THE QUADRUPLE HELIX MODEL OF INNOVATION

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ABSTRACT

Despite its many pitfalls, the process of innovation should be made as attractive and practical as possible. Innovation model formation is an important yet complex process. This paper reviews the hypothetically improved quadruple helix (QH) model of innovation with respect to model concepts, innovation concepts, and current practical case studies. The updated model constitutes four innovation forces (constructs), namely (1) upscaling agility, (2) triple helix ecosystems, (3) triple management theory (TMT) and triple technology theory (TTT), and (4) epochal society. The model also shows a comprehensive interplay between these constructs within the modern digital, biological, legal and physical worlds. The authors reviewed the model through a conceptual explorative research design with narrative data. The evaluation implied the consideration of combining, adding, or omitting model constructs. Besides learner management and the need to provide a guide for how to use the model, the findings ultimately confirmed its value and usefulness.

OPSOMMING

Ten spyte van vele slaggate, moet die innovasieproses so aantreklik en prakties moontlik gemaak word. Die vorming van ’n innovasiemodel is ’n belangrike dog komplekse proses. Hierdie artikel hersien die hipoteties verbeterde viervoudigeheliks-innovasiemodel met betrekking tot modelkonsepte, innovasiekonsepte en huidige praktiese gevallestudies. Die bygewerkte model bestaan uit vier innovasiekragte (-konstrukte), naamlik (1) opskaling van behendigheid, (2) drievoudige heliks-ekostelsels, (3) drievoudige bestuursteorie en drievoudige tegnologieteorie, en (4) epogale samelewing. Die model toon ook ’n omvattende wisselwerking tussen hierdie konstrukte binne die moderne, digitale, biologiese, wetlike en fisieke wêrelde. Die outeurs het die model deur ’n konseptuele verkennende navorsingsontwerp met narratiewe data hersien. Die evaluering het die oorweging geïmpliseer om modelkonstrukte te kombineer, by te voeg of weg te laat. Benewens leerderbestuur en die behoefte om ’n gids te voorsien oor hoe om die model te gebruik, het die bevindinge uiteindelik die waarde en bruikbaarheid daarvan bevestig.

1. INTRODUCTION

This paper focuses on the promotion of innovation on individual, corporate, and international levels with a strong emphasis on innovation leadership, networking, and academic (university) power within the knowledge supply chain. Numerous top historic inventions such as the light bulb (1829), telephone (1876), bicycle (1886), radio (1897), television (1923), computer (1945), and World Wide Web (1989) are outcomes of networking, which is evidently an indispensable dimension of any innovation model in forging an engagement between academia, scientists, and other selected parties in the process of innovation.

To survive, all industries seek sustainability, driving innovation by default. The notion of 'innovate or stagnate' is especially true in the modern economy, demanding new types of leader for exponential organisations with 'triple concepts' such as triple helix, triple bottom-line, triple abilities, triple principles (triple management theory [TMT] and triple technology theory [TTT]), and triple outcomes. Yet history indicates that innovation has not always been popular and that, regardless of its merit, innovation often faces the challenge of strong countervailing forces that restrict the ability to break out of old paradigms and move into new ways. The coronavirus pandemic that forged the development of vaccines and remedies, but with the 'untested' Covid vaccination being widely criticised, serves as an example.

The modern global landscape and epochal societies see a new industrial revolution, with innovation as the DNA for sustainability. While the new ISO 56002 management system for innovation underlines the paradigm and need for innovation standards and models, innovation has no simple or specific recipe or model besides its complex mystery that is too difficult to define [1]. The terms associated with innovation are 're-creation', 'adaptation', 'imitation', and 'invention'. It remains to be determined what forces drive innovation and how the dimensions forging innovation could be formulated in a systematic model of innovation. To encapsulate multiple elements of concepts in a simplified, contrived manner is the challenge of model formation.

The quadruple helix (QH) concept in the context of innovation was originally suggested by Carayannis and Campbell [2] with respect to a quadruple helix model for an innovation ecosystem. The popular triple helix movement of the entrepreneurial universities was combined with this QH concept in the development of the QH model of innovation (see Figure 1). Prominent innovators will note that achievement is based on method (and modelling), not chance. This brings learner management [3] to the fore, since the initial quadruple helix (QH) model of innovation [4] proposes both strategic and micro dimensions in forging innovations without indicating how to use or implement the model.The International Organization for Standardization (ISO) published the first international management standard (MS) for innovation management, namely the ISO 56002:2019, for innovation capabilities (IC) and innovation performance (IP). A study of this innovation system standard conducted by Mir, Llach, and Casadesus [5] revealed strategy, market, and network structure to be the primary dimensions of innovation capabilities for innovation performance. 'Market' relates to the epochal society dimension of the QH model, while 'network structure' relates to the triple helix ecosystem of the model. Like any ISO system standard, the 'how to' is not very prescriptive.

Omelyanenko, Kudrina, Semenikhina, Zihunov, Danilova, and Liskovetska [6] investigated the conceptual aspects of modern innovation policy for countries needing models for participation in the global innovation system. The authors proposed a high technology analysis, the creation of a unique chain of innovations with respect to their own unique competencies, and the building of competitive innovative systems based on an innovative environment, innovative economy, and innovation ecosystem. In respect of academic power, the paper emphasises the importance of learning to take research outputs further, from publication to technology readiness, through collaborative research, consortiums, niche areas, talent management, and knowledge management for the knowledge supply chain in need. This relates to the triple helix ecosystem dimension of the QH model.

This paper further reviews the updated QH model of innovation by means of innovation model concepts, innovation concepts, and case study reviews.

2. RESEARCH PROBLEM

Innovation faces many difficulties, and failure is unavoidable in the innovation process. Yet, in the face of the continuous failure of companies' innovation projects, which is not limited to emerging economies, it is imperative that failure be minimised by any means possible, since innovation is the new DNA of exponential organisations. This could be achieved through the introduction of innovation models. However, the process of modelling is complex, especially for innovation as a social good, and it remains difficult to encapsulate multiple concepts in single constructs. Overly complex models may become non-user-friendly, and the creation of practical models that forge innovation continues to be difficult. Furthermore, models remain iterative and may need to omit, combine, adapt, or add constructs. In respect of its potential and usefulness, the updated QH model with its four primary dimensions promises to be exemplary after further development.

