Proposing a framework for developing innovation districts: a performance assessment

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DOCTORAL THESIS

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1 ABSTRACT

This doctoral dissertation is a compendium of articles in the topic of Innovation Districts. The purpose of this thesis is to propose a framework for developing Innovation Districts (IDs) that advances the scientific knowledge by providing a comprehensive set of Key Performance Indicators for IDs in the Urban, Economic, Social, and Governance dimensions, as well as their relationship.

This study is founded on the theories of Knowledge-based Urban Development, Triple Helix, Clusters of Innovation, the Areas of Innovation lifecycle model, and Performance Indicators underpinnings.

After a deep literature review analysing what science has said regarding Performance Indicators in IDs, the case study approach was implemented, studying two Innovation Districts of global reference (22@Barcelona and Porto Digital), to propose a preliminary framework to assess performance in IDs. Obtaining from them seventy-two main indicators, key dimensions of analysis (urban, economic, social, and governance), evaluable characteristics, and main agents with power of action over the measures evaluated. Then, from these seventy-two initial indicators, using the Fuzzy Delphi approach, a panel of experts was able to select a sub-set of thirty-seven indicators as the most relevant to assess the performance in IDs. And for these thirty-seven selected indicators, using the DEMATEL approach, the level and direction of influence among the indicators and the differential value conferred by these urban areas of innovation was studied.

Several contributions can be derived from this work. (1) A holistic framework of 37 performance indicators in IDs was developed. (2) Insightful information to learn about the role of each agent over the indicators in order to contribute to the development of the urban innovation ecosystems is provided. (3) The relationship between the Performance Indicators in IDs was stablished and validated by a panel of experts. (4) The first two papers of this work contribute to empirical literature with two study cases and a in deep analysis of key performance indicators. Additionally, from an academic standpoint, it could be concluded that the Quintuple Helix and Clusters of Innovation models, and the Knowledge Based Urban Development (KBUD) theory provide an adequate framework for describing the performance assessment of IDs with a thorough understanding. From the perspective of policymakers, this work can inspire other urban areas of innovation that want to be able to focus all their resources on achieving a desired goal, taking into account not only economic growth, but also urban revitalization, governmental competitiveness, and social and environmental awareness. This work provides new knowledge at the scientific literature and deliver to practitioners a tool for deploying and evaluating the performance of IDs.

Keywords

Innovation Districts; Performance Assessment; Key Performance Indicator; Areas of Innovation; Triple Helix; Knowledge Based Urban Development; 22@Barcelona; Porto Digital.

RESUMEN

Esta tesis doctoral es un compendio de artículos en la temática de Distritos de Innovación. El propósito de esta tesis es proponer un marco teórico para el desarrollo de Distritos de Innovación (IDs) que avance en el conocimiento científico al proporcionar un conjunto integral de Indicadores Clave de Desempeño para IDs en las dimensiones Urbana, Económica, Social y de Gobernanza, así como también la relación existente entre los indicadores.

Este estudio se basa en las teorías del Desarrollo Urbano Basado en el Conocimiento (KBUD), la Triple Hélice, los Clústeres de Innovación, el modelo de ciclo de vida de las Áreas de Innovación y los fundamentos teóricos sobre los Indicadores de Desempeño.

Tras una profunda revisión bibliográfica analizando lo que la ciencia ha dicho sobre los Indicadores de Desempeño en IDs, se ha implementado el enfoque de estudio de caso, estudiando dos Distritos de Innovación de referencia mundial (22@Barcelona y Porto Digital), que ha permitido elaborar un conjunto preliminar de indicadores para evaluar el desempeño en IDs. Obteniendo de estos casos setenta y dos indicadores principales, dimensiones clave de análisis (urbanística, económica, social y de gobernanza), características evaluables y principales agentes con poder de acción sobre las medidas evaluadas. Luego, a partir de estos setenta y dos indicadores iniciales, utilizando la metodología Fuzzy Delphi, un panel de expertos pudo seleccionar un subconjunto de treinta y siete indicadores como los más relevantes para evaluar el desempeño en IDs. Y para estos treinta y siete indicadores seleccionados, utilizando la metodología DEMATEL, se estudió el nivel y dirección de influencia entre los indicadores y el valor diferencial que confieren estas áreas de innovación urbanas.

De este trabajo se pueden derivar varias contribuciones. (1) Se ha desarrollado un marco holístico de 37 indicadores de desempeño en IDs. (2) Se proporciona información valiosa para conocer el papel de cada agente sobre los indicadores para contribuir al desarrollo de los ecosistemas de innovación urbana. (3) La relación entre los Indicadores de Desempeño en IDs fue establecida y validada por un panel de expertos. (4) Los dos primeros artículos de este trabajo contribuyen a la literatura empírica con dos casos de estudio y un análisis profundo de los indicadores clave de desempeño. Además, desde un punto de vista académico, se puede concluir que los modelos Quíntuple Helix y Clusters of Innovation, y la teoría del Desarrollo Urbano Basado en el Conocimiento (KBUD) brindan un marco adecuado para describir la evaluación del desempeño de los IDs con una comprensión profunda. Desde la perspectiva de los gestores de políticas públicas, este trabajo puede inspirar a otras áreas urbanas de innovación que quieran enfocar sus recursos en lograr una meta deseada, teniendo en cuenta no sólo el crecimiento económico, sino también la revitalización urbana, la competitividad gubernamental y la conciencia social y medioambiental.

Palabras clave

Distritos de Innovación; Evaluación del rendimiento; Indicador clave de desempeño; Áreas de Innovación; Triple Hélice; Desarrollo Urbano Basado en el Conocimiento; 22@Barcelona; Porto Digital.

RESUM

Aquesta tesi doctoral és un compendi d'articles en la temàtica de Districtes d'Innovació. El propòsit d'aquesta tesi és proposar un marc teòric per al desenvolupament de Districtes d'Innovació (IDs) que avanci el coneixement científic al proporcionar un conjunt integral d'indicadors clau d'acompliment per a IDs en les dimensions urbana, econòmica, social i de governança, així com la relació existent entre els indicadors.

Aquest estudi es basa en les teories del Desenvolupament Urbà Basat en el Coneixement (KBUD), la Triple Hèlix, els Clústers d'Innovació, el model de cicle de vida de les Àrees d'Innovació i els fonaments teòrics dels Indicadors d'Acompliment.

Després d'una revisió bibliogràfica profunda analitzant el que la ciència ha dit sobre els Indicadors d'Acompliment en IDs, s'ha implementat l'enfocament d'estudi de cas, estudiant dos Districtes d'Innovació de referència mundial (22@Barcelona i Porto Digital), que va permetre elaborar un conjunt preliminar d'indicadors per avaluar el rendiment en IDs. D'aquests casos es van obtenir setanta-dos indicadors principals, dimensions clau d'anàlisi (urbanística, econòmica, social i de governança), característiques avaluables i principals agents amb poder d'acció sobre les mesures avaluades. Després, a partir d'aquests setanta-dos indicadors inicials, utilitzant la metodologia Fuzzy Delphi, un panell d'experts va poder seleccionar un subconjunt de trenta-set indicadors com els més rellevants per avaluar la performance en IDs. I per a aquests trenta-set indicadors seleccionats, utilitzant la metodologia DEMATEL, es va estudiar el nivell i la direcció d'influència entre els indicadors i el valor diferencial que confereixen aquestes àrees d'innovació urbanes.

D'aquest treball se'n poden derivar diverses contribucions. (1) S'ha desenvolupat un marc holístic de 37 indicadors de desenvolupament en ID. (2) Es proporciona informació valuosa per conèixer el paper de cada agent sobre els indicadors per contribuir al desenvolupament dels ecosistemes d'innovació urbana. (3) La relació entre els Indicadors d'Acompliment en IDs ha estat establerta i validada per un panell d'experts. (4) Els dos primers articles d'aquest treball contribueixen a la literatura empírica amb dos casos d'estudi i una anàlisi profunda dels indicadors clau d'acompliment. A més, des d'un punt de vista acadèmic, es pot concloure que els models Quíntuple Helix i Clusters of Innovation, i la teoria del Desenvolupament Urbà Basat en el Coneixement (KBUD) ofereixen un marc adequat per descriure l'avaluació de l'acompliment dels IDs amb una comprensió profunda. Des de la perspectiva dels gestors de polítiques públiques, aquest treball pot inspirar altres àrees urbanes d'innovació que vulguin enfocar els seus recursos a assolir una meta desitjada, tenint en compte no només el creixement econòmic, sinó també la revitalització urbana, la competitivitat governamental i la consciència social i mediambiental.

Paraules clau

Districtes d'Innovació; Avaluació de Rendiment; Indicador clau de l'Acompliment; Àrees d'Innovació; Triple Hèlix; Desenvolupament Urbà Basat en el Coneixement; 22@Barcelona; Porto Digital.

2 PREFACE

Five years ago, I completed my master's degrees in Renewable Energies and Energy Sustainability, concentrating on the energy strategy in Smart Cities for my master's dissertation. This guided me to investigate all available performance metrics in order to determine which was the most appropriate for evaluating the energy consumption in smart cities. And because energy is a transversal notion, this analysis entailed looking at all the dimensions involved in creating a smart city.

Then, as I was finishing up two additional master's degrees in Project Management and Smart Cities, I worked and continued to study these topics from a management and performance evaluation standpoint. With time, I began to work with a team on projects with municipalities consortiums that sought to engage their regions in the digital agenda, such as Localret in the case of Catalonia. We also worked with established Innovation Districts that needed to be sure they were making progress toward their objectives. Additionally, we worked on creating innovation ecosystems in the Brazilian states of Goias and Recife. All of this led us to discover that it was crucial for practitioners and policymakers to be able to measure and ensure that they were moving in the right direction, but there were few concrete ideas about how to do so and the scientific community confirmed that there were no deep investigations in this subject.

With all the previous experiences and in accordance with the research lines of Dr. Josep Miquel Piqué and Dr. Didier Grimaldi, who seek to understand the development of Innovation Districts and new forms of innovation for the development of smart cities, we decided to continue analysing the development in these urban areas of innovation, albeit with a greater emphasis on Innovation Districts and with a performance assessment approach. In response to the information gap exposed by the current state of the art in this subject, we decided to develop a systematic and exhaustive research of Performance Indicators for IDs that is the goal of this work.

As a result, we got in touch with the management teams of 22@Barcelona and Porto Digital in Brazil to create a preliminary set of indicators. Furthermore, we communicated with the International Association of Science Parks (IASP) and confirmed that it was crucial for policymakers, practitioners, and governments to understand how to assess performance in these areas and they expressed interest in our research for the application of the findings, they decided to sponsor us and connect us through their platform with several experienced professionals (CEOs, former Presidents, and Directors) of Innovation Districts to be able to validate the relevance of the indicators found in the first steps of the research, obtaining a final subset of indicators already validated. Moreover, based on the interest that this research aroused, the IASP decided to create an Alliance of Innovation Districts to share knowledge and connect ecosystems.

This research has been a phenomenal experience that has provided me with both theoretical and practical knowledge, and whose contribution has not only a scientific but also a practical influence and I am grateful to everyone who has assisted and accompanied me on this journey.

3 ACKNOWLEDGEMENTS

There are many people who have contributed to the process and conclusion of this work.

First and foremost, I am extremely grateful to my supervisors, Dr. Josep Miquel Piqué and Dr. Didier Grimaldi for their invaluable advice, continuous support, and patience during my PhD study. Their immense knowledge and plentiful experience have encouraged me in all the time of my academic research and daily life. I would also like to thank to Dr. Henry Etzkowitz for his treasured support which was influential in shaping my research methods and reviewing the results. I also thank Dr. Jasmina Berbegal-Mirabent, Dr. Aline Figlioli, Dr. Marcelo Perin, Dr. Jorge Duran and Dr. Montserrat Pareja-Eastaway for their mentorship.

I would like to thank all the members in the Research Group, headed by Dr. Francesc Miralles. It is their kind help and support that have made my study and life in Barcelona a wonderful time. A special thanks to Dr. Laurentiu Neamtu who with his wisdom and excellent human quality introduced me to the world of research and was my guide in my first academic steps. My gratitude reaches all the Campus Barcelona of La Salle - Ramon Llull University.

My gratitude is extended to the International Association of Science Parks, which supported this project from the beginning and facilitated its realization by putting me in contact with professionals with deep knowledge and great experience to whom I am immensely thankful.

I also want to thank all the "teachers" that I have had throughout my life, for having fostered the development of my curiosity. I also want to thank those who have shaped me as a professional and as a person, doing a job that can never be valued enough.

Finally, I want to say thank you to my beloved family, my parents Jorge and Mabel; my siblings Sacha, Andrea and Braian, and my brothers and sisters of life: Mau, Vero, Ema, Cris, and Lili who have dedicated all their time, all their effort, support, and affection to me, in order to educate me and train me in values to face life, this whole trip would not have been possible without their company and unconditional love and support. Also to my lovely nephews: Thomas, Benjamin and Valentin that teach me every day about absolute love, joy, and happiness. To my dearest grandmother Ana, who waited for me every late study night to ask me how everything was progressing and encouraging me in the process.

From all of them I learn day by day and I am eternally grateful.

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1. INTRODUCTION

Increasingly, global social, economic and environmental challenges demand greater answers from communities, which calls for rapid adaptation to the changes caused by the current knowledge economy (Pareja-Eastaway & Pique, 2011). One of the key answers for meeting the requirement for an environment that is flexible and offers all-encompassing answers is innovation (Florida, 2002; Pancholi, et al., 2015b). However, the open economy has shifted how it innovates to more open approaches that yearn for workspaces in collaborative ecosystems (Webster, et al., 2021). This generated the need to provide the talented and knowledgeable mobile workforce an increasing sense of belonging (Pancholi, et al., 2015a). All of these trends revalue cities and urban environments for quality living, enjoyment, and development that spur bottom-up innovation (Etzkowitz & Schaflander, 1968; Esmaeilpoorarabi, et al., 2020a; Belussi & Caldari, 2009) as a strategy to both recruit and retain this important qualified personnel. Therefore, talent is the primary resource of these "knowledge cities", which is used to create value through innovation, technology, and brainpower in order to promote social, economic, and territorial welfare (Carrillo, 2006).

The literature presents various frameworks used to describe and understand how contextual factors influence the agents' interactions in the innovation process from National Innovation Systems (Lundvall, 1992; Lundvall, 2007; Nelson, 1993; Freeman, 1995) to Regional Innovation Systems (Cooke, et al., 1997). Regarding the innovation process in the local dimension, the improvement in the development of a new economy in inner cities has aroused a strong interest (Hutton, 2000; Hutton, 2004), as well as the urban knowledge parks (Bugliarello, 2004) and creative and knowledge cities (Lever, 2002; Florida, 2002; Costa, et al., 2008; Pratt, 2008) and knowledge-based urban developments (KBUD) (Carrillo, et al., 2014). This last theory (KBUD) argues that cities may become more competitive by working together to build their urban, economic, social, and governance pillars. (Knight, 1995; Lönnqvist, et al., 2014; Sarimin & Yigitcanlar, 2012; Nikina & Pique, 2016).

In consequence, in the modern world, metropolitan areas are shaping this idea, where core locations are being supported and reorganized by the emergence of intellectual production that supports the creation of knowledge cities (Yigitcanlar, 2011). In addition, during the past few years, this innovative notion of a knowledge city has caught the attention of international organizations, local governments, research groups, and practitioners. Major international institutions, such as the World Bank (1998), European Commission (2000), United Nations (2001), and Organization for Economic Co-operation and Development (OECD 2001), have included knowledge management frameworks into their strategic goals for international development (Yigitcanlar, et al., 2008f). Additionally, governance is at the forefront of harnessing information and innovation as key development tools to increase urban competitiveness and prosper in a knowledge economy (Tull & Dare, 2019; Pancholi, et al., 2017).

According to (Etzkowitz & Leydesdorff, 2000) the three triple helix actors Government, Academia, and Industry can take on various responsibilities in each KBUD dimension (Pique, et al., 2019b) and stages of

evolution in the innovation ecosystems lifecycle from inception to maturity phases (Pique, et al., 2019a). The dynamics of the agents, interactions, forces, and outcomes inside the social system's cultural, political, and economic subsystems, provides the foundation for the smart growth of the innovation ecosystems (Jucevicius & Grumadaitè, 2014).

Urban areas of innovation as Innovation Districts (Pique, et al., 2019a) and their geographical effect on the status quo have been extensively examined. Over the past two decades, researchers have examined how cities adapt to the global economy (Derqui, et al., 2020). From general analyses of the development and organisation of inner cities (Sassen, 1991; Sassen, 1998; Sassen, 2002; Knight, 1995; Gospodini, 2006), to more specific topics such as sustainable development (Hall, 1997), health and urban ecosystem (McMichael, 2000), gentrification effects (Atkinson, 2004), competitiveness of cities (Brotchie, et al., 1995; Jensen-Butler, et al., 1997; Lever, 1999; Strambach, 2002), in addition to urban regeneration policies (Marcotullio, 2003; Atkinson, 2004; Morisson, 2020). Innovation Districts are becoming more and more relevant as a way to address these constantly evolving economic, social and technological concerns.

On the other side, when analysing the evolution of industrial agglomerations, at the beginning of the 20th century, Alfred Marshall introduced the term Industrial District in his article The Principles of Economics, seeking to describe some aspects of the industrial organization of nations (Marshall, 1920). After that, Walter Isard conceptualized industrial complexes as potential building blocks for the industrialization of post-war progress of nations (Isard, 1959; Isard, 1960). Later, Stan Czamanski began to use the concept of industrial clusters (Czamanski & Augusto de Q. Ablas, 1979), and Giacomo Becattini, following Marshall's concept of industrial districts, explained the industrialization of the Italian region of Tuscany and offered the first formal articulation of the concept (Becattini, 1962). Finally, Michael Porter developed a comprehensive notion of industrial clusters to define the spatial concentrations of industries in a group of nations he examined (Porter, 1990).

In the 1990s, capitalist nations began their economic transition to post-Fordist or knowledge-based economies (Amin, 1994; Drucker, 1998). In this transition, with the rise of global economy and the impact of the information and communication technologies, cities were identified as the platforms to generate technical innovation (Castells, 1989; Florida, et al., 2017). In this context, the concept of ID in cities is derived from territorial innovation models such as learning region (Morgan, 1997), innovative milieu (Aydalot & Keeble, 1988; Camagni, 1995; Maillat, 1991; Maillat, 1998), cluster (Porter, 1990; Porter, 1998), industrial district (Becattini, 2004), and knowledge-based urban economy (Knight, 1995), which all emphasise the significance of the spatial dimension of innovation.

To remain relevant, urban strategies have had to adapt to new technology and socioeconomic models. Technological developments, particularly revolutionary and disruptive ones, have a substantial impact on urban planning and urban policies (Hall, 1997). Urban economic development best practices evolved in the late 1990s from suburban greenfield initiatives to urban rehabilitation projects (Smith, 2002). The aims of urban planning in the knowledge economy are to promote variety of uses of the land, densification, new

facilities, preservation of historic buildings and sustainable infrastructures, in order to increase the urban competitiveness while promoting the quality of life (Pareja-Eastaway & Pique, 2011).

Storper and Venables (2004) highlight the importance of face-to-face interactions, co-presence, and co-location of individuals and enterprises within the same sector, locality, or region, which facilitates knowledge spill overs and the flow of tacit information in innovation ecosystems (Storper & Venables, 2004) like Innovation Districts. Indeed, information may be exchanged through serendipitous interactions and cognitive heterogeneity, both of which are more prevalent in dense urban districts (Jacobs, 1961).

The current Innovation Districts are reached as geographic areas where leading-edge anchor institutions as universities, and companies cluster are connected with startups, business incubators and accelerators (Engel, 2022). This connection between corporates and entrepreneurs is beneficial for both sides since the startups can grow in urban ecosystems of innovation connecting with investors and large corporations that can absorb disruptive innovation from new tech ventures (Chesbrough, 2003). Physically compact, transit-accessible, and technically wired, these mixed-use developments also provide housing, office, and retail space (Katz & Wagner, 2014). Being the talent the raw material of the knowledge-based economy (Carrillo, 2006), these districts are situated around them, offering a location for working and living in response to the demands of anchoring talent in the ecosystems.

Then, from a research standpoint, it has become clear that the conditions and surroundings needed for city growth connected with knowledge based on talent, differ from those needed for manufacturing that is based on commodities (Knight, 1995; Yigitcanlar, et al., 2008f).

These knowledge-intensive areas (either cities or districts) provide environments and programmes to facilitate the concentration of creative industries integrated into a supportive social environment (Scott, 2000) by offering specialised amenities (Yigitcanlar & Dur, 2013) and infrastructures (Hutton, 2004; Porter, 1995; Utterback & Afuah, 1998). Such an offering attracts knowledge-based companies, in substituting traditional businesses of old industrial districts, with large urban clusters (Hutton, 2004), stimulating the concentration of talented people (Florida, 2008).

These multidimensional Innovation Districts are made up of a complex web of interconnected elements, including citizens, businesses, transportation, communications, services, and other components of a cluster of innovation (Engel, 2022), each with their own distinct strengths and weaknesses that must constantly adapt to new situations, creating the ongoing challenge of coming up with new strategies to upgrade infrastructure, better quality of life, and create an appealing environment for talent and investment in line with the paradigm of Knowledge-based Urban Development (KBUD) (Metaxiotis, et al., 2010; Yigitcanlar, 2014). Understanding how an ID can change and improve based on these elements is the starting point for the ID to reach its vision and objectives, and this can be achieved by refining its most complex link, but at the same time, essential: its strategy. Defining a strategy can help determine where and when to invest, define an integration and optimization schedule across all components and activities, and uncover new opportunities for growth and progress. Mission statements have been studied in strategic management

literature as a tool for understanding and evaluating how organisations function (Alegre, et al., 2018). Every organisation has its own mission, and how it is articulated can disclose important information about an organisation's strategy. Recent works in the domain of science and technology (Wang et al., 2014; Berbegal-Mirabent et al., 2020) include mission statements of science parks which are scrutinised in order to identify possible links between strategy and actual performance. Organizational performance is operationalized in a variety of ways in these studies, ranging from indicators of a number of startups to indicators of funding. Organizations use performance indicators to monitor and evaluate their behaviour and ensure that their efforts are directed towards achieving their goals. Effective evaluation is critical for demonstrating the worth of projects and initiatives, as well as the benefits provided to city authorities and all city stakeholders. (Caird, et al., 2016). KPIs can be a universal tool for evaluating the progress of strategies to support the monitoring of pertinent projects and initiatives (Dameri, 2017). In terms of a product's or innovation environment's lifecycle, managing the lifecycle maximises value and profitability at each step. The selection of appropriate strategies and KPIs is critical for driving the value maximisation process.

Evaluating the main components and activities of an ID is the first step in defining a strategy towards sustainable prosperity and developing a set of related indicators is the right activity to do so. Indicators show the changes and progress an ID is making towards achieving a specific result. Hence, it becomes essential that the elements evaluated are directly linked to the main activities aimed at achieving specific goals (Berbegal-Mirabent et al., 2020).

Even while there has been research on the topic of indicators in Innovation Districts, this previous studies has tended to concentrate on the more fundamental features of the area, such as: classification (Yigitcanlar, et al., 2020; Adu-McVie, et al., 2021), which proposes a set of conceptual attributes to classify Innovation Districts through a three-prong framework that includes: classification by Function, which highlights the essential functions of Innovation Districts and proposes indicators like Industry type, Investment Type and Management model. Classification by Feature, which draws attention to the shared characteristics of Innovation Districts and proposes indicators like economic scale, locality setting and social activity. And classification by Space-use, which concentrates on the development, design, and plans of Innovation Districts, and propose indicators related to Mixed-use, Urban Design and Natural Environment. All of them could be link with performance in IDs but were not defined for this purpose and have not a comprehensive perspective lacking more measure to evaluate all the dimensions and characteristics that give to these urban areas of innovation their differential value.

By the other hand, Esmaeilpoorarabi and Kamruzzaman, take a different angle and they analyse the best features to ensure assertive emplacement selection of the ID, suggesting five study areas: Context indicators, which focus on regional and city qualities; Form indicators, which focus on spatial and physical aspects; Function indicators, which focus on uses-services and socio-economics aspects; Image indicators, which focus on personal and perceptual aspects and Ambient indicators, focused on socio-equipment and socio-cultural aspects (Esmaeilpoorarabi, et al., 2017; Esmaeilpoorarabi & Kamruzzaman, 2018). Other

research focuses on particular aspects of performance, such as wellbeing (Orii, et al., 2020) or specific district development initiatives, such transportation (Truong & Ta, 2020). But again, there is still no comprehensive framework for analysing the performance indicators across all dimensions of an Innovation District in the academic literature and the relevance in the development of this broad vision has been proven as required in the previous paragraphs as a way to ensure the achievement of their vision and the effective use of their resources (Caird, et al., 2016, Dameri, 2017; Berbegal-Mirabent et al., 2020).

In order to fill this knowledge gap, this thesis intends to analyse the development of IDs proposing a comprehensive framework to assess performance. For this purpose, we will address some specific objectives:

(1) Explore the set of indicators required for a productive decision-making process in each ID dimension.

(2) Analyse the moment when the indicators become active during the IDs stages and the primary agent with action power.

(3) Validate the relevancy of the identified indicators and evaluate their interrelationships.

1.1. ARTICLES OF THE THESIS BY COMPENDIUM

The contribution of the author in each article of this thesis as compendium of publications has been as follow:

Publication 1: Rapetti, C., Pareja-Eastaway, M., Pique, J. M., & Grimaldi, D. (2022a). Measuring the development of innovations districts through performance indicators: 22@ Barcelona Case. *Journal of Evolutionary Studies in Business*, *7*(2), 6-39.

Under the supervision of J. M. Pique and D. Grimaldi, the PhD candidate has contributed: (1) Defining the goal of the study. (2) Analysing the state of the art. (3) Defining the methodology. (4) Collecting the data, which include not just to identify and quantify scientific papers, but also official reports. (5) Elaborating the results. And (6) writing the paper.

Publication 2: Rapetti, C., Pique, J. M., Figlioli, A., & Berbegal-Mirabent, J. (2022b). Performance Indicators for the Evolution of Areas of Innovation: Porto Digital Case. *Journal of evolutionary studies in business*, *7*(2), 219-267.

Under the supervision of J. M. Pique, the PhD candidate has contributed: (1) Defining the goal of the study, this, (2) Analysing the state of the art, (3) Defining the methodology. (4) Collecting the data, (5) Elaborating the results, was also challenging because it includes not just to analyse, quantify and clusterise but also identify the activation schedule for each key performance indicator. And (6) Writing the paper.

Publication 3: Rapetti, C.; Pique, J.; Etzkowitz, H.; Miralles, F.; Duran, J. (2023). 'Innovation Districts Development: A Performance Assessment'. *Triple Helix Journal,* in press.

Under the supervision of J. M. Pique, the PhD candidate has contributed: (1) Defining the goal of the study. (2) Analysing the state of the art. (3) Defining the methodology, this section with the challenge of manage two different methodologies (Fuzzy Delphi and DEMATEL) that are connected but have their own particularities that must be solved and justified during the process of implementation. (4) Collecting the data. (5) Elaborating the results. And (6) Writing the paper.

This document is developed as compendium of publications structured in 10 chapters: 1. INTRODUCTION, where the state-of-the-art that evidences the knowledge gap, relevance and contribution of the author that give foundation to this work are presented. 2. BIBLIOMETRIC ANALYSIS, where the macro tends and evolution of the topic in science is presented, exposing the relevance and main references in the field. 3. THEORETICAL BACKGROUND, where all the theoretical underpinning that delivers base to this investigation and its discussion are described. 4. RESEARCH STRATEGY, where the research structure, question, objective, scope and methodologies are summarised. 5., 6. y 7. Where the three main articles of this compendium are introduced. 8. ETHICAL ASPECTS, where the ethical discussion is open. 9. DISCUSSION AND CONTRIBUTION. Where the current state of the art and the theoretical framework

in the topic in contrasted with the results of this research and the emerging contributions are exposed. 10. CONCLUSIONS, LIMITATIONS AND FUTURE LINES are presented.

2. BIBLIOMETRIC ANALYSIS

The foregoing introduction is a synopsis of an exhaustive bibliometric analysis. This bibliometric study was conducted initially in the subject of Innovation Ecosystems (IE), but subsequently focused on the concepts of Innovation Districts (IE in urban areas) and Performance Assessment, in order to determine: first, who are the reference writers in these fields; second, which areas are currently of interest to scientists; and third, which special aspects of these themes have already been uncovered. This gives us a thorough picture of the state of Innovation Districts and enables us to determine what truly generates value for both practitioners and science.

According to Scopus 1983–2022, over the past 40 years, interest in the study of Innovation Districts has increased, going from almost no papers published annually at the start of the millennium to more than forty articles published per year in 2022 (Figure 2.1). Additionally, Social Science and Business and Management are the areas within the Innovation Districts concept that reunite the most papers (Figure 2.2).

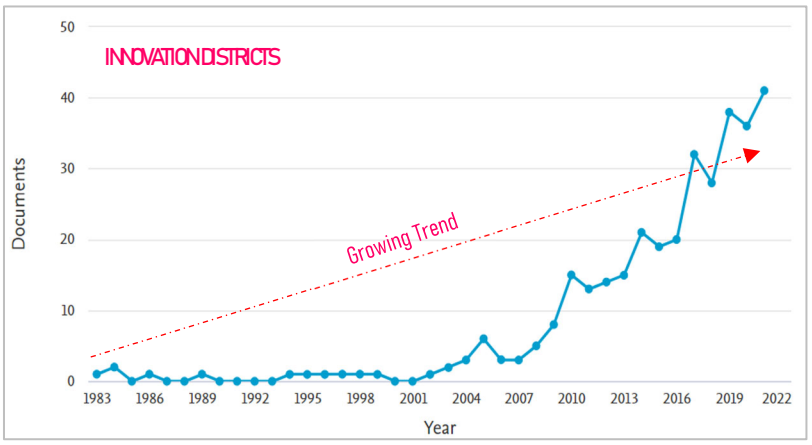

Figure 2-1: Evolution of the topic "Innovation District" in science. Source: Innovation Districts (Scopus 1983 - 2022)

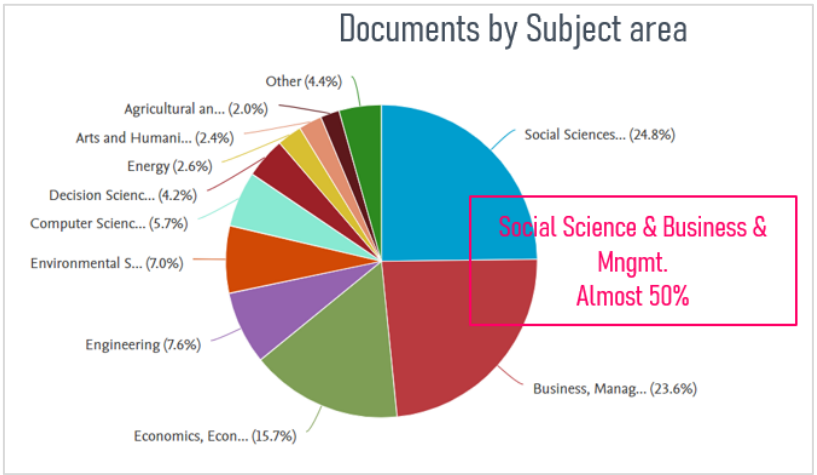

Figure 2-2: Innovation Districts most studied areas. Source: Innovation Districts (Scopus 1983-2022)

Furthermore, the authors: Yigitcanlar, Guardala, Pancholi, Esmaeilpoorarabi, and Kamruzzaman—who are the primary sources and references in the Introduction section—are those who have published the most in this topic in recent years (Figure 2.3).

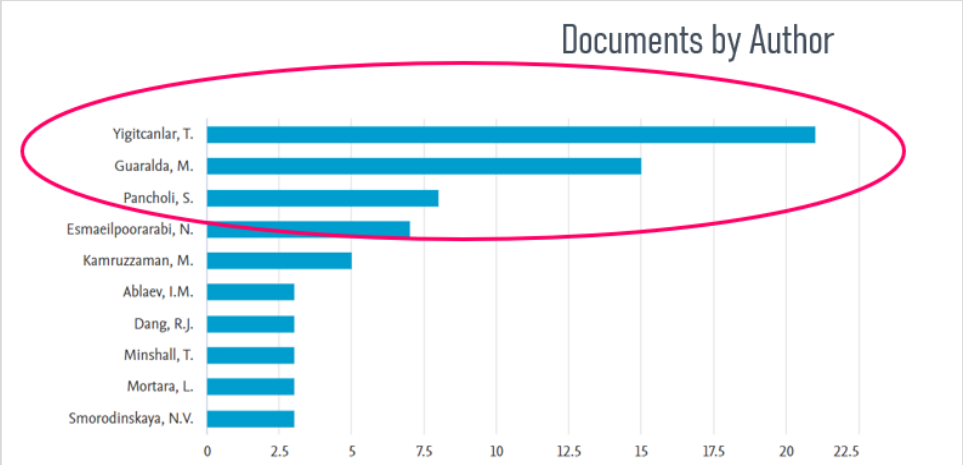

Figure 2-3: Innovation Districts main authors. Source: Innovation Districts (Scopus: 1983-2022)

Finally, when we discuss current trend topics (Figure 2.4), we can observe that science is nowadays mostly focused on:

- The knowledge economy perspective.
- The need to establish conceptual frameworks.
- The examination of urban growth.

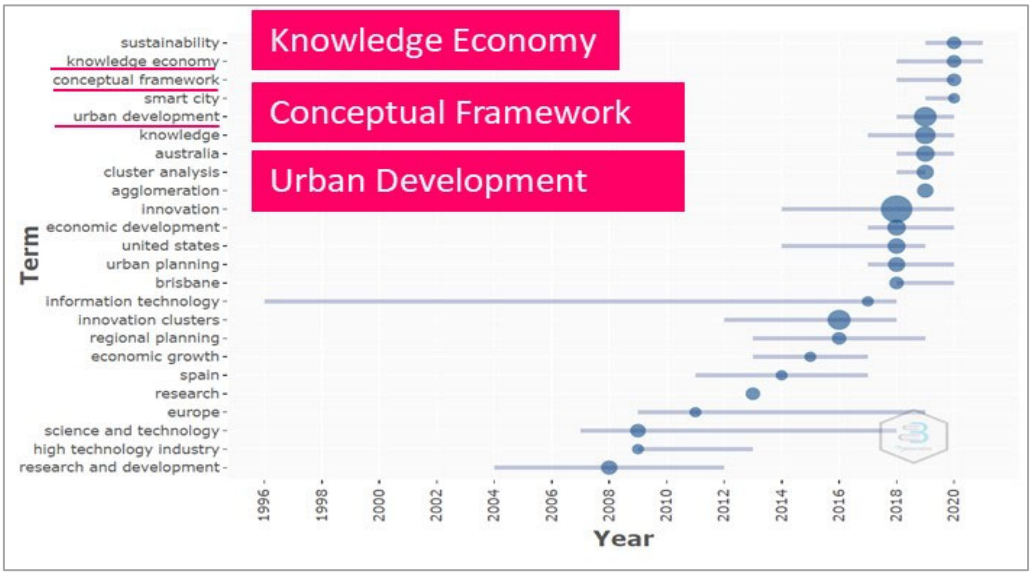

Figure 2-4: Trend Topics => Innovation Districts (Scopus 1983 - 2022)

Also observing a shift in perspective as the thematic evolved over time (Figure 2.5), it can be observed the following migrations:

- From a perspective of economic to urban expansion.
- From discussing a singular standpoint of governance to taking a stakeholder viewpoint approach.
- From a single cluster analysis perspective to considering innovation as a whole.

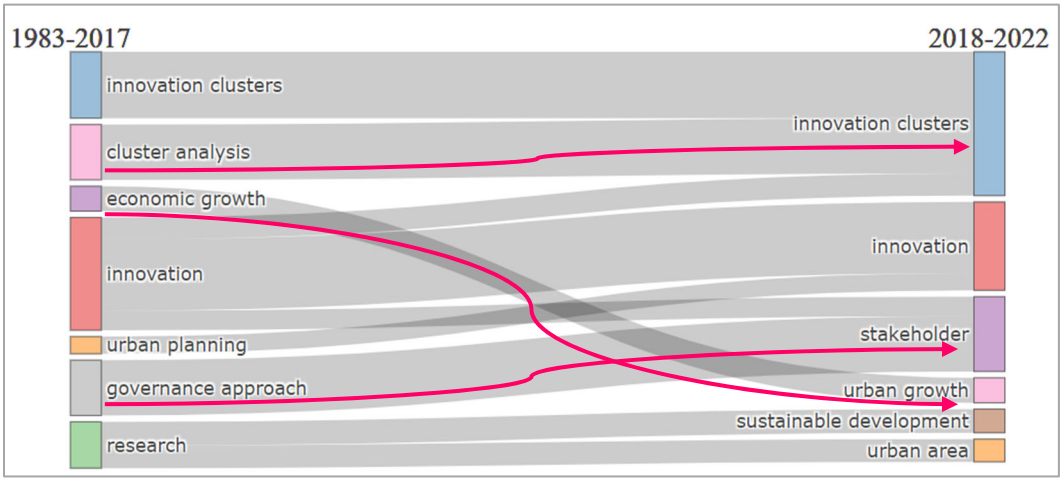

Figure 2-5: Thematic Evolution => Innovation Districts (Scopus 1983 - 2022)

These ideas not only guide, strength and validate the focus of this work, but also reinforce its contribution. All of this provides evidence of the growing importance of Innovation Districts in research, as well as the breadth of perspectives inside them, with the agents shifting from top-down perspectives to a more plural notion that takes other ecosystem actors into consideration. This also made it possible to better outline the theoretical framework that guides this work in the sections that follow, which include the KBUD, Triple, Quadruple, and Quintuple Helix, Cluster of Innovation, and Areas of Innovation Lifecycle, following, among other rationales, the ideas of expanding bases both in terms of dimensions and agents' perspectives inside Innovation Districts, in accordance with the evolution that science reports as occurring.

3. THEORETICAL BACKGROUND

The theoretical foundation that supports this thesis is derived from many models that frame and shape the analysed environment. We have selected five theoretical models in order to comprehend and structure the Innovation Districts' Performance Assessment Framework as follows: (1) the Knowledge-based Urban Development (KBUD) theory (Knight, 1995; Sarimin & Yigitcanlar, 2012), which proposes the existence of four dimensions to explain the knowledge-based development of cities, (2) the Triple Helix (TH) model (Etzkowitz & Leydesdorff, 2000) which seeks to explain the Innovation Ecosystems from the perspective of the interaction between three main actors: Government, Industry, and the Academia, adding Society and Environment more recently (Carayannis & Campbell, 2009; Carayannis, et al., 2012); (4) evolution of Areas of Innovation (AOIs) (Pique, et al., 2018; Pique, et al., 2019a; Pique, et al., 2021), utilised to comprehend the phases in the evolution of AOIs and the role of Triple Helix agents in this development (an ID is understood as an urban AOI); (5) Performance indicators underpinning, exposes as metrics for measuring and evaluating the accomplishment of goals. Key performance indicators (KPIs) can be used as a universal evaluation tool for the progress of strategies to aid in the monitoring of important projects and activities (Dameri, 2017).

3.1. KNOWLEDGE-BASED URBAN DEVELOPMENT

Richard Knight stated in 1995 that a new methodology was required to explain the evolution of cities in light of the knowledge-based growth of Innovation Districts (Knight, 1995). Knowledge-Based Urban Development (KBUD) is "the transfer of knowledge resources into local development," according to his definition (Knight, 1995)(pp. 225-226). Consequently, (Sarimin & Yigitcanlar, 2012) included the following four dimensions into the KBUD: (1) Social and cultural development (such as housing, community facilities, education, social capital, and knowledge workers); (2) economic development (such as R&D centres, knowledge based companies, and start-ups); and (3) environment and urban development (such as green areas, green infrastructures—mobility, energy, waste, and water—and green building); and (4) governance development (such as public and/or private bodies that manage urban transformation and the process of citizen engagement).

In the context of urban development, assets are the resources of ID (Velibeyoglu & Yigitcanlar, 2010). Managing tangible (i.e., physical infrastructure and structures such as transport, property, and utilities) and intangible (i.e., knowledge, cooperation, and creativity) assets helps to the growth of ID. (Figure 3.1).

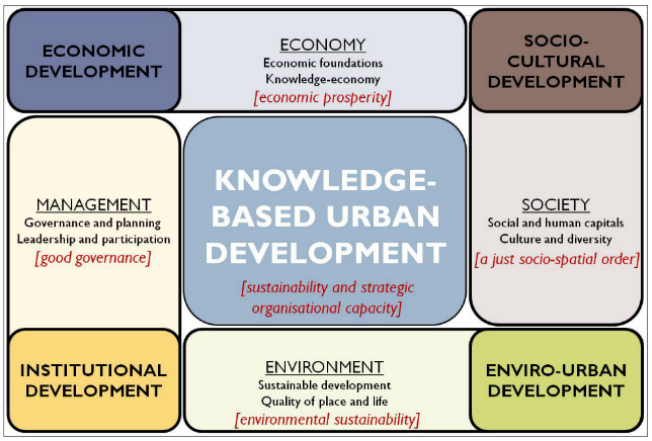

Figure 3-1: Knowledge-Based Urban Development Model.
Source: Sarimin, M. and Yigitcanlar, T. (2012)

Pique et al. (2019b) says IDs require urban, economic, and social change. The infrastructure and urban dimension, the companies and economic dimension, the talent and social dimension, and the governance dimension are crucial to urban revitalization:

> Urban transformation requires an urban plan, an infrastructure plan, and a legal framework that permits the use of land for knowledge-based activities and the attraction of real estate investors for renovating existing buildings and constructing new office and public spaces.
>
> In terms of economic transformation, IDs require smart specialization. This involves determining which sectors (clusters) are to be developed and what technology agenda is required for innovation value chains.
>
> For Social transformation, talent is a key asset of the knowledge-based economy and of the society itself. Innovation Districts must establish a strategy for talent creation, development, attraction, and retention, as well as the provision of comfortable living and working environments.
>
> For Governance, Triple Helix agents play a crucial role in transformation and should establish hybrid organisations (public-private partnership platforms) in order to share the vision for the Innovation District and add activities to be implemented across all project dimensions.

