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Innovation in Living Labs: A Quantum Approach

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Abstract

Living lab research is a well-accepted stream of innovation management literature. Although previous research has documented living labs from a variety of perspectives, the core of living labs and their principles remain largely underexplored. The present study analyses innovation in living labs inspired by the lens of quantum theory and its key concepts, including superposition, entanglement and wave function collapse. More specifically, the study applies insights from quantum theory to improve our understanding of innovation endeavours in living labs. The framework developed in the study illustrates how and why living labs advance innovations: they enhance collisions of individuals with different backgrounds and knowledge, thereby increasing potential realities (superpositions) and their collapses. The study contributes to living lab literature by suggesting that living labs can be seen as a realisation of quantum computing in real-life environments, speeding up innovation activities. While the study explores conceptual aspects, its findings can offer valuable insights for policy makers and practitioners engaged in living labs.

Keywords: Living Labs, Quantum Theory, Quantum Approach, Superposition, Collapse of Wave Function, Entanglement.

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1 Introduction

The concept of living labs has garnered increasing attention in innovation management literature (Greve et al., 2020, 2021; Engels et al., 2019; Furr et al., 2016) because living labs are argued to provide ample innovation benefits to a variety of stakeholders (De Vita & De Vita, 2021; Leminen et al., 2021). In accordance with the definition provided by Westerlund and Leminen (2011, p. 20), living labs in this study are understood as '*physical regions or virtual realities in which stakeholders form public-private-people partnerships (4Ps) of firms, public agencies, universities, institutes, and users all collaborating for creation, prototyping, validating, and testing of new technologies, services, products, and systems in real-life environments*'.

The present study discusses how solving real-life problems in living labs can be grasped by using the quantum approach, which refers to applying the concepts of quantum theory to research fields outside physics. Quantum theory is an umbrella term covering a multitude of research fields that study quantum phenomena, including quantum mechanics, quantum physics and quantum informatics (Hahn & Knight, 2021). Further, it can be considered a mathematical model that predicts the results of experiments at the subatomic level (Van Langenhove, 2020). It suggests that prior to the measurement of a tiny object, a quantum (e.g. a photon) behaves as a probabilistic wave, and when observed or measured, it behaves as a particle (Dyck & Greidanus, 2017; Bhattacharjee, 2017). Nonetheless, there are also more and more suggestions to apply quantum theory as a new approach to studying social phenomena (Van Langenhove, 2020; Hahn & Knight, 2021; Lord et al., 2015). Concurrently, quantum computing, building on the underlying quantum theory, has emerged as a novel technology expected not only to transform societies at large but also the specific ways companies organise their activities and operations (Inglesant et al., 2021). In brief, it refers to the processing of data while relying on the principles of quantum physics, incorporating ideas such as entanglement and superposition (Kietzmann et al., 2021; Inglesant et al., 2021).

The quantum approach has been used in the field of social sciences and management by, for example, Lord et al. (2015) to examine organisational change, Hahn and Knight (2021) to explore organisational paradoxes, and Dyck and Greidanus (2017) to enrich understanding of the sustainable organising theory. Whereas the prevailing economic paradigms still build on Newtonian mechanistic principles based on predictability, objectivity, causality and rationality, the multifaceted modern human reality can probably be better explained with a non-Newtonian quantum approach based on uncertainty, relativity, interconnectedness, indeterminism and complexity (Leong, 2022; Murphy, 2021; Dyck & Greidanus, 2017). Because Newtonian theory is mechanistic, it can explain only systems that are linear, predictable, controllable and isolated (Hahn & Knight, 2021; Bhattacharjee, 2017). Conversely, the quantum approach is especially appropriate for analysing systems that are unstable and sporadic, such as innovation processes (Leong, 2022; Zhao et al., 2022; Ottosson & Björk, 2004; Ottosson, 2003). Given the nature of quantum theory, the quantum approach fosters opening new research avenues for living lab research.

Living labs integrate the knowledge and expertise of versatile participants for innovation, development and testing (Engez et al., 2021; Leminen et al., 2012). Previous research has discussed various types of living labs, including urban living labs in cities and highly populated areas where residents play pivotal roles in innovation and its realisation (Leminen et al., 2012, 2017, 2021). Innovation activities, such as testing, validating, co-developing and co-creating, help to discover and create knowledge. Furthermore, participant diversity tends to promote collisions of knowledge and expertise of various stakeholders, thereby contributing to ideation and problem-solving in living labs that pursue developing products, services or other types of innovation jointly in real-life environments (Leminen et al., 2020). Even though previous research has analysed living labs from multiple different perspectives, their underlying core remains underexplored (Greve et al., 2020; Hossain et al., 2019; Leminen et al., 2017; Paskaleva & Cooper, 2021). This study investigates the essence of living labs inspired by the quantum approach to address this gap. Taking into consideration the diversity of living labs (cf. De Vita & De Vita, 2021; Greve et al., 2020; Leminen et al., 2012), the study addresses innovation endeavours among various stakeholders in living labs.

Specifically, the study applies the quantum approach, that is, the fundamental principles and ideas from quantum theory literature, to the phenomenon of living labs. That way, the study allows us to understand the role of joint innovation endeavours by participants taking place parallelly in living labs in a novel and fruitful manner. Using living labs as the context of our study, we elaborate on the key concepts associated with quantum theory applied to investigating social phenomena. These concepts address, for example, quantum theory's concepts of wave-particle duality, superposition, wave function collapse, field theory and entanglement. Drawing on the ideas by Hahn & Knight (2021) and Murphy (2021), we expect the quantum approach to help us gain novel insights that can enhance our understanding of innovation-related phenomena within living labs and provide fresh conceptual tools alongside the extant research approaches. Nevertheless, instead of establishing direct analogies between social and quantum systems, it is essential to note that we do not assert their similar behaviour. Given that the study aims to apply a quantum approach to living labs, our research question can be articulated as follows: How does the concept of living labs exemplify the application of a quantum approach to solving real-life problems?