After formerly isolated bodies of literature were synthesised into a new conceptualisation of innovation by means of the original QH model, further reviews of the model, such as by the World Economic Forum (WEF), created provocative new perspectives into a fresh conceptual whole in the form of a new hypothetically improved model [7]. The research problem and the paucity of literature highlight the need to review this new hypothetically improved QH model further.

3. RESEARCH METHOD

To address the problem, a conceptual research approach was based on model concepts, innovation concepts, and case study reviews. The initial orientation phase of the investigation was based on experiential knowledge, which in turn was based on qualitative observation of physical artefacts (personal visits to institutions, laboratories, and incubators) and non-behavioural activities [8] at triple-helix ecosystems in Europe (after visiting entrepreneurial universities in the Netherlands, Belgium, Finland, and Germany). According to Saunders, Lewis, and Thornhill [9] and Corley and Gioia [10], concept-driven data is a primary category of qualitative data for theory-building, derived from the existing knowledge and literature. Qualitative exploration is primarily narrative at both the nominal and ordinal levels [11]. Conceptual research implies philosophical discussion and argumentation for deeper insight or new contrived constructs. As noted by Corley and Gioia [10], conceptual research enables the production (moulding or forging) of new knowledge from current or old theories. Trafford and Leshem [12] underscore the value of developing standpoints and practical influences through new perspectives. Conceptual thinking demands effectively bringing things into relation and interconnecting groups of ideas for synthesised theories. This process has led to the four dimensions of the QH model that encapsulate and represent multiple or even ten-fold sub-dimensions important for model formation. McGregor [13] describes the essence of conceptual papers as a process of identifying and defining concepts (and constructs) with respect to their relationship to a specific topic or phenomenon (such as innovation in the QH model). They reflect theoretical thoughts and relate concepts to specific issues so as to advance (enrich or create new ideas) and to systematise knowledge. Model constructs also systematise relations among concepts and the phenomenon in question. They address questions that need a sound argument rather than more facts. Dirkse van Schalkwyk [14] provides an example of a conceptual framework built on well-founded, rigorous, coherent, and convincing argumentation. A new framework (or model) usually needs more validation, since the conceptualisation is abstract and has not yet been fully proven. Cropanzano [15] refers to writing nonempirical articles, while Gilson and Goldberg [16] explain that conceptual papers do not have numeric data, since their focus is on integration and proposing new relationships among constructs. The focus is on developing logical and complete arguments for associations. Moreover, conceptual papers seek to bridge existing theories in interesting ways, across disciplines, providing multi-level insights, and broadening the scope of our thinking.This conceptual paper takes a problem-focused approach in search of perspectives on current constructs and further improvements. Whetton [17] argues that conceptual papers should be ultimately judged on the basis of what is new, their areas of improvement, and their implications or value. Although the current study attempted to confirm the new hypothetically improved QH model, it also sought areas for improvement and a fresh or enhanced view of the concepts or phenomenon by linking previously unconnected or incompatible pieces in a novel way [18]. The research approach was based on a freedom of methodological innovation in the social sciences, with an interdisciplinary enthusiasm from researchers. The research approach therefore included a personal approach of visiting institutions (science parks, innovation centres, and entrepreneurial universities), as indicated in the results. Models develop naturally, and therefore the study did not attempt to provide a final account of the QH model.

4. RESULTS

Section A provides a brief review (summary) of the hypothetically improved QH model, followed by conceptual narrative data with respect to the model. The narrative data are presented in section B, comprising conceptual data of model principles and innovation essentials, and in section C, comprising conceptual data from selected case studies.

A. Summative overview of the hypothetically improved quadruple helix model

A hypothetical improvement of the useful quadruple helix model of innovation was suggested by Dirkse van Schalkwyk and Steenkamp [7]. The QH model (Figure 1) constitutes the interplay of four constructs (with conceptual elements) within the physical, digital, and other worlds, driven by a new type of innovation leadership. The primary improvements suggested were with respect to the ‘legal world’, leadership, and the development of TMT to TTT. A brief discussion of each of these dimensions follows.

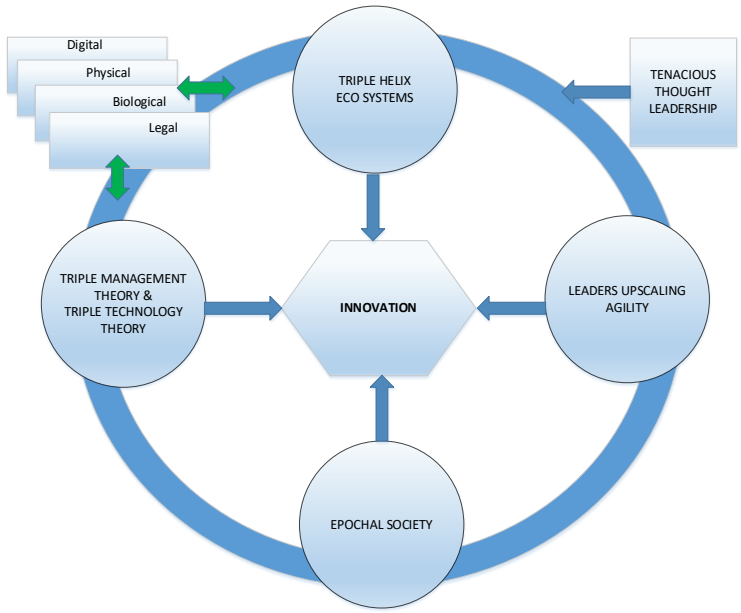

Figure 1: The hypothetical improved quadruple helix model of innovation [7]

The triple helix (TH) ecosystems

The notion is that successful innovators – for example, Apple – rely on multiple sources of information, cross-industry partners, and cross-functional interaction. Rolls Royce, for instance, used several external partners for engine components and the gearbox. The same applies to Sony (for the planar lithium battery), Texas Instruments (for the interface controller), Toshiba (for the hard disk drive), and Wolfson (for the digital-to-analogue converter [19].