Cities are strongly interrelated within an urban agglomeration, making the agglomeration one of the most significant drivers of global economic development (Fang & Yu, 2017). In this context, urban area refers to the highly developed spatial form of cohesive cities.

The essence of cities as urbanised places may be traced back to Weber's (1958) work, which emphasises the importance of the city's economic and political order. This phenomenon arises when the relationships between agents of the triple helix inside cities transition from mostly competitive to both competitive and cooperative.

3.2. THE TRIPLE HELIX MODEL

The Triple Helix concept started in the mid-1990s, when policymakers urged universities and companies to collaborate more closely for the benefit of society, resulting in an increase in the commercialization of new knowledge. In this respect, it is a methodological instrument: the emphasis on the recursive overlay of interaction between universities, industries, and governments enables the organising of research questions in connection to the many models and metaphors (Leydesdorff & Etzkowitz, 1998).

The Triple Helix concept posits that university-industry-government interaction is the key to enhance the ecosystem of innovation in a knowledge-based society (Pique, et al., 2018).

From this point of view, the roles played by each actor in this model are vital to the creation of an Innovation District. Academia is regarded as a source of new programmes and knowledge to ensure the transference of technology and innovation. In addition, as providers and attractants of talent, they are crucial for the continued and sustainable growth. Industry serves as a source of investment and as a centre for the production and development of products and services in accordance with environmental needs. It is the primary agent of economic value generation. Government acts as a generator of incentives and rules to ensure stable contractual connections among the various interest groups (Grimaldi, et al., 2017).

As interactions develop under TH framework, each component adopts features of other agent, culminating in hybrid institutions. In this regard, the interaction between the University and the Industry focuses on two primary elements: education and research. The University provides the research upon which the industry will produce commercial goods, and therefore the transfer of people between the university and the industry represents a significant knowledge transfer. And because innovation is increasingly founded on scientific knowledge, universities' role as knowledge providers is becoming more valuable.

Regarding the interaction between the University and the Government, it depends on the government's engagement in general education policies. That is, in circumstances where higher education is largely public, the government has a bigger influence as the main source of funding. But in cases where higher education institutions are mostly private in origin, greater economic independence can be achieved. Although the presence of the state can continue to exert synergies based on its policies, legislation that favours the birth of companies within the universities themselves or could be a good facilitator by financing strategic disciplines.

Lastly, the interaction between the Industry and the Government is highly dependent on the extent to which the government intervenes in the market; however, the government is primarily responsible for the creation of clear and effective regulations that streamline and promote economic development projects.

Other authors added a fourth sphere, civil society, to the Triple Helix concept and renamed it the Quadruple Helix (Carayannis & Campbell, 2009). A further modification of the original model adds a fifth dimension, resulting in the Quintuple Helix model, which adds the environment as a significant demand component in knowledge and innovation models (Carayannis, et al., 2012) (Figure 3.2).

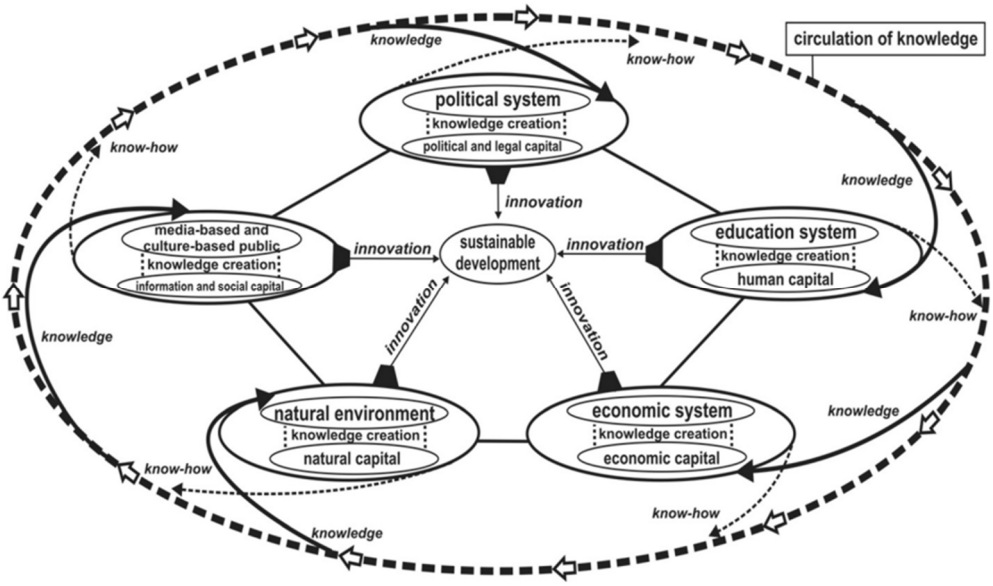

Figure 3-2: Quintuple Helix Model. Source: (Carayannis, Barth, & Campbell, 2012).

In conclusion, the successful management of triple, quadruple, and quintuple helix models demand a long-term strategic direction that takes into account the role of each actor or institution. Each stage of the value chain must be subjected to a comprehensive analysis. In addition, the government could function as a facilitator when spaces for interaction and exchange are favoured, through the design and implementation of mechanisms that enable alliances between actors to make the scenario really favourable.

The Triple Helix model has been utilised for building innovation ecosystems and provides a framework for exploring the functions of the three actors in the urban, economic, and social development of Innovation Districts (Pique, et al., 2019b).

Similarly, (Cai & Lattu, 2019) argue that a shared commitment to social responsibilities and sustainable goals helps connect the interests and objectives of Triple Helix (TH) agents. In this regard, citizen engagement is essential. The activation of a Triple Helix necessitates leadership by respected individuals and organisations, with the understanding that the leadership role can shift from one actor to another during their interaction (Cai & Etzkowitz, 2020).

(Ranga & Etzkowitz, 2013) present another approach to TH by proposing the Triple Helix Spaces to identify the appropriate regions for TH actors to develop their functions: the knowledge space, innovation space, and consensus space. Understanding the function of the TH agent in the establishment of the Innovation District would be advantageous.

3.3. CLUSTER OF INNOVATION

The Cluster of Innovation (COI) framework focuses on the principal components of thriving business agglomerations, where the emergence of rapidly expanding startups is significantly spurred by the behaviours of COI components described below (Engel & Del-Palacio, 2009). In COIs, the disruptive

market potential of new business models held by dynamic entrepreneurs is funded by venture capitalists and/or major corporations in a win-win situation.

Relevant players, such as the government, universities, management (professional managers of startups), and professions (such as attorneys and accountants), play an enabling support role for the interaction of the core components (Engel & Del-Palacio, 2009; Engel & del-Palacio, 2011; Engel, 2015). (Figure 3.3).

A set of hybrid components, including corporate venture capital (CVC), research parks, incubators, and accelerators, arise through interaction between core and supporting actors as new organisations or programmes, broadening the contribution of the original component activities (Engel, 2022).

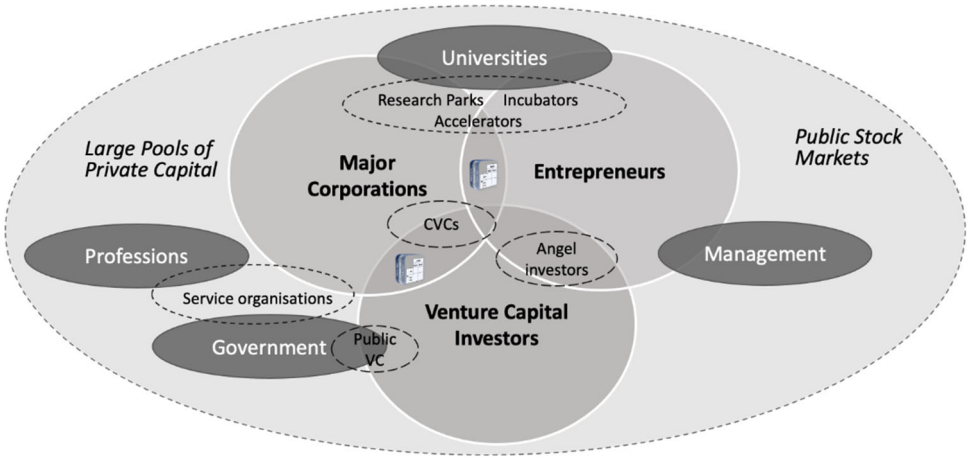

Figure 3-3: Core, Supporting and Hybrid Components of a COI. Source: Engel et al (2022)

Therefore, the establishment of COIs is contingent upon the interaction of the many components in the formation of an innovation cluster. The alignment of components' interests, the collaborative definition and dissemination of a shared agenda enhance interaction and the development of the COI identity (Bittencourt, et al., 2018).

Thus, while the presence of the aforementioned components - or their functions provided by other components - is essential, what actually binds the relationship and enables rapid innovation in COIs are the shared behaviours: entrepreneurial process, high mobility of resources, alignment of interests, global perspective, and global links (Engel, 2022) (Engel, 2015).

The dynamic processes of COIs can expand into a series of contacts with other geographically distant COIs, allowing them to benefit from shared ideas and information as well as the movement of people and resources, so creating new opportunities. In this (Global) Network of COIs, interactions can range from ephemeral contacts to more enduring bonds anchored in contracts and formal partnerships, or, in a more extreme form, two COIs can function in a completely integrated way (Engel & Del-Palacio, 2009; Engel & del-Palacio, 2011).

The worldwide connections help startups and other firms find consumers, collaborators, and investors, as well as discover new disruptive opportunities. Whoever launches a project locally and globally endorses the District of Innovation's brand (Pique, et al., 2021).

3.4. AOI-ID LIFECYCLE MODEL

Pique proposes four phases of evolution for AOIs: inception, launching, growth, and maturity (Pique, et al., 2021; Pique, et al., 2018) based on (1) the analogy of the lifecycle of a new venture (Freeman & Engel, 2007) (conception, launch, growth, and maturity), (2) the ecosystems progress phases from (Moore, 1996) (birth, expansion, leadership, and self-renewal or death) and (3) stages of the evolution of regional innovation ecosystems (Etzkowitz & Klofsten, 2005) (development of the idea of a new regional model; starting of new activities; consolidation, and adjustment; and self-sustaining growth). Innovation District can be considered as urban Area of Innovation.

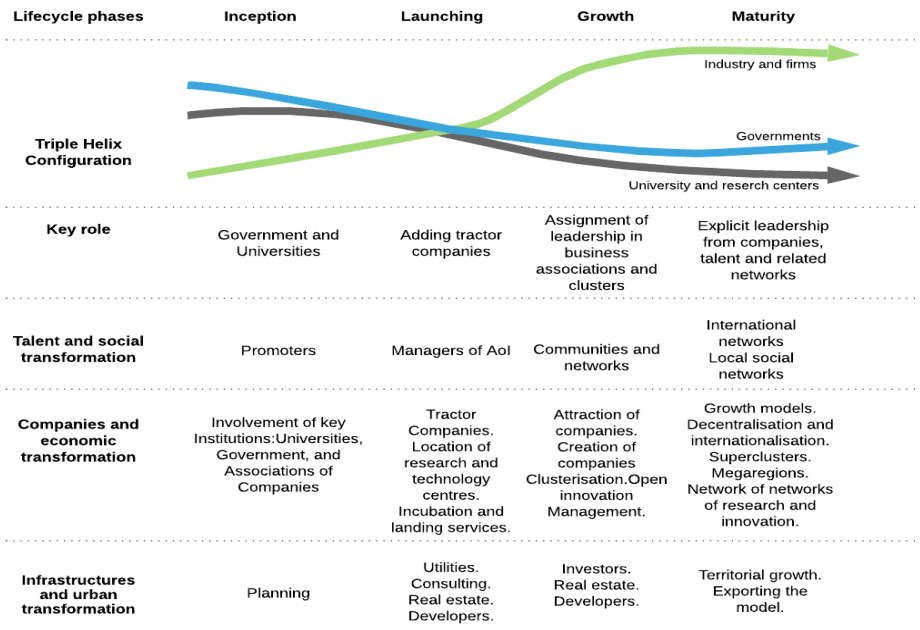

Figure 3-4: Stages of the AOIs development and its dimensions. Source: Pique et al. (2021, p.153)

For each phase, the model illustrates the (re)configuration of the involvement and leadership of TH agents, as well as the evolution of features of each dimension of the KBUD framework. Each phase depends on the contribution of TH actors to government, urban, economic, and social development, since it specifies the succeeding phase and either facilitates or impedes its growth (Pique, et al., 2021). In this setting, the performance evaluation of the dimensions involved in each step becomes vital for the orchestration or redesign of activities, programmes, or processes. (Figure 3.4).

3.5. PERFORMANCE INDICATORS

The literature on strategic management has examined mission statements as a tool for assessing the performance of businesses (Alegre, et al., 2018). Every company has its own purpose, and the manner in which that objective is expressed may provide significant information about the organization's strategy. In the specialised field of science and technology, recent studies (Wang, et al., 2014; Berbegal-Mirabent, et

al., 2020) examine mission statements of scientific parks to identify possible correlations between strategy and actual performance.

Performance indicators are measures used by organisations to track and analyse their behaviour and ensure their efforts are focused on accomplishing their goals (European-Commission, 2004). To demonstrate the value of projects and initiatives and the benefits given to municipal authorities and other city stakeholders, it is crucial to conduct an effective evaluation (Caird, et al., 2016). Key performance indicators (KPIs) may be used as a universal evaluation tool for the progress of plans to aid in the monitoring of important projects and activities (Dameri, 2017). Managing the lifetime of a product or innovation environment maximises value and profitability at every stage, and for this, it is important to the process of value maximisation the identification of appropriate strategies and KPIs.

KPIs are the answers; thus, it is crucial to consider the question that needs to be answered, and since some indicators will be more time and cost intensive to collect and analyse than others, simplicity is essential for a measure to be performed and reproduced frequently. For this reason, it may be preferable to use a known and existing indicator that precisely answers the issue asked than to propose a perfect new but unknown measure. Strong indicators are simple, measurable, and accurate (European-Commission, 2004).

The most widespread category of classification of indicators proposes to classify them based on the various components that the program or project has and allows a temporal analogy (NORAD, 1999; Qinghua, et al., 2022; Badawy, et al., 2016). Within this, the three primary and most prevalent groups of indicators are:

- Input indicators (or Leading indicator). Determine the resources necessary for the program's implementation. KPI that measures activities that have a substantial impact on future performance, are *causal* roots of the outcome they influence, and are actionable for the future performance of one or more Outcome indicators. (Such as funding, personnel, significant partners, and infrastructure).
- Output indicators. Examine the program's actions or activities to see if it is implemented as planned. (For instance, direct deliverables of the activity).
- Outcome indicators (or Impact indicators). Evaluate if the programme is having the expected short-intermediate, and long-term *effects*.

4. RESEARCH STRATEGY

After analysing and cataloguing all the research done in the field of Innovation Districts and performance assessment it was possible to establish a ***knowledge gap*** in the literature that is of interest to science. This was done in accordance with the tendencies examined in the bibliometric studies and presented in sections 1 and 2. Even though there have been some attempts to identify indicators to analyse Innovation District effectiveness, it claims that ***no comprehensive framework for assessing Innovation District performance exists***. Therefore, more research on Innovation District performance metrics is required to expand the field's understanding.

From this point on, the research strategy was outlined by the following scheme: (1) the research topic, (2) theoretical underpinnings, (3) research questions, (4) research objectives, (5) research methodology, (6) research scope, (7) results and publications, (8) discussion and (9) conclusions and future lines. Figure 4.1 graphically illustrates this process.

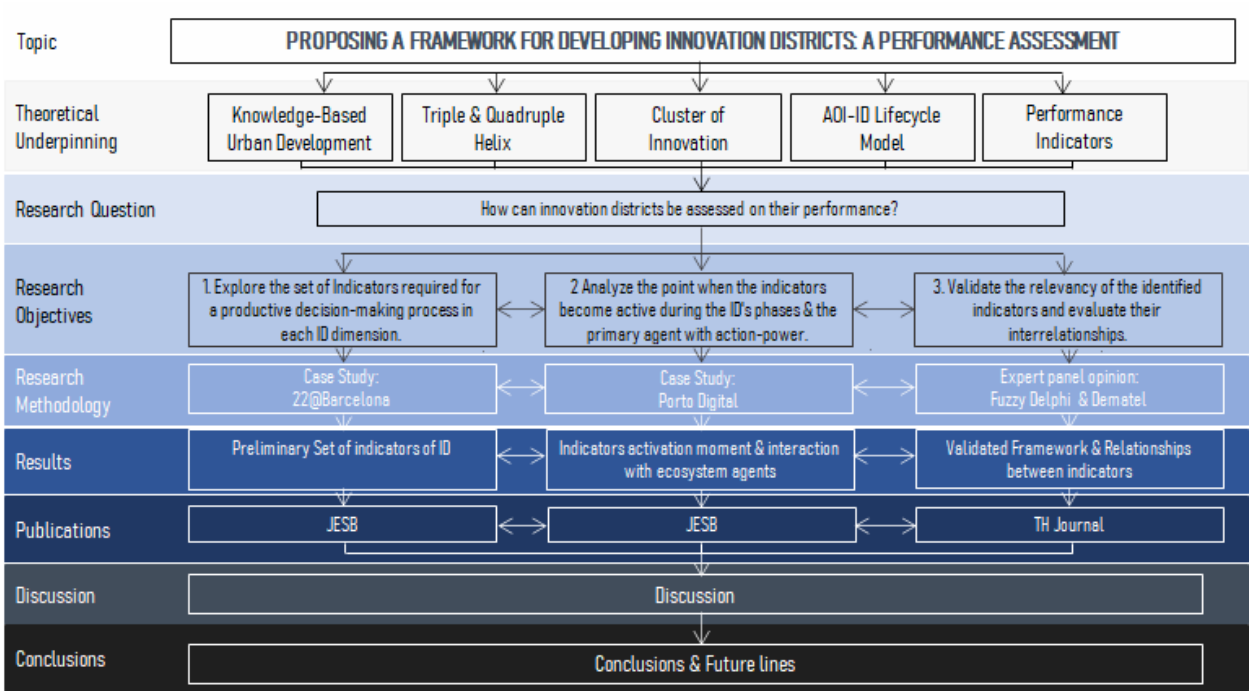

Figure 4-1: Research Strategy

Since the preceding research confirms that there is limited empirical study on examining and developing a holistic performance assessment framework to Innovation Districts, this strategy proposes: First, to create an initial and preliminary set of performance indicators in Innovation Districts, including: main dimensions of analysis, agents with power of actions over main activities, and phases of activation of the indicators through exploratory studies cases (Articles I: 22@Barcelona and Article II: Porto Digital Brazil). And after that, quantitative techniques for validating this preliminary data using a larger sample of expert opinion are suggested in order to strengthen the findings and broaden the analysis looking at the relationship among

the indicators and the differential value that these districts must deliver (Article III: Fuzzy Delphi & DEMATEL experts panel).

4.1. RESEARCH QUESTION

The primary research issue that arises from the literature review is:

1) How can Innovation Districts be assessed on their performance?

And as a result, further sub-questions crop up, guiding the aim of each article. Each response to these sub-questions, which is elaborated in turn in each paper, serves as the foundation for the following one. The compendium will ultimately provide a complete and thorough response to the overall issue.

The sub-questions that are analysed in each article are the following:

(4) What are the key performance indicators for Innovation Districts?

(5) How can the KBUD theory help to clarify the key dimensions of the performance assessment process in Innovation Districts?

(6) Does the Triple Helix Model (University-Industry-Government) and Clusters of Innovation help to understand the main agents with power of action over the activities/concepts that the indicator measures?

(7) What kinds of linkages or interdependencies exist between these indicators? And how does one indicator's action effect or have an impact on another?

4.2. RESEARCH OBJECTIVE

This thesis aims to analyse how Innovation District can be assessed in their performance, therefore solving the primary research question and helping to reduce the knowledge gap.

This target will be addressed by the compilation of three articles with the objectives listed below:

a. The first study, *Measuring the development of innovations districts through performance indicators: 22@Barcelona Case* (Rapetti, Pareja-Eastaway, Pique and Grimaldi, 2022), focuses on examining the collection of key performance indicators required for a successful decision-making process in each dimension of Innovation Districts.
   - This study gives a response to Research sub-questions i and ii.

b. The second study, *Performance Indicators for the Evolution of Areas of Innovation: Porto Digital Case* (Rapetti, Pique, Figlioli and Berbegal-Mirabent, 2022), focuses on analysing the moment when the indicators become active during the evolution phases of the ID, as well as the key (Triple Helix and Cluster of Innovation) actors with action power over the indicators.
   - This study gives a response to Research sub-questions i, ii and iii.

Both cases (22@Barcelona and Porto Digital) are global references of Innovation Districts, they were chosen as unique cases, as they presents three unique characteristics that make they worth being examined: (a) they allows for a longitudinal study, since they have been in operation since 2000, (b) the initiative are recognized as the most comprehensive AOIs in terms of dimensions developed — social, economic, and urban — (Pique et al. 2021), and (c) there is strong engagement of the triple helix actors (university, industry, and government) that is also extended to the fourth helix (society).

c. The third study, *Innovation Districts Development: A Performance Assessment* (Rapetti, Pique, Etzkowitz, Miralles and Duran, 2023), focuses on: (1) validating with a panel of experts the relevance of the indicators established in literature review and prior articles, (2) analysing how the indicators interact, and (3) Identifying what indicators confer distinct value to Innovation Districts.
    - This study gives a response to Research sub-questions i and iv.

4.3. RESEARCH SCOPE

From the Knowledge Based Urban Development paradigm (Sarimin and Yigitcanlar, 2012) we will analyse the set of indicators in each dimension:

- Social and cultural dimension
- Economic dimension
- Environment and Urban dimension
- Governance dimension

From the Triple, Quadruple and Quintuple Helix model (Etzkowitz and Leydesdorff, 2000; Carayannis and Campbell, 2009; (Carayannis, Barth and Campbell, 2012) we will analyse the main agents with greater action power over the indicators:

- The role of the university
- The role of the industry
- The role of the government
- The role of the society (Quadruple Helix)
- The role of the environment (Quintuple Helix)

From the Clusters of Innovation model (Engel and Del-Palacio, 2009) we will analyse the role of:

- Core Components
- Support Components
- Hybrid Components

From the Mission Statements (Wang, et al., 2014) (Berbegal-Mirabent, et al., 2020) and Performance Indicators Underpinnings (Caird, et al., 2016) (Dameri, 2017), we will analyse the relationships between indicators.

- Cause
- Effect

4.4. RESEARCH METHODOLOGY

This collection of articles proposes for its whole development three primary techniques used to find, select, process, and analyse information on the issue under research, in order to evaluate the validity and reliability of the study as a whole.

These three methodologies include: First, Case Studies, to explore the main dimensions and key performance indicators for Innovation Districts (applied in article 1), as well as exploratory analyses of the moment of activation of each indicator in the various stages of the evolution of Innovation Districts and the actors with the ability to influence the activities that the indicators measure (applied in article 2). Second, Fuzzy Delphi methodology, to quantitatively assess the relevance of the indicators from the literature review and the first two articles. Third, DEMATEL methodology to establish the connection and impacts among indicators (Second and Third applied in article 3).

The full methodology flow chart (Figure 4.2) and the three methodologies descriptions and rationales are provided below.

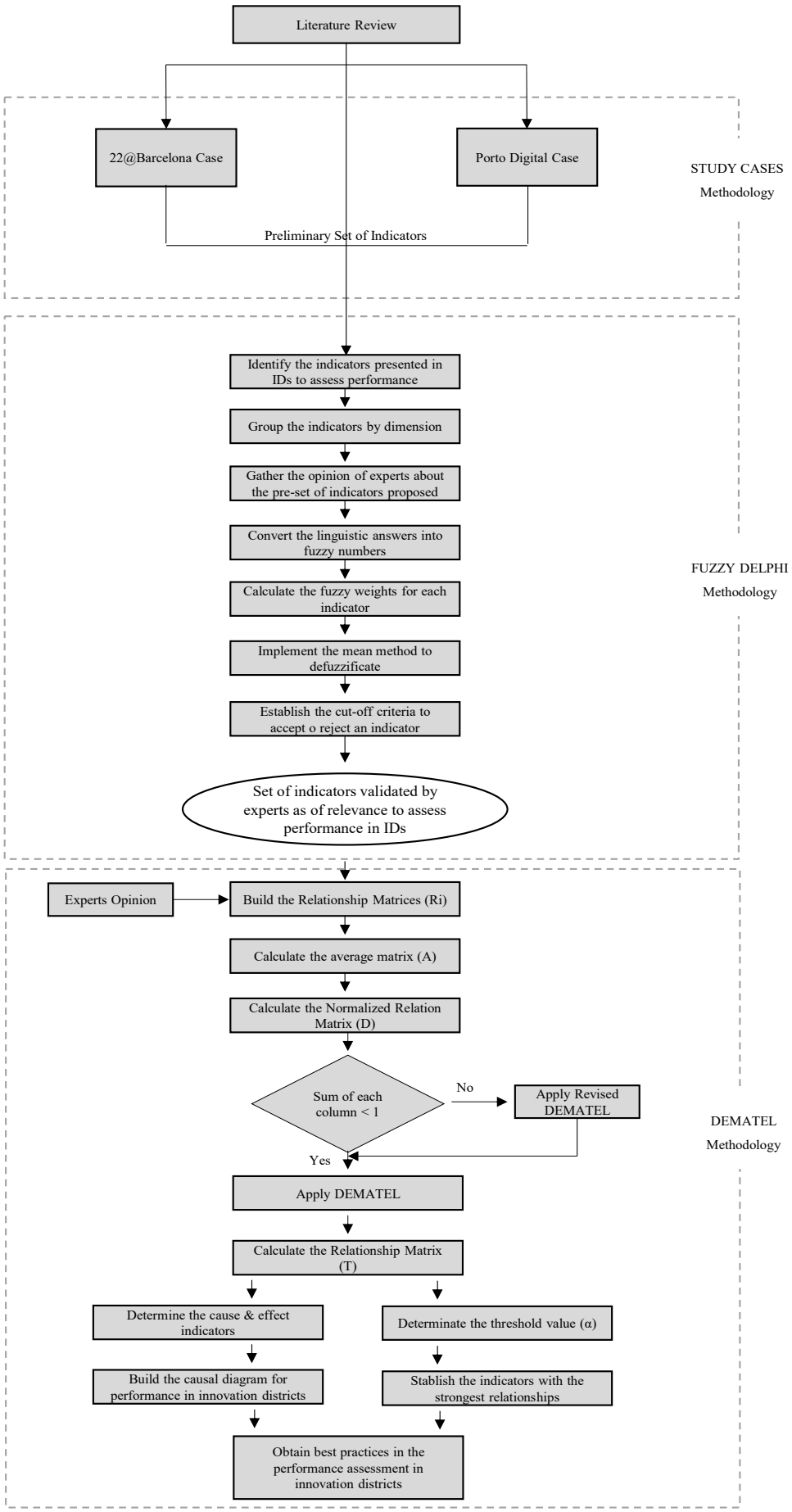

Figure 4-2: Flowchart of the Complete Methodology

4.4.1. CASE STUDY

"*The case method is heuristic— a term for self-guided learning that employs analysis to help draw conclusions about a situation. In English, analysis has two closely related definitions: to break something up into its constituent parts; and to study the relationships of the parts to the whole. To analyse a case, you therefore need ways of identifying and understanding important aspects of a situation and what they mean in relation to the overall situation*."

— (Ellet, 2007).

Case studies are widely utilised in social scientific research (Yin, 2018), comprising both traditional disciplines (psychology, sociology, political science, anthropology, history, and economics) and practice-oriented domains such as urban planning, public administrations, public policy, management science, social work, and education.

The case study is a qualitative method of conducting research in the social sciences used for explored a phenomenon in context, using one or more data collections methods. Describing in deep a case or cases. Case studies are the chosen method when "how" or "why" (Yin, 2018) questions are raised, when the investigators have little control over events, and when the focus is on a contemporary phenomenon in some real-world context.

Case studies are frequently employed as a research approach to advance our understanding of individual, group, organisational, social, political, and related issues. Case studies can also be found in economics, where the structure of a particular industry or city or region can be explored utilising the case study method. In each of these instances, the necessity for case studies stems from the desire to comprehend complicated social events. Briefly, the case study method permits the preservation of the holistic and significant characteristics of real-world events such as life cycles, organisational processes, neighbourhood transformation, and the growth of enterprises. This is the case for the first two articles in this thesis, for which there is no prior information regarding performance assessment in Innovation Districts and an initial set of key performance indicators must be explored in a real-world setting.

4.4.2. FUZZY DELPHI METHODOLOGY

The Delphi Method (DM) is a qualitative/quantitative methodology for gathering the opinions of a panel of experts on a topic with limited scientific investigation. It was invented in the 1950s by Rand Corporation employees Olaf Helmer and Norman Dalkey. Based on the opinions of experts, this method permits forecasting by converging a probability value through the feedback mechanism of questionnaire findings. Among the limitations of this methodology are the following: (1) Two or more repeated surveys are likely to generate a reduction in response rate, which may have detrimental impact on subsequent studies; (2) in general, as the survey is repeated, it becomes more expensive and time-consuming (Ishikawa, et al., 1993).

The Fuzzy Delphi Method (FDM) is an improved version of the traditional Delphi Method (DM). Traditional DM's deficiency, which leads to low convergence in getting results and a sluggish inquiry, has been addressed by means of enhancement by FDM (Saffie, et al., 2016; Ishikawa, et al., 1993; Bojadziev & Bojadziev, 1999) applying an algorithm that, by introducing Fuzzy Sets, reduces the number of iterations to one, while maintaining the same level of accuracy as traditional DM. This reduces the time and cost of the process, as well as the decertification of the experts in surveys, when compared to those that require multiple rounds.

The Fuzzy Delphi methodology is a quantitative technique founded on the concept of fuzzy sets. Fuzzy sets theory is an extension of classical set theory that posits elements have different degrees of membership. Sometimes, a logic based on two truth values is insufficient to describe human reasoning. Fuzzy logic describes human reasoning using the entire interval between 0 (false) and 1 (true). A Fuzzy Set is any set that permits its members to have varying degrees of membership, referred to as the membership function, with the interval [0,1].

The rationale for applying a Fuzzy Delphi technic to validate the proposed performance framework characteristics is as follows. First, the previous research confirms that there is limited empirical research on investigating and developing a holistic performance assessment framework for Innovation Districts. Even when the framework is based on the literature review and study cases, a corroboration method with a larger sample of experts is necessary to confer robustness to the results. Second, the Fuzzy Delphi methodology is applicable in situations when there are limited resources and materials (Ruppert & Duncan, 2017). Incorporating the Fuzzy Set algorithm, the Fuzzy Delphi technique has exhibited accuracy levels comparable to the conventional Delphi method, while reducing the number of rounds of expert surveys to one.

4.4.2.1. FUZZY DELPHI PROCESS

The Fuzzy Delphi technic is based on the theory of fuzzy sets. Fuzzy sets theory is an extension of classical set theory that proposes that elements have varying degrees of membership. A logic based on two truth values is sometimes insufficient when describing human reasoning. Fuzzy Logic uses the whole interval between 0 (false) and 1 (true) to describe human reasoning. A Fuzzy Set is any set that allows its members to have different degrees of membership, called membership function, this having interval of [0,1].

If A is a universal set, then a fuzzy set of A is defined by triangular Membership Function $\int\alpha$ as follow: $\int\boldsymbol{\alpha}\,(\mathbf{x}) \rightarrow [\mathbf{0},\mathbf{1}], \forall \boldsymbol{x \epsilon A}$. ((Zhao & Bose, 2002) compared the response of the system with various Membership Functions (MF) and conveyed that the triangular MF is superior to any other MFs).

$$\int\boldsymbol{\alpha} = \begin{cases} \frac{\boldsymbol{x-p}}{\boldsymbol{q-p}}, \boldsymbol{p} \leq \boldsymbol{x} \leq \boldsymbol{q} \\ \frac{\boldsymbol{r-x}}{\boldsymbol{r-q}}, \boldsymbol{q} \leq \boldsymbol{x} \leq \boldsymbol{r} \\ \mathbf{0} \end{cases} \quad (1)$$

Where p, q and r are the triangular fuzzy numbers (TFNs) and represented as (p, q, r) (Singh & Sarkar, 2020).

The FDM proposes the definition of a linguistic scale for a better understanding of the scores assigned to every value analysed or question performed, and a set of three fuzzy numbers is associated with each linguistic option. The questionnaire with the linguistic options is then provided to the experts who provide their linguistics scale answers as shown in Table 4.1. The level of relevance of each indicator to assess performance in Innovation Districts is investigated by means of this linguistic scale.

Fuzzy Delphi Linguistic Scale	Fuzzy Delphi Number
1. Extremely unimportant	(0,1; 0,1; 0,3)
2. Unimportant	(0,1; 0,3; 0,5)
3. Normal	(0,3; 0,5; 0,7)
4. Important	(0,5; 0,7; 0,9)
5. Extremely important	(0,7; 0,9; 0,9)

Table 4-1: Linguistic scale and Fuzzy Delphi number sets associated (Source: (Singh & Sarkar, 2020))

The processing of the linguistic responses and information gathered through surveys is carried out in four stages:

Stage 1: Input of experts for each indicator is translated into fuzzy numbers. A fuzzy number related to the j_{th} indicator provided by expert n is expressed as follow:

$$\boldsymbol{I_{ij}} = (\boldsymbol{p_{ij}};\ \boldsymbol{q_{ij}};\ \boldsymbol{r_{ij}}) \quad \text{for i= 1, 2, 3, ….n and j=1, 2, 3, ….m.} \tag{2}$$

Where n is the number of expert and m is the number of indicator.

Stage 2: The fuzzy weights of indicator ρj are assigned as follows: ρj = (pj; qj, rj) where:

$$\mathbf{pj} = \max(r_{ij}) \text{ where i=1, 2, 3, …n and j = 1, 2, 3, …m.} \tag{3}$$

$$\boldsymbol{q_j} = \left(\prod_{i=1}^{n}(\boldsymbol{q_{ij}})\right)^{1/n} \tag{4}$$

$$\mathbf{rj} = \text{mín (Fuzzy-1)}(r_{ij}) \text{ where i=1, 2, 3, …n and j = 1, 2, 3, …m.} \tag{5}$$

Stage 3: The mean method is implemented to defuzzificate the value S_j as follows:

$$\boldsymbol{S_j} = \frac{(\boldsymbol{p_j} + \boldsymbol{q_j} + \boldsymbol{r_j})}{3}, \text{ j = 1, 2, 3, …m.} \tag{6}$$

Stage 4: Finally, a cut off number is defined to indicate the point from which the indicators are accepted or rejected as relevant to assess performance in innovation areas.

A diagram of the complete methodological process is presented in Figure 4.4.

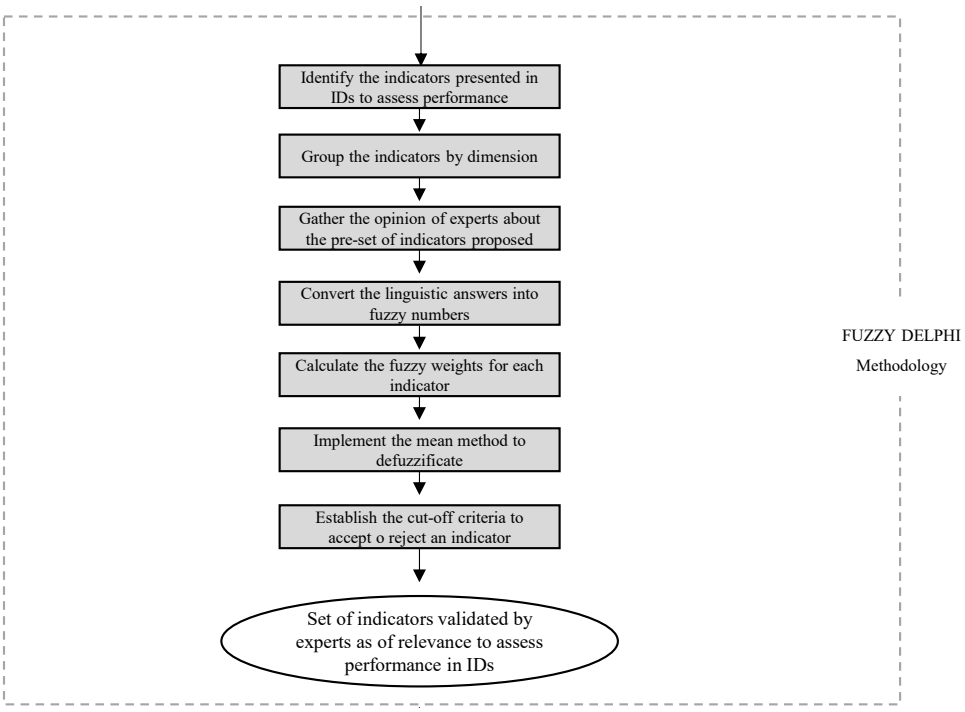

Figure 4-3: Fuzzy Delphi Methodological Process

4.4.3. DEMATEL METHODOLOGY

The Geneva Research Centre of the Battelle Memorial Institute created the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique to depict the structure of complex causal interactions using matrices or digraphs (Sheng-Li, et al., 2018). The DEMATEL method is not only capable of displaying interrelationships among criteria, but also the direction of such relationships (Kumar & Dash, 2016).

This methodology has been implemented in a variety of contexts, including marketing strategies, control systems, safety issues (Liou, et al., 2008), the development of the skills of global managers, and group decision making (Wu, et al., 2010). In addition, hybrid models integrating the DEMATEL and other methodologies have been widely applied in other sectors, such as e-learning evaluation (Tzeng, et al., 2007), aviation safety measurement, and innovation policy portfolios (Hsuan-Shih, et al., 2013). Highlights of the DEMATEL method include the following: i) this method is based on graph theory and facilitates the analysis of difficult problems by using a visualisation method; ii) it develops cause and effect relationships among different factors, making it easy to understand the mutual influence of the factors; and iii) this method is able to determine the strength of the relationships between or among the factors, which is not possible with other multi-criteria decision making methods (Prashant, et al., 2020).

The rationale for employing DEMATEL as the multi-criteria decision-making method that identify the relationships between indicators is as follows: First, it analyses the mutual influences (both direct and indirect effects) between various components and comprehends the intricate cause-and-effect interactions in the decision-making dilemma. Second, it may illustrate the interrelationships between elements using an

IRM (Influential relationship map) and help the decision maker understand which factors have reciprocal influences. Thirdly, the DEMATEL can be used not only to evaluate alternatives, but also to identify essential assessment criteria and quantify the weights of evaluation criteria (Sheng-Li, et al., 2018).

4.4.3.1. DEMATEL PROCESS

DEMATEL models the influences of components of a system with an initial direct relation matrix. Influences of components can ripple transitively to other components, which is modelled by raising the initial direct relation matrix to powers. The total influence is computed by summing up matrices of all powers based on the assumption that the matrix raising to the power of infinity would converge to zero (Hsuan-Shih, et al., 2013).

The stages required in this method are described as follow:

Stage 1: The relationship matrices are built with the opinions of the experts. A panel of experts, with years of experience in the field of research, is consulted on the level of relationship between each indicator, using a linguistic scale presented in Table 4.2 to qualify the answers.

Dematel Linguistic Scale	Score
1. No influence	0
2. Low influence	1
3. Medium influence	2
4. High influence	3
5. Very high influence	4

Table 4-2: DEMATEL linguistic scale
(Source: (Singh & Sarkar, 2020))

A non-negative matrix of the order of n x n as $\boldsymbol{x^k} = [\boldsymbol{x_{ij}^k}]$ where k indicates the number of expert with $\boldsymbol{1} \leq \boldsymbol{k} \leq \boldsymbol{H}$, and n indicates the number of indicators.

Stage 2: The Average Matrix A is constructed with the inputs of all the experts and can be stablished as follow:

$$\boldsymbol{A} = [\boldsymbol{a_{ij}}] = \frac{\boldsymbol{1}}{\boldsymbol{H}} \sum_{\boldsymbol{k=1}}^{\boldsymbol{H}} \boldsymbol{x_{ij}^k} \tag{7}$$

Where k indicates the kth expert and H represents the total amount of experts.

Stage 3: Matrix Average Matrix A is normalized to conform the matrix D:

$$\boldsymbol{D} = \boldsymbol{m} \times \boldsymbol{A} \tag{8}$$

where

$$\boldsymbol{m = mín\left[\frac{1}{maxi\sum_{i=1}^{n} a_{ij}}; \frac{1}{maxj\sum_{j=1}^{n} a_{ij}}\right]} \qquad \boldsymbol{i, j} \in \{\mathbf{1, 2, 3, \ldots m}\} \tag{9}$$

And D must have the sum of each of its columns minor than 1 to be eligible for DEMATEL technic (Kumar, et al., 2017).