This conceptual study contributes to the extant body of literature on living labs in multiple ways. First, the study identifies three quintessential concepts associated with quantum theory, which can be applied to describe innovation endeavours taking place parallelly in living labs, namely (i) superposition, (ii) entanglement, and (iii) collapse. Second, the study constructs a novel conceptual framework entitled SEC (an acronym for superposition, entanglement and collapse), which can be used for the analysis of living lab activities where multistakeholder involvement takes place for innovation in real-life environments. Third, the paper proposes that collisions of participants' thinking and usage of artefacts in real-life environments play central roles in enhancing an expedited and repeated collapse of potential realities ('superpositions') that lead to fostering and speeding up innovation activities. With these contributions, we anticipate that future research on the application of the quantum approach can open innovative paths in understanding complex phenomena in the field of innovation.

The article is organised as follows. The second section describes the research design of the study, followed by the third section, which reviews the literature on living labs and the quantum approach from the perspective of business and management studies. The fourth section highlights the findings. The article concludes with contributions to theory and practice and discusses the study's limitations along with suggestions for future research.

2 Research design

To scrutinise how the quantum approach has been used in the fields of management and business research, we first conducted a preliminary literature search related to quantum theory and quantum computing in Google Scholar. The purpose of this research step was to identify key concepts and comprehend their application opportunities for studying innovation management. After setting a detailed plan for the literature review, we conducted the endeavour by selecting the studies for review, evaluating the data, analysing, synthesising and reporting the results (Cooper, 1989; Tranfield et al., 2003). However, the purpose of our literature review was not to use any systematic methods or analyse the referencing or relationships between articles and the authors. Instead, the aim was to increase our understanding of how quantum theory and its principles have been used in management and business research and to construct a theoretical framework usable in an empirical context related to living labs.

Drawing on the suggestions by Eisenhardt (1989), our theoretical framework was built on constructs applicable to analyse innovations within the living lab literature. We used an integrative approach to gather valuable insights and discover emerging themes rather than analyse all available publications (Snyder, 2019; Torraco, 2005). We designed the search to identify concepts that matter for innovation endeavours. We only included studies focused on business and innovation, thereby excluding those that manifestly focused on technologies or aspects beyond management and business. Further, we only selected papers written in English for our analysis. In this initial step, taking place in February through March 2022, we searched for relevant peer-reviewed articles using Google Scholar with the following search terms: 'quantum theory' AND 'business', 'quantum theory' AND 'innovation', 'quantum theory' AND 'outcome', 'quantum theory' AND 'living lab' and 'quantum theory' AND 'social', as well as 'quantum computing' AND 'business', 'quantum computing' AND 'innovation', 'quantum computing' AND 'outcome', 'quantum computing' AND 'living lab' and 'quantum computing' AND 'social'.

After applying the above variables, the quantum theory literature search resulted in 826, 1210, 2240, 0 and 1600 articles, and the quantum computing search resulted in 822, 1520, 1290, 2 and 1030 articles, respectively, related to the search words listed above. Because of the extensive volume of articles, we organised the results based on their relevance and first chose the most relevant 100 articles from each search (1^{st} round selection). Thereafter, we screened titles, keywords and abstracts of those articles with the aim of finding out whether they provided interesting viewpoints for business and innovation (2^{nd} round selection). For the 3^{rd} round selection, two researchers conducted a tentative analysis of the relevance based on the perceived quality level of publications. We excluded and restrained duplicates. After reading the articles, we selected 23 articles for a more detailed analysis (See Table 1 in the Appendix). In addition, we adopted the snowballing method using the reference lists of the included articles to identify relevant articles further, resulting in five additional articles to our sample of literature on the quantum approach. Finally, 28 articles related to quantum literature were assorted for developing a conceptual framework.

Although the literature on quantum theory and quantum computing is substantial, the majority of the articles found were not relevant to our research purpose due to their focus on technology and computing. To find more research papers for the analysis of the quantum approach applied in the fields of management and business research, we conducted a second literature search in the Scopus database during the summer of 2023. Upon this step, we limited the searches to articles in the subject areas of business. We simplified the search by only applying the term 'quantum', thus omitting 'computing' and 'theory' from the strings. To add the relevance of the search based on the learnings gained in the initial literature search, we also added new search strings, including the terms 'management', 'strategy', 'stakeholder' and 'serendipity'. We applied the same inclusion criteria as used in the preliminary literature search but excluded articles that used the term 'quantum' merely to refer to an amount or size, type of era, or in a methodology or company's name. We also excluded articles which focused on the quantum computing industry or technological issues, as well as brief articles solely reporting interview(s).

Then, we used the same process for analysing the papers as described in the preliminary literature search. In contrast to the initial literature search, we only needed two selection rounds since there was no need to limit the search results due to the moderate number of relevant articles. After carefully reading the articles to have a better grasp of the contents, we selected 67 for a more detailed analysis (See Table 2 in the Appendix). In addition, we added three articles found using snowballing. Although the search in the Scopus database resulted in more relevant articles with a broad discussion on the quantum approach applied in business and management studies, we failed to discover any articles that would discuss living labs through the quantum approach. We only found a few articles related to innovation in general. Of note, given that the extant literature on living labs provides numerous comprehensive and informative literature review studies (e.g. McLoughlin et al., 2018; Westerlund et al., 2018; Hossain et al., 2019; Greve et al., 2020, 2021), we did not conduct a literature search on living labs.

Next, we will briefly discuss the literature on living labs and summarise the findings from our two literature searches on quantum. After that, we will establish a theoretical framework combining critical aspects of the quantum approach with living lab processes and environments. Figure 1 illustrates our research design.

3 Literature on living labs and the quantum approach

To set up a research landscape for conjointly investigating living labs through the quantum approach, we will first discuss the research background for both literature streams.