Several types of ecosystem that forge innovation exist, such as the Ghent entrepreneurship ecosystem and the Brightlands innovation ecosystem in Maastricht. The triple helix concept (the engagement between industry, government, and entrepreneurial universities) usually forms part of these ecosystems, and has thus led to this dimension of the model. The concept refers to the revolution that is based on academic power and industry relations with respect to a sociological paradigm for economic development. This provides an integrative view of academic power, entrepreneurship, and university–business cooperation (UBC). Concepts related to this dimension are discussed in section C.

Epochal society

The more informed and intelligent societies have become actively involved as informal students of the knowledge society. Entrepreneurial universities will therefore identify and respond to the entrepreneurial society. The service excellence demanded by this epochal society needs new models for customer intelligence [20]. Accordingly, the QH model acknowledges society as a new force of innovation. This prominent actor in the QH model is more sophisticated and more involved in the supply chain of things. Since modern society uses all sources of intelligence in a knowledge-based economy (KBE), several industry sectors have shifted towards a customer-based technology-pull approach as the starting point for innovation. See further discussions of concepts related to this dimension in section C.

Upscaling agility

It has always been an objective of operations management performance to be nimble, flexible, and responsive. Agility has become an imperative for innovative companies, and has been highlighted by the *Harvard Business Review* as the distinctive skill of our time [21]. It is a requirement for the effective modern institution, since it enables organisations to facilitate change. Adaptive leadership is vital for creating agile teams and a resilient, agile organisational culture. This specific skill is regarded as an underlying force that is needed for the interplay between the different partners, markets, and operations systems portrayed by the dimensions of the QH model. Concepts related to this dimension are discussed in section C.

Triple management theory

Human technology is a concept related to TMT. This concept is a special ability for the interoperability that is described and encapsulated by TMT, which was introduced by Raheem [22]. It concerns the process intelligence that is inherent in operations management excellence, and relates to several kinds of technology (soft unique human capabilities and hardcore hi-tech) and technology transfer within the full spectrum of technology. Combining multiple capabilities therefore brings another triple concept to the fore, namely triple technology theory (TTT).

This dimension of the QH model is integral to innovation that needs the x-factor and special competence to welcome the arrival of new markets, velocity, scope, and the exponential pace of processes. TMT is a combination of business process management (BPM), adaptive case management (ACM), and human interactive management (HIM), supporting change and interoperability. Concepts related to this dimension are discussed in section C.

Summative overview

As also noted by Dirkse van Schalkwyk and Steenkamp [7], the old perspectives of the award-winning work of Addison [1] provide valuable insight related to the model. Addison [1] stresses the upscaling agility of the QH model in the context of 'thought leadership' and networking 'out of the box', with new thinking applied through higher order routines. He refers to the mind of a fox ('foxy leadership'), and elaborates on this agile leader, who is able to work within systems but also to break out of them. Other noted principles are cross-functional networking and the team sociability concept (with both solidarity and close–distant relationships). Additional terms used are 'sector collaborations' and 'enablement', which relate to vibrant and relevant academic research for commercialising research outputs in the ecosystem of knowledge capital in the global laboratory.

Regarding the TMT dimension of the model, Addison [1] refers to the technological intensive dimension of experts for unique intellectual property with respect to the 'community of practice' when highly intellectual incubators combine their skills. This comes into being when similarly trained experts engage and share professional values for synergy.

B. Conceptual data of fundamental model principles and innovation essentials

The updated QH model for innovation is measured by model and innovation concepts that contain various conceptual elements.

Generic model principles

In general, models provide guidance for discussion, learning, and decision-making. McGregor [13] depicts conceptual frameworks as a systematically organised collection of constructs and concepts related to one phenomenon. Ideally, frameworks used by management should be conceptualised, tested, revisited, and improved to become validated models. Models should provide users with confidence, clarity, and outcomes through either visual illustrations or mathematical and computer models. New models are welcomed, since an alternative choice of model has a profound influence on thinking and how problems are solved.

There is a subtle relationship between meta-models, model syntax, modelling language, and a system framework. Models usually have core and supplementary dimensions, and will therefore express different levels of precision, indicating that no single model would ever be sufficient or perfect. The 'best' operations management models are comprehensive yet concisely connected to practical reality for user-friendliness [23]. Instructional design models [3] provide problem-solving (how to produce innovation), integrated and guided by the model (how to use the model; how components illustrate dependencies and information flow).

The QH model does not provide learner management, which is a potential area of improvement. Nonetheless, it connects the main forces of innovation, and expresses different levels of precision in respect of broad strategic aspects. It is therefore comprehensive, yet concisely connected to practical reality.

Innovation models

Secondary data provide multiple innovation models for different industries. As noted, the QH model is systematically organised with a focus on one phenomenon, and may be improved with respect to learner management (how to use the model). Todd [24] identifies the different innovation models across generations as linear models (pull and technology push), coupling models (interaction between different elements), and the parallel lines model (upstream with key suppliers and downstream with demanding customers), with an emphasis on linkages and alliances. Todd [24] further notes systems integration, extensive networking, agility (flexible and customised responsiveness), and an ongoing cycle of continuous innovation.

Todd [24] supports models without a focus on the hero individual (the TMT and TTT dimension of the QH model) who brings radical change. Breakthrough changes would neglect the potential of incremental innovation, and a focus on key individuals may led to the under-utilisation of the creativity of other members. Networking is therefore also highlighted with respect to regional clusters for best practice, sector forums, multi-company innovation networks, strategic alliances, and sector consortiums, as indicated by the triple helix ecosystem dimension of the QH model.

Innovation essentials and concepts

An analysis of innovation concepts and typologies by Kotsemir and Abroskin [25] revealed that fearlessness is all-important, since innovation means change in the established order, creating resistance from society (sociologists even prefer the term 'technological change' over the term 'innovation'). Meyer [26] relates fearlessness to perseverance, based on the fact that great innovative companies were established in stressful times [19].

The literature indicates several innovation types, namely production innovation (new products and services), process innovations (new methods, devices, tools, or knowledge how to do something), position innovation (to position a product for an industry), and paradigm innovation (shifting long-held assumptions about the modus operandi). The degree of innovativeness can range from low to moderate to high, or be incremental, or range from new generation to radical. The QH model, however, does not distinguish between types of innovation.