Stage 4: Calculate the Total Relationship Matrix (T)

$$\boldsymbol{T = D(I - D)^{-1}} \tag{10}$$

where I represent the Identity matrix.

Stage 5: Compute the factors r y c that will allow to stablish cause and effect indicators as follow:

$$\boldsymbol{r = [r_i]_{nx1} = \left[\sum_{j=1}^{n} t_{ij}\right]_{nx1}} \tag{11}$$

$$\boldsymbol{c = [c_i]_{1xn} = \left[\sum_{i=1}^{n} t_{ij}\right]_{1xn}} \tag{12}$$

Prominence=(r+c) and Relation= (r-c) for each indicator. Indicators that have a Relation number greater than 0 are considered cause factors, and indicators with Relation number lower than 0 are considered effect factors. Cause indicators directly influence effect indicators where the relationship is strong.

Stage 6: A threshold number (α) is stablished to elude minor effects.

$$\boldsymbol{\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}[t_{ij}]}{N}} \tag{13}$$

Where N is the number of elements in matrix T.

The coefficients in the Total Relationship Matrix (T) which are higher than the threshold number compound a sub-matrix that represents the strongest relationships between indicators.

A diagram of the complete methodological processes is presented in Figure 4.4.

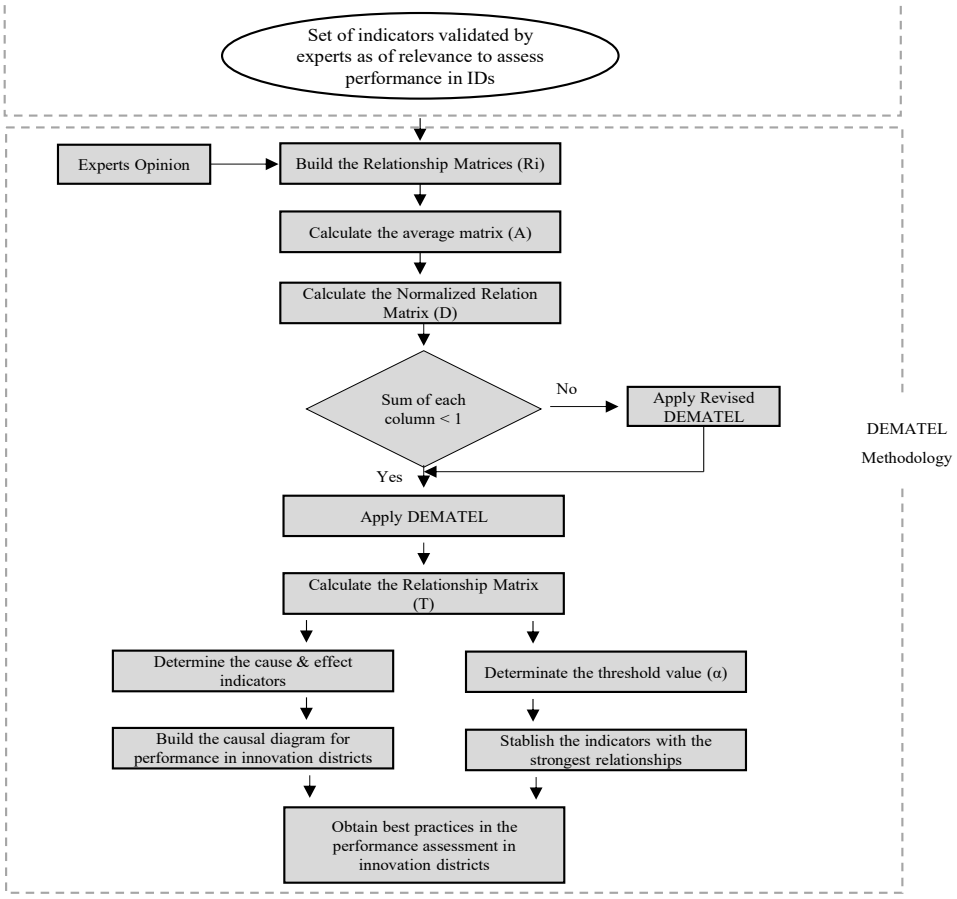

Figure 4-4: DEMATEL methodological processes

5. ARTICLE I: MEASURING THE DEVELOPMENT OF INNOVATIONS DISTRICTS THROUGH PERFORMANCE INDICATORS: 22@BARCELONA CASE

Rapetti, C., Pareja-Eastaway, M., Pique, J. M., & Grimaldi, D. (2022). "Measuring the development of innovations districts through performance indicators: 22@ Barcelona Case". *Journal of Evolutionary Studies in Business*, 7(2), 6-39.

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Measuring the development of innovations districts through performance indicators: 22@Barcelona Case

Abstract

Innovation Districts are rising as the banners of the new urban, economic, and social paradigm and as a solution to the renaissance of inner cities since they expedite the creation and commercialization of new ideas which leverage the city goals and its technologic and economic attributes. The configuration of accurate indicators to measure the degree of achievement of the innovation district goals is one of the main requirements to ensure district proper development. Even when the study of innovation districts is a topic that is increasingly under study, little is still known about the insight, and it is still needed tools that favor their evolution and development. The aim of this paper is two-fold: on the one hand, it seeks to collect and analyze the indicators that have been used in literature to measure the degree of maturity over the course of the 20-year existence of the 22@Barcelona, an area of innovation that transformed an old industrial district into a knowledge-based one. On the other hand, guided by the four dimensions of the Knowledge Base Urban Development theory and the main actors that make up Triple Helix approach, the paper designs a framework of indicators in the four spheres that shape the regeneration of the district, that is, urban, economic, social and governance. As we shall see, a total of 47 indicators are proposed, indicating for each of them: the environment in which it is applied, the main purpose to which it responds, and the main actor with the greatest power of action over it.

Keywords: Innovation District, Indicator, Triple Helix, Knowledge Base Urban Development, 22@Barcelona, Development, Sustainability, Evolution

Entenent el desenvolupament de districtes d'innovació a través d'indicadors: El cas del 22@Barcelona

Resum

Els districtes d'innovació estan augmentant com a abanderats del nou paradigma urbà, econòmic i social i com a solució al renaixement del centre de les ciutats ja que acceleren la creació i comercialització de noves idees que aprofiten els objectius de la ciutat i els seus atributs tecnològics i econòmics. La configuració d'indicadors precisos per mesurar el grau d'assoliment dels objectius dels districtes d'innovació és un dels principals requisits per garantir el desenvolupament adequat del districte. Fins i tot quan l'estudi dels districtes d'innovació és un tema cada vegada més estudiat, encara es coneix poc sobre la seva execució, i calen eines que analitzin i afavoreixin la seva evolució i desenvolupament. L'objectiu d'aquest document és doble: d'una banda, tracta de recollir i analitzar els indicadors que s'han utilitzat en la literatura per mesurar el grau de maduresa durant el transcurs dels 20 anys d'existència del 22@Barcelona, una àrea d'innovació que va transformar un antic districte industrial en un de coneixement. D'altra banda, guiat per les quatre dimensions de la teoria del Desenvolupament Urbà basat en el Coneixement i els principals actors que componen l'enfocament de la Triple Hèlix, l'article dissenya un marc d'indicadors en les quatre esferes que formen la regeneració del districte, és a dir, la urbana, econòmica, social i de governança. Com veurem, es proposen un total de 47 indicadors que indiquen per a cadascuna d'elles: l'entorn en el qual s'aplica, l'objectiu principal al qual respon, i l'actor principal amb el major poder d'acció sobre aquest tema.

Paraules clau: Districte d'Innovació, Indicador, Triple Hèlix, Desenvolupament Urbà Basat en el Coneixement, 22@Barcelona, Desenvolupament, Sostenibilitat, Evolució

La medición del desarrollo de distritos de innovación a través de indicadores de resultados: el caso del 22@Barcelona

Resumen

Los distritos de innovación están aumentando, como abanderados del nuevo paradigma urbano, económico y social, y como solución al renacimiento del centro de las ciudades, ya que aceleran la creación y comercialización de nuevas ideas que aprovechan los objetivos de la Ciudad, y sus atributos económicos y tecnológicos. La configuración de indicadores precisos para medir el grado de desarrollo de los objetivos de los distritos de innovación es uno de los principales requisitos para garantizar el desarrollo adecuado del distrito. Incluso cuando el estudio de los distritos de innovación es un tema cada vez más estudiado, sabemos poco sobre su acción, y se precisan herramientas que analicen y favorezcan su evolución y desarrollo. El objetivo de este documento es doble: de un lado recoger y analizar los indicadores que se han utilizado en la literatura para medir el grado de madurez durante los últimos 20 años de existencia del 22@Barcelona, un área de innovación que transformó un antiguo distrito industrial en un polo de conocimiento. Por otro lado, y guiado por las cuatro dimensiones de la teoría del Desarrollo Urbano basado en el Conocimiento, y los principales actores que componen el enfoque de la Triple Hélice, el articulo diseña un marco de indicadores en las cuatro esferas que forman la regeneración del distrito, es decir: la urbana, la económica, la social, y la de la gobernanza. Como veremos, se proponen un total de 47 indicadores que indican, para cada una de ellas: el entorno en el que se aplica, el objetivo principal al que responde, y el actor principal con mayor poder de acción sobre este tema.

Palabras clave: Distrito de innovación, Indicador, Triple Hélice, Desarrollo Urbano basado en el Conocimiento, 22@Barcelona, Desarrollo, Sostenibilidad, Evolución

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1. Introduction

In recent years, changes in market demands have seen a drive towards products and services with high customer and technology orientation. This, together with increasing confluence of populations in large cities has led to revaluation of urban spaces. The innovation spaces become the "highest and best use" to enhance urban competitiveness according to many land-use policies and urban planning practices (Jiwu Wang 2021) and from here, innovation is a key driver of economic growth and competitiveness, and innovation clusters house much of the innovation generating high-tech and creative industries (Yigitkanlar et. al. 2020).

The behaviour of critical actors in innovative territories and the domains in which urban ecosystems are specialised have been analysed within theories such as the Knowledge Base Urban Development Model (KBUD) (Sarimin and Yigitcanlar 2012), and the Triple Helix (TH) theory (Etzkowitz and Leydesdorff 2000) to understand the generation of wealth and value in the knowledge economy.

Innovation districts and their static territorial impact have been largely studied. Over the past two decades, studies have been conducted on how cities manage to adapt to the global economy (e.g. (Grimaldi and Fernandez 2017). This ranges from general analyses of the development and organization of inner cities (Sassen 1991,1998 and 2002; Knight, 1995; Gospodini 2006), to more specific topics such as sustainable development (Hall 1997), health and urban ecosystem (McMichael 2000), gentrification effects (Atkinson 2004), competitiveness of cities (Brotchie et al. 1995; Jensen-Butler, Sharchar and Van Weesep 1997; Lever 1999; Strambach 2002), to urban regeneration policies (Marcotullio 2003; Atkinson 2004; Thomson et al. 2006). Improvement in the development of a new economy in inner cities has awakened a deep interest (Hutton 2000 and 2004), as well as urban parks of knowledge (Bugliarello 2004), creative and

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knowledge cities (Lever 2002, Florida 2005, Costa et al. 2008, Pratt 2008) and knowledge-based urban developments (Carrillo et al. 2014).

However, evaluation of the process by which these kinds of districts are transformed and their degree of maturity, deserves more attention and it is time to indicate which parameters are the most required or frequent, so that good practices can be repeated in future developments of the Innovation District. This literature gap becames the research question that this paper seeks to answer, which is: what indicators are necessary to assess performance in Innovation Districts. Understanding how innovation districts evolve is the starting point to accomplish their vision and goals. As point of departure, measuring where they are today and identifying the next milestone is essential. To do this, it is necessary to define a set of indicators from a holistic perspective to collect the information to be analysed (Ramírez et al. 2021). Answering this research question becomes the main objective of the present research.

This piece of research sheds new light on the main indicators used in an innovation district to guide its development. Taking as a fundamental idea the main domains proposed by KBUD theory, and the actors anticipated by the Triple Helix model, exploratory work has been carried out on the case study of the 22@ Innovation District of the city of Barcelona (22@Barcelona), analyzing the existing bibliography over the course of its twenty years of evolution.

The 22@Barcelona innovation district has largely been studied in academia (Pareja-Eastaway and Pique 2011; Cohendet, Grandadam and Simon 2011; Casellas and Pallarès 2009; Gianoli and Palazzolo-Henkes 2020; Charnock and Ribera-Fumaz 2011 and 2014; Leon 2008; Piqué, Miralles, and Berbegal-Mirabent 2019; Pareja-Eastaway and Piqué 2014; Dot-Jutgla and Pallares-Barbera 2015, Paül, 2017; Bottero et al. 2020). International stakeholders such as the International Association of Science Parks and Areas of Innovation (IASP) consider

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22@Barcelona as a reference source for policy transferability and experience-based knowledge. As testament to its popularity, the 22@ received more than 354 delegations from all continents (Piqué, Miralles and Berbegal-Mirabent 2019).

2. Theorethical Framework

The theoretical framework that provides the basis for this research comes from two models that frame and structure the environment under analysis. We have chosen two theoretical models, firstly, the Knowledge-based Urban Development theory (KBUD), that propose the existence of four dimensions to explain the knowledge-based development of cities and the Triple Helix (TH) model (Etzkowitz and Leydesdorff 2000) which seeks to explain the operation of R&D&I systems from the perspective of the interaction between three main actors: Government, Industry and Academia. They become a way of contextualizing the dimensions that make up an innovation district (KBUD) and within them the main actors present and their most relevant functions (TH).

Organizing the ecosystem of the innovation district (ID) in domains and knowing the main actions carried out in them, becomes a necessity for proposing indicators, since indicators, by definition, measure how close actions bring us to the objectives established for each of the main stages of a project (development of an ID). This way of modeling the reality under analysis facilitates our understanding of it and helps to give it a structure that orders the work. Therefore, it is necessary to be able to set out the foundations of these areas and their concomitant activity, so that they guide the proposal of indicators in a comprehensive and effective way.

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2.1. Triple Helix Model

The Triple Helix thesis emerged in the mid-1990s, a time when universities and industries were exhorted by policy makers to work together more closely for the benefit of society, generating an upward trend in the commercialization of new knowledge. The thesis became articulated as a confluence between Henry Etzkowitz' long-term interest in the study of university-industry relations and Loet Leydesdorff's focus on an evolutionary model in which there is an overlay of communications between different and independent spheres of activity (Lawton Smith and Leydesdorff 2012). The Triple Helix model is formulated as a model for helping with the explanation of a phenomena. In this sense, it is a methodological tool: the focus on the recursive overlay of communications among universities, industries, and governments allows for the organization of research questions in relation to the various models and metaphors (Leydesdorff and Etzkowitz 1998).

The Triple Helix model postulates that interaction among university-industry-government is the key to improve conditions for innovation in a knowledge-based society (Piqué 2018).

From this perspective, the role played by each actor in this model is crucial for the development of an innovation district. Academia is considered as generators of new programs and knowledge to guarantee the transfer of technology and innovation. It is also regarded as providers and attractors of talent, essential for sustained and sustainable development. The Industry acts as a source of investment and as center of production and development of products and services according to the requirements of the environment. It is the main actor in the creation of economic value. The Government behaves as a generator of incentives and policies to guarantee stable contractual relationships between the different interest groups (Grimaldi and Fernandez 2017).

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As interactions within this framework increase, each component evolves to adopt some characteristics of the other institution, resulting in hybrid institutions. In this sense, in the case of interaction between the university and the industry, it focuses on two main elements: education and research, where the university provides the research on which industry will base production of commercial goods and therefore transmission of people between university and industry constitutes a very important knowledge transfer. And since innovation is increasingly based on scientific knowledge, the role of universities as creators of knowledge is more valuable. In the case of the interaction of the university with the government, it depends on the particular involvement of the government in general education policies. That is, in cases where higher education is largely public, the government has a greater influence as the main source of funding. But in cases where higher education institutions are mostly private in origin, greater economic independence can be achieved. Although the presence of the state can continue to exert synergies based on its policies, legislation that favors the birth of companies within the universities themselves or could be a good facilitator by financing strategic disciplines. Finally, interaction between the Industry and Government depends to a great extent on the degree of government intervention in the market, but in any case the Government is the main party responsible for the creation of a clear and efficient regulation that streamlines and promotes economic development projects.

Other authors added a fourth sphere to the Triple Helix model, that of civil society, relabelling it as the Quadruple Helix (Carayannis and Campbell 2009). In this research, the social sphere is included in the KBUD dimension. Another transformation of the initial model adds a fifth dmension, now a Quintuple Helix model, which adds the environment as a key agent in knowledge and innovation models (Carayannis, Barth and Campbell 2012). In the same

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manner, for the purpose of this research, we include the enviroment in the urban dimension of the KBUD.

To summarize, the successful management of triple, cuadruple and quintuple helix models implies an effective long-term strategic direction taking into account the role played by each actor or institution. A comprehensive analysis of the value chain in each of the stages needs to be assesed. In addition, government might acts as a facilitator, where spaces for interaction and exchange are favored, through the design and application of instruments that allow alliances between actors to turn the scenario into an advantageous one.

2.2. Knowledge Base Urban Development

Knowledge Based Urban Development (KBUD) is spurred by the growth of knowledge economy, which refers to the generation of income through the creation, production, distribution and consumption of knowledge and knowledge based products (Yigitcanlar, Velibeyoglu and Baum 2008a, and 2008b). The outputs of the knowledge economy are not necessarily raw materials and production of quantified goods, but also highly skilled and educated labour force producing abstract goods such as information, software and management, and transferring skills and knowledge particularly via the internet and other online vehicles (Yigitcanlar and Sarimin 2010). KBUD involves contemporary understanding and management of value dynamics, capital systems, urban governance, development, and planning (Yigitcanlar and Velibeyoglu 2008).

Several models have been proposed for the conceptualisation of KBUD (Sarimin and Yigitcanlar 2012), yet, they all include the governance development (e.g. public and/or private bodies that manage the urban transformation and the process of citizen participation), the

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economic development (e.g., R&D centres, knowledge based companies and start-ups), the social and cultural development (e.g., housing, community facilities, education, social capital and knowledge workers) and the environment and urban development (e.g. green areas, green infrastructures—mobility, energy, waste, water—and green building) (Piqué 2018).

KBUD transcends many areas of economic, social and urban policy, and two of its main broad purposes (Yigitcanlar, Velibeyoglu and Baum 2008a) are directly linked to the substrate that is intended to be established in this theoretical framework since they are: firstly, in KBUD perspective instrumentation of the knowledge-based development of cities is critical to bring together all of the key actors and sources, organize and facilitate necessary knowledge-intensive activities and plan strategically for knowledge city transformation. Secondly, KBUD builds a strong spatial relationship among knowledge community precincts for augmenting the knowledge spillover effect that contributes significantly to the establishment and expansion of creative urban regions and supports linkages and knowledge transfer between these precincts (Yigitcanlar, Velibeyoglu and Martinez-Fernandez 2008).

2.3. Case of Study: Innovation District 22@Barcelona

The vision to create the first innovation district in Europe was conceived in Barcelona in 1998 as a way to enhance the competitiveness of the city, betting on innovation, creativity, design and technology. In 2000, the 22@Barcelona, aimed at transforming 198.26 ha in the industrial area of the Poblenou District, became one of the most ambitious and visionary projects in the city. This large project was not merely a planning initiative but signalled a new way of understanding the city (Oliva 2003); its main objective was to transform Barcelona into a leading knowledge society, in particular by encouraging new-generation activities related to

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and requiring education, creativity and innovation (Crossa et al. 2010). In the last thirty years the 22@Barcelona has played a pivotal role in the rebirth of the city.

To achieve these goals, the "Modification of the General Metropolitan Plan (MPGM) for the renovation of the industrial areas of Poblenou" was approved in 2000, which aimed at restructuring the urban concept of the city; protecting and promoting access to housing, redeveloping industrial land in Poblenou to provide adequate infrastructures for businesses and activities, and defining the characteristic activities of the district that would enhance their development. Thus 22@Barcelona was shaped around three axes: the urban, economic, and social renewal of an area, all framed within the overall transformation of the east of the city together with the La Sagrera station, the Vila Olímpica (Olympic Village), and the Forum (Pareja-Eastaway 2017).

The main objectives to be achieved with the development of the three pillars were:

- Urban pillar, that seeks to respond to the need to recycle an obsolete industrial fabric, creating a compact, diverse and balanced environment, in which productive spaces coexist with protected housing, facilities and green areas that improve the quality of life and work (Urbanism22@Barcelona 2012). This axis focuses on the reconditioning of streets (115 blocks), with a comprehensive approach that includes energy, mobility and urban planning aspects. It also involves the renovation of existing houses and the construction of new units. Also in generating the appropriate space and the consequent construction of new facilities and green areas, this includes facilities for the productive fabric (for example, the MediaTIC building or the business incubator Almogàvers Business Factory). Considering the subsequent economic transformation that the area would experience, it was necessary to provide a critical mass of high-density office

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buildings, appropriate to a central business district that aimed to be competitive on a global scale, capable of competing in the real estate market and of attracting new economic activity (Mur and Clusa 2014; Pareja-Eastaway 2017)

- Economic pillar, this axis is supported by backing a model characterized by the 'internationalization of the economy, the tertiarization of activity, the growing productive flexibility, and the emergence of a new technological paradigm around information and communication technologies' (Trullén 2011; Pareja-Eastaway 2017). In this field, focus was placed on the development and attraction of new businesses to the district, thus generating recruitment of professionals of all kinds, focusing on freelance workers with high training levels and also promoting exports and the positive result of the trade balance.

- Social pillar, that is characterized by the creation of space for professionals and citizens, trying to favor the interrelation between the different professionals who work in the area and to promote and support innovative projects that encourage collaboration between companies, institutions, neighbors and entities from social, educational and cultural spheres (Urbanism22@Barcelona 2012). For this purpose, the development of formal and informal relational networks was endorsed, this included collaborative projects, use of new information and comunication technologies and participation of citizens and companies with social, educational and cultural organization in the district. This led to an increase in the population of the district, with a strong presence of residents of foreign nationality, due to the internationalization of the businesses, which has also generated an increase in household disposable income.

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In 2016, a citizen participation movement began to jointly rethink a strategy in the face of the current social, economic and urban challenges of Poblenou and 22@. The local government launched "Repensem el 22@" with the will to develop, through a open and inclusive methodology that guarantees real participation of citizens, shared diagnosis of challenges and needs and a strategic proposal to rethink 22@.

3. Methodology

This study reports on an analysis conducted to start filling the knowledge gap generated around the smart and sustainable development of Innovation Districts and provides insights into what indicators Innovation Districts should consider assessing performance when approaching the design and implementation of strategies for smart development. Since the first step in defining a strategy is to make a diagnosis, and from that, to guarantee the accomplishment of the objectives, controlling the evolution of main factors is essential and key indicators become a factor for success. To meet this aim, twenty years of evolution of 22@ Innovation District in Barcelona are analysed (from its beginning to its maturity) and main variables of analysis are collected, clustered and detailed.

The clustering process is conducted by means of the theoretical approach: first, to understand how cities are transformed with respect to different dimensions: urban, economic, social and governance the Knowledge Based Urban Development (KBUD) approach is considered (Yigitcanlar, Velibeyouglu and Martínez-Fernandez 2008; Yigitcanlar 2008). Second, considering the Triple Helix model (Etzkowitz and Leydesdorff 2000) which focuses on the relationships between universities, government and industry, used as a framework that helps to better understand how ecosystems of innovation develop in cities. From these two theories, KBUD leads to the definition of four innovation Dimensions (Urban, Economic, Social and

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Governance) where indicators will be organized (Table 1). And Triple Helix model actors (University, Government, and Industry) are considered to indicate the main action agents of each indicator (Table 2).

TABLE 1. Knowledge Base Urban Development Dimension

KBUD Dimension	Description
A. Urban	Green areas, green infraestructures —mobility, energy, waste, water— and green building
B. Economic	R&D centres, knowledge-based companies and startups
C. Social	Housig, community facilities, education, social capital, and knowledge workers
D. Governance	Public and/or private bodies that manage the urban transformation and the process of participation citizens

Source: own elaboration.

TABLE 2. Triple Helix Action Agents

TH Action Agent	Description
i. University	Including institutes of technology and research centres, which are the magne for international talent, stimulate the development of local talent, and are sources of scientific and technological knowledge for business.
ii. Government	Large corporations, SMEs and startups, which are the key for the creation of economic value. Entrepreneurship is what translates the knowledge and talent of the individuals, teams and companies into innovation.
iii. Industry	Local, regional, national and international, which becomes the third party providing an active role in scientific, technological, business, and land use policy making.

Source: own elaboration.

The literature review focuses on the science interested to date in 22@Barcelona innovation district over the course of its lifecycle, in the areas of Business Economics and Urban Studies. For this purpose, the articles published under these criterions were analyzed (Web of Science and Scopus databases were used as sources of information). Secondary data was collected from Barcelona City Council and reports from other local bodies that were focused on planning and evolution of this district. This results in 25 documents (Table 3) on which the main concepts for the development of the district have been documented and the indicators found were grouped into the 4 proposed dimensions and ordered by frequency of appearance, from the most

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named to the least. These concepts come from the same literature review, based on the notions that science and public administration have used to measure evolution or propose as important to guarantee the development of the district.

TABLE 3. Sources of information & analysis

Doc no.	Doc Name	Source	Authors	Year
1	Modification of the pgm (general municipal plan) for the renovation of the industrial areas of poblenou	Barcelona City Council	Barcelona City Council	2000
2	Poblenou infrastructures special plan	Barcelona City Council	Barcelona City Council	2000
3	Real estate and urban planning impact of 22 @ 2000-2010 - future perspectives until 2020. - the future central business district of Barcelona	Barcelona City Council	Mur, Sara; Clusa Joaquím	2012
4	10 years of 22@: the innovation district	Barcelona City Council	Barcelona City Council	2012
5	rec64 (economic magazine of catalonia nº 64)	College of economists of catalonia	College of economists of catalonia	2014
6	22@Barcelona plan	Barcelona City Council	Barcelona City Council	2012
7	22@Barcelona 2000-2015	Barcelona City Council	Barcelona City Council	2012
8	Asssessment of the impact and socio-economic function of 22 @ per to the city of Barcelona	Cerdà institute	Cerdà Institute	2018
9	Agreement towards a more inclusive and sustainable 22@ within poblenou	Fundació Barcelona Institute of technology for the habitat	Fundació Barcelona Institute of technology for the habitat	2019
10	Place making facilitators of knowledge and innovation spaces: insights from european best practices	Web of knowledge/Scopus	Srurabhi Pancholi, Tan Yigitcanlar and Mirko Guaralda	2015
11	City of rents: the limits to the Barcelona model of urban competitiveness	Web of knowledge/Scopus	Greig Charnock, Thomas F. Purcell and Ramon Ribera-Fumaz	2014
12	A new space for knowledge and people? henri lefebvre,	Web of knowledge/Scopus	Greig Charnock and Ramon Ribera-Fumaz	2011

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Doc no.	Doc Name	Source	Authors	Year
	representations of space, and the production of 22@Barcelona			
13	Attract and connect: the 22@Barcelona innovation district and the internationalisation of Barcelona business	Web of knowledge/Scopus	Nick Leon	2008
14	The production of urban competitiveness: modelling 22@Barcelona	Web of knowledge	Greig Charnock and Ramon Ribera-Fumaz	2014
15	Areas of innovation in cities: the evolution of 22@Barcelona	Web of knowledge/Scopus	Josep Miquel Pique, Francesc Miralles and Jasmina Berbegal-Mirabent	2019
16	Aplication of the triple helix model in the revitalisation of cities: the case of brazil	Web of knowledge	Josep Miquel Pique, Francesc Miralles, Clarissa Stefani Tteixeira, Jadhi Vincki Gaspar and José Roberto Branco Ramos Filho	2019
17	Spain: creating ecologies of innovation in cities - the case of 22@Barcelona	Web of knowledge/Scopus	Montserrat Pareja-Eastaway and Josep m. Piqué	2014
18	Industrial heritage, economic revitalization and urban compactness in the poblenou-22@Barcelona a new Barcelona model?	Web of knowledge/Scopus	Esteve Dot Jutgla and Montserrat Pallares-Barbera	2015
19	The 22@Barcelona district as part of the businesses relocation process in the city. an analysis of the old and new locations of the corporate headquarters	Web of knowledge	Daniel Paül i Agustí	2017
20	Experimenting community impact evaluation (cie) for assessing urban regeneration programmes the case study of the area 22@ Barcelona	Web of knowledge/Scopus	Marta Bottero, Francesca Bragaglia, Nadia Caruso, Giulia Datola, Federico Dell'anna	2020
21	Innovation districts as turbines of smart strategy policies in us and eu. boston and Barcelona experience	Web of knowledge	Bruno Monardo	2019
22	For a productive city: urban diversity in post industrial transition	Web of knowledge/Scopus	Ana Luisa Barrios and Pedro Brandao	2013
23	Governance, public participacion and economic evelopment: local adaptations to global estrategies	Web of knowledge	Antònia Casellas	2007

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Doc no.	Doc Name	Source	Authors	Year
24	Barcelona - from province to metropolis: a cogent strategy for branding the city	Web of knowledge	Ksenia Piątkowska	2016
25	City as a product. architecture as an economic instrument. are global cities people-friendly places?	Web of knowledge/Scopus	Ksenia Piątkowska	2014

Source: own elaboration.

4. Results

The analysis of the 22@Barcelona District literature allows us to summarize the main aspects that were identified as weight paramenters in this district. Considering the 4 dimensions proposed by the KBUD model, it could be said that the Economic domain is the one that received more attention, in terms of amount of variables of interest detected. Social and Urban domains follow, while governance indicators are by far, less developed. The different findings are presented below for each of the dimensions as follow:

4.1. Urban Sphere Parameters

Related to the urban sphere, 13 parameters could be identified as relevant according to the literature review. Results show that on the one hand, importance is given to the measurement of the areas dedicated to green spaces, which seeks to make the living space more livable and sustainable and, on the other hand to the square meters dedicated to development of new facilities (schools, hospitals, incubators, etc). The intervention surface also was shown to be important and the amount of investment that comes from all these constructions (investment in infrastructure). Another investment that was frequently found was the investment in real estate with a view to the construction of houses, hotels, and residences in the area. On the other handthe definition of the square meters that can be built, meaning, the construction potential,

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the degree of occupancy, which provides information on housing availability and the latent cost in terms of supply and demand, the degree of implementation of construction, as a way of measuring the maturity level of the district, and finally, it was also of interest not only to know the number of dwellings, but also their typology, that is, number of hotels, student residences and the new value of the property in the district driven by the revaluation of the space due to its technological development (Table 4).

TABLE 4. Parameters of the Urban sphere

Nº	Dimension	Concept analysed	Sources
	Urban		
1		Square meters of a stationary or floating district created by a local government to promote sustainable practices, to help reduce environmental impacts, and to help revitalize an area (Green Zone, Green Area or Green Space)	[17]
2		Intervention surface: total area in which a modification of the urban space can been carried out (Area)	[17]
3		Investment in infrastructure	[14]
4		Square meters of spaces or buildings dedicated to special activities for the community (Hospitals, Schools, Business Incubator, etc.) (Facilities)	[13]
5		Houses (Household or Housing Units).	[12]
6		Investment in Real Estate	[12]
7		Constructive Potential: square meters that can be built. (Potential Floor, Potential Ground).	[11]
8		Number of hotels	[10]
9		Linear kilometres of street or road.	[9]
10		How much have been achieved, in terms of construction implementation, with respect to the objectives set.	[7]
11		Number of Student Residences	[7]
12		Square meters that are actually occupied or rented (Degree of Occupability, Occupancy Rate)	[6]
13		Existing houses prices	[3]

Source: own elaboration.

4.2. Economic Sphere Parameters

The economic sphere resulted in the identification of 16 parameters of interest, first of all those that provide information on available jobs and the number of companies, to measure the

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evolution of job and business creation. Secondly, the generation, type and number of business clusters in the district begins to take relevance quickly, as well as the investment and development of start-ups, the turnover, size and quantity exported by these companies. In a similar vein, other concepts were identified that measure generation and attraction of new companies, the number and type of companies that have left, size and intensity of knowledge of these companies, and those that differenciate the companies that are knowledge-based ones, the number of papers written, the number of innovation projects generated and patents registered by this organizations, wich contribute to the strategic positioning. Finally, other indicators of relevance were the creation of technological, research and innovation spaces in the district and the number of freelance workers. (Table 5).

TABLE 5. Parameters of the Economic sphere

Nº	Dimension	Concept analysed	Sources
	Economic		
14		Number of Jobs	[16]
15		Number of Companies	[15]
16		Number of Clustered companies	[13]
22		Number of Start-ups created in the district	[12]
18		Types of existing clusters	[11]
21		Number of Companies that have been attracted, and therefore, relocated in a year.	[11]
17		% Companies or businesses with a higher share of knowledge for production of goods and services compared to other factors. An institute with a minimum of 75% of its assets in intangible form.	[10]
20		% Companies according to their size in terms of the number of employees	[10]
23		% Companies or businesses according to knowledge intensity in the district	[10]
19		Money taken by a business in a particular period (Turnover).	[9]
24		% Companies that export products	[7]
25		Number of Innovation projects generated	[5]
28		Papers written by district organizations	[5]
26		Freelance workers (or Freelance Professional)	[4]
27		Patents registered by district organizations	[4]
29		Investment received by start-ups of the district	[1]

Source: own elaboration.

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4.3. Social Sphere Parameters

14 aspects were identified in Social Domain. Concepts like the number of inhabitants, number of students were identified as a way to measure talent creation. The number of University Centers and the percentage of workers with higher education were identified. Other aspects were also considered in the literature like the number of innovation centres, the number of research centres, and the number of international workers in the district. Additionally,the number of events to develop the community of professionals, the number of cultural activities and the number of people who have participed in cultural activities were taken into account. (Table 6).

TABLE 6. Parameters of the Social sphere

Nº	Dimension	Concept analysed	Sources
	Social		
30		Research Centres or Institutions	[12]
31		Social housing built	[11]
33		Universities Centres	[9]
34		Technologies Centres	[9]
35		Cultural activities (or Cultural offering)	[9]
32		Number of Inhabitants (or Citizens)	[8]
36		Percentage of workers with higher education	[8]
37		Innovation Centres or hubs	[7]
38		International workers who are in the district	[7]
39		Number of Students	[5]
40		People who have participated in district events	[5]
41		People doing internships.	[4]
42		Events to develop the community of professionals	[4]
43		People who have participated in district Cultural Activities	[3]
44		People who have used the district portals to promote their vocation	[3]

Source: own elaboration.

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4.4. Governance Sphere Parameters

Governance sphere, as mentioned at the beginning of this section, is the least developed in terms of the number of registered concepts. But even so, the importance given to the creation of cross-cutting organizations is evident, which enable and increase co-creation and cooperation, with their inherent synergies. Paramenters such as the number of neighbourhood and cluster associations and the number of members of horizontal associations were established here (Table 7).

TABLE 7. Parameters of the Governance sphere

Nº	Dimension	Concept analyzed	Sources
	Governance		
45		Neighborhood associations (or neigborhood group)	[9]
46		Members of horizontal associations	[5]
47		Cluster asociations	[4]

Source: own elaboration.

5. Discussion

Innovation districts are urban areas that host a high concentration of technology companies, research centers, specialized scientific agencies and technology transfer support platforms. Because of this it is of paramount importance for them to have a tool that allows them not only to direct their efforts and actions toward creating this environment, but also to ensure that those actions bring the district closer to its goal on a sustained basis over time. Based on the results obtained in the 22@Barcelona case study, this section proposes and describes a set of indicators to evaluate the process of development of an innovation district. Also analysed here is the ultimate purpose of the indicator proposed and the main agent of the Triple Helix model involved in its implementation and development. This can help in implementation of the

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roadmap for development of the innovation district, shedding light on which aspects must be monitored.

The following table (Table 8) presents the indicators proposed for each dimension of the KBUD model.

TABLE 8. Set of Indicator for the development of an Innovation District

Dimension	Nº	Indicator	Description	Aim	Main TH Action Agent
Urban					
	1	Area	Intervention surface: total area in which modification of the urban space can be carried out	Establishing the dimensions of the intervention project, affects the amount of investment and the impact of the initiatives.	Government
	2	Potential Floor	Constructive Potential: square meters that can be built.	Gives an idea of the economic value of the land.	Government
	3	Degree of Occupability	How many square meters are currently occupied or rented	Provides information on housing availability and the potential cost in terms of supply and demand	Industry
	4	Streets	Linear kilometres of street	Gives an idea of the necessary investment and dimensioning services (for example: mobility, energy, etc).	Government
	5	Green Zones	Square meters of a stationary or floating district created by a local government to promote sustainable practices, to help reduce environmental impacts, and to help revitalize an area	Make living and workspaces more liveable. Quality of life.	Government
	6	Households	Number of houses	Offer spaces for workers and their families. Attract and retain talent	Government/ Industry
	7	Hotels Units	Number of hotels	Attract and retain talent	Industry

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Dimension	Nº	Indicator	Description	Aim	Main TH Action Agent
	8	Student Residences Units	Number of Student Residences	Attract and retain talent	University
	9	Real Estate Investment	Investment in Real Estate	Indicator of investment received in the district. The more investment, the more development, which provides insight into the development of the district.	Industry
	10	Infrastructure Investment	Investment in infrastructure	An indicator of investment received in the district. The more investment, the more development, then it provides insight into the development of the district.	Government
	11	Construction implementation degree	How much has the district achieved, in terms of construction implementation, with respect to the objectives set.	Degree of maturity of the district development	Industry
	12	New facilities	Square meters of spaces or buildings dedicated to special activities for the community (Hospitals, Schools, Business Incubator, etc.)	Meters available to improve quality of life in the district	Government
	13	Second-hand houses price	Existing home prices	Indicates how the area was revalued when developing the innovation district.	Industry
Economic					
	14	Jobs	Number of jobs	Evolution of job creation	Industry
	15	Companies	Number of companies	Evolution of business creation	Industry
	16	Turnover	Amount of money taken by a business in a particular period	Market Position – Competitiveness	Industry
	17	Companies Size	Percentage of companies according to their size in terms of the number of employees	Cost - Barriers to entry	Industry

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Dimension	Nº	Indicator	Description	Aim	Main TH Action Agent
	18	Clusterization of Companies	Number of clustered companies	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	19	Companies clusterization type	Types of existing clusters	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	20	Exporting companies	Number of companies that export products	Trade Balance - Competitiveness	Industry
	21	knowledge-based companies	Number of companies with the higher share of knowledge for production of goods and its services compared to other factors. Institute with a minimum of 75% of its assets in intangible form.	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	22	Companies Knowledge Intensity	Percentage of companies according to knowledge intensity in the district	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	23	Relocated companies	Number of companies attracted, and therefore, relocated in a year.	Business attraction	Industry
	24	Freelance workers	Number of freelance workers		Industry
	25	Number of Startups	Number of startups created in the district	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	26	Startups Investment	Amount of money Amount of money dedicated to the development of startups	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	27	Research Development	Number of papers written by district organizations	R&D&I - Leverage the innovation capacity	University
	28	Technology Created	Number of patents registered by district organizations	R&D&I - Leverage the innovation capacity	Industry/University
	29	Innovation Pilots	Number of innovation projects generated	R&D&I - Leverage the innovation capacity	Industry/ University

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Dimension	Nº	Indicator	Description	Aim	Main TH Action Agent
Social					
	30	Citizens	Number of inhabitants		Government
	31	Students	Number of students	Talent Creation	University
	32	University Centres	Number of universities Centres	Talent Creation	University
	33	Technology Centres	Number of technologies Centres	Talent Attraction - Strategic positioning - Competitiveness - Leveraging innovation capacity	University / Industry
	34	Innovation Centres (private sector)	Number of Innovation Centres	Talent Attraction - Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	35	Research Centres	Number of Research Centres	Talent Attraction	University
	36	Higher Education Qualification	Percentage of workers with university education	Strategic positioning - Competitiveness - Leveraging innovation capacity	Industry
	37	International Workers	Number of international workers in the district	Talent Attraction	Industry
	38	Social Housing Units	Number of social housings built	Diversity and Inclusion	Government
	39	Internship's participation	Number of people doing internships.	Talent Development	Industry
	40	Professional Development Events	Number of events to develop the community of professionals	Talent Retention	Industry
	41	Social Events Participation	Number of people who have participated in district events	Talent Retention - Quality of life - Diversity and Inclusion	Industry
	42	Cultural Activities	Number of cultural activities	Talent Retention - Quality of life - Diversity and Inclusion	Government
	43	Cultural Activities Participation	Number of people who have participated in district cultural activities	Talent Retention - Quality of life - Diversity and Inclusion	Government
	44	Job's vocations	Number of people who have used the district portals to promote their vocation	Promote the vocation of young talent	Industry

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Dimension	Nº	Indicator	Description	Aim	Main TH Action Agent
Governance					
	45	Horizontal Association Size	Number of members of horizontal associations	Social Network creation	Government / Industry / University
	46	Cluster Associations	Number of cluster associations		Government / Industry / University
	47	Neighbourhood Association	Number of neighbourhood associations	Social Network creation. Improve quality of life	Government

Source: own elaboration.