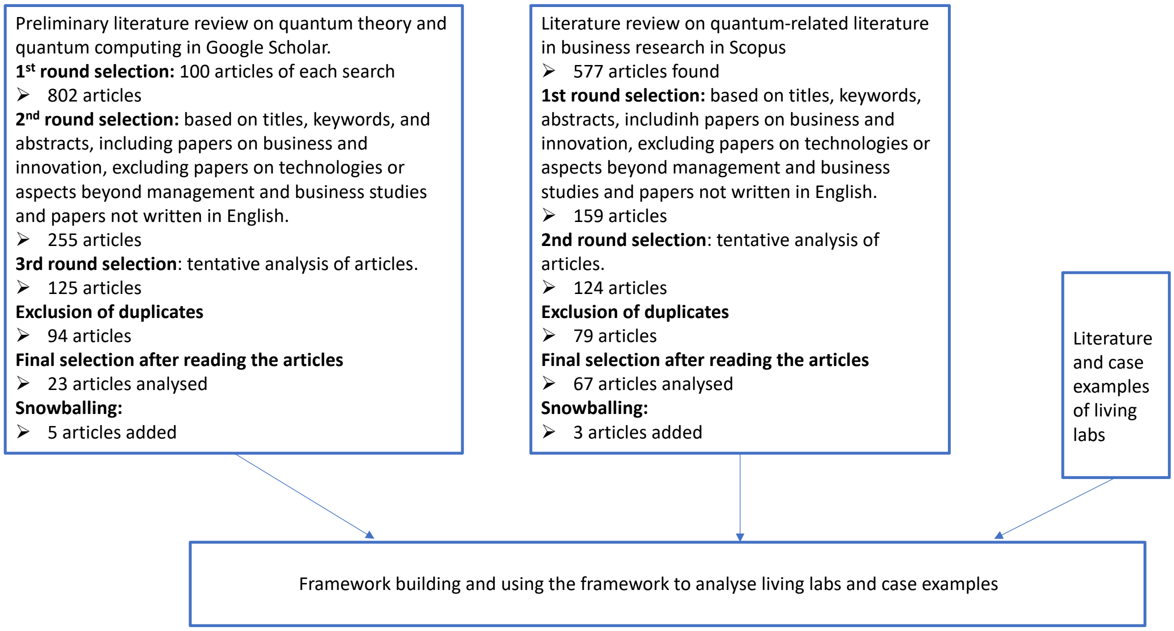

Figure 1. Flowchart illustrating the research design.

3.1 Living labs

Living labs consist of various types of stakeholders, including private organisations, public bodies, users, citizens and residents, that come together for problem-solving and joint innovation activities in real-life environments (Westerlund & Leminen, 2011; Westerlund et al., 2018). Living labs tend to manifest different constellations and are organised in a multitude of ways, typically driven by one of their main participants, namely utiliser, enabler, provider or user (Leminen et al., 2012). Despite the tremendous diversity in terms of the driving parties, type of real-life environments, and variety of participants, living labs have several common characteristics: they focus on testing, validating, co-developing and co-creating innovations with multiple stakeholders in real-life environments (Greve et al., 2020, 2021; Schuurman et al., 2011). Nevertheless, the extant literature on indicates that these environments frequently yield unforeseen outcomes (De Vita & De Vita, 2021; Greve et al., 2020; Paskaleva & Cooper, 2021; Leminen et al., 2020). The essence of living labs consists of multiple and different stakeholders (Ballon et al., 2005) that bring diverse knowledge and expertise and share their knowledge with other participants (Nyström et al., 2014; Leminen et al., 2021).

Previous research has also addressed the effects of different network structures on the outcomes in living labs (Leminen et al., 2016). Participants may take or make different roles in the innovation network, mainly because there is a substantial set of varied user roles to support innovation in living labs (Nyström et al., 2014; Leminen et al., 2014, 2015a). Finally, the relevance of real-life environments has repeatedly been highlighted as a key to solving meaningful real-world problems (Greve et al., 2020; Hossain et al., 2019; Paskaleva & Cooper, 2021). More specifically, previous research on living labs underlines the transformation from a lab-like setting ('space') to tackling the sense of subjectivity, practical knowledge and tradition in 'place' (Dourish, 2006; Schultze & Boland, 2000). Indeed, living labs promote the living part, i.e. 'place' rather than the lab(oratory) part, namely 'space' (Bergvall-Kåreborn et al., 2015; Leminen et al., 2021).

The living part fosters the unintentional collisions of participants' thinking and encourages intentional collisions for the usage of artefacts when testing, validating and co-creating artefacts in real-life environments. Usage of a mobile phone application reveals a hypothetical example of a collision in a city environment. Pedestrians (having the role of an informant or a tester in the living lab, a real-life environment where the user is living) may focus on the use of a gadget rather than the surrounding city environment while crossing a road and be hit or run over by a car. The collision happened because the pedestrian was not monitoring the environment and did not take it into account when they decided to cross the road; instead, a non-functioning or slow application of a gadget grabbed their attention. This is an unintentional collision in the living lab, and it highlights an application that fails to operate properly. A physical space (such as a city environment) is transforming into a place when the collision of the usage of the artefact takes place. Such collisions of artefacts lead to rethinking artefacts or their features and how the aim and focus of innovation activities are organised longitudinally (Leminen et al., 2020, 2021).

3.2 Quantum theory and computing

According to the quantum theory, small particles, such as electrons and atoms, can follow both particle-like and wave-like behaviour (*wave-particle duality*). Our world is built of quantum *fields* consisting of waves, which can *collapse* into particles—as soon as we try to see the waves, they collapse into particles (Leong, 2022; Murphy, 2021; Laszlo, 2020; Dyck & Greidanus, 2017). This duality can be illustrated with a double-slit experiment where light travels through two slits, and if not measured, it exhibits wave-like interference patterns; however, if measured, it shows a particle-like pattern (Hahn & Knight, 2021; Palmer & Parker, 2001). *Superpositions* can be illustrated with wavefunctions corresponding to possible states of a particle when quanta in a probabilistic and indeterminate superposition state prior to measurement hold the potentiality of different locations of a particle (Hahn & Knight, 2021).

The problem can be evaded by the Copenhagen interpretation of Schrödinger's equation, declaring that a measurement of the system causes the wave function to collapse to a particular value (Hahn & Knight, 2021; DeCanio, 2017; Egg & Saatsi, 2021). However, there are also other interpretations, for example, the 'many worlds' view, according to which a measurement splits the universe into separate but equally real worlds, suggesting that all the possible outcomes of reality happen and continue to exist simultaneously without interfering with each other (Hahn & Knight, 2021; Dyck & Greidanus, 2017). Also, particles created precisely at the same time can have shared properties, thereby being *entangled* with each other, leading them to demonstrate 'spooky action at a distance' (DeCanio, 2017; Dyck & Greidanus, 2017). Further, quantum *contextuality* implies that the measurement of a property of a quantum system is linked to the set of measurements chosen (Amaral, 2019). In superposition states, parallel possibilities are in an unspecified state, but when combined with a particular context and its constraints, this potentiality collapses to a specific experienced reality (Lord et al., 2015).