The QH model relates to the three general categories of innovation, namely (1) innovation as a process (imitation, invention, and discovery); (2) innovation as human abilities (creativity, ingenuity, imagination), associated with the TMT and TTT dimension of the QH model; and (3) innovation as change (cultural-social change, organisational change, and technological change), associated with the epochal society and the upscaling agility dimensions of the QH model.

Tenacious thought leadership for innovation

The innovation leadership that is essential is discussed separately, although it is integral to all dimensions of the QH model. Tenacious thought leadership encompasses upscaling agility and the acquisition of talent TTT and TMT. The QH model suggests that the time has come to retrench the hedgehog and become a fox [27]. The hedgehog lives in one burrow, in one home, and in one manner. Once programmed by an idea, he cannot shake it off. Conversely, foxes are responsive, believing that life is all about knowing and experiencing many things. They forage for new ideas and explore new routes. Foxes are agile and react more quickly, and their intuition and readiness enable them to survive in a rapidly changing environment. 'Fox innovators' look with fresh eyes on every phenomenon.

The 'Branson way' of innovation [28] is a good example of leadership that inspires new inventors. Richard Branson rebelled against typical business school and management theory. Instead he chose to be an opportunist and to be a little unrealistic. He has 'bounce-back-ability', and radiates schoolboy enthusiasm, surrounding himself with a network of competent people; this relates to the intelligence and talent required by the TMT and TTT dimension of the QH model.

Max Riedel from the ZEISS Innovation Hub @KIT (the Karlsruhe Institute of Technology) is one of the innovation leaders behind the University Industry Innovation Network (UIIN) initiatives. With his expertise in quantum physics, he supported the ramp-up of the Quantum Technologies Flagship initiative of the European Commission to bring technology from the lab to the market. The CEO of the UIIN, Meerman [29],

also displayed foxy leadership when he built one of the largest networks of university–industry interaction globally [30].

Essentials of innovation leadership

The results of a survey by De Jong, Marston, and Roth [31] among 2 500 executives of 300 companies provided a particularly useful framework for innovation leadership. Eight essentials were revealed, which could be synthesised into the following four groups: (1) *Aspire and mobilise* – to have vision for innovation-led growth and to motivate, organise, and reward people to innovate repeatedly; (2) *Discover and choose* – to differentiate between business, market, and technology insights that translate into winning value propositions, and to invest in coherent time- and risk-balanced initiatives; (3) *Evolve and accelerate* – to create new business models that provide defensible and scalable profit sources and to beat the competition with time to market; and (4) *Scale and extend* – to launch innovations in the right scale in the relevant markets and to win by creating and capitalising on external networks.

These innovation essentials and the leadership essentials (four groups) could be incorporated into the QH model with reference to learner management (how to use the model) [3]. Furthermore, the UIIN's experiential benchmark could be used with respect to their UBC accelerator methodological 'how to' training provided by practitioners.

Principles of Innovation

Although most authors would state that innovation has no absolute rules, the following fundamentals remain: to know the science of innovation, treasure lessons of experience, and design an innovation strategy. Moreover, the principle of managing innovation in an uncertain, complex, disruptive, and creative context will prevail [19], while the art of cultivating interaction by empowering the team could also make the difference when a spirit of individual competition is harnessed within teams [1].

Recently, the emphasis has moved to modern ecosystems that are conducive to engagement and innovation. Idea practitioners think and act 'out of the box' (e.g., the Google case). The re-engineering concept focuses on what exists already and explains innovation as "the fundamental rethinking and radical redesign of business processes to achieve dramatic improvements in critical, contemporary measures of improvement such as cost, quality, service and speed" [32].

Finally, the principle of simplicity is the paradox of innovation. Johnson & Johnson (J&J) serves as a significant example of innovation through simplicity [26]. As one of the most admired international companies, simplifying problems is the essence of their innovation: finding simple solutions for complex problems. When the military needed a strong, waterproof, cloth-based tape that could keep moisture out of ammunition cases, J&J created 'duck tape' (presently known as 'duct tape'). Soldiers soon discovered that the tape was extremely useful in repairing just about anything. The company has become more agile for its diversification strategy, which has led to decentralisation as a driving force.

C. A review based on selected case studies

Conceptual elements give deeper meaning to the constructs of the QH model. The following cases relate to dimensions of the updated QH model, such as technology, epochal society, students, academia, and UBC (configurations of institutional and industry collaboration) for innovation.

Urban innovation case study

The Amsterdam Institute for Advanced Metropolitan Solutions (AMS) is a consortium of private-public partners who collaboratively educate talent and develop and valorise interdisciplinary metropolitan solutions to the urban problems of sustainability and quality of life. The AMS Institute is built on three main pillars: research valorisation, education, and a value platform. The founding partners of the AMS Institute are the Delft University of Technology, the Wageningen University & Research, and the Massachusetts Institute of Technology, in close cooperation with societal and business partners. It is a unique collaboration between knowledge institutions, business, and public stakeholders. The City of Amsterdam and initial funding provided this unique concept with a 10-year runway to use technology and design to resolve, steer, and navigate city flows. The case relates to the epochal society and the triple helix ecosystem dimensions of the QH model. *(http://www.ams-institute.org/)*

Innovation factory case study

The AREA Science Park in Italy develops the growth and competitiveness of enterprises through innovation and technological research, technology transfer, innovation management, research and development (R&D) management, and knowledge-intensive enterprise creation. AREA has an in-house incubator, called the innovation factory, which supports would-be entrepreneurs from their initial idea to the birth of their start-up. This case relates to the TMT and TTT dimension of the QH model. (*http://www.areasciencepark.it/)*

R&D for epochal society case study

Empa (Zurich) is the Swiss Federal Laboratories for Materials Science and Technology, which has existed since 1880. Empa focuses on the creation of marketable innovations from research. The core mission of Empa is to develop scientific-based solutions and innovations through research and vigorous UBC. Empa brings research to society through strategic partnerships and by sharing research facilities. Besides triple helix, this case also relates to the epochal society dimension of the QH model. (https://www.empa.ch/web/empa)

Entrepreneurship ecosystem for students case studies

This case study concerns an entrepreneurship ecosystem consisting of several entities such as the local government, Unizo, Imec, Accio, and Durf Ondernemen. The Student Ghentrepreneur Alliance is an initiative that brings together disparate regional stakeholders to support student entrepreneurship in Ghent. Universities cooperate to encourage students to develop their innovative ideas by bringing together regional entrepreneurship actors to create an economy of scale. A supportive environment for entrepreneurship is created through the formation of this alliance.