5.1. Urban Domain

The urban sphere mainly seeks to convert infrastructure and with it, to provide more amenities that improve quality of life and thus attract talent to the district. Indicators proposed here must satisfy these requirements and information as the total area in which modification of the urban space can be carried out becames essential, since it helps to establish the dimensions of the intervention project, and define the impact of the initiatives and the amount of investment required in infrastructure. Other mandatory information is the constructive potential: square meters that can be built, since it gives an idea of the economic value of the land and the potential uses of the space. The linear kilometres of street, that in addition to the investment, also provide guidance on the dimensioning of services (for exemple: mobility, energy, etc). Additionally, to satisfy the requirement of attraction and retention of talent, it is necessary to provide metrics that promote the development of healthy, harmonious and sustainable living spaces, for this it is fundamental to to have indicators that offer information about square meters of a stationary or floating district, to promote sustainable practices, to help reduce environmental impacts, and to help revitalize an area (green areas). Also about areas for new facilities, which can be measured as the square meters of spaces or buildings dedicated to special activities for the community (hospitals, schools, business incubator, etc.), which are also elements that improve the quality of life in the district, making it more attractive. The number of houses, number of

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hotels, number of student residences also acquires relevance for contributing to the same purpose.

It is also worth discussing whether the incorporation of indicators that measure operational aspects of these ecosystems gives differential value. Aspects related to energy consumption, generated waste, transportation or facility management could also be included as a way to improve the efficiency of services ofered by the district, and with it, quality of life of its inhabitants.

Another discussion that should be addressed is the inclusion of more concepts related to the environment, such as air quality, noise pollution, degree of recycling, energy savings, percentage of companies that use green energy, business carbon footprint; since sustainability is practically inherent in any smart development to ensure its continuity over time, so to include and measure this aspects could generate greater value to improve living conditions by promoting and guaranteeing these practices based on their monitoring.

Additionally, the urban domain presents a clear differentiation between the indicators, according to the life cycle of their use, which is not as noticeable in the other domains. This difference shows two groups, on the one hand, the group made up of indicators typical of urban regeneration projects, which has a beginning and an end in its use, such as the measures that analyze the area of exploitation, the kilometers of streets, the degree of progress of the structural actions implemented, etc; where the use of the indicator begins and ends with the particular project of which it is part. On the other hand, is the group of indicators that analyze the exploitation actions of the district, so that its life extends during the entire time that the district is in activity.

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In terms of the main actor involved in the urban sphere, the government emerges as key, given that urban planning measures predominate here, where its interference and investment is mandatory. Its actions are complemented by the industry as a materializing actor of the planned measures.

5.2. Economic Domain

This domain looks for the internationalization of the economy, the productive flexibility and the emergence of new technological paradigms around information and communication technologies. The set of indicators should be good at offering information about these aspects as a way to ensure compliance. The indicators such us the number of knowledge-based companies, the number of companies with knowledge intensity, the number of start-ups and the number and type of clustered companies, reinforce these objectives and help to improve strategic positioning, competitiveness and to leverage innovation capacity. Indicators such as the number of innovation pilots and technology created, similarly, contribute to increasing the innovation capacity, but also to developing the research and development potential, so necessary for the promotion of continuous improvement through research and technology. The number of international workers, as a talent attraction meter, also contributes to these purposes. Indicators which measure number of job positions, number of companies and turnover help to control and improve, when necessary, the evolution of jobs and business creation, and to define and expand market positioningand competitiveness. Additionally, in order to know the number of relocated companies, provides a clearer picture of of the performance or capacity of the district in terms of business attraction. Knowing the investment in startups serves to guarantee that the district takes actions to promote their proliferation, essential to achieve the goal of developing an economy based on knowledge and innovation.

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In terms of the main actor, industry has emerged as a lead player in the economic sphere. Even so, its association with the University takes on vital importance as a fundamental partner for the development of research that enables the creation of technology.

5.3. Social Domain

Social domain attempts to create networks of social contentment which boost professional and personal development. Indicators that measure the number of students and university centers intended as spaces for talent creation are key. Then, to visualize the number of innovation, research and technology centres and the number of international workers, attracts new and competitive talent, and also contributes to strengthening the muscle necessary to generate the foundations of development, which begins with individuals, but with them, increases the maturity of the district as a whole. Additionally, knowing the percentage of workers with university education favors t strategic positioning, competitiveness and leverage innovation capacity. Furthermore, to measure the number of professional and social events, the participation of people, their integration and the cultural activities, constitues a way to improve the talent development and retention, the quality of life, the diversity and the social inclusion. Finally, the internship participation and the job vocation indicator promote the vocation and development of young talent in the district.

As mentioned in the theoretical framework, a fourth actor is proposed by an evolution of the Triple Helix towards the Quadruple Helix model. This fourth participant is civil society, which is covered precisely by the social domain of the KBUB theory, as a field. Of course, civil society, as an actor, has a strong influence in this field, but the model of three main actors has been maintained, since they are the ones who adopt a role that is mainly a provider of solutions and services, while the social player takes a position of receiving or demanding these solutions.

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As regards main actors in the social sphere, a confluence of players is evident. While in all areas there are hybrid situations, in this particular domain, an even more efficient coordination and joint work is necessary, given the transversality of the social figure.

5.4. Government Domain

Being the main roles of the government leadership, generating environments and clear rules that favor exchange and promote participation, value would be added by the development of direct or indirect measurement that can infer the progress of this role, and to enhance the cross-promotion function of governance. Also, acting as a facilitator or meeting point for different organizations, including measurements that analyze the result of their actions in this area could provide differential value for the development of this type of ecosystems. Indicators that measure horizontal, cluster and neighbourhood associations, help to develop and improve this aspect? However other successful innovation district could still be considered to complement this analysis.

6. Conclusions

Innovation districts are home to economic, physical, intellectual and networking assets. They seek to incorporate all the elements that foster a knowledge-based development economy, which include, shared working spaces, community colleges advancing specific skill sets, tech transfer offices, proof-of-concept centers, accelerators and incubators. Their development requires the coordinated and organized joint action of all actors present in the ecosystem in order to achieve a successful? Result, superior to what would be achieved by the mere sum of individual actions. Being able to count on a set of indicators that establishes the main parameters and, consequently, the actions and actors linked to them, entails a source of support for the

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organization and functionality required, and works as a control and evolution guide for future development of innovation districts.

Through analysis of the bibliography generated over 20 years of evolution of the 22@Barcelona innovation district, this work proposes to provide urban innovation ecosystems, which are those that develop innovation districts, with a set of indicators that serve to identify and establish feasible and measurable objectives in the four main dimensions proposed by the Knowledge Base Urban Development theory (urban, economic, social and governmental). Thus, 47 indicators are proposed. The urban domain consists of 13 indicators which aim to guarantee good design and correct development of infrastructures and appropriate urban spaces for development of the necessary services. The economic domain consist of 16 indicators, which aim to guarantee good performance and improvement of the aforementioned products and services. The social domain consist of 14 indicators, which aim to guarantee that the necessary conditions are met not only for the creation of human talent, but also for its attraction, development and retention. The last three indicators point to the reinforcement of the governance activities, as a link between cross-cutting organizations.

The urban domain also presents a clear differentiation between indicators that are activated and deactivated with infrastructural projects, compared to exploitation indicators that remain active throughout the entire life cycle of the innovation district and are predominant in the other domains (economic, social and governmental).

Additionaly, every indicator belonging to each domain defined by the Knowledge Base Urban Development theory, is linked to the different actors of the triple helix model and its main role in the development of a knowledge economy, which is the driving force in an innovation district. With this, not only is the indicator itself provided, but also the environment to which it

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is applied,the main purpose to which it responds, and the actor with the greatest power of action over it. With this, the districts could be helped to develop actions that respond to their objectives and implement a system of continuous improvement to enhace their virtues.

Even though the discussion section reveals a certain relationship between indicators and moments in which an indicator can be activated or deactivated throughout the district development process, it would add value to delve into these issues in future research to provide tools that complement the entire planning process of this type of ecosystems.

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6. ARTICLE II: PERFORMANCE INDICATORS FOR THE EVOLUTION OF AREAS OF INNOVATION - PORTO DIGITAL CASE

Rapetti, C., Pique, J. M., Figlioli, A., & Berbegal-Mirabent, J. (2022). "Performance Indicators for the Evolution of Areas of Innovation: Porto Digital Case". *Journal of Evolutionary Studies in Business*, 7(2), 219-267.

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Performance Indicators for the Evolution of Areas of Innovation: Porto Digital Case

Abstract

Areas of Innovation (AOIs) need urban, economic, social and governance development. Building upon the theories of Triple Helix, Knowledge-Based Urban Development, Clusters of Innovation, and the evolution phases of AOIs, this study presents in a novel way, key performance indicators (KPI) that can be used to track and monitor the progress of an innovation district in distinct phases of development towards the achievement of its goals. Using the Porto Digital Case in Recife, the most awarded project in Brazil underway for 20 years at a Triple Helix hybrid organization Núcleo Gestor do Porto Digital (NGPD), performance indicators are analysed and classified. This yields further understanding of which stage of development they have become operative (from inception to maturity), which dimensions affected (namely, urban, economic, social and governance), and who (Triple Helix agents) has been involved with the major action power over it.

Keywords: Porto Digital, Areas of Innovation, Evolution, Indicators, Triple Helix, Knowledge Based Urban Districts

Indicadors de rendiment per a l'evolució de les àrees d'innovació: el cas de Porto Digital

Resum

Les àrees d'innovació (AOI) necessiten un desenvolupament urbà, econòmic, social i de governança. Sobre la base de les teories de Triple Hèlix, Desenvolupament Urbà basat en el Coneixement, Clústers d'Innovació i les fases d'evolució de les AOI, aquest estudi presenta de manera nova, indicadors clau de rendiment (KPI) que es poden utilitzar per seguir i supervisar el progrés d'un districte d'innovació en fases diferents de desenvolupament cap a la consecució dels seus objectius. Utilitzant el cas de Porto Digital a Recife, el projecte més premiat al Brasil durant 20 anys, en una organització híbrida de Triple Helix, Núcleo Gestor do Porto Digital (NGPD), els indicadors de rendiment són analitzats i classificats. Això dona una major comprensió de quines fases de desenvolupament s'han convertit en operatives (des de la creació fins a la maduresa), quines dimensions han afectat (urbana, econòmica, social i governança), i qui (agents de la triple hèlix) ha estat involucrat amb el poder d'acció principal sobre ella.

Paraules clau: Porto Digital, Àrees d'Innovació, Evolució; Indicadors, Triple Hèlix, Districtes Urbans Basats en el Coneixement

Indicadores de rendimiento para la evolución de las áreas de innovación: el caso de Porto Digital

Resumen

Las áreas de innovación (AOI) necesitan un desarrollo urbano, económico, social, y de gobernanza. Sobre la base de las teorías de Triple Hélice, Desarrollo Urbano basado en el Conocimiento, Clústers de Innovación,y las fases de evolución de las AOI, este estudio presenta de manera original indicadores clave de rendimiento (KPI), que se pueden utilizar para seguir y supervisar el progreso de un distrito de innovación en fases diferentes de desarrollo hacia la consecución de sus objetivos. Utilizando el caso de Porto Digital en Recife, el proyecto más premiado en Brasil durante los últimos 20 años, en una organización híbrida de Triple Hélice, Núcleo Gestor de Porto Digital (NGPD), los indicadores de rendimiento se analizan y clasifican. Esto permite una mejor comprensión de cuáles son las fases de desarrollo que se han convertido en operativas (desde la creación a la madurez), qué dimensiones han influido (urbana, económica, social, de gobernanza), y quién (agentes de la triple hélice) ha estado involucrado con el mayor poder de acción sobre ella.

Palabras clave: Porto Digital, Áreas de Innovación, Evolución; Indicadores, Triple Hélice; Distritos Urbanos Basados en Conocimiento

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1. Introduction

Areas of Innovation (AOIs) are novelty ecosystems development initiatives deployed in urban contexts leading to major impacts in dimensions other than district economic development – through entrepreneurship, education, and innovation programmes – including the social and urban spheres. AOIs designed for converting degraded districts into dynamic hubs have attracted interest from policymakers and academics alike (Piqué, Miralles and Berbegal-Mirabent 2019a)

These knowledge-intensive areas (either cities or districts) provide environments and programmes to facilitate the concentration of creative industries integrated into a supportive social environment (Scott 2000) by offering specialised amenities (Yigitcanlar and Dur 2013) and infrastructures (Hutton 2004, Porter 1995, Utterback and Afuah 1998). Such an offering attracts knowledge-based companies, in substituting traditional businesses of old industrial districts of large urban clusters (Hutton 2004), stimulating the concentration of talented people (Florida 2008).

Each AOI is a complex network of components (citizens, business, transportation, communications, services, and other components of a cluster of innovation (Engel 2022) with their own unique strengths and weaknesses that face a constant change that generates the permanent challenge of developing new strategies under the development paradigm of the knowledge-based urban development (KBUD) (Yigitcanlar 2014). Understanding how an AOI can change and improve based on these elements is the starting point for it to achieve its vision and objectives and this can be achieved by refining its most complex link, but at the same time, essential: its strategy. Defining a strategy can help determine where and when to invest, define

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an integration and optimization schedule across all components and systems, and uncover new opportunities for growth and progress.

Evaluating the main systems and activities of an AOI is the first step in defining a strategy towards sustainable prosperity and developing a set of related indicators is the right activity to do so. Indicators show the changes and progress a program is making towards achieving a specific result. Hence, it becomes essential that the elements evaluated are directly linked to the main activities aimed at achieving specific goals. Even when indicators in innovation districts have been studied in order to define a framework that classify these areas of innovation (Yigitcanlar, Adu-McVie and Erol 2020), indicators evaluating performance (Lerro and Jacobone 2013) and their evolution through the lifecycle of these spaces, still require further development.

Following the recent works of (Piqué, Miralles and Berbegal-Mirabent 2019a), we assume that AOI evolve over time, consequently they evolve, certain aspects of the dimensions stand out and consequently, their performance requires close management and monitoring, as they are essential for the development of the next phase and reflect the more active participation of a certain actor in the ecosystem.

In each of the different phases of an AOI lifecycle (Moore, 1996; Etzkowitz 2005) the triple helix actors assume a diverse configuration in terms of role and leadership of the initiative. Specific characteristics and activities related to the social, economic, and urban dimensions are also involved (Pique 2019b, Pique et al. 2021).

Aimed at shedding new light on how to assess the performance of AOIs along their lifecycle, this study proposes a set of KPI for each lifecycle phase of an AOI that considers the four main dimensions (a) urban and infrastructure, (b) economic (c) talent and social transformation, and

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(d) governance. To do so, different conceptual frameworks – triple helix, knowledge-based urban development, clusters of innovation, lifecycle of AOIs, and performance indicators – are used as the theoretical foundations that support our exploratory framework.

We believe this study contributes to the existing literature in two main ways. First, it takes a step forward in the use of indicators, specifying the precise timing in which each indicator is meaningful and therefore, worthy of consideration, offering a more nuanced approach that facilitates planning, execution, and decision-making. Second, this study shows how these indicators can be put into practice. Specifically, we validate their suitability with the analysis of the case of Porto Digital, a reference innovation district located in Brazil.

Section 2 below presents the theoretical underpinnings and section 3 the methodology employed to explore the subject. Section 4 provides an overview of Porto Digital and presents the findings obtained. Section 5 discusses the main indicators for each stage of an AOI development relating them to the case. Finally, section 6 describes the main contributions of this work followed by concluding remarks.

2. Theoretical underpinnings

The theoretical foundations that support the use of different indicators to assess AOIs at their different stages of development can be found in different models and conceptual foundations. Specifically, we build upon the previous works that focus on the evolution of AOIs (Pique, et al., 2021; Piqué, Miralles and Berbegal-Mirabent 2019a), Pique, Berbegal-Mirabent and Etzkowitz 2018), expanding and refining these models, and combining them with performance evaluation theories.

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The foundation for understanding the components and behaviours of AOI ecosystem lies in the TH model (Etzkowitz and Leydesdorff 2000), which focuses on the relationships between universities, government, and industry, and on the Global Cluster of Innovation framework (Engel 2022, Engel 2015, Engel and Del-Palacio 2009). Both provide a comprehensive description of different agents' roles in developing ecosystems of innovation. The latter also analyses the interactions of new ventures, investors, and large companies, and describes the behaviours that lead to international engagements. The knowledge-based urban development (KBUD) theory (Yigitcanlar, Velibeyoglu and Baum 2008a and 2008b) is employed to understand the various dimensions of an AOI and its framework is used as a basis for tracing the elements of each dimension throughout its evolution.

Key performance indicators are explored in order to understand the main categories that apply to each AOI dimension and its applicability and to each development stage.

In the subsections that follow we briefly describe each of these frameworks.

2.1. The Triple Helix Model

The triple helix (TH) model analyses the development of knowledge-based economies from the perspective of the mutually reinforced interactions of three institutional spheres: university, government, and industry. It has been employed as a framework to foster regional economic growth and to promote entrepreneurship, through the understanding of the dynamics of such interactions (Cai and Etzkowitz 2020). Such interactions provide reciprocal benefits for each agent that tends to improve their original performance and expand initial activities, supporting the generation of new business. This process often requires institutional reconfiguration to provide support to startups and technology transfer as well as the creation of new mechanisms (Etzkowitz and Zhou 2017). AOIs, technology parks, business incubators and accelerators are

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examples of (hybrid) mechanisms resulting from these interactions and joint innovation strategies and processes (Kim, Kim and Yang 2012).

TH agents involved in these types of mechanisms assume complementary roles in supporting startups which benefit from the resources provided by TH agents in their path to growth, providing robustness to the ecosystem. TH agents also assume specific responsibilities in supporting the development of the mechanism itself: they evolve and remodel their role, accordingly, adopting new functions - at the different stages of the evolution of these mechanisms (Piqué, Etzkowitz and Solé 2007, Pique, et al. 2021). Individuals or organizations that initiate the interactions and have gained power and respect among TH agents, particularly at local and regional levels, and are key to bringing to fruition the full potential of the knowledge base (Cai and Etzkowitz 2020).

The inclusion of two further elements in the model is suggested: society (and its context), as a fourth helix, and the natural environment as a fifth helix. The quadruple helix model considers that knowledge should be democratized, therefore a knowledge society would evolve jointly with a knowledge economy. This expanded model endorses the role of society in using, applying, and generating knowledge, as well as encompassing the effect of culture and creativity. Building upon the quadruple helix, the Quintuple Helix elevates sustainable development as one of the main elements for collaboration, knowledge sharing and innovation that leads to a socio-ecological transition (Carayannis, Barth and Campbell 2012).

2.2. Clusters of Innovation

The Cluster of Innovation (COI) framework focuses on the main components of thriving business agglomerations in which the generation of fast-growing startups are strongly stimulated by the behaviours of those components (Engel and Del-Palacio 2009). In COIs, the

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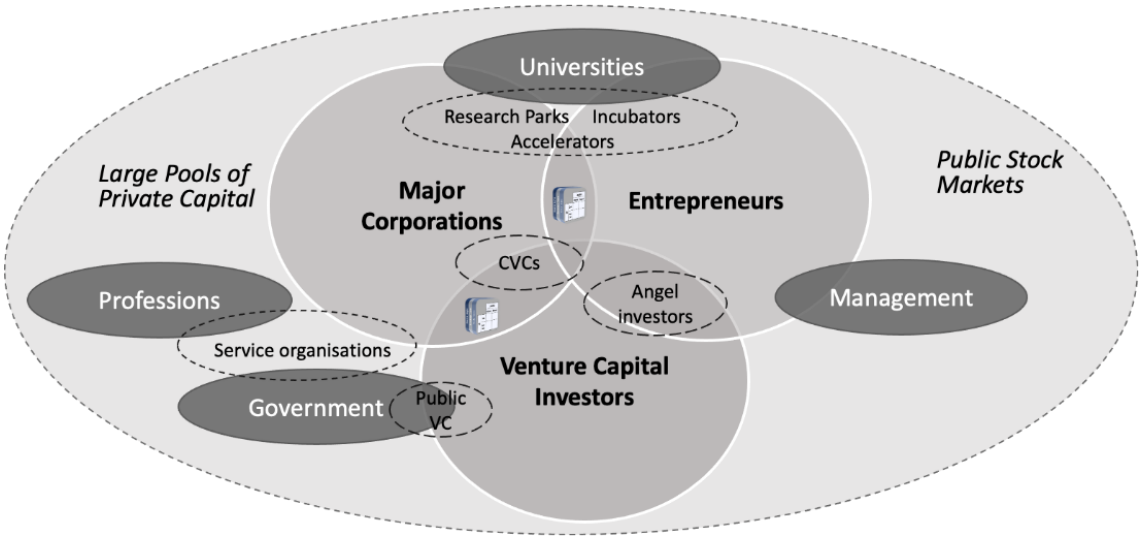
market potential disruption of innovative business models carried by dynamic entrepreneurs are resourced by venture capitalists and/or major corporations in a win-win game result. Relevant actors, as the government, universities, management (professional managers of startups) and professions (such as lawyers and accountants) play a highly enabling support role for the core components interaction (Engel and Del-Palacio 2009, Engel and del-Palacio 2011, Engel 2015). A set of hybrid components – such as corporate venture capital (CVC), research parks, incubators, accelerators, and service organizations – emerge from interaction between core and supporting actors, as new organizations or programmes, expanding the remits of the original component activities (Engel 2022).

FIGURE 1. Core, Supporting and Hybrid Components of a COI



Source: Engel (2022).

The emergence of COIs therefore depends on the interaction of the different components in the development of an innovation cluster. The interest alignment among components, joint definition and communication of a common agenda enables the interaction and facilitates the building of the COI identity (Bittencourt, et al. 2020). Thus, although the presence of the

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aforementioned components - or their functions provided by other components - are crucial, what actually bonds the relation and allows fast innovation in COIs are the shared behaviours: entrepreneurial process, high mobility of resources, alignment of interests, global perspective and global linkages (Engel 2015 and 2022).

The dynamic processes of COIs can evolve into a set of interactions with other physically remote COIs, enabling them to avail of shared ideas and information as well as people and resource mobility, leading to new opportunities. In this (Global) Network of COIs the interactions can vary from ephemeral contacts to more durable bonds embedded in contracts and formal partnerships, or, in a more radical form, two COIs essentially operate in a fully integrated manner (Engel and Del-Palacio 2009, Engel and del-Palacio 2011). Startups and other companies benefit from the international connections for finding customers, partners, and investors, and for exploring new disruptive opportunities. The brand of the AOI is endorsed by whoever creates a project locally and internationally (Pique et al. 2021).

2.3. Knowledge-based Urban Development

Talent is the raw material of the knowledge-based economy and society (Nikina and Pique 2016). Cities that want to be the platform of talent, need to develop strategies to create, develop, retain and attract talent (Bontje, Musterd and Pelzer 2011, Esmaeilpoorarabi, Yigitcanlar and Guaralda 2016, Nikina and Pique 2016) striking a balance with economic and social activities in the same place (Scott 2006). The role of the city is crucial in developing a strategy to cluster highly skilled people and to provide the platform for economic and social development (Pareja-Eastaway and Piqué 2010).

Innovative and creative talent is clustered in knowledge-intensive cities (Florida 2008). In the new economy the trend is to develop modern urban science parks that combine talent and

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technology in the innovation milieu of the cities (Pique et al. 2021). Urban planners replace old urban industrial districts into innovation districts, regenerating the old economy into a new knowledge-based economy in city centres (Knight 1995). Cities have been transformed into 'knowledge community precincts' (Carrillo 2006, Yigitcanlar, Velibeyoglu and Baum 2008b), that is, innovation districts hosting communities of talent that generate new knowledge (Yigitcanlar and Dur 2013).

City centres are the platforms of ecosystems of innovation taking advantage of the city amenities and the vibrant urban life. Innovation districts host significant concentrations of high technology sectors with creative and cultural industries which are integrated in the social context (Scott 2000) and provide socio-cultural amenities (Yigitcanlar and Dur 2013).

Knight (1995) provided an explanation about the knowledge-based development (KBUD) in cities, defining KBUD as the transformation of knowledge in local development. KBUD framework (Sarimin and Yigitcanlar 2012) includes social, economic, urban and governance development. (Piqué, Miralles and Berbegal-Mirabent 2019b), developed the framework in (1) Urban transformation: urban plan, infrastructure plan, legal framework and buildings, (2) Economic transformation: clusters and agenda of technologies, (3) Social transformation: creation, development, attraction and retention of talent, (4) Governance: government, universities and industry (the triple helix agents) playing a key role sharing the vision, and developing actions in all dimensions of the project.

Tangible (e.g., physical infrastructure or buildings) and intangible (e.g., knowledge or creativity) assets are necessary attributes of the innovation districts (Velibeyoglu and Yigitcanlar 2010) for living and working in the cities. TH agents play different roles building innovation districts in the urban, economic, and social dimensions (Pique et al. 2021).

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Innovation districts like Porto Digital, 22@Barcelona, or One-North in Singapore are illustrations of this transformation (Piqué, Miralles and Berbegal-Mirabent 2019b, Yigitcanlar 2011).

2.4. AOIs evolution phases

Based on the analogy of the lifecycle of a new venture of (Freeman & Engel 2007) (inception, launch, growth, and maturity), the ecosystems progress phases from (Moore 1996) (birth, expansion, leadership, and self-renewal or death), and (Etzkowitz 2005) stages of regional innovation ecosystems evolution (development of the idea of a new regional model; starting of new activities; consolidation, and adjustment; and self-sustaining growth), (Piqué, Berbegal-Mirabent and Etzkowitz 2018, Pique et al. 2021) propose four evolution phases for AOIs: inception, launching, growth and maturity.

For each of the phases, the model presents the evolving (re)configuration of the engagement and leadership of the TH agents, as well as the evolution of aspects of each dimension of the KBUD framework. Each phase depends on the contribution of the TH agents for governance, urban, economic, and social development, as it outlines the subsequent stage, strengthening or obstructing its evolution (Pique et al. 2021). In this context, the performance evaluation of the aspects of the dimensions involved in each phase becomes crucial for the orchestration or redesign of activities, programmes or processes.

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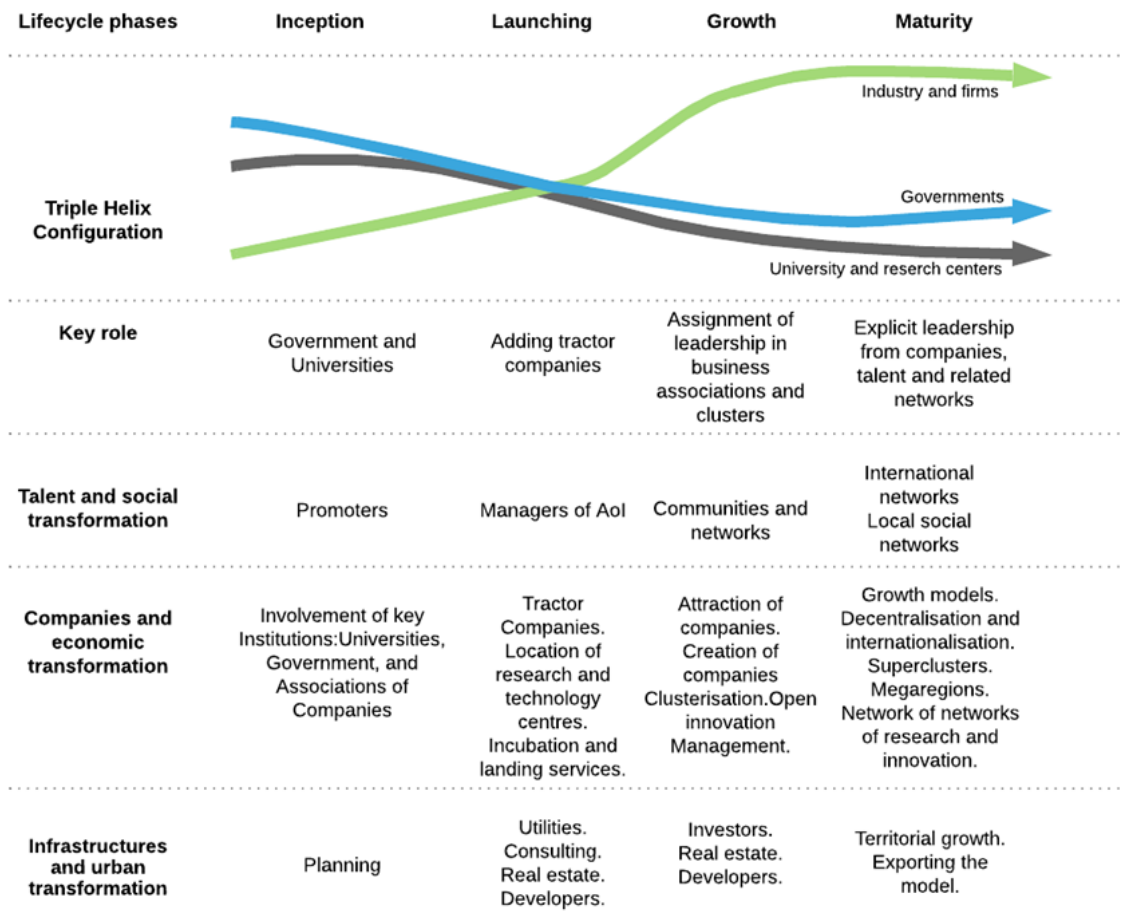
FIGURE 2. Stages of the AOIs development and its dimensions



Source: Pique et al. (2021, 153).

2.5. Performance Indicators of AOIs

Strategic management literature has analysed mission statements as a tool to understand and evaluate how organizations perform (Alegre et al. 2018). Every organization has its own mission, and the way it is articulated can reveal crucial information about the strategy an organization is following. In the specific domain of science and technology we can find the recent works of (Wang, Wan and Zhao 2014) and (Berbegal-Mirabent, et al., 2020) in which mission statements of science parks are scrutinized in order to find potential links between the strategy and the real performance. In these studies, organizational performance is

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operationalized in a variety of ways, ranging from indicators of a number of startups to the indicators of funding.

Performance indicators are metrics used by organizations to measure and evaluate their behaviour and ensure that their efforts are directed towards achieving their objectives. Effective assessment is significant to prove the value of projects and initiatives and the benefits delivered to city authorities and all city stakeholders (Caird, Hudson and Kortuem 2016). To support the monitoring of relevant projects and initiatives, KPIs can be a universal instrument to evaluate the progress of strategies (Dameri 2017). With regard to the lifecycle of a product or innovation environment, managing the lifecycle generates maximum value and profitability at each stage. The selection of correct strategies and KPIs is important to drive the value maximization process.

KPIs are the answers, therefore, it is important to think about the question that needs to be answered and since some indicators will be more time-consuming and costly than others to collect and analyse, simplicity is paramount for a measure to be taken and reproduced periodically. For this reason, an existing and known indicator that answers exactly the required question may be better than proposing a perfect new but unknown measure. Strong indicators are simple, precise, and measurable.

Within the different categories in which the indicators can be grouped, there is one that is related to the different parts of a program or project, which also allows a temporal analogy. Within this, there are three main and most common categories of indicators.

- Input indicators. Measure the resources required to allow the program to be implemented. (e.g., funding, staff, key partners, infrastructure).

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- Process indicators. Measure the program's activities and outputs assessing whether the program is implemented as planned. (e.g., direct products/deliverables of the activities).

- Outcome indicators (or Impact indicators). Measure if the program is achieving its expected effect in the short, intermediate, and long term.

3. Method and Data

AOIs require urban, economic, social and governance transformation over its lifecycle. Although some evidence can be found concerning the elements that trigger and favour these transformations (Piqué et al. 2019), (Piqué, Miralles and Berbegal-Mirabent 2019b**)**, it is not clear how to measure this evolution. This situation calls for the development of performance indicators able to capture the different phases of development of an AOI, when these indicators are activated, and the agents involved in this process. Aimed at tackling this problem, we present a framework of key performance indicators that is expected to become a useful tool for controlling and monitoring how AOIs evolve.

This paper adopts the form of a case study (Yin 2018), since it analyses (1) "how" and "why" is the process of urban revitalisation, (2) there is no control over the AOI analysed, and (3) it is a contemporary phenomenon with real-life context. More precisely, a single-case study approach was adopted to explore and pilot the validity of a set of key performance indicators. Porto Digital in Brazil was chosen as a unique case, as it presents three unique characteristics that make it worth being examined: (a) it allows for a longitudinal study, since it has been in operation since 2000, (b) the initiative is recognized as one of the most comprehensive AOIs in terms of dimensions developed — social, economic, and urban — (Pique et al. 2021), and (c) there is strong engagement of the triple helix actors (university, industry, and government) that is also extended to the fourth helix (society).

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The indicators presented in this study, as well as overall data were collected from multiple sources, including official reports and webpages, as well as scholarly articles describing the case of Porto Digital, compiled and fed during 20 years of the district's evolution, from its inception to its maturity (see Table 1). Also, primary data was considered by means of two interviews carried out in December 2021 with the past president of Porto Digital (Francisco Saboya) and the current innovation director (Heraldo Ourem).

TABLE 1. Source of Data of Porto Digital

Year	Source of the Data – Official reports and webpage
2001	• DECRETO Nº 23.212, DE 20 DE ABRIL DE 2001 Qualifica a Associação Núcleo de Gestão do Porto Digital como Organização Social - OS, e dá outras Providências • Plano Bi-anual 2001-2002
2002	• Relatório de Metas e Atividades para 2002 • Anexo J – Prestação de contas 2002
2003	• Plano de Atividades e metas financeiras de Março 2003 a Março 2004 • Anexo B - Prestação de contas 2003
2004	• Metas Físicas do Contrato de Gestão Mar 2004-Mar2005 • Resultados Metas Físicas Contrato de Gestão Mar2004 - Mar2005
2005	• Relatório de Desempenho de Atividades do Plano de Trabalho de Março a Dezembro de 2005
2006	• Monitoramento do Planejamento Estratégico Período 2006 – 2008 Balanço do Cumprimento das Metas do período 2006
2007	• Relatório de Prestação de Contas – 2007
2008	• Prestação de Contas 2008 - Relatório Gerencial 2008
2009	• Prestação de Contas 2009 - Relatório Gerencial 2009
2010	• 5º Relatório Semestral de Progresso. Contrato de Gestão SEE e NGPD • 4º Relatório Semestral de Progresso. Contrato de Gestão SEE e NGPD
2011	• Relatórios de Prestação de Contas dos Contratos de Gestão 2011
2012	• Relatórios de Prestação de Contas dos Contratos de Gestão 2012
2013	• Relatórios de Prestação de Contas dos Contratos de Gestão 2013
2014	• Relatório de Prestação de Contas dos Contratos de Gestão 2014
2015	• Relatório de Prestação de Contas do Contrato de Gestão nº 4 – 2015
2016	• Relatório de Prestação de Contas do Contrato de Gestão SECTI/PE – 2016 • Relatório de Prestação de Contas do Contrato de Gestão 04/2014 PCR - 2016
2017	• Relatório de Prestação de Contas do Contrato de Gestão SECTI/PE – 2017 • Relatório de Prestação de Contas do Contrato de Gestão 04/2014 PCR - 2017
2018	• Relatório de Prestação de Contas do Contrato de Gestão 04/2014 PCR – 2018 • Décima_Reforma_do_Estatuto_Social – 2018
2019	• Relatório de Prestação de Contas do Contrato de Gestão 04/2014 PCR - 2019
2020	• Extrato de Relatório de Execução Contrato de Gestão No 001/2019 – 2020
WEB	• https://www.portodigital.org/parque/o-que-e-o-porto-digital/documentacao

Source: Own elaboration.

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To link the data to the proposition, the key categories in which the indicators were grouped were derived from the main domains proposed by the KBUD to model a knowledge-based development. From here, the indicators were analysed to arrange them within the urban, economic, social and governmental categories, to later locate them in the different stages of evolution of an innovation district (Inception, Launching, Growth and Maturity). It means the moment in which each indicator begins to be used or "activated" is indicated on a timeline that outlines the different phases of evolution of an innovation district. An active indicator is conceived, in this case, as the period of time in which the information provided by the indicator is necessary for an accurate decision-making process essential for the district to reach its goals in time and complete its evolution. Knowing which indicator comes into action in each phase could help the main decision makers to decide what type of data to generate and start measuring from the beginning of each phase to guarantee compliance with their actions and anticipate future decisions.

The activation period was identified through the information presented in the district's official reports and websites. That is, when the need to start measuring a parameter was mentioned or when it began to record its measurement according to different evolution needs of the district. That done, the analysis was complemented with contextual and validation information, which was obtained from the interviews carried out with the experts and from scientific articles prepared in advance.

Additionally, the TH agent that has the most influence on each indicator was also analysed. Here, the greatest influence is conceived as who has the greatest power of action to create measures that modify these observed data.

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Below the framework for allocation the aforementioned indicators are presented in order to link data to proposition.

TABLE 2. Framework for the Key Performance Indicators by Dimension and Phase

Phase / Dimension	Inception	Launch	Growth	Maturity	TH Agent
Infrastructures and urban transformation	Name of the indicators that are activated and remain active in each phase for each dimension				TH Agent with the biggest influence
Companies and economic transformation					
Talent and social transformation					

Source: Own elaboration.

4. The case of Porto Digital

"Porto Digital is a public policy" (Ourem 2022)[1]

4.1. Overview

Launched in 2000 in the city of Recife, capital of Pernambuco State in the northeast of Brazil, Porto Digital (PD) is one of the most awarded AOIs in the country. In 2020, there were around 330 small and medium companies, knowledge institutions, research, and innovation centres (including from multinational companies), development organizations and governmental

[1] Ourem Heraldo (Innovation Director of Porto Digital). Notes of interview, December 2021.

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agencies in the area, with approximately 11 thousand professionals in total, generating an annual revenue of around BRL 2.3 billion in 2019 (Porto Digital 2021).

PD is an open well-defined urban AOI[2] that covers an area of 171 hectares of the Recife old historic neighbourhood and part of three adjacent neighbourhoods, with one unit in the countryside (Caruaru). Most of the area is listed by public heritage and, therefore, follows strict rules regarding its modification. The city law 17244/2006 and its further modifications provide the basis for its operation, that aims at urban revitalization and economic and cultural development with focus on information and communication technology (ICT), creative economy (games, videos, digital media, animation, design, photography, and music), urban and future of technologies applied to cities (Albuquerque Neto, Calheiros and Targino 2012, Porto-Digital 2021).

Established as a non-profit private association, the management organization of PD (NGPD) has deliberately pulverized governance. Its steering committee includes representatives of the government, academia (universities and research centres), industry (business associations) and the civil society (people of notorious knowledge), but without any group reaching the majority of representation[3] .

PD is a product resulting from the formation of human capital and capacity to generate research at the Federal University of Pernambuco (UFPE), in its three fronts: teaching, research and extension activities. In the beginning, PD was positioned around the UFPE competencies but with its consolidation, other institutions were attracted to the area or for joint projects.

[2] Best Technological Park/Innovation Habitat in Brazil in 2007, 2011, and 2015 (ANPROTEC 2021)

[3] Porto Digital Statute. https://www.portodigital.org/arqSite/Decima_Reforma_do_Estatuto_Social.pdf

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Currently, more than 15 institutions integrate the human capital formation ecosystem, offering research and extension activities as well: UFPE, Rural University, Catholic University of Pernambuco, and private ones, such as Cesar School (which started in 2010 and offers undergraduate, master and doctorate programs). Most institutions do not have a physical presence in the PD area but offer co-branded courses. These involve the co-creation of a curriculum, adapted to the needs of the ecosystem, and a mandatory module of professional technological residency (analogous to medical residencies, but in this case carried out in PD companies), in which students have the opportunity to experience the AOI. Co-branded courses facilitate the development of hard and soft skills required by the companies in the selection process, as well as the development of joint projects between companies and the universities.

When it comes to economic development, since its inception, a threefold strategy was in place:

- Creation of new companies (through incubation, acceleration programs, etc.).
- Strengthening of established businesses (internationalization, obtaining certification, support for financing).
- Attracting large companies.

The 3-element strategy allowed for more formal action on a given element depending on the context. For instance, currently the trade-off in undertaking entrepreneurship through startups is considerable due to the high salaries paid to IT professionals (there is a high demand for this type of professional). Thus, the focus shifted to strengthening existing companies and attracting large companies to PD. It is important to mention that the PD has already reached a considerable level of maturity through endogenous generation of strong business: from the 10 most important companies in the area, 7 were created in Porto itself.

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PD is in one of the more prestigious areas of the city, where Recife was founded, and which has a series of cultural facilities (bars, restaurants, museums, a shopping mall, handcraft market, and areas for cyclists). In the area there are several political and cultural manifestations (such as Carnival) on a city landmark, the "Ground Zero" square. As the creative economy is one of the PD's areas of interest, the NGPD carries out a series of monitored activities to engage with the cultural movements that take place in the area. One of the cinemas is linked to Porto Media, a laboratory for experimentation of the creative economy that offers post-production services, which has already participated in Brazilian and foreign productions.

4.2. PD Performance Indicators and TH agent roles at each stage of the lifecycle

As described in section 3, 67 indicators were found. Their breakdown, by stage and dimension, is shown in Table 3. By closely examining which indicators are more relevant through the different stages, it is possible to obtain a better grasp of how an AOI has evolved and where was the focus at each stage of its lifecycle.