In the early 1980s, Richard Feynman, an American theoretical physicist, pointed out the need for a quantum machine working on quantum mechanical principles because nature is not classical. This represented one of the first ideas of quantum computers replacing standard computers (Rieffel, 2010). In classical computing, an individual data bit, illustrated by an individual atom, can be in either of the two states represented by 0 (ground level) or 1 (elevated energy level). In quantum computing, a quantum bit (*qubit)* can be represented as a linear combination of 0 and 1, and it can take on any of these values (*superposition*). Further, entanglement can be seen as a resource for quantum computation (Rieffel, 2010; Akbar & Saritha, 2020).

There certainly are some problems to which quantum computing is unable to provide solutions. However, many problems would take millions or even billions of years for a classical computer to solve, whereas a quantum computer could solve them in a couple of days (Rieffel, 2010). For example, if a maze contains hundreds of possible paths, a classical computer will analyse the options for the correct route one by one. In contrast, a quantum computer would work with all the paths simultaneously, thereby arriving at a resolution much earlier (Ruane et al., 2022). Given the superior problem-solving power and computational capacity of quantum computing, it seems somewhat natural that the rapidly expanding literature on quantum computing tends to focus on the technology core, challenges and implementation of quantum solutions rather than identifying and conceptualising solutions by applying them in the context of social sciences (Van Langenhove, 2020; Wendt, 2015). Table 3 illustrates some fundamental concepts within the quantum theory.

Table 1. Some fundamental concepts of the quantum theory.

Concept	Explanation
Wave-particle duality	Small particles, such as electrons and atoms, can follow both particle-like and wave-like behaviour. When measured, waves collapse into particles (Leong, 2022; Murphy, 2021; Laszlo, 2020; Dyck& Greidanus, 2017).
Superposition	Probabilistic and indeterminate state of quanta prior to measurement, holding the potentiality of different locations of a particle (Hahn& Knight, 2021).
Wave function collapse	The world is built—not of particles—but only of quantum probability fields consisting of waves, which can 'collapse' into particles (Leong, 2022; Van Langenhove, 2020; Lord et al., 2015).
Entanglement	Particles created at the same time can have shared properties, thereby being entangled with each other, demonstrating 'spooky action at a distance' (DeCanio, 2017; Dyck& Greidanus, 2017).

3.3 Quantum approach in business and innovation studies

There is an ongoing debate about the Newtonian causality concept and its challenges in social sciences (Van Langenhove, 2020; Harré & Secord, 1972; Lewin, 1951). In contrast to theories built on causality, quantum theory examines probabilities rather than causalities, and quantum probability fields consisting of waves which may 'collapse' into particles propose that the world is built—not of particles—but of information (Van Langenhove, 2020; Shelton & Darling, 2003). Shelton and Darling (2003) point out that the universe is constructed of a field of information, and it is more like 'a great thought' than 'a machine' used as a metaphor by Newton. Hence, the quantum approach is proposed to provide excellent results when examining social phenomena (Van Langenhove, 2020; Bhattacharjee, 2017; Ottosson & Björk, 2004; Shelton & Darling, 2003; Palmer & Parker, 2001).

Van Langenhove (2020) classifies social phenomena as *directly observable* and *not directly observable*. The former includes persons, social artefacts (cities, roads, food, books, etc.) and speech acts, and the latter consists of networks people belong to, knowledge people possess, and moral orders giving rights and duties to them. While people, artefacts and conversations are *particle*-like and located in time and space, moral orders, knowledge and networks can be better understood as *fields*. This notion is discussed by Murphy (2021), who refers to Wendt's (2015) thought experiment of extraterrestrials who observe the Earth and can never directly see a state but rather only its effects, such as governmental buildings and police officers. Murphy (2021) also discusses the idea of quantum game theory, where choices are not limited to 'cooperate' or 'defect', but a superposition of the two is extant until plays are made. Throughout the entire game, the players are entangled. Entanglement can also be described by connectedness, leaning toward the idea that in the contemporary world of digital technologies, humans are more and more connected to each other across space (Murphy, 2021; Laszlo, 2020; Bhattacharjee, 2017).

While the ideas and logic of the quantum approach are slowly spreading to the fields of business and social science, management and innovation areas especially could benefit significantly from the novel thinking offered by the quantum theory (Yin, 2019). Yin (2019) provides an example of a company where people abandoned binary and linear thinking based on Newtonian mechanics, representing a turning point that led to enterprise innovation. The quantum approach will undoubtedly have a profound impact on management science in the new era, where space and time limitations will disappear, things will become dynamic, complex, and unpredictable, and everything will be linked together (Yin, 2019). The traditional Newtonian scientific foundation assumes at least six imperfect principles: 1) materialism, 2) atomism (separateness), 3) determinism, 4) mechanism, 5) space and time and 6) subject-object distinction (Wendt, 2015; Steinmo, 2017). The mechanistic Newtonian theory explains only machine-like systems that are linear, predictable, controllable and isolated, and management theory based on Newtonian logic emphasises laws, rules and control (Hahn & Knight, 2021; Bhattacharjee, 2017; Ottosson & Björk, 2004; Shelton & Darling, 2003; Palmer & Parker, 2001; Youngblood, 2000; Uphoff, 1994). In contrast, quantum management, based on the quantum approach, is characterised by flexibility, plurality, improvisation, participation, bottom-up self-organisation and value-seeking integrity (Yin, 2019). Especially for dynamic and unstable systems like innovation development, the Newtonian view is inadequate because outcomes from the interaction between two or more members of a product development team are impossible to predict. Even small changes in their opinion or actions can easily affect the situation and its outcomes (Ottosson & Björk, 2004).