The business of science has the university as a business with a broader value creation mission. The Ghentrepreneur concept (also noted under selected case studies) serves as an example of incubator support, where, for instance, the Startersfabriek serves as a gateway for new ventures, and the Idea Factory for art students (ARTEpreneurs from the Arteveldehogeschool) is supported by business partners and the Flemish government. This case relates to the triple helix ecosystem dimension of the QH model.

During recent visits (September 2022) to Wageningen University, it was observed how their global network supports start-ups with respect to the 'Startlife' concept via the 'Starthub' department with a focus on food security (related to a Agrifoodtech network and the Unilever foods innovation centre). A visit to the Amsterdam science park and Amsterdam University revealed the office for innovation exchange (IXA) as partnering science for impact in assisting students to identify the best valorisation and grant applications strategies for ideas, inventions, and technology. (http://www.studentghentrepreneur.be/)

Technology transfer companies case studies

A recent visit (September, 2022) to the technology transfer office (TTO) at Leuven University in Belgium underlined the role and function of all types of technology transfer. This office is regarded as a benchmark for TTOs, with evidence of the following artefacts: a display of evidence related to high-tech entrepreneurship (supported by the Gemma Frisius Fund), the Reuters honorary title "New Flemish Master in Science", the IPTEC technology transfer award, software for digital dentistry, reduced tyre noise at Goodyear, refined cochlear implants, and drug design such as the leading anti-HIV drug technology.

In the evolution from TTOs to technology transfer companies (TTCs), Yissum, the TTC of the Hebrew University of Jerusalem, which is one of the top 15 TTCs in the world in respect of revenues, serves as an example. Yissum has partnerships with numerous industry leaders such as Johnson & Johnson, Roche, Merck, Teva, Adobe, and Google [33]. The company promotes technology transfer from university research outputs while maximising streams of income for research, education, and scientific excellence. Its success is based on its autonomy and legal status as a private entity, hiring talent (specific industry experience and academia) and equity profit-sharing. Its triple helix and UBC consist of the university, government (the Israeli Ministry of Trade and Industry and the Office of the Chief Scientist), industry (long-term business partners), researchers (benefitting through the financial returns of patenting and commercialisation), and students (with funding opportunities for their start-

up and other entrepreneurial initiatives). The macro, meso, and micro levels of technology transfer are described by Cunningham, O'Reilly, and Macro [34]. These cases relate to the triple helix ecosystem and TMT and TTT dimensions of the QH model. (*http://www.yissum.co.il*)

University supply chain case

Siemens works in close cooperation with numerous global universities and research institutes. The company follows an open innovation strategy that strengthens its innovative power. UBC is core for Siemens with its Centre of Knowledge Interchange (CKI) programme. Collaboration extends not only to individual departments but also to joint research activities and talent acquisition. To reinforce academic power, academics profit extensively from the proposed framework for strategic collaboration with Siemens. The CKI universities are: the Technical University of Berlin, the Technical University of Munich, the University of Erlangen-Nuremberg in Germany, the Graz University of Technology in Austria, the Technical University of Berlin, the Tsinghua University in China, the University of California (USA), and the Georgia Institute of Technology (USA). The partner universities benefit substantially from the relationship with Siemens through future-oriented focused and funded R&D. This case relates to the triple helix ecosystem (of universities) dimension of the QH model. (*http://www.siemens.com/content/dam/inter-net/siemens-com/innovation/innovation/pdfs/innovations-at-siemens.pdf)*

Regional high-tech innovation case

Higher education obtained a new dimension in the Netherlands (recently observed during a personal visit in September, 2022) with the Dutch University of Twente (UT), the number one valorisation university in the Netherlands in 2015 and, together with the Kennispark Twente, the key driver behind regional high-tech innovation. The UT has grown into a world-class entrepreneurial university through its top-to-bottom innovative and entrepreneurial institutional culture and strong regional network.

Twente is renowned for medical technology, with a Techmed center and the SIRIUS study association for health sciences for product and process development in 'medtech', supported by Holland Innovative. The Advanced Manufacturing Center is being established in the Kennispark Twente near the university. The university actively builds technology companies with the support of the Technano Fund and the Innovatiefonds Twente.

Its activities have led to more than a hundred new start-ups per year, with 20 000 jobs created. The UT spin-offs also account for 10 per cent of the fastest-growing high-tech companies in the Benelux countries. This case relates to the TMT (and TTT) and the triple helix ecosystem dimensions of the QH model. (*https://www.utwente.nl/en/; http://www.kennispark.nl/)*

Technology readiness – the ICT4RED case study

The principles of the QH model promote valorisation and start-up companies. In the conventional world of academia, the 'publish or perish' mode of operation is common, with the majority of published IPs not taken further for commercialisation. An example of IP being used for commercialisation is the South African project that gets people 'plugged into' tablet technology [35], supporting learners in rural schools. This project, called ICT4RED, uses Stellenbosch University's telematics services division to broadcast extra lessons to 324 schools around the country, transmitting them via a satellite dish on the schools' roofs.

The TTOs of entrepreneurial universities are strategically located to operate in a large and dynamic innovation system. These offices do not have to be situated on the main campus, but should remain a dynamic open system to bring business and industry into the science and academic society. TTOs are recognised as crucial intermediaries in the commercialisation process. UBC configurations converge into a few distinct archetypes with unique entrepreneurship curricula and concepts of innovation pedagogy. Graduate employability is a social responsibility, and new initiatives and programmes (pedagogical structures) are needed for young entrepreneurs.