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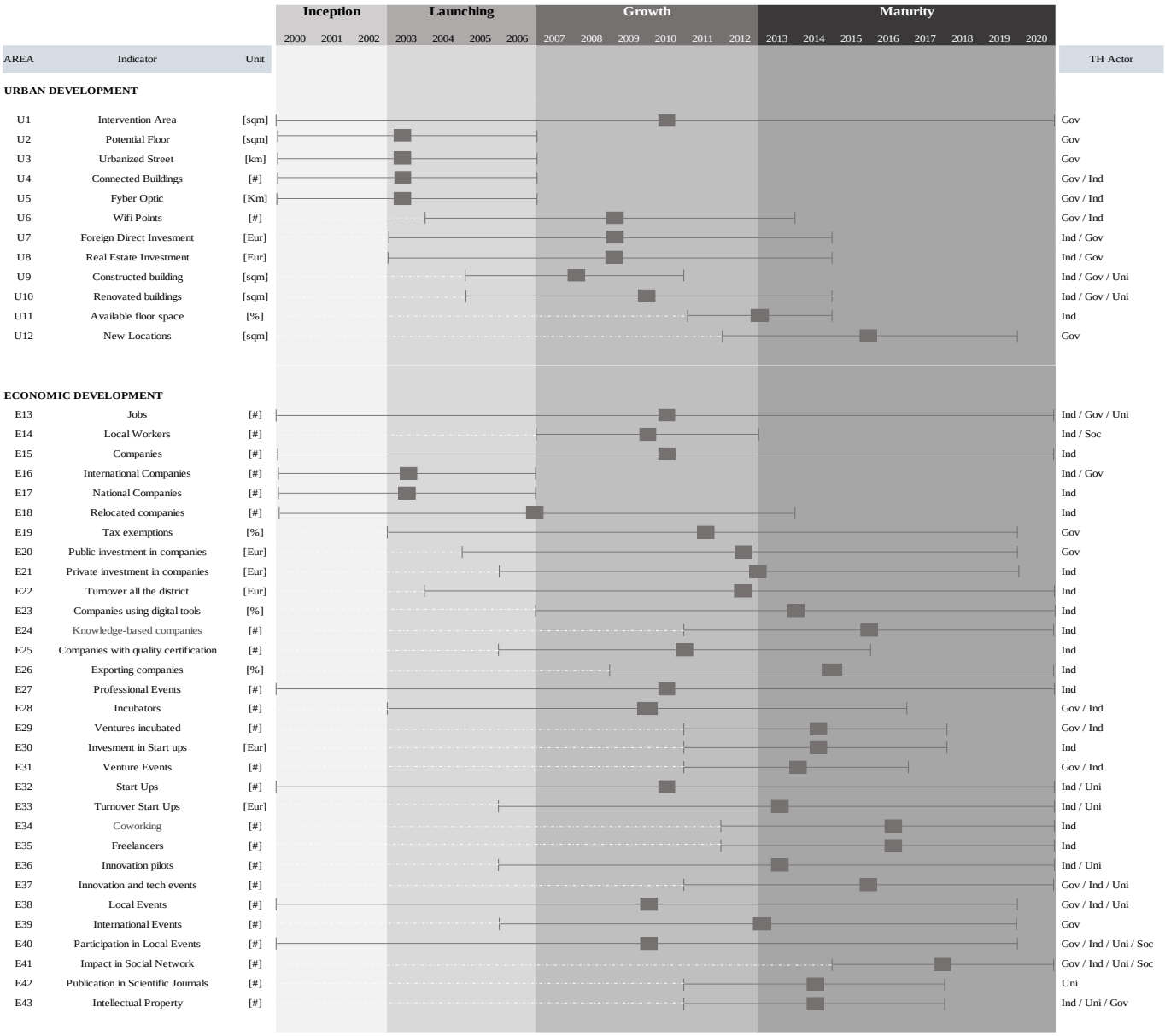
TABLE 3. Indicators activated in each stage of the AOI lifecycle



AREA	Indicator	Unit	TH Actor
URBAN DEVELOPMENT			
U1	Intervention Area	[sqm]	Gov
U2	Potential Floor	[sqm]	Gov
U3	Urbanized Street	[km]	Gov
U4	Connected Buildings	[#]	Gov / Ind
U5	Fyber Optic	[Km]	Gov / Ind
U6	Wifi Points	[#]	Gov / Ind
U7	Foreign Direct Invesment	[Eur]	Ind / Gov
U8	Real Estate Investment	[Eur]	Ind / Gov
U9	Constructed building	[sqm]	Ind / Gov / Uni
U10	Renovated buildings	[sqm]	Ind / Gov / Uni
U11	Available floor space	[%]	Ind
U12	New Locations	[sqm]	Gov
ECONOMIC DEVELOPMENT			
E13	Jobs	[#]	Ind / Gov / Uni
E14	Local Workers	[#]	Ind / Soc
E15	Companies	[#]	Ind
E16	International Companies	[#]	Ind / Gov
E17	National Companies	[#]	Ind
E18	Relocated companies	[#]	Ind
E19	Tax exemptions	[%]	Gov
E20	Public investment in companies	[Eur]	Gov
E21	Private investment in companies	[Eur]	Ind
E22	Turnover all the district	[Eur]	Ind
E23	Companies using digital tools	[%]	Ind
E24	Knowledge-based companies	[#]	Ind
E25	Companies with quality certification	[#]	Ind
E26	Exporting companies	[%]	Ind
E27	Professional Events	[#]	Ind
E28	Incubators	[#]	Gov / Ind
E29	Ventures incubated	[#]	Gov / Ind
E30	Invesment in Start ups	[Eur]	Ind
E31	Venture Events	[#]	Gov / Ind
E32	Start Ups	[#]	Ind / Uni
E33	Turnover Start Ups	[Eur]	Ind / Uni
E34	Coworking	[#]	Ind
E35	Freelancers	[#]	Ind
E36	Innovation pilots	[#]	Ind / Uni
E37	Innovation and tech events	[#]	Gov / Ind / Uni
E38	Local Events	[#]	Gov / Ind / Uni
E39	International Events	[#]	Gov
E40	Participation in Local Events	[#]	Gov / Ind / Uni / Soc
E41	Impact in Social Network	[#]	Gov / Ind / Uni / Soc
E42	Publication in Scientific Journals	[#]	Uni
E43	Intellectual Property	[#]	Ind / Uni / Gov

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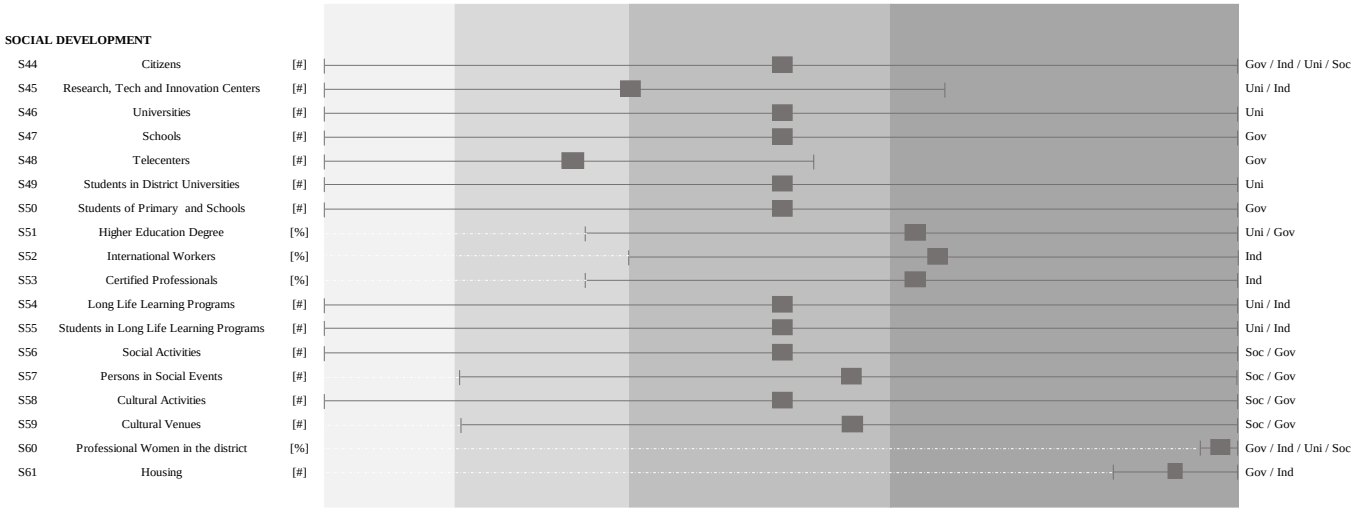

Source: Own elaboration.

Below we elaborate on each stage of the lifecycle of PD and discuss the rationale behind the relevance of the indicators taking into account the strategy adopted by the AOI.

4.2.1 Inception

In terms of infrastructure and urban transformation, a new planning regulation[4] was created at this stage in order delimit the area of PD, the type of uses intended for the land – streets, business and commerce, cultural equipment, etc – and to provide incentives for attracting investors to the innovation district. At that time, social housing was not available in the area. Accordingly, KPIs refer to the intervened area (measured as the total surface in which a modification of the urban space can been carried out), the potential floor available (proxied as the square meters that can be built), the urbanized streets (in kilometres), connected buildings (number of buildings with internet coverage) and high connectivity (kilometres of optical fibre cable). All measures here are linked and belonged to the Master Plan of the PD's project definition. Apart from the first indicator (Intervention Area) that was used over the 20 years of evolution of the

[4] City Law 17.244/2006 and further modifications

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district, the remaining indicators that pertain to this dimension were measured during the first 7 years, that is, during the Inception and Launching phases.

Moving on to the economic dimension, the participation of universities, government and industry was prioritized to articulate the collaboration that stimulated the strategic development of the knowledge-based economy in a formerly deprived area. At this stage, the State Government of Pernambuco, in partnership with Informatics Centre (Centro de Informatica – CI), involved the Association of Software Companies (Softex Recife) to explore the potential companies and jobs to be attracted/generated in the area through the regeneration of the port warehouses and historic real estate in the case of Recife.

KPIs that capture the interventions in the economic sphere where measures such as the number of current companies and jobs, could be used as a starting point to establish future development objectives. These two measures remained operative throughout the district's lifecycle. During the first two stages (inception and Launch), it was also important to differentiate between national and international companies, for this reason two different indicators were defined (National Companies and International Companies). Another parameter that was activated during this stage was an indicator that measured the number of companies attracted to the area (relocated company indicator), and they kept active up to the beginning of the Maturity phase. The number of professional events (professional events indicator), local events and the quantity of people that participate in them, were also analysed from the origin and their values, were recorded throughout development of the district. Finally, the number of startups was also activated at the inception stage and is still in use. Note that even when economic viability of the project is analysed, the focus here is not that much on measuring profit.

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As for the social dimension, the State of Pernambuco was the main stakeholder for converting the old quarter of the city into a new innovation district, thus the knowledge about the demographics of the area and the involvement of the residents, business owners and real estate owners were of utmost importance. The University of Pernambuco (UFPE), through its Informatics Centre (Centro de Informatica – CIn/) and the Recife's Advanced Studies and Systems Centre (CESAR) were also involved at the time of inception. In this sphere, the role of citizens acquires prominence, as can be seen in the suggested KPI as knowing the number of citizens is used to forecast the future number of inhabitants, and thus, the number of houses and other infrastructures that will need building. The number of research, technology and innovation centres, universities, schools and telecentres also began to be registered at this stage, as well as the number of students attending university or primary school. Accounting for the number of students was an activity maintained throughout the four stages, while measurement of numbers of research, technology and innovation centres stopped when the district reached maturity. The measurement of number of telecentres was discontinued in the growth stage.

Additionally, continuous training was also analysed and maintained from the beginning to the end of the development (indicators Long Life Learning Programs and Students, which seek to record the number of programs offered and the students enrolled, respectively).

Finally, the number of social and cultural activities was recorded as a measurement parameter of how lively the AOI was. Recording of this indicator started during the inception stage and has been maintained as of today.

Finally, looking at the governance dimension, main KPIs refer to quantify the monetary value made available for district activities and projects (district budget), and the number of

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professionals in the management team (district management team professionals' indicator). Both metrics have and are still being used since inception.

4.2.2. Launching

In order to coordinate the efforts of the main actors in terms of the talent and social transformation, it was established the management organisation of the AOI, the Núcleo Gestor do Porto Digital (NGPD), a private not-for-profit company that represents the Triple Helix actors and that has as its mission to the promotion of competitive conditions that create, attract and strengthen innovative information technology and creative economy ventures to the innovation district.

The implementation in the district of organisations, such as the State Secretariat of Science, Technology and Environment (SECTMA), research institutes as the CIn – UFPE and the Institute for Innovation in Informatics (I3) and the continuous involvement of incubators like CESAR and Cais do Porto, and the support of the Interamerican Development Bank, created the trust for attracting other institutions and companies to engage with the project. CESAR also oversaw the development of physical and logical conditions for the creation and growth of startups, matching startups with entrepreneurship programmes and connections with investors.

New indicators were created and identified in the Launch phase, indicators such as Foreign Direct Investment and Real Estate Investment, which measure the money invested both externally and internally. The Constructed building and Renovated buildings indicators, which measure square meters built and renovated respectively. Wi-Fi Points were also considered here, which counted the number of Wi-Fi connection points within the district. All these new indicators remain active until the beginning of the Maturity phase.

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Similarly, the economic dimension also begins to measure the investments amount in this Launching stage. Indicators such as Public Investment in companies and Private investment in companies are activated here and will continue to be measured until the end. The percentage of tax exemptions (Tax exemptions), the invoicing of the existing companies and the startups (indicators of Turnover all the district and Turnover Startups respectively). The number of companies with quality certification (Companies with quality certification indicator), the number of incubators (Incubator indicator), the number of innovation pilots (Innovation Pilot indicator) and international events (International Events indicator), begin to be measured in this phase, remaining operational throughout the development cycle.

In terms of the Social dimension, measurement of the following indicators began during Launch stage: Higher Education Degree: percentage of students with higher education; Certified Professionals: percentage of professionals who have participated in certification training; Persons in Social Events: number of people participating in social events and Cultural Venues: number of Cultural Venues.

The Governance dimension activated here the District Companies Associated indicator, that measures the number of associated companies and the number of professionals that belong to district company associations (Professionals in district companies associations indicator).

4.2.3 Growth

The management organisation of the area, NGDP, drove the building and integration of communities and networks. In terms of cultural activities, the tax incentives and local projects led to an enhancement of social facilities for the district workers, local citizens, and tourists. Several facilities were implemented in the area, such as bars, restaurants, museums, a shopping mall, a handcraft market, and Recife's most famous space for festivities, especially during

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Carnival. On Sundays and holidays, itinerant artistic presentations animate the district, and the streets are exclusively for pedestrians and cyclist use.

Companies of two clusters — IT and the creative economy — were attracted to the area. Other companies, such as FIAT, Accenture, IBM, Uber were also attracted once the district became a reference for infrastructure, open innovation, and talent.

It also attracts the interest of real estate investors and developers, that see opportunity in the rising demand and tax incentives to regenerate the real estate.

Urban indicators were created in previous phases, here it was only registered indicators that measure the percentage of Available Floor Space and the New Locations, which is the expansion in square meters of the district.

In the economic field, indicators are developed to measure Knowledge-based companies: number of knowledge-based companies. Exporting companies: the percentage of companies that export. Ventures incubated: the number of ventures incubated. Investment in Startups, the monetary amount of investment in Startups. Venture Events: the number of venture Events. Coworking: the number of collaboration spaces. Freelancers: number of freelancers. Innovation and tech events: number of innovation and technology events.

In the social sphere, the indicators detected in the Growth stage were: International Workers: percentage of international workers in the district. Publication in Scientific Journals: the number of scientific publications made by works within the district. Intellectual Property: the number of patents registered within the district.

The governance dimension began to register at this stage, the number of clusters that the district had (indicator of Cluster).

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4.2.4 Maturity

The efforts made to consolidate Porto Digital attracted national and international events and visibility to the project, as well as enhanced competitiveness. It appeared in the *Financial Times* in 2014 as ”Recife: rebirth of the Brazilian Venice”, which entitles Porto Digital as a main driver in containing the region’s brain drains through the nurturing of a dynamic economic ecosystem based on culture, information, and knowledge.

NGPD consolidates its engagement with international networks (e.g., International Association of Science Parks and Areas of Innovation -IASP, American Chamber of Commerce, and Triple Helix Association), as well within Brazilian Networks (e.g., ANPROTEC, ASSESPRO, Softex Recife). In 2013, Porto Digital hosted the Annual Conference of IASP, strengthening its engagement with the international community. These engagements created a robust platform for the internationalisation of Porto Digital and to export the model to other regions/countries.

Porto Digital also expanded its operation to the countryside of Pernambuco State, through the innovation lab “Armazém da Criatividade” in Caruaru, and also expanded its companies cluster from IT and creative economy to include urban and future of cities technologies.

Apart from the indicators activated in previous phases that remain active in this phase, the following are created in this instance: Impact in Social Network: level of impact on social networks (High, medium or Low). Professional Women in the district: percentage of women working in the district. Housing: number of dwellings in the district. Regarding this last indicator, currently, Porto Digital does not have housing in the district and PD staff still commute to their homes in the satellite areas. However, there is in place a large-scale project to convert 35 thousand meters of idle areas into residential areas. This area, currently degraded, will be regenerated via private investment. Although priority will be given to housing for PD

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workers, the housing project is a mix of buildings of various categories, including social housing. The NGPD developed the concept and sought out the investor (they have a Memorandum of Understanding for the development of this project).

In the governmental sphere, measurement of the number of existing indicators that record the development of open data (Indicators in Open Data) began in the Maturity stage.

4.2.5 Triple Helix agents

The Triple Helix model allows the different actors (i.e., government, university and private sector) to engage at different speed and levels of commitment. When analysing the evolution of PD, one notices that indeed, Triple Helix agents show diverse strategies which differ not only in the type of activity but also in terms of when (timing along the lifecycle) and how (resources they put into play and level of influence). In the paragraphs that follow we briefly explain how each of the Triple Helix agents behaved.

Government had a dominant role in urban development (defining the area of intervention, the potential floor, and the streets that qualified for urbanization), although a joint collaboration with the industry was needed in order to develop the infrastructure and define new locations. In the economic dimension the government also stood out, holding in his hands the capacity to stimulate economic activity by means of tax exemptions, public investment, easing the creation of entrepreneurial ecosystems (e.g. incubator, ventures incubated) and promoting the district through events (e.g. venture events). In the social sphere, the government was responsible for defining the number of houses to be built and, consequently, setting an estimate for the number of citizens that will be able to live in the district, and therefore, the need for schools and social services (which will be in hands of the public administration). Finally, in the governance

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dimensions, the government plays a key role promoting the association of companies, the clusterization and the budget of the organization in charge of developing the district.

The Industry, in urban development, will deploy the infrastructures and buildings and will offer all the offices to the tenants and investors. In terms of economic development, the industry will also be in charge of generating and developing companies, with the job creation that this entails. This occupation could be analysed by local workers and freelancers among others. Also, as an expression of economic impact and development, industry will have indicators that follow the turnover of companies and the private investment in startups (Business angels in venture capital and corporate venturing). The competitiveness of the companies using digital tools and the quality certifications (organizational and personal) are also measures led by the industry. The number of knowledge-based companies and the number of pilots are expressions of the innovative industry in the district. The internationalization degree analysed by the number of the international companies and the participation in international events, are also measures managed by the industry. In Social development the industry contributes with the number of workers that live in the district being able to specify between international, women and others that will be neighbours in the district. In the governance development the number of the companies associated in the district and the number of clusters are indicators that have the industry as a relevant agent.

Universities, in urban development, can participate creating or renovating their own buildings. In terms of economic development, universities contribute with the development of new science, papers, and patents, the development of innovation pilots and new startups and finally with the participation in events. In Social development, Universities contribute with students and professors as citizens of the district and improving the education of workers. Also,

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providing education degrees and long-life learning programs. In Governance development, Universities are also involved in the cluster and the company's associations.

Society will be the user of the district, participating actively as workers in the economic development and as students in the social development. The dynamics of the district will be measured with social and cultural activities. In the case of Recife, the society was not deeply involved in the governance at the beginning.

4.2.6 Indicators' Categories

In terms of the part in the program that the indicator can be related to, three main categories can be observed (See Table 4)

- Input indicators, which measure the resources needed to implement the program (U1, U2, U7, U8, U12, E14(1), E19, E20, E21, S46, S47, S48, S49, S50, S61, G62, G63).
- Process indicators, which measure program activities and outputs (U3, U4, U5, U6, U9, U10, U11, E18, E23, E25, E27, E28, E29, E30, E31, E34, E36, E37, E38, E39, E40, E41, S51, S53, S54, S55, S56, S57, S58, S59, G64, G65, G66).
- Outcome indicators (2), which measure if the program reaches its expected effects (E13, E15, E16, E17, E22, E24, E19, E32, E33, E35, E42, E43, S44, S45, S52(3), S60, G67).

(1) Local workers, considered as a means of inclusion, it can be classified as an outcome, but at the same time if it is conceived as available resources, it could be classified as an input.

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(2) The indicators that measure outcome should be measured from the beginning in order to set the benchmark on which to improve.

(3) International workers are on one side, input for the internationalization of the company and could be the result of activities of attraction of talent. In our case, as an outcome because of the goal of the district of increasing the international diversity.

It could be observed here that some outputs became inputs of new activities and the addition of many outputs derived from the accomplishment of outcomes.

TABLE 4. Indicators' Categories

AREA		Indicator	Unit	Indicator Category
URBAN DEVELOPMENT				
	U1	Intervention Area	[sqm]	Input
	U2	Potential Floor	[sqm]	Input
	U3	Urbanized Street	[km]	Output
	U4	Connected Buildings	[#]	Output
	U5	Fyber Optic	[Km]	Output
	U6	Wifi Points	[#]	Output
	U7	Foreign Direct Invesment	[Eur]	Input
	U8	Real Estate Investment	[Eur]	Input
	U9	Constructed building	[sqm]	Output
	U10	Renovated buildings	[sqm]	Output
	U11	Available floor space	[%]	Output
	U12	New Locations	[sqm]	Input
ECONOMIC DEVELOPMENT				
	E13	Jobs	[#]	Outcome
	E14	Local Workers	[#]	Input
	E15	Companies	[#]	Outcome
	E16	International Companies	[#]	Outcome
	E17	National Companies	[#]	Outcome
	E18	Relocated companies	[#]	Output
	E19	Tax exemptions	[%]	Input
	E20	Public investment in companies	[Eur]	Input
	E21	Private investment in companies	[Eur]	Input

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AREA		Indicator	Unit	Indicator Category
	E22	Turnover all the district	[Eur]	Outcome
	E23	Companies using digital tools	[%]	Output
	E24	Knowledge-based companies	[#]	Outcome
	E25	Companies with quality certification	[#]	Output
	E26	Exporting companies	[%]	Outcome
	E27	Professional Events	[#]	Output
	E28	Incubators	[#]	Output
	E29	Ventures incubated	[#]	Output
	E30	Invesment in Start ups	[Eur]	Output
	E31	Venture Events	[#]	Output
	E32	Start Ups	[#]	Outcome
	E33	Turnover Start Ups	[Eur]	Outcome
	E34	Coworking	[#]	Output
	E35	Freelancers	[#]	Outcome
	E36	Innovation pilots	[#]	Output
	E37	Innovation and tech events	[#]	Output
	E38	Local Events	[#]	Output
	E39	International Events	[#]	Output
	E40	Participation in Local Events	[#]	Output
	E41	Impact in Social Network	[#]	Output
	E42	Publication in Scientific Journals	[#]	Outcome
	E43	Intellectual Property	[#]	Outcome
SOCIAL DEVELOPMENT				
	S44	Citizens	[#]	Outcome
	S45	Research, Tech and Innovation Centers	[#]	Outcome
	S46	Universities	[#]	Input
	S47	Schools	[#]	Input
	S48	Telecenters	[#]	Input
	S49	Students in District Universities	[#]	Input
	S50	Students of Primary and Schools	[#]	Input
	S51	Higher Education Degree	[%]	Output
	S52	International Workers	[%]	Outcome
	S53	Certified Professionals	[%]	Output
	S54	Long Life Learning Programs	[#]	Output
	S55	Students in Long Life Learning Programs	[#]	Output
	S56	Social Activities	[#]	Output
	S57	Persons in Social Events	[#]	Output
	S58	Cultural Activities	[#]	Output
	S59	Cultural Venues	[#]	Output
	S60	Professional Women in the district	[%]	Outcome

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AREA		Indicator	Unit	Indicator Category
	S61	Housing	[#]	Input
GOVERNANCE DEVELOPMENT				
	G62	District Budget	[€]	Input
	G63	District management team Professionals	[#]	Input
	G64	District Organizations associated	[#]	Output
	G65	Professionals in district companies assoc	[#]	Output
	G66	Indicators in Open Data	[#]	Output
	G67	Clusters	[#]	Outcome

Source: Own elaboration.

5. Discussion

The transformation of a district of innovation implies changes in the urban, economic, social and governance dimensions, with a holistic approach between all of them (Piqué, Miralles and Berbegal-Mirabent 2019a). The final result is the convergence of a common agenda in which government, universities, private companies and the society at large, collaborate and find synergies. The consolidation of an AOI implies going through a number of stages, and at each stage (from inception to maturity), the different agents will adopt different roles, get involved in different activities and interact with the other stakeholders differently. Within this context, we posit that identifying key performance indicators to monitor the progress of an AOI is of paramount importance in order to take more informative decisions at each stage and thus, allow policymakers to concentrate on those aspects that lead to successful implementation of the AOI. Using data that covers a 20-years period, in this study we have been able to analyse the case of Porto Digital and provide key insights at each phase of its development. To do so, we have defined a framework of indicators, established at which moment each indicator enters into play, and identified the role played by each of the Triple Helix agents.

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We believe this work will provide new knowledge for researchers and policymakers in order to prioritize actions that will impact the desired goals. In the subsections that follow we dive deeper in the implications that can be drawn from this study.

5.1. Triple Helix Agents

Under the lens of the Triple Helix model, the case examined evidence that triple helix actors play different roles and that the role each agent adopts evolves over time. According to the preponderance of the different actors in each stage of the lifecycle of an AOI, we observed that at the beginning, the government should take a leading role, particularly in urban planning and the development of infrastructures, not only making the location and the amenities surrounding them attractive, but also implementing financial incentives. This shows that the government power of action is preponderant in the urban dimension. The government is also the main driving agent for social development in the initial stages, therefore, actions undertaken should also be directed towards increasing and improving the number of citizens, schools, students and related areas. Concerning the role played by academic institutions (in the specific case under analysis, the University of Recife), the main contribution in the initial stages consisted of provision of the right talent and technology, to make the area attractive. As the AOI evolved, the industry came into play. First, being in charge of the construction of buildings and infrastructure, and later, settling national and international companies in the district and creating jobs. These companies formed clusters of innovation, which in turn, trigged the creation of startups, attracted venture investment, and contributed to corporate innovation and the establishment of a formalized innovative community. Last but not least, the society in PD, as a quadruple helix agent, was in charge of the cultural development and the organising of social events beyond professional life. Involving people was seen as critical to ensuring success,

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therefore, their participation began to be measured, particularly in the third and fourth stages, once opportunities were granted, and also as a strategy to monitor if the planning of housing and services was enough or required further investment to meet demand.

5.2. Evolution phases of the AOIs

At the *inception* stage, the AOI is conceptualized. A first decision is defining the location and what kind of transformation the area will require. According to the stages of AOI model, in the urban dimension the government should lead urban planning, infrastructure, and the foundation of the entity that will manage the district involving key institutions. In this phase, in tune with the theoretical model, the activated indicators reflect that in the case of study, evaluation of activities related to urban planning (indicators U1 and U2) and infrastructures (U3, U4, U5 and U6) commenced. It is important to mention here that the indicators U2 (Potential Floor) and U3 (Urbanized Streets) stopped being measured in the growth phase because the area was fully built, if there had been more space, this parameter would continue to be measured throughout all phases. On the other hand, the indicator that measured the kilometers of fiber optics (U5), was also discontinued in the growth stage, but for a different reason, related to the fact that it became a commodity, and every house was offered fiber optics. Also, the NGPD was created involving the Triple Helix Agents, applying the first budget (G62) and hiring the District Management Team (G63). Additionally, advancing the phase of launching of the AOI Model, PD activities related to the attraction of companies (E15), national (E17) and international (E16) were developed, but from the Growth stage, further census start to consider just companies, and make no differentiation with Multinational or National companies. Furthermore, in confrontation with the AOI model, PD activities linked to generation and development of talent (S46, S47, S49, S50, S51, S54 and S55) were developed. Also, in the case of PD, NGPD started

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promotion of the entrepreneurial ecosystem with creation of startups (E32) that in the AOI's evolution model was introduced in the growth phase. Overall, and after the analysis of this PD case, activities related to talent and startups, as well as social and professional activities could advance the inception stage of the AOI Model. This opens up or facilitates a debate about the importance of the relationship or dependence of the activities (conditions or resources previously required to carry out tasks or projects) over a fixed temporary disposition of each one of them in these promotional and social activities.

The *Launching* phase takes all the guidelines established at the Inception phase and puts them into practice. According to the stages of the AOI model, the district deploys the utilities and starts the activity of the Real Estate, the first tractor companies and research and technology centres are located, and the incubation and landing programs are developed. The PD case coincides in this aspect since the indicators that measure the investment in real estate (U7 and U8) and the construction and renovation of buildings (U9 and U10) are activated in this instance. Besides, anchor institutions (E15, E16, E17 and E18) were landing in the district and Incubators (E28) promoted the activities of startups (E33) and the innovation pilots (E36) that agrees with what the model proposes. In contrast, PD was continuing the talent development (S51 and S53), social and cultural activities (S57 and S59) that do not appear directly in the AOI Model. Also, the first associations of companies in the district started at the launch stage (G64), unlike what is established in the AOI Model, which proposes that these activities begin in the growth phase. It implies that as soon as the district has companies located, the networking could be activated, and the sense of belonging is necessary to be developed by tools as associations. This makes the relationship and dependence between indicators visible again, but not a temporary rigidity in terms of social activities.

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After the AOI has performed well on their KPIs in the Launching phase, the next step is the *Growth* stage. According to the Stages AOI Model, it's the moment of clustering and strengthening communities, while activities related to the urban and economic dimension (creation of startups, attraction of companies and open innovation) continue. In the case of PD, all the effort went into attracting new business and investment, and into boosting business clustering (G67) and networking, which made the indicators that measure the variations of these concepts operational at this stage. The Entrepreneurial ecosystem was growing with the ventures incubated (E29) investment in startupss (E30) and venture events (E31) building the clusters of innovation. A special mention should be made of these indicators (E28, E29, E30 and E31) during the maturity phase, since even when the reports do not continue to record their evolution in the traditional way, and during and after this stage, the data was and is collected through a tool, (now a prototype, that is self-declaratory). PD asks the ecosystem to register and disclosure information, which is then validated. Besides, the technology made possible the competitiveness of the firms and the knowledge-based companies (E23 and E24) and the tech base was boosted by tech events (E37) that are diffusing the research and the intellectual property (E42 and E43). PD started in this phase the involvement of the local residents as workers (E14) and international workers (E52), that the AOI Model is focusing on the maturity stage. A special mention must be made about the measurement of the number of local workers (E14), which began and ended during the growth stage; this situation arose because this measure was carried out through censuses, and these were solved with money from the projects, then, at the end of the associated project, the census was also stopped.

At the Maturity stage, according with the Stages AOI Model, this is the moment of territorial growth, internationalization and growth of companies, and social networks. In the case of PD, new locations (U12) started in the Growth Model. The Internationalization of the District started

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in the launch phase (E39). In the case of PD, in the urban dimension, the district deployed all the floor and infrastructure, and the indicators finalized depending on the fulfilment of the project. In economic development the jobs and companies are performance indicators of the success of the district and the community creation is fully activated (E41). In the social development, the talent of the district is provided by educational institutions and promoting the inclusion of gender in the case of PD (S60), incorporated as a strategic objective, gender equity was not emerging in Porto's strategy before. This conjunctural factor is evidence of the importance of the appropriate incorporation of the indicators over time, since an early measurement of female participation would have allowed for identification of its imbalance and for addressing it earlier on. Paradoxically, the debate of the housing started in the maturity phase (S61). Housing projects were not possible by PD authorities because the area is highly regulated. New projects with the city hall opened opportunities during this stage. Housing and social dimension measures should be included from first phases, as a way of attracting and retaining talent and in order to be a co-author of the unique identity that the district will have, generating commitment and a sense of belonging; measuring these parameters from the beginning would have made it possible to highlight this shortcoming and address it, through inclusion actions, at earlier stages.

5.3. Clusters of Innovation

This study also serves to provide new evidence for the clusters of innovation (COI) theory. From the data collected, it can be concluded that PD is an innovation district that behaves as a COI. If we look at the core components of a COI, they are all covered, with specific indicators to capture their breadth and depth:

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- Major corporations and entrepreneurs are present and active throughout the entire lifecycle. Specifically, major corporations are embedded in a set of indicators in the economic dimension (E15, E16, E17, E18, E24, and E26). Entrepreneurs are measured in startupss related indicators (E24, E29, E32, and E33).

- Venture capital indicators appear since the beginning (launching phase) in the economic dimension. See for instance private investment in companies (E21) and investment in startupss (E30).

Regarding supporting components:

- Universities related indicators are reflected in the social dimension and are measured through a set of indicators which are relevant during the entire life cycle (see indicators S46, S45 and S51).

- Government: the impact of government related activities in the area can be drawn from indicators connected with the area development (urban dimension), such as intervention area (U1), potential floor (U2), urbanized street (U3) and fiber optics (U5), which were relevant in the inception and launching phases. Also, it is related to the economic dimension in terms of tax exemptions (E19), relevant from the launching phase on, and in the governance dimension, particularly in the district budget (G62);

- Supporting professionals, such as lawyers and accountants specialized in entrepreneurial issues, did not find any particular indicator in this particular case.

- Professional managers of startupss appear indirectly in Professionals in district companies associated (G65).

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COIs are also characterized by hybrid components. In the case of PD, these components have materialized as detailed below:

- Research Parks, Tech Parks, Incubators: there are specific indicators to measure the presence of such components, relevant from the launching phase on: Incubators (E28), Coworkings (E34).

- Corporate Venturing Capital (CVC) and Angel investment: the indicators found do not make distinction between private investment (E21) in terms of regular Venture Capital, CVC and Angel investment.

- Public VC: public investment in companies (E20) is measured from the launching phase on, but it includes grants as well, which precludes a more detail information on public VC.

- Service organizations and corporate foundations: there are no measures that capture information about this type of organizations (normally charities and a mix between governments and major corporations) in providing general support to the innovation process.

Finally, COIs embed a series of behaviours among the components. These behaviours are almost all present in PD, and can be captured by some of the indicators included in our framework:

- Entrepreneurial process: innovation pilots (E36), is the only indicator that provides some information on the topic. Although there are indicators related to infrastructures to support entrepreneurship (such as Incubators – E28), indicators to capture more detailed information for this category were not found, such as number of serial

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entrepreneurs, number of failed projects, number of grants approved (and from these the successful ones and the failed ones).

- High mobility of resources: there were no indicators found related to turnover of personnel or any other that disclosed or yielded information on the topic. Success rates of private investment (volume, number, series) and grants awarded could provide more information on the mobility of resources. As regards technology mobility, some indicators such as certified professional (S53), companies using digital tools (E23), companies with quality certifications (E25), and Innovation and Tech events (E37).

- Alignment of interests: although difficult to measure, and does not appear in specific indicator, PD has in its governance (PD Statute), the participation of the different actors in the ecosystem. One measure that would be helpful for the validation of interest, is the variation of the budget allotted by government, industry, and academy for activities to foster PD innovation ecosystem.

- Global perspective: some indicators which provide the interest of the AOI on global engagement were found, such as foreign direct investment (U7), international companies (E16), international events (E39), international workers (S52), all from the launching phase.

- Global linkages: no indicator was found that addresses more formal linkages, such as number of joint international projects, memorandums of understanding with international organizations, soft-landing programmes.

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5.4. Input, process and outcome indicators

When analysing the indicators according to the part of the program to which the indicator can be related and its three main categories (input, output and outcome indicators), the case analysed shows that the indicators that measure outcome, that is, that control that the district reaches its expected effect; they are concentrated in the economic and social dimensions, not registering outcome indicators in the urban and governance domains. Although, the strategic goals are specific to each project and this may vary from one particular case to another, it makes it possible to ask whether in the case of innovation districts, the data and measures related to infrastructures and governance are means to an end (input and output of intermediate projects), but not a goal in itself.

Additionally, also in the case of outcome indicators, measurement should begin before carrying out any activity that modifies the parameters they evaluate, so that it serves as a benchmark for improvement or growth. In the case of PD, there are certain outcome indicators that begin to be active after carrying out actions and projects that modify them (their respective output indicators are activated before), which prevents their growth from being accurately measured.

6. Conclusions

Areas of Innovation (AOIs) need urban, economic, social and governance development (Sarimin and Yigitcanlar 2012, Nikina and Piqué 2016). Building upon the frameworks of Triple Helix, Knowledge-Based Urban Development, Clusters of Innovation, AOIs evolution phases, and the knowledge in Performance Indicators, this study presents a new way of organizing performance indicators of the mission of the AOI activated in different phases of the development transformation. Using the Porto Digital Case in Recife, the most awarded project in Brazil, that has been ongoing for 20 years at a Triple Helix hybrid organization

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(NGPD), a set of performance indicators were defined, classified and analysed in order to understand when they have been activated at every stage of development in the urban economic, social and governance dimension, from inception to maturity, and what Triple Helix agents have been involved in every indicator with the major action power over it.

Four main conclusions emerge from the in-depth study of the case of Porto Digital district of innovation. First, to correctly monitor the progress and development of an AOI, indicators that capture the urban, economic, social and governance transformations that the territory will undergo are needed. Porto Digital is a brownfield transformation that has been developing for 20 years acting in (1) Urban revitalization renewing buildings and preserving historic patrimony, (2) Economic regeneration promoting entrepreneurship and Innovation, and developing Clusters in IT and Media, (3) Social activation with Amenities and activities beyond work, (4) Governance orchestration with an Administrative Council with members of Universities, Industry and Government.

Second, the indicators measure the result of the work in actions developed by Triple Helix Agents individually or collectively. (1) Likewise, Government defining the urban planning, infrastructure, and the new locations. Government also plays a key role providing investment, developing attractiveness of the district, and activating the ecosystem of innovation. Additionally, Government is the one that define the number of citizens that will live in the district and encouraging the location of main institutions. Overall, create the conditions for management and the orchestration of the AOI. (2) The industry acts through the Real Estate investment, through construction of building and the deployment infrastructures. It is also the main party responsible for the occupation, the number and size of companies, adoption of technology and turnover. (3) The University through talent creation and development, scientific

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productions, providing a tech base and research and technological centres, creates the foundations for innovation and scientific development that will also act as a means of attracting and retaining talent.

Third, Indicators are activated in different stages. In the (A) Inception phase, the number of Citizens, Jobs and Companies are important to establishing the boundary conditions on which development of the district will be planned. The Area of Intervention and potential floor are also included and relevant measures for this initial conceptual work definition, which seeks the enrichment of a specific area with the aim of creating an ecosystem of urban innovation, which requires identifying a local context that ensures that talent, technology and capital can flow freely (Etzkowitz and Leydesdorff, 2000). In the (B) Launching phase the number of anchor universities and centres and the tractor companies are essential to promote and drive innovation. Anchor institutions are key links to connect startups and business incubators aligning research interests with business needs (Pique et al. 2019b). Measuring the development of infrastructures makes it possible to guarantee the existence of the necessary structure for the settlement of the first tenants. Innovation pilots, district organizations, cultural activities, public and private investment and the economic impact starts to be measured here, granting a global perspective that fosters the innovative community, elevates its key competencies and allows for interaction with analogous communities. Housing and social dimension should begin to be measured at this stage as a way to guarantee and promote measures that retain talent and attract investment. In the (C) Growing phase, indicators related to the number of knowledge-based companies, number of exporting companies and the square meters of new locations begin to become operatives. The focus here is to attract business and investors promoting business clustering and networking. The indicators that measure the entrepreneurial ecosystem, the internationalization of the talent, and the Companies Clusterization are activated seeking to guarantee the actions

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that will be a source of attraction for innovative and international talent and business. In the (D) Maturity phase, the district deploys all the floor and infrastructure, and the indicators finalized depending on fulfilment of the project. The jobs and companies are performance indicators of the success of the district and the promotion and community creation is fully activated. The talent of the district is provided by educational institutions and promoting the inclusion of gender in the case of PD.

Fourth, being able to distinguish between input, output and outcome indicators allows us to glimpse the impact that the measures that are evaluated have on the general objectives and how they can affect other measurements of related indicators. In the case of PD, the indicators of the urban domain were identified as a means to an end, rather than a goal in itself, and this also conditioned the moments in which the measurements were carried out and generated boundary conditions for the other activities. Measurement of outcome indicators should begin before taking measures that modify the parameters, they assess so that there is a reliable benchmark against which to compare.