Nonetheless, the quantum approach has already been applied outside physics, for example, in cognitive and social sciences, economics (including behavioural economics, finance and decision-making) and biology (Khrennikov et al., 2019; DeCanio, 2017). However, our literature review suggests that the extant literature on the quantum approach relevant to business research is still in its early stages and remains highly fragmented. There are different islands of theory-oriented discussion around a few key themes, such as quantum management, quantum learning and quantum game theory. While pioneering scholars of business and innovation have detected problem types and potential application areas for the quantum approach (e.g. Kietzmann et al., 2021; Inglesant et al., 2021; Hahn & Knight, 2021; Bhattacharjee, 2017; Ottosson & Björk, 2004; Shelton & Darling, 2003; Palmer & Parker, 2001; Youngblood, 2000; Uphoff, 1994), few conceptualisations exist regarding how the quantum approach can be used in innovation research, thus impeding the full exploitation of its potential.

4 Development of the SEC framework

Our study proceeds to develop a theoretical framework based on the concepts derived from the quantum approach. The resulting framework, labelled as SEC (an acronym for the quantum concepts of superposition, entanglement and collapse), should be useful in describing living labs and their potential for multidimensional, parallel innovation activities (Figure 2). Of note, the SEC framework represents the living lab process, where the bubbles represent different superpositions. One, the (black) coloured bubble, is realised (becomes a reality) as the wave function collapses at a particular Time phase. Participants interact in the living lab, and the outcomes of interactions 'evolve' along the arrows in the process through time. Furthermore, participants interact and create the reality by selecting from manifold possibilities (superpositions) regarding the realised joint realities. Entanglement is shadowed in each Time phase, revealing the interconnectedness as an indirectly observable field factor and the realised joint reality among the many possible unrealised realities.

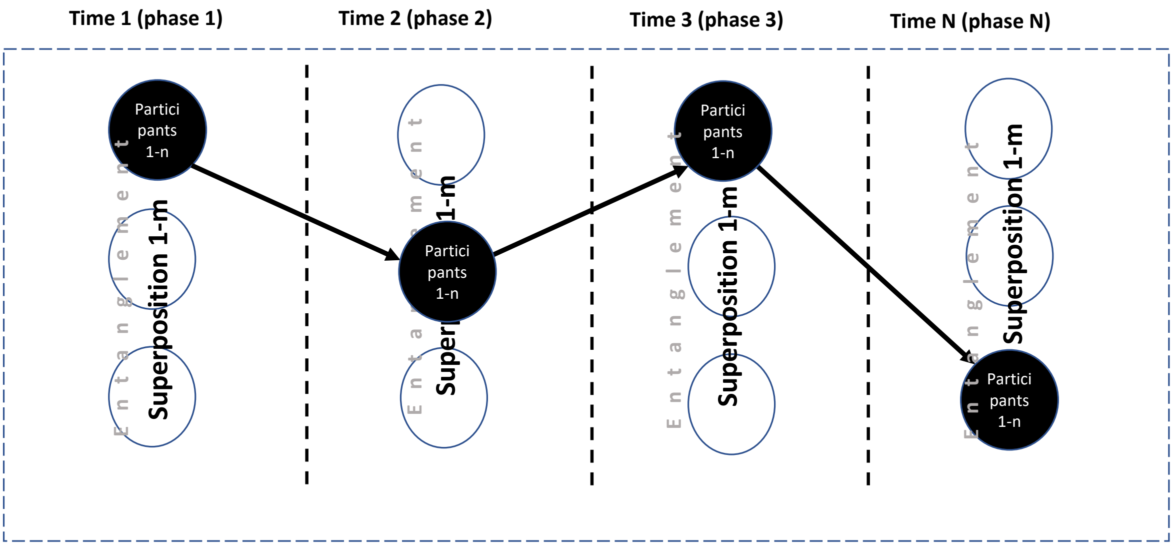

Figure 2. The SEC framework for innovation in a living lab.

As Van Langenhove (2020) and Murphy (2021) point out, many social phenomena are not directly observable, including (but not limited to) knowledge, networks and moral orders. Living labs gather stakeholders with varied backgrounds, experiences and contexts to collaborate and innovate together. Those stakeholders bring not only their knowledge and expertise but also their expectations, needs and wishes, including shared properties (Leminen & Westerlund, 2012). By stakeholders, we stress not only the objective factors, particularly the diversity of stakeholders such as them representing utilisers, enablers, providers or users, including academia (university and research centres), industry, citizens, users and public and private organisations (Ballon et al., 2005; Schuurman et al., 2011; Westerlund & Leminen, 2011) but also the subjective factors such as their richness in terms of unique and varied backgrounds, knowledge, beliefs and expertise (Leminen & Westerlund, 2012; Leminen et al., 2021). Indeed, according to the quantum approach, reality is subjective and over 80% of how we experience the world is based on our subjective assumptions and beliefs (Shelton & Darling, 2003).

In living labs, participants may, for example, co-create innovations or test various products and services (Nyström et al., 2014). Participants are entangled in their interaction—they may decide to cooperate, not cooperate or hold their options open (i.e. stay in a superposition state). As soon as participants' actions are finalised to meet other participants and communicate with them, one reality realises (i.e. the wave function collapses). If these interactions continue, new realities are realised continuously, one after another. In living labs, there can be multiple finalised actions and other communications ongoing all the time, allowing innovation activities among participants to take place parallelly and encompass their diverse thinking, knowledge and expertise. The latter part may be seen as multidimensional. The SEC framework illustrates innovation activities in living labs by superpositions, entanglement and collapses; the idea is inspired by quantum approach scholars, including Lord et al. (2015), Dyck and Greidanus (2017), Van Langenhove (2020), Hahn and Knight (2021), Leong (2022) and more (see Figure 2). Furthermore, Table 4 presents the concepts of the SEC framework in living labs.

Table 2. Concepts of the SEC framework in living labs.

Concept	Explanation in quantum theory and quantum approach	Concepts and their meanings are seen in the living lab literature
Superposition	Probabilistic and indeterminate state of quanta prior to measurement holding the potentiality of different locations of a particle (Hahn& Knight, 2021).	An unlimited number of potential multidimensional realities in living labs. These include (but are not limited to) real-life environments, methods, tools, roles, networks, systems, participants, expertise and knowledge (Leminen& Westerlund, 2012, 2017; Leminen et al., 2016; Nyström et al., 2014; McNeese et al., 2000).
Wave function collapse	The world is built—not of particles—but only of quantum probability fields consisting of waves, which can 'collapse' into particles (Leong, 2022; Van Langenhove, 2020; Lord et al., 2015).	Collapse ends up with one possible potential solution—multidimensional realities. Such a solution is invisible before innovation activities (Leminen, 2015; Leminen et al., 2015a).
Entanglement	Particles created precisely at the same time can have shared properties, thereby being entangled with each other; this demonstrates 'spooky action at a distance' (DeCanio, 2017; Dyck& Greidanus, 2017).	Entanglement refers to the interconnectedness of innovation participants, especially their commitment to collaborate and solve any upcoming issues in cooperation, where everyone knows what the degree or depth of collaboration is.