The QH model accommodates mid-size companies

Recently the *Harvard Business Review* noted how midsize companies can compete in AI (artificial intelligence) with a network and ecosystem approach [36]. The authors of that article are well-acquainted with triple helix, with Bammens being from the entrepreneurial Maastricht University in the heart of the

Brightlands open innovation community, which connects four campuses in the province of Limburg. AI is upcoming general-purpose technology, poised to create new business opportunities for start-ups. It can also disrupt industries. Corporate AI innovation companies account for more than 15 per cent of AI patents. Big data and AI talent are the two most critical resources, residing mostly at giant corporations that support start-up companies. Accordingly, midsize companies struggle to keep up. Bammens and Hunermund [36] suggest that these firms join forces by pooling data and talent in an AI joint-venture structure and ecosystem to remain competitive in the new data-fueled economy.

Cases of academic power

Van Looy, Ranga, Callaert, Debackere, and Zimmerman [37] propose a combined entrepreneurial and scientific performance in academia leading to a compounded and reciprocal Matthew effect. The principle is based on synergy and cumulative advantage. Academic entrepreneurs use opportunities for research, valorisation, and engagement, making for better academia. It is about empowerment and seeking the Matthew effect for innovation.

Valorisation and the Matthew effect are some of the outcomes of scientific performance and entrepreneurial activity in academia. The cooperation between the Delft University of Technology, Wageningen University, and the Massachusetts Institute of Technology (MIT) in the Amsterdam Institute for Advanced Metropolitan Solutions serves as an example. Another example is the group of universities involved in the Siemens ingenuity strategy. (See the discussion of this case study.)

The Triple Helix Association (THA) (www.triplehelixassociation.org) promotes the academic power of engagement as the new wave of the future in respect of entrepreneurial universities and an academic revolution. Stanford University and MIT are the benchmarks for triple helix consultation (as incubators similar to Silicon Valley). They advocate vocational PhDs, and believe that consulting professors become better teachers as professors of practice. The Triple Helix Association (THA) actively promotes valorisation, research incubator hubs, and the Matthew effect.

Valorisation is making knowledge and research output applicable and available for economic and societal adoption. Academia could transform IPs into technology for TTOs and TTCs. They could commercialise solutions as intrapreneurs (for the university) and entrepreneurs by other means. Van der Sijde, Bossink, Van Hoorn, Van Gogh, Dekker, De Esch, and Rozendal [38] report on such examples from the high-tech VU University, Amsterdam. (See discussion of this case study.)

A triple technology theory case

Zawislak, Fracasso, Alegre, and Tello-Gamarra [39] refer to the full spectrum of technology by combining multiple human and hardcore high-tech capabilities to forge innovation. The initial QH model referred to 'TMT', and it was suggested that a more holistic term be used in the context of the triple concepts. This led to TMT (triple management theory) to encapsulate all dimensions of the technology spectrum. During a recent (September, 2022) visit to the Netherlands, it was observed how this concept is described as "thematic technology transfer" (TTT) with reference to the University of Twente working in partnership with other entrepreneurial universities such as Maastricht, Delft, and Wageningen in order to take cutting-edge technology to the next level together.

This evolution of technology management (and technology intensity) includes a technology-pull approach with respect to a new kind of business intelligence in order to understand better and to satisfy the epochal society. The modern paradigm of technology (TTT) also sees a new focus on human talent (intelligence) and high-tech technology, TMT management skills as technology, different types of technology, technology partners, digital transformation, quantum computing, AI, process technologies, technology readiness, and operations excellence.

The case of the entrepreneurial University of Twente through hi-tech and human touch relates to TTT. The university is connected to all Dutch technical universities and innovation industries supported by the Twente Technology Fund. An example of the evolution from a TTO (common at most entrepreneurial universities) to a TTC is Yissum, the TTC of the Hebrew University of Jerusalem, mentioned earlier. This underlines the TTT concept of the QH model.

The World Economic Forum case

Schwab [40], the chairperson of the World Economic Forum (WEF), in clarifying how to respond to the Fourth Industrial Revolution (4IR), explains innovation in this context. The expert views of Schwab [41], together with the institutional publications of the WEF [42], serve as a useful measure for the QH model.

Institutions are becoming more integral to society, and ethics has become a new standard for human dignity, identity, privacy, and choice. The social fabric changes, and modern leaders will use the 'human cloud' of experts to assist. A new type of leadership will be imperative to integrate with a triple helix ecosystem. To be customer-centric will require agility at the next level as real-time data and analytics bring a new paradigm to the way customers are targeted. Moreover, these new leaders will be futurists who understand and anticipate mega-trends [41] in the biological, physical, and digital worlds. This evidently supports the QH model in many direct and indirect ways [43].

Table 1 presents a summary of recent cases used for the review of the QH model dimensions.

Table 1: Recent cases and QH model dimensions

Recent cases used for the review	The QH model's dimension focus
Urban innovation case	Epochal society and the triple-helix ecosystem
Innovation factory case	Technology excellence; focus on TMT and TTT
R&D for epochal society case	Epochal society
Entrepreneurship ecosystem for students case	Triple-helix ecosystem
Technology transfer companies case	Triple-helix ecosystem; TMT and TTT
University supply chain case	Triple-helix ecosystem
Technology readiness case	TMT and TTT
Triple technology theory case	TMT and TTT
World Economic Forum case	Entire QH model; all dimensions

Source: Authors

Non-recent cases measured against the four dimensions of the original QH model

Table 2 presents three cases of cooperation between universities and organisations in Europe, as prepared for the European Commission by Davey, Baaken, Deery, and Muros [44]. The three case studies indicate collaboration in research, mobility of academics, mobility of students, and commercialisation of research outputs.

Table 2: Case studies reviewed against the original QH model dimensions

	QH model dimension			
	Epochal society	**TMT**	**Upscaling agility**	**Triple helix ecosystem**
Case 1: SPEED (student placements for entrepreneurship in education); students are budding entrepreneurs who create a self-employed placement; project-leading institution was Wolverhampton University.	In support of social and economic regeneration, the project addresses the UK's need for new businesses and issues raised by the Lambert review of UBC and the innovation network white paper.	Not prominent in the case description.	The leadership's commitment to adapt is significant in its target to support 1 200 students with 140 ventures. Initially, 11 universities were involved, including Birmingham, Central England, Coventry, and Derby.	The impact is the develop-ment of an innovation ecosystem. Engagement among HEIs, enterprises, and students beyond their expected academic disciplines.