This study is not free of limitations, indicators are required for a comprehensive understanding of the dynamics of the PD ecosystem. Although the indicators found do provide a good overview of the AOI ecosystem components, more detailed indicators are needed in order to reveal the actual existence of supporting actors such as supporting professionals, professional managers, and a distinct approach to private investment (CVC, Angel, Public VC). It is also crucial that the AOI understands the behaviours, mainly the dynamics of the entrepreneurial process (for which just one indicator was identified), mobility of resources (personal and funds), the actual commitment of the main actors, and global linkages. Other limitations are that this research has been focused on one case study, in a brownfield transformation and that started 20

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years ago. Future research could analyse other projects in other countries with different starting points (green field and brownfield transformation) and might analyse different AOIs in a comparative base in order to find common indicators in the urban, economic, social and governance dimension and the relationship between them. Other future research could analysis the systemic relationship of the different indicators (input, output, outcomes) and how they impact or modify each other.

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7. ARTICLE III: DEVELOPMENT OF INNOVATION DISTRICTS: A PERFROMANCE ASSESSMENT

Rapetti, C., Pique, J. M., Etzkowitz, H., Miralles, F. and Duran, J. (2023). "Development of Innovation Districts: A Performance Assessment". *Triple Helix Journal*. 1-48

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Development of Innovation Districts: A Performance Assessment

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Abstract

Global challenges demand more competitiveness from cities, calling for quick adaptation to changes brought about by the current knowledge economy. Innovation Districts (ID) stand out as the most favourable ecosystems to create economic, urban, social and governance solutions proactively and at the speed demanded by

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this rapid renewal of knowledge. Effective assessment is important in these areas to ensure efforts are guided to achieve the objectives set. Following validation by a panel of 17 experts through an international Fuzzy Delphi survey, and 15 experts in the DEMATEL multi-criteria decision-making approach, this study builds a conceptual framework in four dimensions (Urban, Economic, Social and Governance), with a set of 37 indicators identified as relevant to assess performance in ID and the power of influences among them. The resulting multidimensional innovation assessment framework is a powerful tool, being useful in determining the key impact indicators of existing innovation districts.

Keywords

Performance Assessment – Indicators – Innovation District – Knowledge Based Urban Development – Triple Helix

1 Introduction

Increasingly, from Marshallian industrial district conceptualisation, derived from the industrial revolution (Bellandi and De Propris, 2015), that focuses on industrial agglomerations, to the knowledge revolution (Chichilnisky, 1998) where human capital is the engine of development, urban development relies on a knowledge-based economy as the means to ensure sustainable growth through urban areas of innovation (Pareja-Eastaway and Pique, 2011) with a holistic perspective to address interrelated social, economic and environmental challenges. Innovation is one of the most important strategies for answering the need for a flexible and all-encompassing environment (Florida, 2002; Pancholi et al., 2015). The literature presents various frameworks used to describe and understand how contextual factors influence the agents' interactions in the innovation process from National Innovation Systems (Lundvall, 1992; Lundvall, 2007; Nelson, 1993; Freeman, 1995) to Regional Innovation Systems (Cooke et al., 1997). Regarding the innovation process in the local dimension, the improvement in the development of a new economy in inner cities has aroused a strong interest (Hutton, 2000; Hutton, 2004), as well as the urban knowledge parks (Bugliarello, 2004) and creative and knowledge cities (Lever, 2002; Florida, 2002; Costa et al., 2008; Pratt, 2008) and knowledge-based urban developments (KBUD) (Carrillo et al., 2014). This last theory (KBUD) argues that cities may become more competitive by working to build their urban, economic, social, and governance pillars together. (Knight, 1995;

Lönnqvist et al., 2014; Sarimin and Yigitcanlar, 2012; Nikina and Pique, 2016). In consequence, in the modern world, metropolitan areas are shaping this idea, where core locations are being supported and reorganized by the emergence of intellectual production that supports the creation of knowledge cities (Yigitcanlar, 2011). All of these tendencies revalue cities and urban environs for quality living, enjoyment and growth that stimulates bottom-up innovation (Esmaeilpoorarabi et al., 2020; Belussi and Caldari, 2009) as a recruitment and retention strategy for the vitally important qualified talent. Therefore, talent is the key resource of these 'knowledge cities', which creates value through innovation, technology and brainpower to advance social, economic and territorial prosperity (Carrillo, 2006).

Innovation Districts (ID), as urban areas of innovation, and their spatial impact on the status quo have been thoroughly studied as well. Researchers have explored how cities adapted to the global economy during the past two decades (Derqui et al., 2020). From general analyses of the development and organisation of inner cities (Sassen, 1991; Sassen, 1998; Sassen, 2002; Knight, 1995; Gospodini, 2006) to more specific topics such as sustainable development (Hall, 1997), health and urban ecosystem (McMichael, 2000), gentrification effects (Atkinson, 2004), competitiveness of cities (Jensen-Butler et al., 1997; Lever, 1999; Strambach, 2002), in addition to urban regeneration policies (Marcotullio, 2003; Atkinson, 2004; Morisson 2020).

Nowadays, ID are becoming increasingly relevant as a way to address these constantly evolving technological concerns. Targeting the development of these urban areas has become crucial for a territory to remain competitive in the innovation economy and achieve sustainable socioeconomic growth (Yigitcanlar et al., 2020). Moreover, ID play an important role as infrastructure for personal networking in the knowledge economy (Landry, 2000). The trends of urban planners to develop ID are balancing between working and living, since ID stimulate forms of knowledge that serve as knowledge centers and attract creative and highly skilled talent. Additionally, ID combine the clusterisation of activities related to science, technology and innovation in urban areas, operating as engines of economic development. Universities, industries and governments promote knowledge-based activities for urban development as innovation districts (Pareja-Eastaway and Pique, 2011). Cities like Barcelona, Melbourne and Singapore are examples of this development (Yigitcanlar, 2011). Furthermore, these kinds of districts are considered geographic areas where leading-edge anchor institutions and company clusters relate to start-ups, business incubators and accelerators. They are also physically compact, transit-accessible and technically wired and offer mixed-use housing, office and retail. ID are the manifestation of mega-trends altering the

location preferences of people and firms and, in the process, re-conceiving the very link between economy shaping, place making and social networking (Katz and Wagner, 2014).

Finally, these multidimensional ID are comprised of a complex web of interconnected elements, including citizens, businesses, transportation, communications, services and other components of an innovation cluster (Engel, 2022), each with their own distinct strengths and weaknesses that must constantly adapt to new situations, posing the ongoing challenge of devising new strategies in accordance with the paradigm of Knowledge-based Urban Development (KBUD) (Yigitcanlar, 2014). Understanding how an ID can develop and improve based on these factors is the first step in achieving its vision and goals, and this can be accomplished by refining its most complex, yet vital link: its strategy. Defining the strategy can assist in determining where and when to invest, in deciding what integration and optimisation timeline across all components and operations is required, and in identifying new growth and development prospects.

Evaluating the primary components and activities of an ID is the first step in designing a strategy for sustainable success (Caird et al., 2016), and developing a set of associated indicators is the appropriate activity for this purpose. Indicators represent the changes and progress made by an ID towards accomplishing a particular goal activity (Dameri, 2017). Therefore, it is crucial that the elements analysed are closely related to the primary activities aimed at achieving particular objectives.

Previous research has been conducted on the concept of indicators in innovation districts. However, such research focuses on more initial aspects of the field such as: classification (Yigitcanlar et al., 2020; Adu-McVie et al., 2021), which proposes a set of conceptual attributes to classify ID through a three-prong framework that includes: classification by function, highlighting the key functions of ID; classification by feature, pointing out the common features of innovation districts; and classification by space-use, focusing on the plans, design and development of ID.

Another view is studied by (Esmaeilpoorarabi et al., 2018a; Esmaeilpoorarabi et al., 2018b), which analyses the most favourable aspects to guarantee assertive emplacement selection of the districts, and propose five areas of study: Context Indicators, Form Indicators, Function Indicators, Image Indicators and Ambience Indicators.

Complementary studies recommend investigation of a singular feature of performance such as well-being (Orii et al., 2020) or particular activities in the district development such as transport (Truong and Ta, 2020). But lacking to date in the research literature is a holistic framework for analysing the performance indicators in all the dimensions of an innovation district.

To answer the research question that analyses how ID can be assessed in their performance, the present research seeks first, to propose a validated and comprehensive framework to assess performance through indicators in innovation districts. Second, to find the level of influence between the indicators allowing this to have a broad vision of all the dimensions and actors required for the development of these areas, to facilitate the decision-making process. The set of indicators proposed is formed by four dimensions (Urban, Economic, Social and Governance) and three agents (Academia, Industry and Government), based on Knowledge Based Urban Development and Triple Helix theories; and drawing on key sources: first, the literature review in performance indicators in ID; second, completed with two case studies of innovation districts that are international references: 22@Barcelona in Spain and Porto Digital in Brazil; and finally, confronted by the IASP's Global Survey 2018 to confirm that these measurable aspects are also valuable to practitioners. Then, a validation of the set of indicators that compound this framework is performed implementing the Fuzzy Delphi Method which is suitable for topics where there is little previous research or information, and consulting expert opinion is required to properly validate the hypotheses.

After the selection of the most relevant key performance indicators (KPIs), the DEMATEL approach is applied to this set, to identify the level of influence of one indicator over another. Similarly to the Fuzzy Delphi methodology, consulting expert opinion is required to properly set the level of power of one indicator over another.

Following on from the present introduction, section 2 presents the literature background and section 3 the two methodologies employed, and data required to validate the framework and to establish the relationships. Section 4 presents the findings obtained from the consultation of experts, the set of indicators selected and their influences. Section 5 discusses the main indicators that were accepted and the interaction between them established by the panels of experts for each dimension and the role of the Triple Helix Agents. Section 6 describes the main contributions of this work together with concluding remarks.

2 Literature Background

At the beginning of the 20th century, Alfred Marshall introduced the term 'Industrial District' in his article 'The Principles of Economics', seeking to describe some aspects of the industrial organisation of nations (Marshall, 1920). Then, Walter Isard conceptualised industrial complexes as potential building blocks for the industrialisation of post-war progress of nations (Isard,

1959; Isard, 1960). Later, Stan Czamanski began using the concept of industrial clusters (Czamanski and Augusto de Q. Ablas, 1979), and Giacomo Becattini, following Marshall's concept of industrial districts, explained the industrialisation of the Italian region of Tuscany and offered the first formal articulation of the concept (Becattini, 1962). Finally, Michael Porter developed a comprehensive notion of industrial clusters to define the spatial concentrations of industries in a group of nations he examined.

In the 1990s, capitalist nations began their economic transition to post-Fordist or knowledge-based economies (Amin, 1994) (Drucker, 1998). In this transition, cities were identified as the platforms to generate technical innovation (Castells, 1989; Florida et al., 2017). In this context, the concept of an ID in cities is derived from territorial innovation models such as the regional innovation system (Cooke and Morgan, 1994; Cooke, 2001), learning region (Morgan, 1997), innovative milieu (Aydalot and Keeble, 1988; Camagni, 1995) (Maillat, 1991; Maillat, 1998), cluster (Porter, 1990; Porter, 1998), industrial district (Becattini, 2004), and knowledge-based urban economy (Knight, 1995), which all emphasise the significance of the spatial dimension of innovation.

Storper and Venables (2004) highlight the importance of face-to-face interactions, co-presence and co-location of individuals and enterprises within the same sector, locality or region, which facilitates knowledge spill-overs and the flow of tacit information in innovation ecosystems (Storper and Venables, 2004). Indeed, information may be exchanged through serendipitous interactions and cognitive heterogeneity, both of which are more prevalent in dense urban districts (Jacobs, 1961).

To remain relevant, urban strategies have had to adapt to new technology and socioeconomic models. Technological developments, particularly revolutionary and disruptive ones, have a substantial impact on urban planning and urban policies (Hall, 1997). Urban economic development best practices evolved in the late 1990s from suburban green-field initiatives to urban rehabilitation projects (Smith, 2002). The aims of urban planning in the knowledge economy are to promote variety of uses of the land, densification, new facilities, preservation of historic buildings and sustainable infrastructures, in order to increase the urban competitiveness while promoting quality of life (Pareja-Eastaway and Pique, 2011).

From the 1960s to the 1990s, local and regional governments developed technology parks in suburban areas, out of the cities, such as Sophia-Antipolis in France or the Research Triangle Park in North Carolina. However, since the 2000s, innovation-driven developments have been urban developments involving the Triple Helix Agents (government, universities and industry).

Since innovation is considered as one of the most crucial factors for competitiveness and success, urban plans increasingly involve initiatives to attract innovative companies and creative talent. Technological advancements launched the paradigm shift from mass production to knowledge-based production, which has profoundly altered socioeconomic systems. The transition to a knowledge-based economy is eliminating the barriers that formerly divided innovation from production, the laboratory from the factory, and is reorganising the whole production system. Alongside a technological paradigm shift that favours knowledge-based activities for economic growth, there is a preference shift from suburban working to urban working and living.

In order to enhance economic competitiveness, regional and municipal policymakers are developing measures to promote the shift from mass manufacturing to the knowledge economy and from the suburbs to the interior of the cities. Consequently, ID reflect how innovation is developed in urban areas.

Urban areas are the centres for economic and social development, and knowledge is a key factor driving city development. ID are the sites of one kind of knowledge precincts (Carrillo, 2006), that allow development of knowledge communities. The knowledge-based economy is decisive for urban spatial transformation like ID (Powell and Snellman, 2004). ID are the result of the contribution of Government, Industry and Universities to the urban, economic and social transformation (Pique et al., 2019) with different levels of leadership in the evolution of the ID. ID have become the localities of 'knowledge community precincts' (Carrillo, 2006), that is, spaces for knowledge generation and places for knowledge communities.

There are different types of innovation districts according to their purpose and the geographical context in which they are circumscribed. This study, following the analysis carried out by (Yigitcanlar et al., 2020), will include under the scope of "Innovation Districts", terms such as "knowledge and innovation spaces", 'innovation clusters' (Huggins, 2008), 'innovation milieu' (Evans and Hutton, 2009), "knowledge (community) precincts", "innovation precincts" (Esmaeilpoorarabi et al., 2017), "Technopole" (Caves, 2013), and "Area of Innovation" (IASP, 2022) (International Association of Science Parks).

2.1 *Knowledge-Based Urban Development*

In 1995, Richard Knight argued the need for a new approach to explain the development of cities given the knowledge-based development of Innovation Districts. He defined Knowledge-Based Urban Development (KBUD) as "the transformation of knowledge resources into local development" (Knight, 1995: 225–226). Accordingly, (Sarimin and Yigitcanlar, 2012) included four

dimensions in the KBUD: (1) Social and cultural development (e.g. housing, community facilities, education, social capital and knowledge workers); (2) economic development (e.g. RandD centres, knowledge-based companies and start-ups), (3) environment and urban development (e.g. green areas, green infrastructures – mobility, energy, waste, water – and green building); and (4) governance development (e.g. public and/or private bodies that manage urban transformation and the process of citizen participation).

Researchers have identified knowledge and creative talent, universities, IT infrastructures, real estate development and citizen decision-making as essential knowledge assets for cities of knowledge. Universities and research centres are critical assets for these knowledge cities as they are the backbone of a knowledge-based economy. In broader terms, knowledge assets in ID might also be considered the combination of both hard (tangible) and soft (intangible) assets.

In the urban development context, assets are defined as attributes of ID (Velibeyoglu and Yigitcanlar, 2010). Managing both the tangible (i.e., physical infrastructure and buildings such as transport, property and utilities) and intangible assets (i.e., knowledge, collaboration and creativity) contributes to the competitiveness of ID.

Pique et al. (2019) argue that ID need urban, economic and social transformation. Urban regeneration needs an integral approach, including (1) the infrastructure and urban dimension, (2) businesses and economic dimension, (3) talent and social dimension, and (4) governance dimension (Pique et al., 2019). For the Urban transformation each project needs: (1) an urban plan, (2) an infrastructure plan, and (3) a legal framework that allows the use of land for knowledge-based activities, and the attraction of real estate investors for retrofitting old buildings and creating new office and public spaces. As regards Economic transformation, ID need smart specialisations. This implies selecting (1) what sectors (clusters) to be developed and (2) what agenda range of technologies is needed for the value chains of innovation. For Social transformation: Talent is a key asset of the knowledge-based economy and society. Innovation districts must develop a strategy for talent (1) creation, (2) development, (3) attraction and (4) retention, and for providing enjoyable spaces in which to live and work. For Governance: The Triple Helix Agents play a key role in transformation and should create (1) hybrid organisations (public private partnership platforms) in order to (2) share the vision for the innovation district, and to (3) add actions to be developed across all dimensions of the project.

The present research focuses on urban areas. Urban area is here understood as a highly developed spatial form of cohesive cities. This phenomenon occurs

when the associations of the Triple Helix Agents inside cities move from mainly competition to both competition and cooperation. Cities are highly integrated within an urban agglomeration, which renders the agglomeration one of the most important carriers for global economic development (Fang and Yu, 2017). The nature of cities as urbanised spaces can be traced back to the work of (Weber, 1958), whereby two aspects of the city are crucial, namely the economic and the political organisation. Economically defined, the "city is a settlement the inhabitants of which live primarily off trade and commerce rather than agriculture … the city is a marketplace" (Weber, 1958: 66–67). As regards the political dimension, "the city must … be considered to be a partially autonomous association, a community with special political and administrative arrangements" (1958: 74).

2.2 *The Triple Helix Model*

The Triple Helix model (Etzkowitz and Leydesdorff, 2000) describes that ecosystems of innovation are composed of three types of agents (1) Universities and Research Centres as a source of talent and technology for companies, (2) Industry combining mature companies with start-ups and investors, to create economic value, and (3) Government at different levels from local to regional and national developing legal frameworks, taxation and policy making, all of which stimulates research and innovation.

The university is a key infrastructure for innovation, providing trained talent, research results and knowledge to industry. Also, academia is a source of new ventures, founded on entrepreneurs and technologies originated at the university.

The role of each agent of the Triple Helix model (Government, Universities and Industry) is different depending on the dimension of the transformation (Pique et al., 2019). Government, at local, regional (state) and national (federal) levels plays a key role in transformation. Within the urban dimension, it defines the uses of land, the infrastructure plan, green spaces, and incentives for real-estate developers. Within the economic dimension it invests in research and technology, works to attract companies and promotes the creation of new start-ups and clusters, and creates conditions for pilots. Within the social dimension, it creates the conditions for living and working, including housing and schools. University is the key source of talent and technology and has far reaching impact across all dimensions. Within the urban dimension, universities develop land and buildings as anchor institutions (for research, teaching, incubation and residences). In the economic dimension, they provide science, technology, labs and entrepreneurs to the ecosystem. In the social dimension, they provide fresh talent to the district and experienced staff that will

live in the district. Industry represents all the companies – of different sizes and sectors – in the area. In the urban dimension, the real estate companies develop and build new buildings and retrofit old ones for new proposals; utilities companies provide the key infrastructures; end users use the buildings and provide the return of investment. In the economic transformation dimension, large corporations, SMEs and new start-ups are clustered with universities and institutions, creating jobs and turnover. Lastly, in the social dimension, industry supplies the district with professionals and talent by means of internships and job creation. Thus, as noted by (Cai and Etzkowitz, 2020), despite positive progress in terms of theoretical underpinnings of the Triple Helix model, its explanatory power still has room for improvement through meso-level theories that have the capacity to connect both the macro and micro levels of analysis. When it comes to the coordination for developing the Triple Helix interactions, the core is to enable functional mechanisms mediating between top-down and bottom-up initiatives. In this way the innovation district development provides the context where we can examine these mechanisms.

The Quadruple Helix can add a fourth sphere, that is, the public and larger society (Carayannis and Campbell 2009). By acknowledging the role of the public in using, applying and generating knowledge, this formulation is conducive to the democratisation of knowledge production and innovation, as well as the impact of culture and creativity. Culture encompasses both diversity in terms of values, lifestyles and multiculturalism, and in terms of multilevel local, regional, national and global approaches. This diversity promotes creativity, a key component in spurring innovation and knowledge (Nikina and Pique, 2016).

As another driver of innovation, the Quintuple Helix adds the natural environment as a fifth sphere for knowledge and innovation models (Carayannis et al., 2012), thereby positioning sustainable development and social ecology as a component equivalent to the other four helices for knowledge production and innovation. Since socioecological concerns are incorporated as a key driver of innovation, this model is aimed at supporting the development of innovations and facilitating problem solving and sustainable development, while informed by multilateral interactions with the four other helices (Nikina and Pique, 2016).

In summary, the Triple Helix model of university-industry-government relations serves as both an illustration of and a roadmap for moving from linear knowledge flows to non-linear and interactive modes of innovation. The Quadruple Helix incorporates the viewpoints of civil society and media and culture-based publics while the ecologically sensitive Quintuple Helix adds the perspective of the natural environment.

The Triple Helix model has already been used for developing ecosystems of innovation. This paper aims to explore the role of the three agents in the performance indicators of urban, economic, social and governance factors of Innovation Districts. Accordingly, posit that a shared commitment to social responsibilities and sustainable goals helps align the interests and goals of Triple Helix actors. In doing so, civic engagement is crucial. The activation of a Triple Helix requires leadership by persons and organisations who have the respect of all the key players, with a recognition that the leadership role can move from one actor to another during their interaction.

Another approach of Triple Helix is proposed by (Ranga and Etzkowitz, 2013), defining the Triple Helix Spaces to characterise the proper areas of the Triple Helix actors to develop their functions: the knowledge space, innovation space and consensus space. It will help to understand the role of the Triple Helix Agent in the development of the innovation district.

3 Method and Data

This study starts with the multidimensional framework based on 4 dimensions (Table 1). The list of indicators is derived from:

a. A systematic review of scientific journal publications of the terms: 'indicator' and 'performance assessment'. Developing the study with the keywords supplied in the theoretical framework section for innovation districts ('Innovation Districts', 'District of Innovation', 'knowledge and innovation spaces', 'innovation clusters', 'innovation milieu', 'knowledge (community) precincts', 'innovation precincts', 'Technopole', 'Area of Innovation').
b. Enriching this initial list with two articles that analyse two international case studies (22@Barcelona in Spain (Rapetti et al., 2022a) and Porto Digital in Brazil (Rapetti et al., 2022b)) that already provide indicators used in these cases.

This information was consolidated based on the above-mentioned sources and confronted by the IASP's annual report (IASP Global Survey, 2018) to confirm that the measuring aspects proposed by research are also acknowledged as advantageous by practitioners.

Table 1 summarises the preliminary set of indicators.

The elements proposed in Table 1 are the potential main attributes for building a comprehensive framework to assess performance in Innovation Districts.

TABLE 1 Multidimensional Performance Indicators Framework (Initial)

Nº	Area	Indicator	Unit	Description
	URBAN			
1	U1	Intervention Area	sqm	Intervention surface: total area in which a modification of the urban space can been carried out
2	U2	Potential Floor	sqm	Constructive potential: square metres that can be built.
3	U3	Urbanised Street	sqm	Square metres paved.
4	U4	Connected Buildings	#	Number of buildings that are connected to the internet
5	U5	Optical Fibre	Km	Kilometres of fibre optic cables
6	U6	Wi-Fi Points	#	Number of Wi-Fi coverage points
7	U7	Foreign Direct Investment	Eur/year	Investment received by foreign organisations
8	U8	Real Estate Investment	Eur/year	Investment in real estate
9	U9	Constructed Buildings	sqm	Square metres of buildings constructed in the district
10	U10	Renovated Buildings	sqm	Square metres of buildings that have been restored or rehabilitated
11	U11	Available Floor Space	%	Percentage of square metres available for offices
12	U12	New Locations	sqm/year	Number of square metres that the district expands per year
13	U13	Green Zones	%	Percentage of square metres of stationary or floating districts created by the local government to promote sustainable practices, to help reduce environmental impacts, and to help revitalise an area
14	U14	New Facilities	sqm	Square metres of spaces or buildings dedicated to special activities for the community (Hospitals, Schools, Business Incubator, etc.)
15	U15	Occupancy Rate	%	Percentage of square metres that are occupied or rented

TABLE 1 Multidimensional Performance Indicators Framework (*cont.*)

Nº	Area	Indicator	Unit	Description
16	U16	Construction Implementation Degree	%	How much have been achieved, in terms of construction implementation, with respect to the objectives set
	ECONOMIC			
17	E1	Jobs	#	Number of jobs available in the district
18	E2	Local Workers	#	Number of local people working in the district
19	E3	Companies	#	Number of companies located within the district
20	E4	International Companies	%	Percentage of international companies located in the district
21	E5	National Companies	%	Percentage of national companies located within the district
22	E6	Relocated Companies	#/Year	How many companies have been attracted, and therefore, relocated a year?
23	E7	Tax Exemptions	%	Percentage of discounts as tax incentives for companies located in the district
24	E8	Public Investment in Companies	Eur	Amount of public money invested in companies within the district
25	E9	Private Investment in Companies	Eur	Amount of private money invested in companies within the district
26	E10	Turnover of the District	Eur/Year	Amount of money taken by a business in a particular period
27	E11	Companies Using Digital Tools	%	Percentage of companies that use digital tools (Business Competitiveness (Use of ICTs))
28	E12	Knowledge-based Companies	#	Companies with a higher share of knowledge for production of goods and services compared to other factors. According to one definition, a knowledge-based company is an organisation with a minimum of 75% of its assets in intangible form.

TABLE 1 Multidimensional Performance Indicators Framework (*cont.*)

Nº	Area	Indicator	Unit	Description
29	E13	Companies with Quality Certification	#	Number of companies with quality certification
30	E14	Exporting Companies	%	Percentage of companies that export products
31	E15	Professional Events	#/Year	Number of business events held per year
32	E16	Incubators	#	Number of incubators in the district
33	E17	Ventures Incubated	#	Number of ventures incubated
34	E18	Investment in Start-ups	Eur/Year	Amount of euros invested per year for the development of start-ups
35	E19	Start-ups	#/year	How many start-ups does the district create per year
36	E20	Turnover Start-ups	Eur/year	Euros billed by companies annually
37	E21	Co-working	#	Number of collaborative workspaces
38	E22	Freelancers	#	Number of freelance workers
39	E23	Innovation Pilots	#	Number of innovation projects generated
40	E24	Innovation and Tech Events	#	Number of innovation and tech events
41	E25	Local Events	#	Number of local events to promote and publicise the district
42	E26	International Events	#	Number of international events to promote and publicise the district
43	E27	Participation in Local Events	#	Number of people participating in internal events
44	E28	Impact in Social Network	#	Number of views or interactions with posts about the district on social media
45	E29	Publication in Scientific Journals	#	Number of scientific articles published
46	E30	Intellectual Property	#	Number of patents registered by district organisations
47	E31	Clusterisation of Companies	#	Number of clustered companies
48	E32	Companies Clusterisation Type	-	Types of existing clusters

TABLE 1 Multidimensional Performance Indicators Framework (*cont.*)

Nº	Area	Indicator	Unit	Description
	SOCIAL			
49	S1	Citizens	#	Number of inhabitants in the district
50	S2	Research, Tech and Innovation Centres	#	Number of Research, Tech, and Innovation Centres in the district
51	S3	Universities	#	Number of university centres in the district
52	S4	Schools	#	Number of schools in the district
53	S5	TeleCentres	#	Number of connectivity centres (TeleCentres/InfoCentres)
54	S6	Students in District Universities	#	Number of students in universities in the district
55	S7	Number of School Students	#	Number of students of primary and secondary schools
56	S8	Higher Education Degree	%	Percentage of workers with university education
57	S9	International Workers	%	Percentage of international workers in the district
58	S10	Certified Professionals	%	Percentage of professionals certified
59	S11	Long-life Learning Programmes	#	Number of long-life learning programmes
60	S12	Students in Long-life Learning Programmes	#	Number of students in long life learning programmes
61	S13	Social Activities	#	Number of activities and social projects
62	S14	Persons in Social Events	#	Number of persons that participate in social events
63	S15	Cultural Activities	#/Year	Number of cultural activities
64	S16	Cultural Venues	#	Number of cultural and sports establishments
65	S17	Professional Women in the District	%	Percentage of professional women in the district
66	S18	Housing	#	Number of houses in the district
67	S19	Jobs Vocation	#	Number of people who have used the district portals to promote their vocation
68	S20	Internships	#	Number of people doing internships.

TABLE 1 Multidimensional Performance Indicators Framework (*cont.*)

Nº	Area	Indicator	Unit	Description
	GOVERNANCE			
69	G1	District Budget	€/year	Budget of the organisation in charge of the district
70	G2	District Management Team Professionals	#	Number of professionals in the district management team
71	G3	Professionals in District Companies Associations	#	Number of professionals of the companies associated at the district association
72	G4	Indicators in Open Data	#	Number of indicators in open data

A Fuzzy Delphi methodology was implemented to validate the relevance of the indicators proposed in Table 1. Seventeen experts in the field of Innovation Districts with multidisciplinary backgrounds from America, Europe, Asia and Africa were consulted to validate the most suitable attributes, represented by indicators, to define this framework.

The rationale for employing Fuzzy Delphi study as the corroboration method for the proposed performance attributes is as follows. First, there is limited empirical research on investigating and developing a holistic performance assessment framework for Innovation Districts. Second, the Fuzzy Delphi study is suitable for circumstances where there is limited resources and documents (Ruppert and Duncan, 2017). The Fuzzy Delphi method has proven to have accuracy levels comparable with the traditional Delphi method, even when rounds with experts are reduced to one by introducing the Fuzzy Set algorithm in the process.

After the selection of the best KPIs obtained by Fuzzy Delphi method, Multi-Criteria Decision Making (MCDM) DEMATEL was implemented to establish the level of influence among the indicators and to be able to predict how a measure taken in one indicator could affect another, helping the decision-making process. This methodology proposes one initial matrix, built up by the (n) indicators selected in the previous (Fuzzy Delphi) step and their relationships. And then facilitates the determination of the indicators that act as cause and the ones that are effect. Cause indicators directly influence effect indicators where the relationship established is strong.

The rationale for employing DEMATEL as the multi-criteria decision-making method is as follows. First, it effectively analyses the mutual influences (both direct and indirect effects) among different factors and understands the complex cause and effect relationships in the decision-making problem. Second, it can visualise the interrelationships between factors via an IRM (influential relationship map) and enable the decision maker to clearly understand which factors have mutual influences on one another. And third, the DEMATEL can be used not only to determine the ranking of alternatives, but also to find out critical evaluation criteria and measure the weights of evaluation criteria (Sheng-Li et al., 2018).

3.1 *Fuzzy Delphi*

3.1.1 Fuzzy Delphi Introduction

The Delphi method (DM) is a qualitative technique used to collect opinions of a panel of experts about a subject on which there is sparse scientific research to date. It was originally conceived in the 1950s by Olaf Helmer and Norman Dalkey of the Rand Corporation. This method allows forecasting by converging a possibility value through the feedback mechanism of questionnaire results, based on experts' judgements. Some limitations of this methodology lie in: (1) Two or more repetitive surveys are likely to cause a decline in the response rate, which may produce negative effects in the ensuing analyses. (2) In general, as it is repeated, the survey becomes more costly and time-consuming (Ishikawa et al., 1993).

The Fuzzy Delphi Method (FDM) is the upgraded version of the classic DM. Improvement was made to rectify the limitation of the traditional DM that leads to low convergence in retrieving outcomes, and long progress of investigation (Saffie et al., 2016). Ishikawa and Bojadziev developed an algorithm whereby the introduction of Fuzzy Sets reduces the number of iterations to one, and the level of accuracy remains comparable with that obtained through traditional DM, which also reduces the time and cost of the process and the desertion of the experts in the survey, compared with those requiring more than one round (Ishikawa et al., 1993; Bojadziev and Bojadziev, 1999).

3.1.2 Fuzzy Delphi Description

The Fuzzy Delphi technique is based on the theory of fuzzy sets. Fuzzy sets theory is an extension of classical set theory that proposes that elements have varying degrees of membership. A logic based on two truth values is sometimes insufficient when describing human reasoning. Fuzzy Logic uses the whole interval between 0 (false) and 1 (true) to describe human reasoning.

A Fuzzy Set is any set that allows its members to have different degrees of membership, called membership function, having an interval of [0,1].

If A is a universal set, then a fuzzy set of A is defined by triangular Membership Function $\int\alpha$ as follows: $\int\alpha(x) \to [0, 1]$, $\forall x \epsilon A$. (Zhao and Bose, 2002) compared the response of the system with various Membership Functions (MF) and found that the triangular MF is superior to any other MFs.)

$$\int\alpha = \begin{cases} \dfrac{x-p}{q-p}, p \le x \le q \\ \dfrac{r-x}{r-q}, q \le x \le r \\ 0 \end{cases} \quad (1)$$

Where p, q and r are the triangular fuzzy numbers (TFNs) and represented as (p, q, r) (Singh and Sarkar, 2020).

The FDM proposes the definition of a linguistic scale for a better understanding of the scores assigned to every value analysed or question performed, and a set of three fuzzy numbers is associated with each linguistic option. The questionnaire with the linguistic options is then passed to the experts who provide their linguistic scale answers as shown in Table 2. The level of relevance of each indicator to assess performance in Innovation Districts is investigated by means of this linguistic scale.

TABLE 2 Linguistic scale and Fuzzy Delphi number sets associated

Fuzzy Delphi Linguistic Scale	**Fuzzy Delphi Number**
1. Extremely unimportant	(0,1; 0,1; 0,3)
2. Unimportant	(0,1; 0,3; 0,5)
3. Normal	(0,3; 0,5; 0,7)
4. Important	(0,5; 0,7; 0,9)
5. Extremely important	(0,7; 0,9; 0,9)

SOURCE: (SINGH AND SARKAR, 2020)

The processing of the linguistic responses and information gathered through consultation with experts is carried out in three stages:

Stage 1: Input of experts for each indicator is translated into fuzzy numbers. A fuzzy number related to the j_{th} indicator provided by expert n is expressed as follow:

$$I_{ij} = (p_{ij}; q_{ij}; r_{ij}) \text{ for i = 1, 2, 3,. ... n and j = 1, 2, 3,. ... m.} \quad (2)$$

Where n represents the number of the expert and m is the number of the indicator.

Stage 2: The fuzzy weights of indicator ρj are assigned as follows: ρj = (pj; qj, rj) where

$$pj = \max(rij) \text{ where i = 1, 2, 3, ... n and j = 1, 2, 3, ... m.} \quad (3)$$

$$q_j = \left(\prod_{i=1}^{n} (q_{ij})\right)^{1/n} \quad (4)$$

$$rj = \text{mín (Fuzzy-1)}(rij) \text{ where i = 1, 2, 3, ... n and j = 1, 2, 3, ... m.} \quad (5)$$

$rj = \max(r_{ij})$ where i = 1, 2, 3, ... n and j = 1, 2, 3, ... m.

Stage 3: The mean method is implemented to defuzzificate the value S_j as follows:

$$S_j = \frac{\left(p_j + q_j + r_j\right)}{3}, \text{ j = 1, 2, 3, ... m.} \quad (6)$$

Finally, a cut off number is defined to indicate the point from which the indicators are accepted or rejected as relevant to assess performance in innovation areas.

A diagram of the complete methodological process is presented in Figure 1.

3.1.3 Fuzzy Delphi Experts Panel

A total of 30 experts in the field of Innovation Districts from Europe, America, Asia and Africa were contacted. Out of these 30 experts, 17 agreed to participate. All of them have or have had a leading role in Innovation Districts – leading role here being understood as Director, CEO or President, as well as having solid experience in the field. Backgrounds such as Innovation Systems, Urban and Economic Development, Engineering, Academia and Sociology were included among the experts consulted. Demographic information on the panel of experts is provided in Table 3.

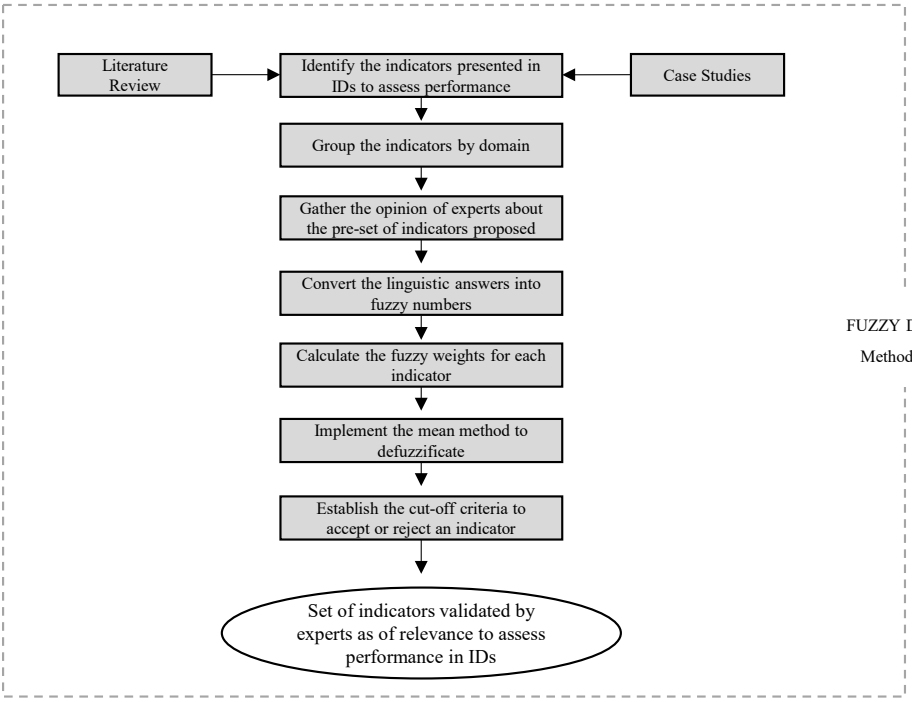

FIGURE 1 Fuzzy Delphi Methodological Process

TABLE 3 Fuzzy Delphi Panel of experts' demographic information

Expert	Highest position	Education	Country	Experience (Years)
Expert 1	President	B. of Commerce	USA	27
Expert 2	General Director	PhD Engineering	Mexico	40
Expert 3	Director	PhD Biology	Uruguay	10
Expert 4	Board Member	PliD City' Competitiveness	Spain	13
Expert 5	President	PliD Sociology'	Spain	16
Expert 6	Deputy-Director	B. Economics	Spain	24
Expert 7	President	B. Political Science	USA	17
Expert 8	Technology Transfer Officer	Engineering	Germany	12
Expert 9	CEO	MBA	Kenya	7
Expert 10	CEO	PhD Maths	France	23
Expert 11	Innovation Manager	M. Innovation	Canada	12

TABLE 3 Fuzzy Delphi Panel of experts' demographic information (*cont.*)

Expert	Highest position	Education	Country	Experience (Years)
Expert 12	CEO	MBA	Denmark	12
Expert 13	Director	M. Engineering	Brazil	25
Expert 14	CEO	MBA	UK	10
Expert 15	CEO	B. Sociology	Spain	24
Expert 16	General Director	M. Urbanism	France	11
Expert 17	President	Engineering	South Korea	15

3.2 *DEMATEL*

3.2.1 DEMATEL Introduction

The Geneva Research Centre of the Battelle Memorial Institute created the Decision-Making Trial and Evaluation Laboratory (DEMATEL) technique to depict the structure of complex causal interactions using matrices or digraphs (Sheng-Li et al., 2018). The DEMATEL technique can not only demonstrate the interaction between criteria, but also the direction of the relationship (Kumar and Dash, 2016).

This methodology has been used in a variety of settings, including marketing strategies, control systems, safety issues problems (Liou et al., 2008), the development of global managers' competences, and group decision (Wu et al., 2010). Hybrid models that combine the DEMATEL and other methodologies have also been widely employed in a variety of domains, including e-learning evaluation (Tzeng et al., 2007), aviation safety measurement, and innovation policy portfolios (Hsuan-Shih et al., 2013). The advantages of the DEMATEL method are as follows: i) it is based on graph theory and simplifies the analysis of difficult problems through the use of a visualisation method; ii) it develops cause and effect relationships among different factors, making it easy to understand the mutual influence of the factors; and iii) this method can determine the strength of the relationships between or among the factors, which is not possible in other multi-criteria decision-making methods (Prashant et al., 2020).

3.2.2 DEMATEL Description

With an initial direct relation matrix, DEMATEL models the influences of system components. Influences from one component can spread to other components in a transitive manner, which is represented by elevating the initial

TABLE 4 DEMATEL linguistic scale

Dematel linguistic scale	Score
1. No influence	0
2. Low influence	1
3. Medium influence	2
4. High influence	3
5. Very high influence	4

SOURCE: (SINGH & SARKAR, 2020)

direct relation matrix to powers. The overall influence is calculated by adding matrices of all powers and assuming that the matrix raised to the power of infinity will converge to zero.

The stages required in this method are described as follows:

Stage 1: The relationship matrices are built with the opinions of the experts. A panel of experts, with years of experience in the field of research, is consulted on the level of relationship between each indicator, using a linguistic scale presented in Table 4 to qualify the answers.

A non-negative matrix of the order of n x n as $x^k = [x_{ij}^k]$ where k indicates the number of experts with $1 \leq k \leq H$, and n indicates the number of indicators.

Stage 2: The Average Matrix A is constructed with the inputs of all the experts and can be established as follow:

$$A = [a_{ij}] = \frac{1}{H} \sum_{k=1}^{H} x_{ij}^k \tag{7}$$

Where k indicates the kth expert and H represents the total number of experts.

Stage 3: Matrix Average Matrix A is normalised to conform the matrix D:

$$D = m \times A \tag{8}$$

where

$$m = mín \left[\frac{1}{maxi \sum_{i=1}^{n} a_{ij}}; \frac{1}{maxj \sum_{j=1}^{n} a_{ij}} \right] \quad i, j \in \{1,2,3, \ldots m\} \tag{9}$$

And D must have the sum of each of its columns lower than 1 to be eligible for the DEMATEL technique (Kumar et al., 2017).