Innovation activities, such as testing, validating, co-development and co-creation, occur simultaneously and parallelly with diverse stakeholders (users and citizens, private companies, public organisations such as universities, financiers, city development agencies, etc.), surrounded by different artefacts and conversations, and different contexts (e.g. moral orders, knowledge and networks they bring into living labs).

Like in quantum fields, there is an unlimited number of potential multidimensional realities, that is, ***superpositions***, in living labs. The extant literature on living labs focuses on documenting and analysing potential realities, including real-life environments, methods, tools, networks, systems, participants, expertise and knowledge, while not being limited to those realities (cf. Leminen, 2015). In other words, there are multiple potential contexts in real-life environments. They may include work environments or living environments of various stakeholders, such as educational institutes or people's homes and workplaces ranging from a classroom to an entire country (Leminen et al., 2016; Nyström et al., 2014). Potential superpositions also include different methodologies and tools (Leminen & Westerlund, 2017; McNeese et al., 2000) applied in living labs as well as participants with their expertise and knowledge and the moral codes participants may bring to activities (cf. Leminen & Westerlund, 2012).

Collapse ends up with one possible solution from diverse superpositions in living labs. Such a solution is invisible before innovation activities (cf. Leminen, 2015; Leminen et al., 2015a). The solution may be an intangible or tangible outcome of innovation activities. An intangible outcome includes but is not limited to the decision regarding further steps in innovation endeavours (Leminen, 2015), knowledge and practices (Femeniás & Hagbert, 2013), needs and preferences (Edwards-Schachter et al., 2012), ideas and products, services, prototypes and platforms (Leminen et al., 2012, 2020). It may also revolve around actor roles and role sets; for example, co-developer or co-creator roles support co-creation activities, but informant or tester roles may not be well suited for co-creation purposes (Nyström et al., 2014; Leminen et al., 2014, 2015a). Network structures governed by particular types of stakeholders have been associated with radical or incremental innovations (Leminen et al., 2016). As Lord et al. (2015, p. 264) state, 'The future offers many potentialities, which we define as alternative states and possible outcomes that could occur but have not yet occurred because, to be actualised, they require the enactment of individual, social, and environmental events that are often serendipitous'. These events can be accelerated by offering serendipitous collisions of thinking and contexts for individuals in real-life environments of living labs, and they may be better understood through a quantum approach.

When organising innovation activities, superpositions may *collapse* into different realities at different stages in the innovation process. An individual collapse may be understood as the realisation of one of the potential realities (superpositions) for participants in a living lab. The wave function collapses into one reality, forming a constellation in which the problem can be solved. For example, a collapse takes place when a specific context and a method have been chosen for the living lab. Consecutive collapses occur when participants are involved or engaged in observing, validating, testing, co-developing or co-creating artefacts, services or systems in the context of a real-life environment of the living lab. Such collapses are unlikely to occur to participants when they are not present in that real-life environment. It can be understood that we are living in a reality, selected from all the potential realities, as wave functions collapse or reduce into one reality. However, in living labs, superpositions can also be generated simultaneously and repeated to create multiple realities, illustrating the 'many worlds' view of the quantum theory. The many worlds reality may appear when users, companies and public bodies bring their expertise to living lab activities. For example, Leminen et al. (2020) discuss how citizens and end users bring their expertise to city planning and energy-efficient houses in one Northern city. Participants with different backgrounds, resources, knowledge and skills pay attention to these problems in a city or buildings they are planning to live in (real-life environment), and this attention creates an energy field with elevated energy, increasing potential realities among the problems. Then, participants start to ideate solutions. As they select these ideas among a vast number of potential realities (superpositions), wave functions collapse into realities. Discussions and working together with other participants lead to consecutive collapses when participants choose ideas and develop solutions. For example, Leminen and Westerlund (2012) reveal development and validation concepts related to information technology-assisted shopping carts in a retail store, leading to more collapses of realities.

The present study argues that repeatedly generating wave function collapses in living labs potentially speeds up innovation processes by expanding and narrowing down the field of potential realities. Participants constantly co-create alternatives and reject ineffective and poorly functioning alternatives and solutions of artefacts in their specific environments. This is enabled by the fact that a living lab combines participants with unique backgrounds and resources, including knowledge, expertise, shared properties and social networks, to experiment and develop artefacts such as products or services in real-life contexts (social artefacts, conversations, moral orders). Put together, all this leads to different outcomes, enabling participants to tackle parallelly different options in a similar manner to how quantum computers operate. Participants exploit both intended and unintended collisions when experimenting and utilising products and services in real-life environments as well as across participants and their potential realities (superpositions).

Our previous example of a pedestrian using a mobile phone application in a busy city environment illustrates collapse. A traffic accident is one of the possible outcomes that occurred because the individual used the device while crossing the road. In order to realise this outcome, it demanded a specific combination of individual and contextual events which were serendipitous by nature: usage of the gadget, walking in a busy city environment, crossing the road, a car approaching the pedestrian, as well as lack of awareness and attention to the surroundings. These events offer an abundance of information for the development work of the device in a living lab. Prior literature describes other examples of collapses, where companies offered their product and service versions, such as thermometers, lighting, or other technology solutions, to validate, test and co-create in the settings of technology health centres, schools and city planning (Leminen et al., 2020, 2017; Leminen & Westerlund, 2012). Any collision(s) of usage(s) of such services and products in real-life environments changed product development avenues and service versions. Living lab literature also implicitly suggests the importance of collisions of people's mindsets by including the diversity of multiple and many living lab participants such as users, citizens, providers, enablers and universities for co-development and co-creation (Leminen et al., 2020; Ballon et al., 2005; Schuurman et al., 2011; Westerlund & Leminen, 2011).