	Epochal society	TMT	Upscaling agility	Triple helix ecosystem
Case 2: Master of Entrepreneurship and Technology (ETM); University of Tartu	The region in Estonia identified the need to establish more high-tech companies. The ETM programme was a pioneering initiative in the Baltic states. Students work closely with industry, the public sector, and other entrepreneurs.	The focus was on high-tech companies. Some students ended up in Silicon Valley (USA) as incubators for creative industries. This relates to the TMT dimension of the QH model.	The wide engagement and adaptability indicate agile leadership, such as new and similar incubators in Tartu and Tallinn. The unique ETM programme offered by the university is another sign of agility attracting non-regular students.	Very prominent example of triple helix and how the ecosystem and its impact spreads widely beyond Tartu and Estonia.
Case 3: Demola platform, Finland; universities in Tampere.	Southern Finland is an international growth centre for versatile services and creativity. Society recognised that growth in well-being must be enhanced through investment in culture and structures that enable innovation. Their open innovation approach involves citizens in innovation.	The open innovation approach was enhanced with its 'new factory' platform to engage professionals for new development. This relates to elements of TMT.	The objective of the Demola platform is to boost agile multi-disciplinary innovation and to encourage entrepreneurship in the Tampere region. To engage Hermia (Ltd), three universities, and 500 students for new product concepts, 110 completed projects of which 96% are licensed, creating new jobs, speaks of agility.	Very prominent example of triple helix and how the ecosystem (Demola platform) had an impact on the environment as a whole. The project was the winner of the 2010 regional innovation award from the Assembly of European Regions.

Source: Authors

5. CONCLUSION

The identified research problem and the paucity of studies in the literature provided evidence of the need to review further the new hypothetically improved QH model. The problem was addressed through a conceptual and case study review of the updated QH model and its primary constructs, without the need to add, adapt, omit, or combine constructs. With regard to innovation essentials, the QH model adheres to all three categories, namely innovation as a process, innovation as human abilities, and innovation as change. Regarding perspectives on innovation models, the emphasis is on the linkages and alliances that are inherent in the QH model with respect to systems integration, extensive networking, agility, and continuous innovation. It was also underlined that the QH model advocates successful innovations based on cross-industry partners and cross-functional interaction that triggers valorisation and the Matthew effect.

The QH model strongly emphasises innovation leadership in the context of the entire model. This is the primary 'essential of innovation', with innovation leadership traits synthesised into four groups: aspire and mobilise, discover and choose, evolve and accelerate, and scale and extend. Innovation leadership (with different potential terminologies), together with the necessary leadership essentials, is revealed as the primary force behind the interplay of the four dimensions of the model in the digital, biological, physical, and legal worlds. The new TTT concept was also highlighted as a further development of TMT.

In general, the reviews based on case studies related strongly to the QH model as an innovation tool and a best-practice frame of reference. The model is complete without the need for more dimensions, thus encapsulating the primary forces of innovation. Although comprehensive, it is regarded as a well-balanced model in the context of complex model formation and user-friendliness. Johnson & Johnson (J&J) served as an example of innovation through simplicity that cautions us about using complex models. Learner management and an appropriate term for 'innovation leadership' should improve a well-established model.

A balance will be needed for learner management with respect to user-friendliness and the principle of simplicity for a complex phenomenon. It was noted that models will always express different levels of precision, indicating that no single model would ever be sufficient or perfect. The best models are comprehensive yet concisely connected to practical reality (the innovation phenomenon) for user-friendliness. Accordingly, it is recommended that the QH model include a design for a step-by-step 'learner management' guide on how to use the model. A point of departure could be to use both the ISO 56002:2019 standard for innovation and the UIIN, with its experience of the success factors for UBC and triple helix partnerships as a benchmark. The UIIN shares this knowledge by means of a partnership canvas as a tool to assess and develop an institution's partnership approach to these success factors [38]. The themes include an engagement-readiness monitor, valorisation training for social sciences and humanities (SSH), signposting the possible options to spin out high-potential new companies, and creating immediate social value. The UBC accelerator methodological 'how to' training provided by practitioners is not a complete guide, but could be valuable with respect to an important additional construct of the QH model. Regardless of the value of this, it is expected that the principles for managing innovation will remain, namely uncertainty, complexity, disruption, and creativity.

The complex process of model formation and validation was therefore enforced to review further the new hypothetically improved QH model. The conceptual and case study reviews ultimately confirmed the QH model and its usefulness. Any model is in flux for improvement, and learner management and a guide on how to apply the model is supported.

REFERENCES

[1] **Addison, G.** 2005. *The competitive edge — Creating innovations*. Meyersdal, Gauteng: The Engineering Association.

[2] **Carayannis, E.G., & Campbell, D.F.J.** 2009. Mode 3 and quadruple helix model towards a 21st century fractal innovation ecosystem. *International Journal of Technology Management,* 46(3/4), pp 201–234. https://doi.org/10.1504/IJTM.2009.023374

[3] **Pappas, C.** 2014. Instructional design models and theories: The discovery learning model. *eLearning industry.com*.

[4] **Steenkamp, R.J.** 2019. The quadruple helix model of innovation for Industry 4.0. *Acta Commercii,* 19(1), a820. https://doi.org/10.4102/ac.v19i1.820

[5] **Mir, M., Llach. J., & Casadesus, M.** 2022. Degree of standardization and innovation capability dimensions as driving forces for innovation performance. *Quality Innovation Prosperity,* 26(2), pp 1-20. doi: 10.12776/QIP.V26I2.1678

[6] **Omelyanenko, V., Kudrina, O., Semenikhina, O., Zihunov, V., Danilova, O., & Liskovetska, T.** 2020. Conceptual aspects of modern innovation policy. *European Journal of Sustainable Development,* 9(2), pp 238–249. doi*: 10.14207/ejsd.2020.v9n2p238*

[7] **Dirkse van Schalkwyk, R., & Steenkamp, R.J**. 2022. A hypothetical improvement of the quadruple helix model of innovation. *Acta Commercii*, 22(1), a1037. https://doi.org/10.4102/ac.v22i1.1037

[8] **Cooper, D.R., & Schindler, P.S**. 2011. *Business research methods,* 11th Edition. McGraw-Hill.