Stage 4: Calculate the Total Relationship Matrix (T)

$$\boldsymbol{T} = \boldsymbol{D}(\boldsymbol{I} - \boldsymbol{D})^{-1} \tag{10}$$

where I represents the Identity matrix.

Stage 5: Compute the factors r and c that will allow to establish cause and effect indicators as follows:

$$\boldsymbol{r} = \left[\boldsymbol{r}_i\right]_{nx1} = \left[\sum_{j=1}^{n} \boldsymbol{t}_{ij}\right]_{nx1} \tag{11}$$

$$\boldsymbol{c} = \left[\boldsymbol{c}_i\right]_{1xn} = \left[\sum_{i=1}^{n} \boldsymbol{t}_{ij}\right]_{1xn} \tag{12}$$

Prominence = (r + c) and Relation = (r – c) for each indicator. Indicators that have a Relation number greater than 0 are considered cause factors, and indicators with a Relation number lower than 0 are considered effect factors. Cause indicators directly influence effect indicators where the relationship is strong.

Stage 6: A threshold number (α) is established to exclude minor effects.

$$\alpha = \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} \left[\boldsymbol{t}_{ij}\right]}{\boldsymbol{N}} \tag{13}$$

Where N is the number of elements in matrix T.

The coefficients in the Total Relationship Matrix (T) which are higher than the threshold number compound a sub-matrix that represents the strongest relationships between indicators.

A diagram of the complete methodological processes is presented in Figure 2.

3.2.3 DEMATEL Experts Panel

Out of the 17 experts who took part in the Fuzzy Delphi consultation, 8 were able to participate in the DEMATEL round. In addition, the invitation was extended to 7 more experts in the field of study, using the same criteria of selecting people with relevant backgrounds. All of them have or have had a leading role in Innovation Districts, leading role here being understood as Director, CEO or President, as well as having solid experience in the field. Backgrounds such as Innovation Management, Urban and Economic Development, Engineering, Academia, and Sociology were included among the experts that were consulted. Demographic information on the panel of experts is provided in Table 5.

TABLE 5 DEMATEL Panel of experts' demographic information

Expert	Highest position	Education	Country	Experience (Years)
Expert 1	CEO	MBA	Denmark	12
Expert 2	General Director	PhD Engineering	Mexico	40
Expert 3	Director	PhD Biology	Uruguay	10
Expert 4	Technology Transfer Officer	Engineering	Germany	12
Expert 5	CEO	MBA	Kenya	7
Expert 6	President	PhD Sociology	Spain	16
Expert 7	Director	M. Engineering	Brazil	25
Expert 8	President	B. Political Science	USA	17
Expert 9	Director	M. Engineering	China	20
Expert 10	Director	TICs Engineering	Spain	32
Expert 11	President	B. Psychologist	Argentina	20
Expert 12	Director	Electronic Engineer. MSC TICS	Colombia	13
Expert 13	CEO	MSc Architecture	Sweden	10
Expert 14	Board Member	MBA	France	13
Expert 15	President	B. Political Science & Urban Planning	USA	19

4 Findings

4.1 *Fuzzy Delphi*

This research was built firstly to validate the relevance of 72 indicators identified to assess performance in Innovation Districts and to develop a comprehensive assessment framework. The Fuzzy Delphi method (discussed in Section 3) was implemented as an appropriate methodology to validate the level of relevance sought. The results of the FDM are presented in Table 6, where the 'Defuzzification' term represents the calculated mean of the scores assigned by the experts in relation to the degree of relevance to assess the performance of each indicator. The final assessment framework proposed to assess performance in Innovation Districts is presented in Table 7.

The framework proposes 4 dimensions (Urban, Economic, Social and Governance) as fields to evaluate performance. The results show that the

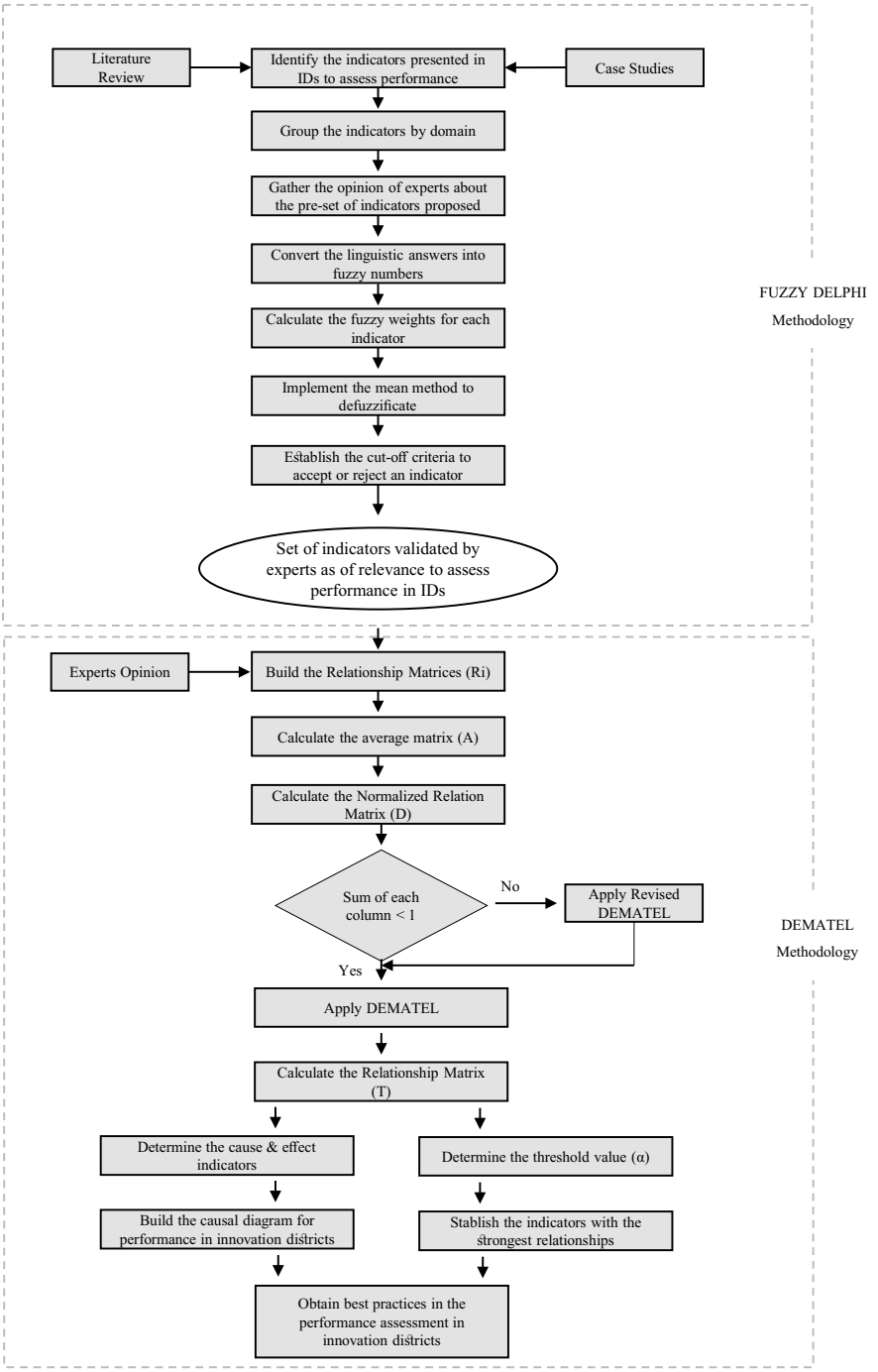

FIGURE 2 Fuzzy Delphi and DEMATEL Methodological Processes (Own Elaboration)

TABLE 6 Fuzzy Delphi Results – Indicators accepted as relevant (Own Elaboration)

		INDICATOR	Unit	Minor	Geometric Me	Major	Defuzzification	Decision
1	U1	Intervention Area	sqm	0,3	0,671052929	0,9	0,62368431	Accepted
2	U2	Potential Floor	sqm	0,3	0,685254898	0,9	0,628418299	Accepted
3	U3	Urbanized Street	km	0,1	0,570600226	0,9	0,523533409	Rejected
4	U4	Connected Buildings	#	0,1	0,633590711	0,9	0,544530237	Rejected
5	U5	Fibre Optic	Km	0,1	0,684786985	0,9	0,561595662	Rejected
6	U6	Wi-fi Points	#	0,1	0,558392937	0,9	0,519464312	Rejected
7	U7	Foreign Direct Invesment	Eur	0,1	0,587023392	0,9	0,529007797	Rejected
8	U8	Real Estate Investment	Eur	0,3	0,652498383	0,9	0,617499461	Accepted
9	U9	Constructed Building	sqm	0,3	0,675831982	0,9	0,625277327	Accepted
10	U10	Renovated Buildings	sqm	0,1	0,625305205	0,9	0,541768402	Rejected
11	U11	Available Floor Space	%	0,3	0,740120091	0,9	0,646706697	Accepted
12	U12	New Locations	sqm	0,3	0,638975295	0,9	0,612991765	Accepted
13	U13	Green Zones	%	0,1	0,625305205	0,9	0,541768402	Rejected
14	U14	New Facilities	#	0,3	0,690135094	0,9	0,630045031	Accepted
15	U15	Degree of Occupancy	%	0,3	0,671052929	0,9	0,62368431	Accepted
16	U16	Construction Implementation Degree	%	0,3	0,604128598	0,9	0,601376199	Accepted
17	E1	Jobs	#	0,3	0,845193974	0,9	0,681731325	Accepted
18	E2	Local Workers	#	0,1	0,638538983	0,9	0,546179661	Rejected
19	E3	Companies	#	0,3	0,827677253	0,9	0,675892418	Accepted
20	E4	International Companies	#	0,3	0,634456869	0,9	0,611485623	Accepted
21	E5	National Companies	#	0,3	0,671052929	0,9	0,62368431	Accepted
22	E6	Relocated Companies	#	0,1	0,509193863	0,9	0,503064621	Rejected
23	E7	Tax Exemptions	%	0,3	0,666307669	0,9	0,622102556	Accepted
24	E8	Public Investment in Companies	Eur	0,1	0,638538983	0,9	0,546179661	Rejected
25	E9	Private Investment in Companies	Eur	0,3	0,714566897	0,9	0,638188966	Accepted
26	E10	Turnover all the district	Eur	0,1	0,61192757	0,9	0,53730919	Rejected
27	E11	Companies Using Digital Tools	%	0,1	0,570210603	0,9	0,523403534	Rejected
28	E12	Knowledge-based Companies	#	0,3	0,821824446	0,9	0,673941482	Accepted
29	E13	Companies with Quality Certification	#	0,1	0,532063979	0,7	0,444021326	Rejected
30	E14	Exporting Companies	%	0,1	0,675370503	0,9	0,558456834	Rejected
31	E15	Professional Events	#	0,1	0,643086481	0,9	0,547695494	Rejected
32	E16	Incubators	#	0,3	0,782539641	0,9	0,660846547	Accepted
33	E17	Ventures Incubated	#	0,3	0,804792061	0,9	0,66826402	Accepted
34	E18	Invesment in Start-ups	Eur	0,3	0,845193974	0,9	0,681731325	Accepted
35	E19	Start-Ups	#	0,3	0,804792061	0,9	0,66826402	Accepted
36	E20	Turnover Start-Ups	Eur	0,3	0,684786985	0,9	0,628262328	Accepted
37	E21	Coworking	#	0,1	0,689663849	0,9	0,563221283	Rejected
38	E22	Freelancers	#	0,1	0,550899831	0,9	0,51696661	Rejected
39	E23	Innovation pilots	#	0,3	0,704740913	0,9	0,634913638	Accepted
40	E24	Innovation and tech events	#	0,3	0,740120091	0,9	0,646706697	Accepted
41	E25	Local Events	#	0,1	0,570600226	0,9	0,523533409	Rejected
42	E26	International Events	#	0,3	0,675831982	0,9	0,625277327	Accepted
43	E27	Participation in Local Events	#	0,1	0,520681125	0,7	0,440227042	Rejected
44	E28	Impact in Social Network	#	0,1	0,599245316	0,9	0,533081772	Rejected
45	E29	Publication in Scientific Journals	#	0,3	0,680409212	0,9	0,626803071	Accepted
46	E30	Intellectual Property	#	0,3	0,734886433	0,9	0,644962144	Accepted
47	E31	Number of Clustered Companies	#	0,3	0,777275363	0,9	0,659091788	Accepted
48	E32	Companies Clusterization Type	#	0,3	0,719655845	0,9	0,639885282	Accepted
49	S1	Citizens	#	0,1	0,510061559	0,9	0,503353853	Rejected
50	S2	Research, Tech and Innovation Centers	#	0,3	0,821824446	0,9	0,673941482	Accepted
51	S3	Universities	#	0,3	0,827677253	0,9	0,675892418	Accepted
52	S4	Schools	#	0,1	0,582676244	0,9	0,527558748	Rejected
53	S5	Telecentres	#	0,1	0,35568933	0,9	0,451896443	Rejected
54	S6	Students in District Universities	#	0,1	0,724286133	0,9	0,574762044	Rejected
55	S7	Students of Primary and Secondary Schools	#	0,1	0,424429668	0,9	0,474809889	Rejected
56	S8	Higher Education Degree	%	0,3	0,777275363	0,9	0,659091788	Accepted
57	S9	International Workers	%	0,3	0,652498383	0,9	0,617499461	Accepted
58	S10	Certified Professionals	%	0,1	0,581223667	0,9	0,527074556	Rejected
59	S11	Long Life Learning Programs	#	0,1	0,537117912	0,9	0,512372637	Rejected
60	S12	Students in Long Life Learning Programs	#	0,1	0,496359091	0,9	0,498786364	Rejected
61	S13	Social Activities	#	0,3	0,632702312	0,9	0,610900771	Accepted
62	S14	Persons in Social Events	#	0,1	0,591366759	0,7	0,46378892	Rejected
63	S15	Cultural Activities	#	0,1	0,534369159	0,9	0,511456386	Rejected
64	S16	Cultural Venues	#	0,1	0,516477574	0,7	0,438825858	Rejected
65	S17	Professional Women in the District	%	0,1	0,703405687	0,9	0,567801896	Rejected
66	S18	Housing	#	0,1	0,621850235	0,9	0,540616745	Rejected
67	S19	Jobs Vocation	%	0,1	0,519418053	0,7	0,439806018	Rejected
68	S20	Internships	#	0,3	0,684283008	0,9	0,628094336	Accepted
69	G1	District Budget	€	0,3	0,761166261	0,9	0,653722087	Accepted
70	G2	District Management Team Professionals	#	0,3	0,813925625	0,9	0,671308542	Accepted
71	G4	Professionals in District Companies Assoc	#	0,1	0,628607596	0,9	0,542869199	Rejected
72	G5	Indicators in Open Data	#	0,3	0,680409212	0,9	0,626803071	Accepted
	W			0,20277778	0,655267796	0,886111111	**0,581385562**	

Governance and Economic spheres obtained the highest scores in relation to the mean average of their indicators.

37 indicators out of 72 were accepted. Out of these 37 indicators, 19 belong to the Economic dimension, 9 to the Urban dimension, and 6 and 3 indicators to the Social and Governance dimension respectively.

4.1.1 Economic Dimension

Within the Economic dimension, the indicators that measure the number of Jobs generated (E1) and the Investment in Start-ups (E18) in the area obtained the highest scores. Followed by the indicator measuring the number of Companies located in the district (E3), and within it, giving more importance to the visualisation of Knowledge-based Companies (E12). The number of Ventures Incubated (E17), Start-ups (E19) and Incubators (E16) also scored among the highest. (E31) Number of Clustered Companies, (E24) Innovation and Tech Events, (E30) Intellectual Property, (E32) Companies Clusterisation Type, (E9) Private Investment in Companies, (E23) Innovation Pilots, (E20) Turnover Start-ups, (E29) Publication in Scientific Journals, (E26) International Events, (E5) National Companies, (E7) Tax Exemptions and (E4) International Companies make up the final part of the list of accepted indicators, in descending order of score.

The indicators that did not receive a high enough score to be considered meaningful in the Economic dimension are summarised as follows: (E21) Co-working, (E14) Exporting Companies, (E15) Professional Events, (E2)

TABLE 7 Innovation Districts Performance Assessment Framework

Area		Indicator	Unit
URBAN	U1	Intervention Area	sqm
	U2	Potential Floor	sqm
	U8	Real Estate Investment	Eur
	U9	Constructed Buildings	sqm
	U11	Available Floor Space	%
	U12	New Locations	sqm
	U14	New Facilities	#
	U15	Occupancy Rate	%
	U16	Construction Implementation Degree	%
ECONOMIC	E1	Jobs	#
	E3	Companies	#
	E4	International Companies	#
	E5	National Companies	#

TABLE 7 Innovation Districts Performance Assessment Framework (*cont.*)

Area		Indicator	Unit
	E7	Tax exemptions	%
	E9	Private Investment in Companies	Eur
	E12	Knowledge-based Companies	#
	E16	Incubators	#
	E17	Ventures Incubated	#
	E18	Investment in Start-Ups	Eur
	E19	Start-Ups	#
	E20	Turnover Start-Ups	Eur
	E23	Innovation Pilots	#
	E24	Innovation and Tech Events	#
	E26	International Events	#
	E29	Publication in Scientific Journals	#
	E30	Intellectual Property	#
	E31	Number of Clustered Companies	#
	E32	Companies Clusterization Type	#
SOCIAL	S2	Research, Tech and Innovation Centers	#
	S3	Universities	#
	S8	Higher Education Degree	%
	S9	International Workers	%
	S13	Social Activities	#
	S20	Internships	#
GOV	G1	District Budget	€
	G2	District Management Team Professionals	#
	G4	Indicators in Open Data	#

Local Workers, (E8) Public Investment in Companies, (E10) Turnover All the District, (E28) Impact in Social Network, (E25) Local Events, (E11) Companies Using Digital Tools, (E22) Freelancers, (E6) Relocated Companies and (E27) Participation in Local Events.

4.1.2 Urban Dimension

Within the Urban dimension, the greatest importance was assigned to the indicators (U11) Available Floor Space and (U14) New Facilities, which measure the projected square metres for the development of facilities. (U2) Potential

Floor, (U9) Constructed Buildings, (U1) Intervention Area, (U15) Degree of Occupancy, (U8) Real Estate Investment, (U12) New Locations and (U16) Construction Implementation Degree were also deemed relevant.

While the indicators Intervention Area (U1) and Potential Floor (U2) have been deemed relevant, the latter is of greater productivity and was thus assigned a slightly higher valuation compared to the indicator Intervention Area (U1).

The indicators: (U5) Fibre Optic, (U4) Connected Buildings, (U10) Renovated Buildings, (U13) Green Zones, (U7) Foreign Direct Investment, (U3) Urbanised Street and (U6) Wi-Fi Points were not considered as relevant enough to pass the threshold number.

4.1.3 Social Dimension

Within the Social dimension, the number of (S3) Universities and (S2) Research, Technology and Innovation Centres as well as the (S8) percentage of professionals in possession of a Higher Education Degree emerged as the indicators with the highest scores. Then, the (S20) number of people doing Internships, the (S9) percentage of International Workers in the district and (S13) the number of Social Activities and projects complete this set of selected indicators.

(S6) Students in District Universities, (S17) Professional Women in the District, (S18) Housing, (S4) Schools, (S10) Certified Professionals, (S11) Long-life Learning Programmes, (S15) Cultural Activities, (S1) Citizens, (S12) Students in Long-life Learning Programmes, (S7) Students of Primary and Secondary Schools, (S14) Persons in Social Events, (S5) Telecentres, (S19) Jobs Vocation, (S16) Cultural Venues have not reach the level set by experts.

4.1.4 Governance Dimension

Finally, within the Governance dimension, the (G2) District Management Team of Professionals indicator, which looks at the number of professionals on the district's management team, had the highest score. This was followed by the quantification of (G1) the District Budget and (G5) the Indicators in Open Data.

The indicator District Management Team Professionals was among those rated with the highest score by all the experts.

4.2 *DEMATEL Findings*

After the Fuzzy Delphi method determined the 37 most relevant indicators, the DEMATEL method was applied, to establish the power of influence that

one indicator has over another. The results obtained by the DEMATEL application are presented in the heat diagram in Table 8, where higher numbers (darker red on the graph) represent the indicators with a higher correlation.

Table 9 shows the direction of the influences, specifying the indicators of cause and effect, and the threshold number to be considered a strong correlation.

Tables 9 shows that indicators in which the sum of their row coefficients is greater than the sum of their column are classified as mostly cause. Analogously, but in the opposite direction, indicators in which the sum of their column is greater than the sum of their row, are mostly influenced by others and for this reason they are mostly considered as an effect. In any case, the matrix information must be seen to determine the function (cause or effect) in relation to each indicator and its level of influence.

Following this idea, in the case of the main indicators of the economic sphere (Jobs (E1), Companies (E3) and Knowledge-based Companies (E12)), they are strongly influenced by each other, and by the urban sphere. Additionally, these indicators are identified as mostly effect indicators, this means, the indicator is a consequence of the others. The Universities indicator is shown to have a significant transversal influence, meaning it impacts significantly over several indicators in different spheres. All Governance indicators present a strong impact over the main economic ones (Jobs (E1), Companies (E3), Private Investment in Companies (E9), Knowledge-based Companies (E12), Start-ups (E19), Innovation Pilots (E23), Innovation and Tech Events (E24), International Events (E26), Publication in Scientific Journals (E29), Intellectual Property (E30)). Particularly, Knowledge-based Companies (E12) is sensitive to most of the indicators classified as cause indicators, this means it could be affected by a decision taken in many areas.

Additionally, Tax Exemptions (E7), Internships (S20) and Publications in Scientific Journals, although they are considered measures of relevance, show a certain autonomy in the results, since they do not have a strong influence on the other indicators, nor do they affect them significantly.

5 Discussion

Innovation Districts are metropolitan zones with a high concentration of technology enterprises, research institutes, specialised scientific organisations, and technology transfer support platforms. It is therefore critical that ID have a tool that not only assists them in directing their efforts and activities toward

TABLE 8 Power of Influence among Indicators

AREA	INDICATOR	Unit		Intervention Area	Potential Floor	Real Estate Investment	Constructed Building	Available floor space	New Locations	New Facilities	Occupancy Rate	Construction Implementation Degree	Jobs	Companies	International Companies	National Companies	Tax Exemptions	Private Investment in Companies	Knowledge-based Companies	Incubators	Ventures Incubated	Investment in Start-Ups	Start-Ups	Turnover Start-Ups	Innovation Pilots	Innovation and Tech Events	International Events	Publication in Scientific Journals	Intellectual Property	Number of Clustered Companies	Companies Clusterization Type	Research, Tech and Innovation Centers	Universities	Higher Education Degree	International Workers	Social Activities	Internships	District Budget	District Management Team Professionals	Indicators in Open Data	
				U1	U2	U8	U9	U11	U12	U14	U15	U16	E1	E3	E4	E5	E7	E9	E12	E16	E17	E18	E19	E20	E23	E24	E26	E29	E30	E31	E32	S2	S3	S8	S9	S13	S20	G1	G2	G5	
URBAN	U1	Intervention Area	sqm	0.0848	0.1083	0.1019	0.1021	0.1089	0.1012	0.1118	0.1104	0.0986	0.1214	0.1172	0.1136	0.1154	0.0758	0.1043	0.1235	0.1060	0.1121	0.1082	0.1158	0.0978	0.1025	0.1067	0.0985	0.0742	0.0952	0.0978	0.0975	0.1095	0.0910	0.0958	0.1062	0.0811	0.0740	0.0984	0.0982	0.0913	
	U2	Potential Floor	sqm	0.1171	0.0000	0.1147	0.1120	0.1210	0.1144	0.1211	0.1206	0.1115	0.1349	0.1275	0.1203	0.1332	0.0838	0.1254	0.1423	0.1138	0.1204	0.1194	0.1284	0.1098	0.1151	0.1178	0.1052	0.0829	0.1085	0.1108	0.1078	0.1193	0.0998	0.1038	0.1061	0.1020	0.0851	0.1125	0.1084	0.1031	
	U8	Real Estate Investment	Eur	0.1224	0.1183	0.0028	0.1132	0.1193	0.1140	0.1205	0.1141	0.1112	0.1310	0.1251	0.1274	0.1293	0.0897	0.1209	0.1383	0.1100	0.1166	0.1184	0.1205	0.1075	0.1049	0.1109	0.1013	0.0798	0.1004	0.1043	0.1043	0.1183	0.0956	0.0969	0.1011	0.0971	0.0815	0.1091	0.1048	0.1004	
	U9	Constructed Buildings	sqm	0.1155	0.1112	0.1032	0.0777	0.1119	0.1056	0.1102	0.1097	0.1029	0.1245	0.1201	0.1210	0.1228	0.0859	0.1119	0.1296	0.1041	0.1099	0.1064	0.1140	0.1004	0.0977	0.1034	0.0961	0.0750	0.0963	0.0988	0.0973	0.1121	0.0875	0.0904	0.0983	0.0892	0.0773	0.1022	0.0979	0.0904	
	U11	Available Floor Space	%	0.1114	0.1077	0.0999	0.0971	0.0811	0.1036	0.1096	0.1107	0.0985	0.1205	0.1179	0.1137	0.1268	0.0763	0.1182	0.1258	0.1036	0.1058	0.1058	0.1154	0.1000	0.0972	0.1038	0.0918	0.0720	0.0919	0.0984	0.0969	0.1099	0.0903	0.0887	0.0925	0.0875	0.0713	0.0973	0.0946	0.0980	
	U12	New Locations	sqm	0.1131	0.1107	0.1056	0.1044	0.1114	0.0806	0.1127	0.1108	0.0998	0.1270	0.1213	0.1227	0.1225	0.0853	0.1150	0.1323	0.1038	0.1101	0.1106	0.1162	0.1045	0.1015	0.1090	0.0957	0.0760	0.0960	0.0998	0.0983	0.1118	0.0944	0.0913	0.0953	0.0901	0.0731	0.1002	0.1005	0.0995	
	U14	New Facilities	#	0.1169	0.1172	0.1074	0.1092	0.1185	0.1059	0.0922	0.1176	0.1094	0.1331	0.1273	0.1295	0.1299	0.0870	0.1203	0.1453	0.1123	0.1174	0.1193	0.1242	0.1097	0.1087	0.1152	0.1038	0.0834	0.1072	0.1081	0.1080	0.1221	0.1047	0.0998	0.1003	0.0947	0.0803	0.1067	0.1055	0.1043	
	U15	Occupancy Rate	%	0.1181	0.1185	0.1129	0.1102	0.1181	0.1125	0.1148	0.0939	0.1052	0.1384	0.1301	0.1307	0.1382	0.0879	0.1230	0.1433	0.1115	0.1201	0.1206	0.1284	0.1123	0.1113	0.1180	0.1084	0.0827	0.1038	0.1155	0.1091	0.1218	0.0972	0.0985	0.1014	0.0972	0.0813	0.1063	0.1061	0.1057	
	U16	Construction Implementation Degree	%	0.1137	0.1112	0.1045	0.1062	0.1158	0.1064	0.1148	0.1145	0.0798	0.1278	0.1235	0.1258	0.1276	0.0846	0.1151	0.1377	0.1102	0.1122	0.1127	0.1218	0.1049	0.1052	0.1096	0.0976	0.0746	0.0964	0.1043	0.1048	0.1169	0.0962	0.0930	0.0987	0.0918	0.0755	0.1020	0.0993	0.1029	
ECONOMIC	E1	Jobs	#	0.1207	0.1104	0.1079	0.1067	0.1169	0.1119	0.1216	0.1197	0.1046	0.1052	0.1311	0.1290	0.1284	0.0831	0.1241	0.1429	0.1132	0.1185	0.1188	0.1237	0.1091	0.1153	0.1186	0.1062	0.0857	0.1081	0.1097	0.1077	0.1245	0.0986	0.1028	0.1100	0.1014	0.0841	0.1088	0.1065	0.1070	
	E3	Companies	#	0.1257	0.1196	0.1081	0.1128	0.1203	0.1151	0.1252	0.1232	0.1097	0.1365	0.1063	0.1299	0.1363	0.0842	0.1249	0.1457	0.1168	0.1191	0.1255	0.1261	0.1140	0.1200	0.1253	0.1153	0.0929	0.1129	0.1120	0.1105	0.1268	0.1018	0.1059	0.1118	0.1014	0.0847	0.1150	0.1141	0.1146	
	E4	International Companies	#	0.1286	0.1258	0.1120	0.1167	0.1278	0.1192	0.1295	0.1275	0.1174	0.1415	0.1368	0.1105	0.1307	0.0889	0.1310	0.1533	0.1243	0.1267	0.1287	0.1295	0.1183	0.1233	0.1329	0.1241	0.0979	0.1187	0.1162	0.1177	0.1360	0.1057	0.1113	0.1188	0.1067	0.0899	0.1192	0.1212	0.1203	
	E5	National Companies	#	0.1210	0.1180	0.1066	0.1115	0.1215	0.1136	0.1220	0.1218	0.1093	0.1360	0.1307	0.1296	0.1056	0.0859	0.1269	0.1451	0.1165	0.1172	0.1178	0.1198	0.1124	0.1174	0.1266	0.1126	0.0915	0.1098	0.1074	0.1089	0.1250	0.1002	0.1035	0.1058	0.1000	0.0834	0.1091	0.1126	0.1131	
	E7	Tax Exemptions	%	0.0810	0.0795	0.0772	0.0759	0.0815	0.0790	0.0822	0.0818	0.0756	0.0877	0.0887	0.0912	0.0920	0.0879	0.0859	0.1019	0.0779	0.0864	0.0853	0.0877	0.0765	0.0764	0.0796	0.0699	0.0643	0.0804	0.0814	0.0828	0.0877	0.0656	0.0659	0.0745	0.0690	0.0558	0.0818	0.0715	0.0811	
	E9	Private Investiment in Companies	Eur	0.1027	0.0965	0.0933	0.0936	0.0990	0.0986	0.1023	0.1034	0.0977	0.1228	0.1188	0.1194	0.1198	0.0804	0.0927	0.1379	0.1124	0.1232	0.1222	0.1238	0.1099	0.1104	0.1146	0.1041	0.0865	0.1108	0.1067	0.1097	0.1187	0.0895	0.0859	0.0961	0.0921	0.0757	0.1084	0.1026	0.1034	
	E12	Knowledge-based Companies	#	0.1205	0.1230	0.1127	0.1144	0.1193	0.1169	0.1250	0.1269	0.1155	0.1410	0.1365	0.1375	0.1422	0.0955	0.1382	0.1233	0.1276	0.1324	0.1330	0.1367	0.1194	0.1261	0.1325	0.1191	0.1035	0.1244	0.1232	0.1247	0.1371	0.1124	0.1166	0.1153	0.1044	0.0936	0.1201	0.1221	0.1199	
	E16	Incubators	#	0.1207	0.1173	0.1057	0.1069	0.1181	0.1143	0.1217	0.1228	0.1099	0.1396	0.1353	0.1298	0.1348	0.0891	0.1356	0.1506	0.1081	0.1345	0.1348	0.1369	0.1215	0.1251	0.1328	0.1152	0.0971	0.1235	0.1223	0.1229	0.1299	0.1072	0.1093	0.1129	0.1022	0.0910	0.1146	0.1160	0.1160	
	E17	Ventures Incubated	#	0.1174	0.1127	0.1037	0.1040	0.1158	0.1054	0.1198	0.1195	0.1070	0.1343	0.1300	0.1281	0.1311	0.0837	0.1306	0.1466	0.1241	0.1095	0.1313	0.1347	0.1183	0.1203	0.1298	0.1127	0.0948	0.1174	0.1162	0.1148	0.1295	0.1028	0.1069	0.1099	0.1019	0.0824	0.1098	0.1133	0.1129	
	E18	Investment in Start-Ups	Eur	0.1192	0.1131	0.1075	0.1064	0.1138	0.1086	0.1187	0.1213	0.1038	0.1391	0.1347	0.1268	0.1328	0.0868	0.1294	0.1480	0.1287	0.1325	0.1113	0.1369	0.1214	0.1191	0.1266	0.1095	0.0961	0.1191	0.1165	0.1180	0.1281	0.1015	0.0996	0.1072	0.1011	0.0882	0.1088	0.1065	0.1102	
	E19	Start-Ups	#	0.1197	0.1134	0.1078	0.1081	0.1156	0.1104	0.1207	0.1233	0.1061	0.1413	0.1369	0.1286	0.1365	0.0898	0.1350	0.1494	0.1293	0.1332	0.1352	0.1093	0.1234	0.1226	0.1302	0.1142	0.0978	0.1211	0.1184	0.1199	0.1302	0.1033	0.1034	0.1094	0.1000	0.0914	0.1090	0.1143	0.1100	
	E20	Turnover Start-Ups	Eur	0.1146	0.1101	0.1048	0.1050	0.1123	0.1043	0.1126	0.1182	0.1014	0.1341	0.1259	0.1201	0.1250	0.0847	0.1251	0.1413	0.1227	0.1249	0.1269	0.1272	0.1097	0.1146	0.1205	0.1079	0.0922	0.1147	0.1156	0.1136	0.1219	0.1003	0.0978	0.1044	0.1000	0.0875	0.1059	0.1080	0.1103	
	E23	Innovation Pilots	#	0.1099	0.0951	0.0872	0.0890	0.0943	0.0910	0.1005	0.1002	0.0887	0.1191	0.1201	0.1192	0.1210	0.0760	0.1167	0.1311	0.1093	0.1127	0.1152	0.1205	0.1064	0.1047	0.1133	0.1014	0.0900	0.1030	0.1022	0.1171	0.0955	0.0937	0.0979	0.0908	0.0793	0.0975	0.1067	0.1049	
	E24	Innovation and Tech Events	#	0.1073	0.0984	0.0918	0.0906	0.0976	0.0937	0.1084	0.1066	0.0917	0.1236	0.1224	0.1215	0.1233	0.0740	0.1204	0.1369	0.1205	0.1208	0.1228	0.1273	0.1103	0.1159	0.0925	0.1106	0.0882	0.1053	0.1051	0.1069	0.1207	0.1015	0.0997	0.1039	0.0903	0.0849	0.1051	0.1090	0.1066	
	E26	International Events	#	0.0954	0.0900	0.0854	0.0842	0.0891	0.0861	0.0979	0.0962	0.0839	0.1101	0.1092	0.1100	0.1071	0.0647	0.1046	0.1195	0.0952	0.1051	0.1070	0.1097	0.0955	0.0988	0.1071	0.0733	0.0812	0.0949	0.0907	0.0923	0.1049	0.0895	0.0876	0.0962	0.0848	0.0690	0.0893	0.0915	0.0891	
	E29	Publication in Scientific Journals	#	0.0757	0.0723	0.0715	0.0702	0.0728	0.0703	0.0753	0.0760	0.0701	0.0920	0.0866	0.0910	0.0923	0.0606	0.0877	0.1035	0.0875	0.0915	0.0932	0.0939	0.0826	0.0857	0.0874	0.0821	0.0828	0.0698	0.0765	0.0767	0.0909	0.0806	0.0803	0.0775	0.0702	0.0609	0.0737	0.0774	0.0813	
	E30	Intellectual Property	#	0.1055	0.1038	0.1073	0.1093	0.1044	0.1011	0.1021	0.0943	0.0988	0.1183	0.1188	0.1288	0.1182	0.0791	0.1243	0.1320	0.1127	0.1190	0.1180	0.1223	0.1067	0.1122	0.1118	0.1043	0.0963	0.1026	0.0828	0.1023	0.0995	0.1174	0.1073	0.0954	0.1005	0.0909	0.0784	0.0961	0.0967	0.1047	
	E31	Number of Clustered Companies	#	0.1181	0.1138	0.1069	0.1086	0.1160	0.1124	0.1192	0.1210	0.1066	0.1331	0.1287	0.1281	0.1286	0.0880	0.1247	0.1378	0.1152	0.1219	0.1228	0.1258	0.1062	0.1146	0.1181	0.1041	0.0905	0.1101	0.0879	0.1122	0.1256	0.1185	0.1067	0.1090	0.1058	0.0946	0.1079	0.1068	0.1100	
	E32	Companies Clulterization Type	#	0.1127	0.1070	0.1018	0.1020	0.1076	0.1042	0.1157	0.1118	0.1030	0.1242	0.1250	0.1223	0.1226	0.0821	0.1177	0.1368	0.1115	0.1180	0.1164	0.1217	0.1060	0.1096	0.1137	0.1031	0.0878	0.1081	0.1086	0.0845	0.1210	0.0987	0.0970	0.1041	0.0910	0.0818	0.1027	0.1032	0.1054	
SOCIAL	S2	Research, Tech and Innovation Centers	#	0.1182	0.1135	0.1079	0.1082	0.1142	0.1103	0.1206	0.1172	0.1091	0.1351	0.1337	0.1345	0.1349	0.0872	0.1283	0.1448	0.1217	0.1269	0.1268	0.1309	0.1144	0.1210	0.1271	0.1143	0.1025	0.1210	0.1151	0.1138	0.1028	0.1039	0.1032	0.1091	0.1015	0.0915	0.1137	0.1099	0.1151	
	S3	Universities	#	0.1250	0.1200	0.1141	0.1144	0.1207	0.1154	0.1230	0.1254	0.1139	0.1443	0.1397	0.1380	0.1409	0.0930	0.1340	0.1511	0.1192	0.1356	0.1347	0.1398	0.1212	0.1279	0.1328	0.1224	0.1083	0.1247	0.1158	0.1188	0.1373	0.1043	0.1154	0.1179	0.1092	0.1000	0.1186	0.1194	0.1210	
	S8	Higher Education Degree	%	0.1087	0.1014	0.0947	0.0931	0.1006	0.0987	0.1060	0.1079	0.0987	0.1278	0.1252	0.1248	0.1282	0.0753	0.1190	0.1305	0.1170	0.1178	0.1198	0.1224	0.1055	0.1106	0.1158	0.1059	0.0939	0.1030	0.1021	0.1024	0.1043	0.0787	0.1052	0.0950	0.0831	0.0869	0.0997	0.1004		
	S9	International Workers	%	0.0887	0.0837	0.0791	0.0793	0.0843	0.0800	0.0883	0.0850	0.0759	0.1010	0.0960	0.1029	0.0983	0.0659	0.0913	0.1066	0.0908	0.0955	0.0924	0.0950	0.0875	0.0891	0.0971	0.0809	0.0748	0.0854	0.0828	0.0844	0.0978	0.0821	0.0819	0.0653	0.0791	0.0674	0.0797	0.0837	0.0858	
	S13	Social Activities	#	0.0927	0.0877	0.0834	0.0836	0.0883	0.0884	0.0939	0.0920	0.0852	0.1067	0.1030	0.1059	0.1054	0.0678	0.0999	0.1128	0.0948	0.0958	0.0948	0.0969	0.0897	0.0913	0.0966	0.0876	0.0713	0.0859	0.0836	0.0836	0.1002	0.0779	0.0807	0.0867	0.0841	0.0627	0.0476	0.0855	0.0829	0.0894	
	S20	Internships	#	0.0890	0.0861	0.0812	0.0829	0.0866	0.0829	0.0907	0.0869	0.0827	0.0985	0.0930	0.0932	0.0944	0.0650	0.0874	0.0932	0.0844	0.0850	0.0904	0.0740	0.0775	0.0765	0.0799	0.0728	0.0742	0.0770	0.0690	0.0561	0.0843	0.0654	0.0656	0.0799	0.0728	0.0742	0.0625	0.0654	0.0666	0.0600	0.0423	0.0721	0.0771	0.0711	0.0644	
GOV	G1	District Budget	€	0.1118	0.1076	0.1040	0.0993	0.1083	0.1079	0.1144	0.1088	0.1022	0.1232	0.1176	0.1166	0.1202	0.0875	0.1123	0.1310	0.1166	0.1226	0.1160	0.1225	0.1052	0.1100	0.1188	0.1037	0.0854	0.1042	0.1048	0.1034	0.1179	0.0956	0.0946	0.0958	0.0978	0.0822	0.0823	0.1065	0.1016	
	G2	District Management Team Professional	#	0.1099	0.0982	0.0947	0.0920	0.1004	0.0986	0.1051	0.1046	0.0965	0.1212	0.1216	0.1185	0.1216	0.0816	0.1121	0.1298	0.1134	0.1158	0.1144	0.1190	0.1061	0.1116	0.1178	0.1025	0.0847	0.1044	0.0988	0.1033	0.1109	0.0951	0.0933	0.1004	0.0965	0.0847	0.1078	0.0811	0.1001	
	G4	Indicators in Open Data	#	0.1091	0.0989	0.0955	0.0928	0.0996	0.0948	0.1042	0.1038	0.0924	0.1188	0.1192	0.1185	0.1202	0.0840	0.1157	0.1303	0.1168	0.1147	0.1166	0.1196	0.1044	0.1048	0.1090	0.1002	0.0887	0.1083	0.1023	0.1026	0.1176	0.0969	0.0971	0.1002	0.0942	0.0793	0.0965	0.1016	0.0810	

TABLE 9 Cause, Effect indicators & Threshold number

AREA		INDICATOR	Unit	Ri	Ci	Ri + Ci	Ri - Ci	Identify	Threshold FACTOR 0,1061
URBAN	U1	Intervention Area	sqm	3,75	4,07	7,82	- 0,32	Effect	
	U2	Potential Floor	sqm	4,17	3,88	8,05	0,29	Cause	
	U8	Real Estate Investment	Eur	4,07	3,65	7,72	0,42	Cause	
	U9	Constructed Buildings	sqm	3,81	3,66	7,46	0,15	Cause	
	U11	Available Floor Space	%	3,71	3,91	7,62	- 0,20	Effect	
	U12	New Locations	sqm	3,85	3,76	7,61	0,10	Cause	
	U14	New Facilities	#	4,09	4,05	8,15	0,04	Cause	
	U15	Occupancy Rate	%	4,15	4,03	8,18	0,11	Cause	
	U16	Construction Implementation Degree	%	3,94	3,64	7,57	0,30	Cause	
ECONOMIC	E1	Jobs	#	4,13	4,60	8,73	- 0,47	Effect	
	E3	Companies	#	4,29	4,48	8,77	- 0,18	Effect	
	E4	International Companies	#	4,49	4,45	8,94	0,04	Cause	
	E5	National Companies	#	4,22	4,53	8,75	- 0,31	Effect	
	E7	Tax exemptions	%	2,91	2,96	5,87	- 0,06	Effect	
	E9	Private Investment in Companies	Eur	3,88	4,30	8,18	- 0,42	Effect	
	E12	Knowledge-based Companies	#	4,54	4,93	9,47	- 0,39	Effect	
	E16	Incubators	#	4,42	4,09	8,51	0,33	Cause	
	E17	Ventures Incubated	#	4,27	4,25	8,52	0,02	Cause	
	E18	Investment in Start-Ups	Eur	4,28	4,27	8,55	0,01	Cause	
	E19	Start-Ups	#	4,37	4,42	8,79	- 0,05	Effect	
	E20	Turnover Start-Ups	Eur	4,15	3,91	8,06	0,24	Cause	
	E23	Innovation Pilots	#	3,81	4,00	7,81	- 0,18	Effect	
	E24	Innovation and Tech Events	#	3,96	4,19	8,16	- 0,23	Effect	
	E26	International Events	#	3,49	3,78	7,27	- 0,29	Effect	
	E29	Publication in Scientific Journals	#	2,96	3,15	6,11	- 0,19	Effect	
	E30	Intellectual Property	#	3,82	3,87	7,69	- 0,05	Effect	
	E31	Number of Clustered Companies	#	4,16	3,82	7,98	0,34	Cause	
	E32	Companies Clusterization Type	#	3,99	3,82	7,81	0,16	Cause	
SOCIAL	S2	Research, Tech and Innovation Centers	#	4,30	4,32	8,62	- 0,01	Effect	
	S3	Universities	#	4,54	3,51	8,06	1,03	Cause	
	S8	Higher Education Degree	%	3,95	3,50	7,45	0,45	Cause	
	S9	International Workers	%	3,20	3,69	6,89	- 0,49	Effect	
	S13	Social Activities	#	3,30	3,44	6,74	- 0,14	Effect	
	S20	Internships	#	2,58	2,95	5,53	- 0,36	Effect	
GOV	G1	District Budget	€	3,95	3,76	7,71	0,19	Cause	
	G2	District Management Team Professionals	#	3,88	3,78	7,66	0,10	Cause	
	G4	Indicators in Open Data	#	3,84	3,81	7,65	0,02	Cause	

developing these urban innovation ecosystems, but also ensures that those actions lead the district to its goal over time.