Entanglement can be understood as participants' interconnectedness and how they choose to 'play the game' in living labs. There are complex relationships or shared experiences and properties that are at play in the background, enabling the entanglement of innovation outcomes. Therefore, entanglement can be viewed as a 'field concept', wherein participants may 'play the quantum game' and think or behave similarly or differently regarding given artefacts without any direct interaction. Entanglement takes place in the background without participants directly expressing their knowledge, experiences, properties or co-creating with other participants, and it only realises as the wave function collapses into one reality and 'the cards are revealed'.

Entanglement predominantly refers to the commitment of all participants to collaborate and solve upcoming issues in cooperation where everyone knows what the degree or depth of collaboration is. In entanglement, participants share a common characteristic in living labs: upon expressing willingness to collaborate and solve a common problem, make a commitment, and share what we know, everyone brings their own expertise and unique background understanding and indicating that they value others' expertise. The appreciation of other stakeholders' expertise includes the roles they represent. For example, Leminen and Westerlund (2012) discussed shared commitment in terms of how living lab participants changed their operations and roles to ensure agreed goals jointly. More specifically, the participants replaced the expertise and competence of a person from other organisations, who left the project in the critical phase in a living lab. Nyström et al. (2014) analyse an extensive portfolio of living lab projects that assume different degrees of openness and the way participants share knowledge. Also, Leminen et al. (2015b) discuss the role of openness in open and closed innovation networks.

5 Discussion and conclusion

This study applied the quantum approach to investigate innovation in living labs. Specifically, it aimed to explore how living labs that focus on solving problems in real-life environments can be analysed using the key concepts and principles of quantum theory.

5.1 Theoretical implications

The present study makes a threefold contribution to the scholarly field of living labs, specifically to the debate on parallel innovation endeavours solving real-world problems in real-life environments. First, the study introduced useful key concepts from quantum theory, mainly (i) superposition, (ii) entanglement, and (iii) collapse, to innovation research to advance our understanding of joint innovation activities in living labs. In so doing, our study analysed the essence of collaboration in living labs inspired by the quantum approach. In this vein, the quantum approach applied in the present study contributes to our knowledge by introducing relevant key concepts and providing their interpretations into the context of living labs and the non-Newtonian worldview—all these combined open new research avenues for future living lab studies.

The extant literature on living labs puts forward various concepts and conceptualisations that help us understand living labs and their activities, including (but not limited to) stakeholders and their typologies, roles and role sets, networks, outcomes and methodologies (Leminen et al., 2012; Greve et al., 2020, 2021). The quantum concept of superposition is essential for our understanding of living labs because it explicitly refers to the unlimited number of potential multidimensional realities, including contexts where innovation activities take place, networks and participants, and tools and methodologies while not being limited to these.

Although a living lab, by its definition, is built on diversity and engages a variety of stakeholders in innovation activities, previous literature offers little advice or concepts on how such joint innovation activities take place (Hossain et al., 2019). The quantum concept of collapse, in turn, can help living lab researchers advance their understanding by revealing joint innovation as a realisation of one of the potential realities (superpositions) for participants in a living lab. Such realisation may take place at any time during innovation endeavours within living labs. Prior studies tend to differentiate living labs from other research and development approaches or suggested principles for innovation activities (Bergvall-Kåreborn et al., 2009; Bergvall-Kåreborn & Ståhlbröst, 2009). The quantum concept of entanglement proposes a new view because entanglement may be understood as participants' interconnectedness and how they commit to collaborate and 'play the game' in living labs. The suggested key concepts derived from the quantum theory bring about novel views in this respect.

Second, the study established a conceptual SEC (i.e. superposition, entanglement and collapse) framework to analyse joint innovation endeavours that take place parallelly in living labs. The framework illustrates innovation endeavours exploiting the encounter of real-world problems with potential multidimensional realities ('superpositions') that realise, or in terms of the quantum approach, 'collapse' into different realities. Living lab scholars gain valuable knowledge on innovation endeavours even though options remain invisible during the endeavours. Previous literature underlines the importance of stakeholders and the unique expertise they bring to innovation processes (Leminen et al., 2014, 2021). Of note, some living lab frameworks consider innovation endeavours with several options simultaneously (Hossain et al., 2019; Leminen & Westerlund, 2012, 2017; Leminen et al., 2012, 2020, 2021). Extant literature on living labs suggests validating, testing, co-developing and co-creating artefacts (products and services) in actual real-life environments (Leminen et al., 2016; Leminen & Westerlund, 2019). Such multidimensional innovation endeavours assume a collision of ideas between participants in their real-life environments (Leminen et al., 2021).

Third, the present study suggested that a collapse of potential realities ('superpositions') into one reality, including the entanglement of participants, can speed up joint innovation activities in living labs. These collapses into realities can take place numerous times in living labs, leading to different learnings and outcomes. This finding is particularly interesting for innovation management scholars, especially in the context of living labs. A collapse represents a potential realisation of an option. At the same time, entanglement illustrates how commitment to cooperate, along with shared experiences and attributes within the social context (which may not be directly observable among participants in living labs), can exert influence even in the absence of direct interaction. Previous literature on living labs has stressed the importance of learning (Hakkarainen & Hyysalo, 2013; Paskaleva & Cooper, 2021) and knowledge sharing across participants (Leminen et al., 2020). The present study offers novel ideas and concepts from the quantum theory to analyse learning and interaction among participants in living labs in an effort to speed up innovation activities.

5.2 Practical implications

While the present study explores conceptual aspects, its findings can potentially offer valuable insights for policy makers and practitioners engaged in the realm of living labs. For instance, it unravels the essence of living labs by identifying novel concepts derived from the quantum theory, namely superposition, entanglement, and collapse. Superposition refers to potential multidimensional realities that companies may take or make in their innovation endeavours. Hence, the fact that a company has a multitude of different paths or ways to select how they may reach their targets in living labs provides an important managerial implication. An individual collapse realises one of the potential realities (superpositions) for participants in a living lab, suggesting that a company may exclude some of the pre-seen potential avenues or open unforeseen avenues for development. The entanglement reveals participants' interconnectedness and explains how they 'play the game' to share knowledge and expertise in living labs. Understanding, applying and exploiting these concepts in joint innovation activities and validating products and services in living labs can be highly beneficial.