[9] **Saunders, M., Lewis, P., & Thornhill, A**. 2012. *Research methods for business students*, 6th Edition. Pearson.

[10] **Corley, K.G., & Gioia, D.A.** 2011. Building theory about theory building: What constitutes a theoretical contribution? *Academy of Management Review,* 36(1), pp 12–32.

[11] **Plowright, P.** 2011. *Using mixed methods — Frameworks for an integrated methodology*. SAGE.

[12] **Trafford, V., & Leshem, S**. 2012 *Stepping stones to achieving your doctorate*. Open University Press / McGraw Hill.

[13] **McGregor, S.L.T.** 2018. *Conceptual and theoretical papers*. SAGE.

[14] **Dirkse van Schalkwyk, R.** 2018. A total quality service framework for private higher education in South Africa. PhD dissertation, University of South Africa.

[15] **Cropanzano, R.** 2009. Writing nonempirical articles for *Journal of Management*: General thoughts and suggestions. *Journal of Management,* 35, pp 1304–1311.

[16] **Gilson, L.L., & Goldberg C.B.** 2015. Editors' comment: So, what is a conceptual paper? *Group & Organization Management,* 40(2), pp 127–130. doi: 10.1177/1059601115576425

[17] **Whetten, D.** 1989. What constitutes a theoretical contribution? *Academy of Management Review,* 14, pp 490–495.

[18] **Jaakola, E.** 2020. Designing conceptual articles: Four approaches. *AMS Review,* 10, pp 18–26. https://doi.org/10.1007/s13162-020-00161-0

[19] **Smith, D.** 2010. *Exploring innovation*, 2nd Edition. McGraw-Hill.

[20] **Caruso, L**. 2018. Digital innovation and the Fourth Industrial Revolution: Epochal social changes? *AI & Society*, 33(3), pp 379–392. https://doi.org/10.1007/s00146-017- 0736-1
[21] **Rigby, D.K., Sutherland, J., & Noble, A.** (2018). Agile at scale. *Harvard Business Review,* May–June, pp 88–96.
[22] **Raheem, R.O.** 2018. Triple management theory and agility, technology interoperability and flexibility challenges in a specified domain. *The IUP Journal of Knowledge Management*, 16(2), pp 7–48.
[23] **Schonberger, R.J., & Knod, E.M**. 2001. *Operations management — Meeting customers' demands*, 7th Edition. McGraw-Hill Irwin.
[24] **Todd, J.** 2006. *A review of innovation models*. Science and Technology Policy Research Unit, University of Sussex, Imperial College, London.
[25] **Kotsemir, M.N., & Abroskin, A.S.** 2013. *Innovation concepts and typology — An evolutionary discussion*. Higher School of Economics Research Papers No. WP BRP 05/STI/2013.
[26] **Meyer, T**. 2010. *Innovate — How great companies get started in terrible times*. Wiley.
[27] **Ilbury, C., & Sunter, C.** 2001. *The mind of a fox — Scenario planning in action*. Human & Rousseau/Tafelberg.
[28] **Dearlove, D.** 2007. *Business the Richard Branson way — 10 secrets of the world's greatest brand builder*, 3rd Edition. Capstone.
[29] **Meerman, A.** 2019. Different types of engaged universities: No one size fits all. Presented at University Industry Collaboration Indaba: Creating an inclusive innovation ecosystem. Pretoria, South Africa, October 16–17.
[30] **UIIN Newsletter**. 2021. *University industry innovation network*, Science Park, The Netherlands. www.uiin.org.
[31] **De Jong, M., Marston, N., & Roth, E.** 2015. The eight essentials of innovation. *McKinsey Quarterly*, April.
[32] **Pycraft, M., Sing, H., Phihlela, K., Slack, N., Chambers, S., & Johnston, R.** 2010. *Operations management — Global and Southern African perspectives*, 2nd Edition. Pearson Education.
[33] **Vise, D.A**. 2005. *The Google story*. Pan-Macmillan.
[34] **Cunningham, J.A., & O'Reilly, P.M.** 2018. Meso and micro perspectives of technology transfer. *The Journal of Technology Transfer*, 43(3), pp 545-557. doi:10.1007/s10961-018-9658-4
[35] **Wild, S.** 2015. *Innovation — Shaping South Africa through science*. Macmillan.
[36] **Bammens, Y., & Hunermund, P**. 2021. How midsize companies can compete in AI. *Harvard Business Review,* September.
[37] **Van Looy, B., Ranga, M., Callaert, J., Debackere, K., & Zimmerman E**. 2003. Combining entrepreneurial and scientific performance in academia towards a compounded and reciprocal Matthew-effect. *Research Policy* 33, pp 425-441.
[38] **Van der Sijde, P.C., Bossink, B., Van Hoorn, P.K.R., Van Gogh, A.T.M., Dekker, J.P., De Esch, I.J.P., & Rozendal, I.** 2013. Entrepreneurship and innovation in science education. University-Industry Interaction Conference, Amsterdam, The Netherlands, 2013.
[39] **Zawislak, P.A., Fracasso, E.M., Alegre, P., & Tello-Gamarra, J.** 2018. Technological intensity and innovation capability in industrial firms. *Innovation & Management Review,* 15(2), pp 189–207. https://DOI 10.1108/INMR-04-2018-012
[40] **Schwab, K.** 2016. *The Fourth Industrial Revolution: What it means, how to respond*. https://www.weforum.org/agenda.
[41] **Schwab, K.** 2017. *The Fourth Industrial Revolution*. Penguin Random House.
[42] **World Economic Forum**. 2019. *Leading through the Fourth Industrial Revolution: Putting people at the centre*. White paper, World Economic Forum, Geneva, January.
[43] **Steenkamp, R.J.** 2020. A World Economic Forum perspective on the quadruple helix model of innovation. *South African Journal of Industrial Engineering,* 31(4), pp 59-69.
[44] **Davey, T., Baaken, T., Deery, M., & Muros, V.G**. 2011. *Thirty good practice case studies in university-business cooperation*. Science-to-Business Research Centre, Munster University of Applied Sciences.