The proposed SEC framework helps policy makers to comprehend how and why living labs advance innovations. Living labs produce purposeful collisions of individuals with different backgrounds and knowledge and, in this vein, increase potential realities (superpositions) and collapses. Therefore, the SEC framework and its concepts aid policy makers to see that superposition virtually refers to potential multidimensional realities, and they may take or make their action to support joint innovation endeavours. To put it differently, policy makers have potentially different paths or ways to select how they may reach their targets through living labs. An individual collapse realises one of the potential realities (superpositions) for participants in a living lab, meaning that a policy maker may exclude some of the pre-seen potential avenues of development or open unforeseen avenues for industrial development.

Further, the proposed SEC framework emphasises the importance of entanglement, in other words, the interconnectedness of participants and their commitment to collaborate and solve issues together in settings where everyone knows what the degree or depth of collaboration is. This is especially interesting for innovation managers and practitioners as the conceptual SEC framework canvases how innovation boosting can take place when pursuing solutions to real-world problems through collapse from multidimensional superpositions in living labs. The results are also interesting for business managers because the framework addresses anchored knowledge and expertise that are entangled with different stakeholders. Lastly, the study avails the SEC framework by conceptualising living labs and their innovation endeavours. Realising and unravelling their essence is prominent for further contemplation of innovation in living labs.

5.3 Limitations

As usual, every study has its limitations. The present study reviewed the literature on quantum theory and quantum computing in the intersection of business research to understand how the quantum approach can be applied to innovation research. That said, it was obvious that the extant quantum literature primarily focuses on technology and quintessential challenges related to software, hardware, and the implementation of quantum computing solutions rather than trying to discuss quantum applications in the context of social sciences (Van Langenhove, 2020; Wendt, 2015). Consequently, our aim was not to provide a comprehensive literature review on the theory, computing and approaches of quantum but rather to discover critical concepts of the quantum approach, which could be applied to study and advance innovation in living labs. Therefore, we conducted literature searches and selected relevant articles for our purposes. We reckon the possibility that a broader and more systematic literature review could result in different findings, although any signs supporting the possibility were non-apparent.

Nonetheless, to 'live what we teach', we recall that according to the quantum approach, 'reality' is utmost subjective, based on our backgrounds, experiences and beliefs (Shelton & Darling, 2003). We are bound to acknowledge that researchers with diverse backgrounds and experiences could make different conclusions and establish a very distinct framework based on the literature. In addition, while the application of the quantum approach to business research is still in an early phase, the latest research on the topic could reveal new and emerging ideas in this area. Accordingly, we suggest further focus on areas related to co-creation, complexity and interdisciplinarity, ethical and societal considerations, as well as rapid development and adaptability with respect to how living labs can be applicable for benefitting the quantum approach and technologies. Moreover, based on our best understanding, this is the first attempt to bridge the disciplines of quantum and living labs. Hence, the theoretical contribution cannot be precisely derived and should be tested and validated in different contexts, for example, through case studies reassuring the applicability of the quantum approach in living labs.

Incorporating the longitudinal dimension into the quantum approach in the context of innovation is essential. Also, extant research on living labs supports and encourages the understanding of longitudinal and processual perspectives (Hyysalo & Hakkarainen, 2016; Leminen et al., 2020; Nyström et al., 2014; Schuurman et al., 2011). Thus, we call for more conceptual models that can help us to understand the essence of living labs when exposed to novel concepts such as superpositions and collapses and their roles for longitudinal and processual perspectives, as well as the interplay between them in living labs.

Finally, we call for more research on the entanglement behind innovation endeavours in living labs. Future research should especially take place in the context of wicked problems to solve several major challenges at the same time, as suggested by the quantum theory, focusing on collapses of realities in superpositions where entanglement exists for such multiple challenges. This would be beneficial because of the connectedness of many problems and their solutions. Put differently; we encourage future research to analyse learning and interaction among participants and how properties, experiences and knowledge can affect the innovation outcomes even without direct interaction in public-private partnerships, which aim at speeding up innovation activities by collisions in (different) living labs. Finally, we call for an advanced understanding of the relationships and joint innovation activities in public-private partnerships to comprehend the role of contexts for collisions in living labs.

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Appendix

Table 1. Number of selected articles in the preliminary (first) literature search.

Search string	Search result	1st round selection (100 most relevant)	2nd round selection (based on titles, keywords and abstracts)	3rd round selection (based on browsing whole articles)	Selection after eliminating duplicates	Final selection after reading articles
‘quantum theory’ AND business	826	100	30	15	15	3
‘quantum theory’ AND innovation	1210	100	36	17	11	1
‘quantum theory’ AND outcome	2240	100	34	23	22	8
‘quantum theory’ AND ‘living lab’	0	0	0	0	0	0
‘quantum theory’ AND social	1600	100	41	29	17	5
‘quantum computing’ AND business	822	100	36	5	5	2
‘quantum computing’ AND innovation	1520	100	23	4	3	0
‘quantum computing’ AND outcome	1290	100	27	15	11	3
‘quantum computing’ AND ‘living lab’	2	2	2	0	0	0
‘quantum computing’ AND social	1030	100	26	17	10	1
Total	802	255	125	94	23	

Table 2. Number of selected articles in the second literature search.

Search string	Search result	1st round selection (based on titles, keywords and abstracts)	2nd round selection (based on browsing whole articles)	Selection after eliminating duplicates	Final selection after reading articles
quantum AND business	101	35	23	23	18
quantum AND outcome	34	8	6	6	3
quantum AND ‘living lab’	0	0	0	0	0
quantum AND social	75	32	25	17	17

Search string	Search result	1st round selection (based on titles, keywords and abstracts)	2nd round selection (based on browsing whole articles)	Selection after eliminating duplicates	Final selection after reading articles
quantum AND stakeholder	15	3	1	1	1
quantum AND management	180	45	37	21	19
quantum AND serendipity	0	0	0	0	0
quantum AND strategy	119	17	17	8	7
quantum AND innovation	53	19	14	3	2
Total	577	159	124	79	67

Biographies

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