The goal of this research is to first establish and test a complete framework for assessing performance in innovation districts using indicators. Second, to determine the level of influence between the indicators, allowing this to have a wide perspective of all the dimensions and actors essential to the growth of

these regions, from the conception stage to the maturity of the district, and to assist decision making.

5.1 *Indicators' Relevance*

5.1.1 Economic Dimension

When discussing the indicators of the Economic dimension, the four indicators with the highest scores were Jobs (E1), Investment in Start-ups (E18), Companies (E3) and Knowledge-based Companies (E12). As a consequence, it is possible to recognise an emerging need to identify and weigh those indicators that demonstrate the differential characteristics of these different types of districts. This means signs that shape the identity of these locations and provide them with a distinct value. For example, it is not only interesting to know the number of companies located in the district, but also to know how many of them are Knowledge-based (E12) (differential value). Even when private investment in firms is of interest in the investment industry, it is far more useful to know what type of companies are being encouraged, with a concentration on Start-ups (E19) (differential value). Consistent with the above, Innovation Pilots (E23) was deemed an essential indicator for understanding as it demonstrates: first, the actual activity of what an innovation area is; second, that innovation works; third, that it has an impact on the territory and that it produces exchanges. Additionally, the clustering of businesses (E31) was deemed a very effective technique for developing an innovation area, and as such it was given a high ranking. Furthermore, the existence of unique clusters (E32) is included into the district's plan, guiding the district's speciality (Differential Value).

On the other hand, although the impact on the specific territory is of interest, Local Worker (E2) was not valued with high criteria, since it could be considered relevant that employment be generated, but whether these jobs are occupied by local people or international people, it is not considered a relevant criterion to assess performance in Innovation Districts. Because a person from outside that comes to work in the area and stays for years or even settles there also generates an impact on the local territory. When discussing Relocated Companies (E6), they were not recognised as a meaningful indicator to evaluate performance, because whether new companies are generated or arrive from outside, the main element is the existence of companies, and what matters is the quality of the firm, whether it is generated or relocated. Moreover, it is also critical to distinguish between public and private investment because public money is required in the early stages of development to construct a quality innovation system for private investment in later stages of

development. Infrastructure development is linked to public investment. As a result, private investment is attracted to create the service layer on the infrastructure layer.

In terms of Companies Using Digital Tools (E11), they are now considered basic, not as a differentiating value, because all competitive companies use them, so it was no longer a relevant indicator. This could be because organisations that do not employ digital tools are not directly involved in the innovation process.

When discussing the Companies with Quality Certification (E13), it can be said that they are viewed as a measure that is strongly dependent on national legislation and criteria. Despite the fact that there are international standards and that each company must adapt to what the market requires in its segment, it is not regarded as a differentiating factor for evaluating innovation performance.

On the other hand, although the results show that an indicator that measures the number of Incubators (E16) must exist, an additional study could be established to ensure that the products developed by them have commercial value. As a result, while this indicator was accepted, Ventures Incubated (E17) received a slightly higher score.

Additionally, the Investment in Start-ups (E18) was deemed extremely important since it is being invested in a business opportunity, and the mere existence of the investment ultimately determines whether the business would be successful or not. Moreover, keeping control of the number of Start-ups (E19), even if this was accepted, could only be regarded as essential if something productive is done with them. Considering a supplemental measure that governs their concurrent level of achievement could be subject to analysis in future research. Finally, in the field of start-ups, the Turnover of Start-ups (E20) was not considered relevant for understanding as, while it may not be high in the first stages, does not necessarily show a failing business.

5.1.2 Urban Dimension

Similar circumstances surround the Urban dimension's indicators. Higher ratings were given to: Available Floor Space (U11), New Facilities (U14), Potential Floor (U2), Intervention Area (U1) and Degree of Occupancy (U15). It is relevant to note that while it is important to know how much space is available to build or use as an office in the district (Potential Floor and Available Floor Space, respectively), it is more important to identify how much of this space is dedicated to New Facilities, which are spaces dedicated to special activities such as business incubators and other functions that distinguish the district

from others (Differential Value). The facilities are regarded as the primary source of productivity in these areas; hence their monitoring is crucial. In addition, the measurement of New Facilities, which is an indicator of future client and company potential, is seen as vital.

When discussing the indicator that measures the kilometres of Urbanised Streets (U3), the results showed that it is regarded as a basic means rather than an end, something that must be done from the ground up of every district, with no differential value to evaluate performance. Something analogous happened with the types of connections: the kilometres of Fibre Optic cables (U5) received a higher score than the Connected Buildings indicator (U4), although it is still considered basic and is not weighted to measure performance. A similar scenario occurs for the number of Wi-Fi Points indicator (U6), which was not accepted as relevant either, since these are basic features that must always be present, but do not confer a differential character.

In terms of investment, it can be said that it is relevant in general, not necessarily because it is foreign or local, and thus the kind of investment, Foreign Direct Investment (U7) is rated moderately in general, and it has not exceeded the cut-off level to differentiate between national and international investment, therefore these indicators were discarded.

When it comes to Constructed Buildings (U9), when this is done well and with a focus on the type of company or centre (client) planned in the area, it gains prominence because it represents well-equipped buildings.

In relation to the New Locations (U12) indicator, it was qualified or categorised as really relevant. Beyond the initial projection that can be made, given the long-term nature of these projects, a static forecast at the start is extremely difficult to get right. Purchasing these places for expansion too early (by locking in a current land value) risks robbing other investments of funds. However, running out of space, having a need to develop, and not planning for it is a costly mistake. As a result, the indicator New Locations is seen as complex, yet strategically important to account for.

Moreover, when analysing the results obtained by the Green Zones (U13) indicator, it can be said that they are extremely significant in any district. However, the concept has become naturalised, and depending on the location of the district, it may be more important. Nonetheless, this area has been fading as a measure of measuring performance in Innovation Districts, despite the fact that its creation is not excluded for this purpose and the validity of its value is maintained.

To conclude, the Degree of Occupancy (U15) shows the space available for future companies to come and the need for more investment in new building.

5.1.3 Social Dimension

The Social dimension exhibits or presupposes a similar situation; the difference in value of this type of district in the social field rests in the presence of Centres that enable the growth of technology and innovation, as well as the performance of qualified personnel in these surroundings. For this reason, the linked indicators, Universities (S3), Research, Technology and Innovation Centres (S2), as well as the percentage of professionals with advanced Degrees (S8) and Internships (S20), received the highest marks. Social Activities (S13), on the other hand, are weighted as long-term positive effect initiatives. Intangibles, which generate the most value, function better in a social activity than in a professional one, and their evaluation is regarded as a means of ensuring their development. It is also noteworthy to examine how various indicators that were included in Districts of Innovation like 22@Barcelona, such as Housing (S18), Students in the District's Universities (S6), and Citizens (S1), were eliminated by experts after the FDM since they were deemed irrelevant to assess performance. As previously said, the social component (Number of dwellings) is crucial in these instances for the recruitment and retention of talent, but experts were divided as to whether the resources to serve these social demands should be located in the innovation area or nearby. Because there is agreement on the importance of these factors' existence, their evaluation within the district can be considered as a way to ensure their continuous development.

5.1.4 Governance Dimension

The governance dimension has very few indicators (in comparison to the other dimensions), but with very high scores (impact). This may illustrate the significance of having a competent management group, but the effectiveness of its actions is judged in terms of benefits obtained rather than input. In other words, if measurement, control and monitoring are viewed as the first steps in ensuring that an activity works as expected, in terms of governance, it will be interesting to ensure first: that there is a governance (G2), second, that the number of human resources dedicated to governance is competent and sufficient (in quantity) to respond to the needs of the district (G2), and third, that the economic resources are adequate (G1). Other performance consequences of governance acts are measured in the previous dimensions' indicators already mentioned.

To conclude, each type of innovation district may place a higher focus or value on specific measures than others. However, this is a comprehensive framework that strives to provide a broad foundation, and with this broad set, secondary decisions based on the district's specific typology can be made.

Likewise, the varying goals based on the physical or economic sizes of innovation districts are not differentiating criteria for the selection of indicators, because what matters here is the value of the data provided by the indicator.

5.2 *Indicators' Relationships*

Concerning the level of impact between indicators in each dimension, it is crucial to consider how a modification to one indicator may affect (improve or deteriorate) the measurement of another, which may also be applied in reverse. This refers to using knowledge of interdependencies to decide on one action, knowing that it would ultimately benefit another.

5.2.1 Urban Dimension

When contemplating the urban dimension, it was possible to see that it contains mostly cause indicators. Real Estate Investment (U8) and Construction Implementation Degree (U16) are the biggest cause indicators in this dimension, notably influencing the indicators that measure the number of Jobs (E1) and the number of Knowledge-based Companies (E12), which have direct effects on economic activity. Beyond the role of real estate investment in stimulating the economy, it is important to note that since the focus in these Innovation Districts, in the urban dimension, is on the development of hard factors to attract Knowledge-based Companies (E12), new Ventures (E17), and trained individuals (S8), Real Estate Investment (U8) is directly linked to the attraction and retention of qualified talent. Following this pattern of cause indicators is the Potential Floor indicator (U2), which describes the area available for construction and is closely linked to the Constructed Buildings indicator (U4). In addition, the Available Floor Space (U11) may be seen as a result of the Constructed Buildings (U4) and New Locations (U12) and concurrently impact the Occupancy (U15).

5.2.2 Economic Dimension

The majority of economic dimension indicators are effect indicators. Jobs (E1), Private Investment (E9), and Knowledge-based Companies (E12) are the indicators most influenced by other metrics. In the case of Jobs, the creation of Start-ups (E19) and the number of Universities (S3) have the greatest impact. The number of Knowledge-based Companies (E12), Incubators (E16), Universities (S3) and Start-ups (E19) has a direct and strong relationship with Private Investment (E9). Indicating that private investment will increase if any of these variables is increased. Incubators (E16), Incubated Ventures (E17) and Start-ups Investment (E18) are the most commonly cited as causes of other indicators. This is because the greater the number of incubators, incubated

ventures and start-ups funding, the greater the number of start-ups and private investment in the district's enterprises. Alternatively, the Number of Clustered Companies (E31) and the Number of Cluster Types (E32) are determinants in the attractiveness of companies to the district; hence, if the cluster is already mature, the district will be more attractive to new corporations. According to the data, the Turnover of Start-ups (E20) can be considered a strong cause of other indicators such as Jobs (E1) and Investment in Start-ups (E18). This could be explained by the fact that the larger the return on investment of a business (start-ups), the bigger the number of jobs it could create, and these enterprises are therefore more appealing to investors.

5.2.3 Social Dimension

The bulk of social dimension indicators are effect indicators, with the exception of Universities (S3) and Higher Education Degrees indicator (S8), which influence employment (E1) as they are the source of educated people. In contrast, the Research, Technology, and Innovation Centres indicator (S2) has a greater level of both effect and cause factors, as it promotes Knowledge-based Companies (E12) and Intellectual Property (E30) and is the result of the number of Universities (S3) and International Companies (E4) locating their Innovation Centres in the district (S2).

5.2.4 Governance Dimension

Indicators of the governance dimension are predominantly cause indicators since they provide the necessary cash (G1) and staff (G2) for the district's development. They primarily influence economic indicators such as Employment (E1), Companies (E3), Private Investment (E9) and Knowledge-Based Companies (E12). This is because the district management team determines the terms of engagement for these participants and directly encourages or discourages their development within the Innovation District.

5.3 *Triple Helix Actors*

5.3.1 The Role of Government

According to the majority of different actors in the development of an ID, it is observed that the government should play a leading role at the start of the district's evolution, especially in urban planning, defining the Intervention Area (U1) and the Potential Floor (U2) and the development of infrastructures, facilitating the legal processes for Constructing Buildings (U9), and sending messages of transparency and legal stability to Real Estate developers (U8). In later phases, the government should investigate New Locations (U12) when there is a high level of Construction Implementation (U16) and the level of

Occupancy (U15) satisfies the demand for buildings or other urban regeneration zones. In addition, the government promotes the development of the district with amenities to increase the area's appeal. This illustrates that the government's ability to take action is predominately urban. Student housing, hotels and residences are significant difficulties that did not pass the Fuzzy Delphi filter.

Government is also the primary agent for early-stage social development; hence, efforts should also focus on expanding and enhancing the number of Universities (S3) and Research, Tech and Innovation Centres (S2). Additionally, it provides New Facilities (U14) as hard variables for students with the number of Universities (S3) (differential value), schools and hospitals.

In terms of Governance, the government should allocate and mobilise resources for the District's development (G1), forming organisations or units. Open Data (G5) strategies can support the formation of new businesses in the district.

5.3.2 The Role of Academia

Concerning the function of academic institutions, their initial contribution consisted mostly of supplying the appropriate talent and technology to make the location desirable.

Indicators pertaining to Universities (S3) are mirrored in the social dimension and quantified by a collection of indicators pertinent to providing talent from Internships (S20) to those with a Higher Education Degree (S8) (differential value). On the other hand, universities provide technology, originated from Research, Technology and Innovation Centres (S2) (differential value), Publications in Scientific Journals (E29) (differential value), and Patents and Intellectual Property (E30) to protect innovative ideas and businesses (differential value).

Universities play a crucial role, encouraging Innovation, Tech, and Entrepreneurial Events (E24) and offering facilities such as Incubators (E16) in order to develop Ventures Incubated (E17) and assist them in securing funding (E18) in order to grow (E20).

5.3.3 The Role of Industry

Industry is responsible for the Construction of Buildings (U9) and its Implementation Degree (U16) in the Urban dimension, operating as Real Estate Investors (U8).

Having a vital role in the economy, Companies (E3), National Companies (E5) or International Companies (E4) will fill offices with enterprises (U15)

that create new Jobs (E1). Innovation Districts will be distinguished by their Knowledge-based Companies (E12) (differential value).

These companies participate in the entrepreneurial ecosystems, which stimulates the creation of Start-ups (E19) (differential value), attracts venture capital (E18) (differential value), and contributes to corporate innovation and the formalisation of the innovation ecosystem.

6 Conclusions

Innovation districts are becoming an increasingly favourable breeding ground in urban spaces for the development of technology and inventive solutions that address current concerns and enhance the economic ecosystem through knowledge. However, there is a dearth of research that contributes to the evaluation of the performance of these spaces, as a means of ensuring their development in the desired direction and within the allotted timeframe. Although various indicators at the conceptualisation stage, such as placement and innovation district classification, have been analysed, there is still a lack of comprehensive and holistic frameworks to assess innovation districts effectively. This study aimed to build and validate a complete framework to give researchers and decision-makers a valuable instrument.

After discussing the results, several conclusions can be drawn:
First, a framework was established with a multidimensional perspective constituted of four dimensions ('Urban', 'Economic', 'Social', and 'Governance) and 37 indicators (9 belong to the Urban dimension, 19 to the Economic dimension and 6 and 3 to Social and Governance respectively). The Economic dimension proved to be the most helpful, both in terms of score and number of acceptable indicators, while the Governance dimension produced few accepted measures but high rated. The Urban and Social dimensions obtained intermediate values in terms of both the number of indicators and the scores, but they are intensively considered by experts at various stages of the district's evolution (urban indicators) and as a means to attract and retain the qualified talent that is so crucial in this type of ecosystem (social indicators).

Second, the interdependencies between each dimension's indicators can now be expressed. Highlighting the importance of determining how a change to one indicator may affect (increase or decrease) the value of another indicator. This refers to employing a knowledge of interdependencies to make a decision on an action in advance, knowing that it will ultimately benefit another party.

Examining the Urban component revealed that it represented the majority of cause indicators. The majority of indicators of the Economic dimension are effect indicators. The remainder of the Social dimension indicators are effect indicators, with the exception of universities and higher education degrees, which impact employment as the source of educated individuals.

Third, it can be determined from this study that Triple Helix Agents function in each dimension from their perspective, but that all agents must activate the indicators to produce an urban, economic and social transformation:

- The role of the Government is crucial in the Urban dimension, with the Intervention Area (U1) and the Potential Floor (U2), and allowing the Construction of Buildings (U9), for developers' Real Estate Investment (U8). In the Economic dimension, the Government can use Tax Exemptions (E7), promote Urban Clusters (E31), activate the entrepreneurial ecosystem with Incubators (E16) incubating new Ventures (E17), and provide urban labs for Innovation Pilots (E23). The Government can act by promoting the establishment of Universities (S3) and Research, Tech and Innovation Centres (S2) in the ID and developing New Facilities (U14) in the Social dimension. Government also should allocate resources for the District (G1), create hybrid organisations for the Management of the District (G2) and develop strategies of Open Data (G4).
- The role of Universities, and their primary contribution, is to provide the necessary talent and technology to make the area more attractive. The impact of Universities (S3) is measured through a set of indicators that are relevant for providing talent and, on the other hand, providing technology, also coming from Research, Technology and Innovation Centres (S2). Universities also play a key role in promoting Tech and Entrepreneurial Events (E24) and providing facilities like Incubators (E16) in order to incubate new Ventures (E17), helping them to find Investment (E18) and increasing Turnover (E20).
- The role of Industry impacts all the dimensions. In the Urban dimension, Industry is responsible for the Construction of Buildings (U9) (U16) and infrastructure, acting as Real Estate Investors (U8). Moreover, as key players in the economy, Companies (E3), National Companies (E5) or International Companies (E4) will fill the offices with firms (U15), creating new Jobs (E1). Knowledge-based Companies (E12) will be the differentiating factor of Innovation Districts. These companies contribute to innovation ecosystems by interacting with Start-ups (E19) and venture capital Investment attraction (E18). In the case of Civil Society, its role focuses on cultural development and the organisation of extra-professional Social Activities (S13). Involving people, local and International Workers (S9), was seen as critical

to ensuring success; therefore, their participation began to be measured and also used as a strategy to monitor if the planning of housing and services was sufficient or required further investment to meet demand.

Futures research lines can focus on understanding and evaluating the actions and activities of Triple Helix Agents for impacting performance indicators. Also, it could be interesting to analyse the System Dynamics of the components of an ID in order to simulate more accurately the impact of the indicators. Lastly, an analysis of the sources of data for performance indicators will be needed to understand how to implement a Performance Indicators Assessment.

Supplementary Material

A larger version of Table 8 is available online at: https://doi.org/10.6084/m9.figshare.23146064.

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8. ETHICAL ASPECTS

The ethical concerns in research are a collection of ideals that guide the study designs and practises. Voluntary involvement, informed permission, anonymity, confidentiality, potential for harm, and results communication are the main ethical considerations for research. To examine the ethical implications of this research, we must highlight that its theoretical foundations are derived from a variety of views.

First, Triple Helix Theory focuses on determining how Triple Helix actors (Universities, Industry, and Government) contribute to the growth of innovation ecosystems in cities. Second, comprehending Urban Development needs an examination of the urban, economic, social, and governance components of urban development. Thirdly, Clusters of Innovation theory assists in comprehending the components of the Ecosystem of Innovation from the perspective of the interaction between start-ups, venture capitalists, and corporations that contribute to the establishment and growth of high-potential entrepreneurial enterprises. In order to offer four phases of the lifetime of an AOI, the evolution stages of AOIs are based on the lifecycle of a new endeavour (inception, launching, growing and maturity).

This thesis excludes research on the human embryo, foetus, children, patients, genetics, animals, the military, and the potential for terrorist abuse. The ethical components of this research are considerate and consistent with the standards of the European Union's Charter of Fundamental Rights.

In terms of the ethics of the data gathering procedure, it was assured that the acquired data were pertinent and relevant for the objective of giving insightful evidence. In accordance with the European Charter for Researchers and in order to analyse the performance of Innovation Districts in the urban, economic, social, and governance dimensions, the data collecting procedure did not violate any privacy or personal concerns.

Regarding the quality of the collected data, two primary techniques were implemented. On the one hand, to guarantee that information acquired was pertinent (avoiding superfluous details). In contrast, when conducting surveys, the data gathering approach was balanced and non-intrusive, ensuring that the researcher did not influence the findings (Creswell, 2009; Fayolle and Wright, 2014).

Providing each respondent with thorough and comprehensible information about the research as a whole and addressing any potential concerns at the outset and during the study was also crucial. Thus, at the outset of each survey, respondents were briefed about the purpose of the study, the sort of data to be gathered, and the technique for doing so. In accordance with this, experts were provided with an outline of the process and were told about the sort of data that would be gathered using a template (Fayolle and Wright, 2014; Myers, 2009).

Due to the provenance of the data (public) and the manner in which the survey was conducted, there is no ethical risk associated with this study's focus on the type of data (the experts were informed of the aim of the research and the kind of data collected). Neither related with the identity of the experts.

9. DISCUSSION

This chapter seeks to analyse and discuss the relevance of the findings in respect to what was previously investigated from the scientific community about the study problem under consideration, as well as to explain any new understanding or insights that was developed because of this thesis. To accomplish this, the current section is broken into three major sub-sections: (1) Opening sub-section, where research aims, objectives, questions are remembered; (2) Overview of Key Findings, where the main results and methodologies of the research are summarised; and (3) Interpretation of Findings, where how the findings compare to previous research in performance assessment in ID is evaluated and how the Theoretical Background is contrasted with the findings in order to complete the framework proposed.

9.1. OPENING

Innovation Districts are urban areas of innovation. These mixed-use developments, which are physically compact, transit-accessible, and technically wired, also offer housing, office, and retail space (Katz & Wagner, 2014). It is thus of utmost significance that IDs have a tool that not only helps them to aim their efforts and activities toward establishing this urban innovation ecosystems, but also to guarantee that those actions get the district directly to the achievement of its objective over time.

The purpose of this study is to examine how the performance of Innovation Districts can be evaluated (Research Question). For this reason the main objectives of the research focus on: (a) stablish a set of indicators suitable to assess performance in Innovation Districts (Research sub-questions i), (b) define the key dimensions to assess performance in an ID in order to have a comprehensive perspective (Research sub-question ii), (c) analyse the main agents with power of influence over the activities measured by the indicators (Research sub-questions iii), (d) study the relationships between the indicators to analyse the level of impact between them (Research sub-questions iv).

9.2. OVERVIEW OF KEY FINDINGS

The targets mentioned in the previous section (9.1) were achieved by aggregating the findings reported in the three publications. First, article 1 and 2, implementing the case study methodology, provides a set of preliminary indicators in four main dimensions of an ID (Urban, Economic, Social and Governance). Second, article 2, additionally, analyses the main agents (Government, Academy, and Industry -New Ventures, Investors, Corporates-) within the ecosystem that have a bigger impact on the measurements analysed by the indicators (Table 9.2). Third, article 3, applying Fuzzy Delphi and DEMATEL Methodologies, exploiting the information provided in articles 1 and 2, proposes a set of 37 (Table 9.2) indicators that have been evaluated and validated by a panel of worldwide experts as the most relevant to

assess performance in the four main dimensions of an Innovation District (9 indicators belong to the Urban Dimension, 19 indicators belong to the Economic Dimension, 6 indicators belong to the Social dimension and 3 indicators belong to the Governmental dimension). This also included: the rationale for the election of the indicator, the differential value that these selected indicators confer to Innovation Districts, the linkages between indicators (*cause* and *effect*) (Table 9.1 & Figure 9.3), the descriptions and units of measure. The analytic framework of the study reveals and reinforces the worth of a holistic view of these urban innovation areas, including their main assets and interactions, in order to make strategic decisions that boost the spirit of these Innovation Districts and maximise the use of their key resources.

DIMENSION	INDICATOR	UNIT	CAUSE-EFFECT
URBAN			
U1	Intervention Area	sqm	Effect
U2	Potential Floor	sqm	Cause
U8	Real Estate Investment	Eur	Cause
U9	Constructed Buildings	sqm	Cause
U11	Available Floor Space	%	Effect
U12	New Locations	sqm	Cause
U14	New Facilities	#	Cause
U15	Degree of Occupability	%	Cause
U16	Construction Implementation Degree	%	Cause
SOCIAL			
S2	Research, Tech and Innovation Centers	#	Effect
S3	Universities	#	Cause
S8	Higher Education Degree	%	Cause
S9	International Workers	%	Effect
S13	Social Activities	#	Effect
S20	Internships	#	Effect
GOVERNMENTAL			
G1	District Budget	€	Cause
G2	District Management Team Professionals	#	Cause
G5	Indicators in Open Data	#	Cause

DIMENSION	INDICATOR	UNIT	CAUSE-EFFECT
ECONOMIC			
E1	Jobs	#	Effect
E3	Companies	#	Effect
E4	International Companies	%	Cause
E5	National Companies	%	Effect
E7	Tax exemptions	%	Effect
E9	Private investment in companies	Eur	Effect
E12	Knowledge-based companies	#	Effect
E16	Incubators	#	Cause
E17	Ventures incubated	#	Cause
E18	Invesment in Start ups	Eur/Year	Cause
E19	Start Ups	#/year	Effect
E20	Turnover Start Ups	Eur/year	Cause
E23	Innovation pilots	#	Effect
E24	Innovation and tech events	#	Effect
E26	International Events	#	Effect
E29	Publication in Scientific Journals	#	Effect
E30	Intellectual Property	#	Effect
E31	Number of clustered companies	#	Cause
E32	Companies clusterization type	-	Cause

Table 9-1: Set of Key Performance Indicators in Innovation Districts by dimension

DIMENSION	INDICATOR	UNIT	Helix AGENT
URBAN			
U1	Intervention Area	sqm	Gov
U2	Potential Floor	sqm	Gov
U8	Real Estate Investment	Eur	Ind / Gov
U9	Constructed Buildings	sqm	Ind / Gov / Uni
U11	Available Floor Space	%	Ind
U12	New Locations	sqm	Gov
U14	New Facilities	#	Gov
U15	Degree of Occupability	%	Ind
U16	Construction Implementation Degree	%	Ind
SOCIAL			
S2	Research, Tech and Innovation Centers	#	Uni / Ind
S3	Universities	#	Uni
S8	Higher Education Degree	%	Uni / Gov
S9	International Workers	%	Ind
S13	Social Activities	#	Soc / Gov
S20	Internships	#	Ind
GOVERNMENTAL			
G1	District Budget	€	Gov
G2	District Management Team Professionals	#	Gov
G5	Indicators in Open Data	#	Gov

DIMENSION	INDICATOR	UNIT	Helix AGENT
ECONOMIC			
E1	Jobs	#	Ind / Gov / Uni
E3	Companies	#	Ind / Gov
E4	International Companies	%	Ind
E5	National Companies	%	Ind / Gov
E7	Tax exemptions	%	Gov
E9	Private investment in companies	Eur	Ind
E12	Knowledge-based companies	#	Ind
E16	Incubators	#	Gov / Ind / Uni
E17	Ventures incubated	#	Gov / Ind / Uni
E18	Invesment in Start ups	Eur/Year	Ind / Gov
E19	Start Ups	#/year	Ind / Uni
E20	Turnover Start Ups	Eur/year	Ind / Uni
E23	Innovation pilots	#	Ind / Uni
E24	Innovation and tech events	#	Gov / Ind / Uni
E26	International Events	#	Gov
E29	Publication in Scientific Journals	#	Uni
E30	Intellectual Property	#	Ind / Uni / Gov
E31	Number of clustered companies	#	Ind
E32	Companies clusterization type	-	Ind

Table 9-2: Helix Agent by Power of action over the indicator

AREA	INDICATOR	Unit		Intervention Area	Potential Floor	Real Estate Investment	Constructed building	Available floor space	New Locations	New Facilities	Occupancy Rate	Construction implementation degree	Jobs	Companies	International Companies	National Companies	Tax exemptions	Private investment in companies	Knowledge-based companies	Incubators	Ventures incubated	Invesment in Start ups	Start Ups	Turnover Start Ups	Innovation pilots	Innovation and tech events	International Events	Publication in Scientific Journals	Intellectual Property	Number of clustered companies	Companies clusterization type	Research, Tech and Innovation Centers	Universities	Higher Education Degree	International Workers	Social Activities	Internships	District Budget	District management team Professionals	Indicators in Open Data
AREA	INDICATOR	Unit		U1	U2	U8	U9	U11	U12	U14	U15	U16	E1	E3	E4	E5	E7	E9	E12	E16	E17	E18	E19	E20	E23	E24	E26	E29	E30	E31	E32	S2	S3	S8	S9	S13	S20	G1	G2	G5
URBAN	U1	Intervention Area	sqm	1	0,0848	0,1083	0,1019	0,1021	0,1089	0,1012	0,1118	0,1084	0,0986	0,1214	0,1172	0,1136	0,1154	0,0738	0,1045	0,1235	0,1060	0,1121	0,1082	0,1158	0,0978	0,1025	0,1067	0,0965	0,0742	0,0952	0,0976	0,0975	0,1093	0,0910	0,0938	0,0962	0,0881	0,0749	0,0994	0,0982	0,0913
	U2	Potential Floor	sqm	2	0,1171	0,0900	0,1147	0,1120	0,1210	0,1144	0,1211	0,1206	0,1115	0,1349	0,1275	0,1283	0,1332	0,0838	0,1234	0,1423	0,1138	0,1204	0,1194	0,1244	0,1098	0,1131	0,1178	0,1052	0,0829	0,1085	0,1108	0,1078	0,1193	0,0990	0,1018	0,1061	0,1020	0,0831	0,1125	0,1084	0,1031
	U8	Real Estate Investment	Eur	3	0,1224	0,1183	0,0828	0,1132	0,1191	0,1140	0,1205	0,1141	0,1112	0,1310	0,1251	0,1274	0,1293	0,0897	0,1209	0,1381	0,1100	0,1166	0,1184	0,1205	0,1075	0,1049	0,1109	0,1015	0,0794	0,1004	0,1043	0,1043	0,1183	0,0956	0,0969	0,1011	0,0971	0,0813	0,1091	0,1048	0,1084
	U9	Constructed building	sqm	4	0,1135	0,1112	0,1032	0,0777	0,1119	0,1056	0,1102	0,1097	0,1029	0,1243	0,1201	0,1210	0,1228	0,0859	0,1118	0,1296	0,1041	0,1089	0,1064	0,1140	0,1004	0,0977	0,1034	0,0961	0,0750	0,0963	0,0988	0,0973	0,1121	0,0875	0,0904	0,0943	0,0892	0,0771	0,1022	0,0979	0,0984
	U11	Available floor space	%	5	0,1114	0,1077	0,0999	0,0971	0,0811	0,1036	0,1096	0,1107	0,0965	0,1205	0,1179	0,1157	0,1204	0,0763	0,1082	0,1256	0,1006	0,1054	0,1058	0,1134	0,1000	0,0972	0,1058	0,0914	0,0720	0,0929	0,0984	0,0969	0,1099	0,0903	0,0887	0,0925	0,0875	0,0712	0,0973	0,0946	0,0980
	U12	New Locations	sqm	6	0,1131	0,1107	0,1056	0,1044	0,1114	0,0806	0,1127	0,1108	0,0994	0,1270	0,1213	0,1221	0,1225	0,0831	0,1130	0,1323	0,1038	0,1101	0,1106	0,1182	0,1045	0,1033	0,1090	0,0957	0,0760	0,0960	0,0998	0,0983	0,1118	0,0944	0,0913	0,0953	0,0901	0,0735	0,1002	0,1005	0,0995
	U14	New Facilities	#	7	0,1199	0,1172	0,1074	0,1092	0,1135	0,1099	0,0922	0,1176	0,1056	0,1331	0,1273	0,1295	0,1299	0,0870	0,1203	0,1433	0,1123	0,1174	0,1193	0,1242	0,1097	0,1087	0,1132	0,1038	0,0834	0,1072	0,1080	0,1080	0,1221	0,1007	0,0990	0,1003	0,0947	0,0805	0,1067	0,1055	0,1061
	U15	Occupancy Rate	%	8	0,1181	0,1183	0,1129	0,1102	0,1161	0,1125	0,1148	0,0929	0,1052	0,1344	0,1301	0,1307	0,1342	0,0879	0,1220	0,1433	0,1135	0,1201	0,1206	0,1284	0,1123	0,1113	0,1189	0,1094	0,0827	0,1038	0,1135	0,1091	0,1218	0,0972	0,0985	0,1014	0,0972	0,0813	0,1063	0,1081	0,1057
	U16	Construction implementation degree	%	9	0,1137	0,1112	0,1045	0,1062	0,1134	0,1084	0,1148	0,1143	0,0798	0,1278	0,1235	0,1258	0,1276	0,0846	0,1151	0,1377	0,1102	0,1122	0,1127	0,1218	0,1049	0,1052	0,1096	0,0976	0,0746	0,0964	0,1063	0,1048	0,1169	0,0962	0,0930	0,0987	0,0918	0,0735	0,1020	0,0993	0,1029
ECONOMIC	E1	Jobs	#	10	0,1207	0,1104	0,1079	0,1067	0,1169	0,1119	0,1216	0,1197	0,1046	0,1052	0,1311	0,1290	0,1294	0,0831	0,1241	0,1429	0,1132	0,1183	0,1188	0,1237	0,1091	0,1155	0,1186	0,1062	0,0857	0,1081	0,1057	0,1057	0,1245	0,0986	0,1028	0,1100	0,1014	0,0841	0,1058	0,1063	0,1070
	E3	Companies	#	11	0,1257	0,1196	0,1081	0,1128	0,1203	0,1151	0,1252	0,1232	0,1107	0,1365	0,1063	0,1299	0,1363	0,0842	0,1249	0,1457	0,1168	0,1191	0,1255	0,1261	0,1140	0,1205	0,1253	0,1155	0,0929	0,1129	0,1120	0,1105	0,1268	0,1018	0,1059	0,1118	0,1014	0,0867	0,1150	0,1141	0,1146
	E4	International Companies	#	12	0,1286	0,1238	0,1120	0,1167	0,1274	0,1192	0,1295	0,1275	0,1176	0,1415	0,1384	0,1105	0,1397	0,0889	0,1310	0,1525	0,1243	0,1267	0,1287	0,1295	0,1183	0,1235	0,1329	0,1241	0,0979	0,1187	0,1162	0,1177	0,1360	0,1057	0,1113	0,1188	0,1067	0,0899	0,1192	0,1212	0,1203
	E5	National Companies	#	13	0,1210	0,1180	0,1066	0,1113	0,1217	0,1136	0,1220	0,1215	0,1093	0,1360	0,1347	0,1296	0,1056	0,0859	0,1260	0,1452	0,1165	0,1172	0,1178	0,1198	0,1124	0,1174	0,1264	0,1124	0,0915	0,1098	0,1074	0,1089	0,1250	0,1002	0,1015	0,1058	0,1000	0,0854	0,1091	0,1126	0,1131
	E7	Tax exemptions	%	14	0,0810	0,0795	0,0772	0,0759	0,0815	0,0790	0,0822	0,0818	0,0756	0,0877	0,0887	0,0912	0,0926	0,0479	0,0859	0,1019	0,0779	0,0864	0,0853	0,0877	0,0765	0,0764	0,0766	0,0699	0,0643	0,0804	0,0814	0,0828	0,0877	0,0656	0,0639	0,0745	0,0690	0,0550	0,0818	0,0715	0,0811
	E9	Private investment in companies	Eur	15	0,1027	0,0983	0,0933	0,0936	0,0990	0,0986	0,1023	0,1034	0,0977	0,1228	0,1188	0,1194	0,1198	0,0804	0,0927	0,1375	0,1124	0,1232	0,1222	0,1238	0,1099	0,1104	0,1146	0,1041	0,0865	0,1108	0,1067	0,1097	0,1187	0,0893	0,0859	0,0961	0,0921	0,0757	0,1004	0,1026	0,1034
	E12	Knowledge-based companies	#	16	0,1293	0,1230	0,1127	0,1144	0,1193	0,1169	0,1259	0,1269	0,1155	0,1410	0,1365	0,1373	0,1422	0,0955	0,1382	0,1235	0,1270	0,1324	0,1330	0,1367	0,1194	0,1261	0,1325	0,1191	0,1035	0,1244	0,1232	0,1247	0,1371	0,1124	0,1106	0,1153	0,1060	0,0938	0,1201	0,1221	0,1199
	E16	Incubators	#	17	0,1207	0,1173	0,1057	0,1089	0,1181	0,1143	0,1217	0,1228	0,1099	0,1396	0,1351	0,1298	0,1348	0,0891	0,1356	0,1506	0,1001	0,1343	0,1348	0,1369	0,1215	0,1251	0,1328	0,1152	0,0971	0,1235	0,1223	0,1209	0,1299	0,1072	0,1053	0,1129	0,1022	0,0950	0,1146	0,1168	0,1160
	E17	Ventures incubated	#	18	0,1174	0,1127	0,1057	0,1060	0,1134	0,1054	0,1198	0,1195	0,1070	0,1343	0,1300	0,1261	0,1311	0,0837	0,1306	0,1466	0,1241	0,1005	0,1313	0,1347	0,1183	0,1203	0,1250	0,1121	0,0945	0,1174	0,1162	0,1148	0,1293	0,1028	0,1009	0,1069	0,1024	0,0896	0,1100	0,1151	0,1129
	E18	Investment in Start ups	Eur	19	0,1192	0,1131	0,1075	0,1064	0,1138	0,1086	0,1187	0,1213	0,1058	0,1391	0,1347	0,1264	0,1328	0,0868	0,1294	0,1440	0,1287	0,1325	0,1013	0,1349	0,1214	0,1191	0,1266	0,1093	0,0961	0,1191	0,1165	0,1180	0,1281	0,1015	0,0996	0,1072	0,1011	0,0882	0,1058	0,1065	0,1102
	E19	Start Ups	#	20	0,1197	0,1134	0,1078	0,1081	0,1156	0,1104	0,1207	0,1233	0,1061	0,1413	0,1369	0,1286	0,1365	0,0898	0,1330	0,1494	0,1293	0,1332	0,1352	0,1069	0,1234	0,1226	0,1302	0,1142	0,0978	0,1211	0,1184	0,1199	0,1303	0,1033	0,1014	0,1090	0,1014	0,0882	0,1106	0,1143	0,1180
	E20	Turnover Start Ups	Eur	21	0,1146	0,1101	0,1048	0,1050	0,1123	0,1043	0,1126	0,1182	0,1016	0,1341	0,1239	0,1201	0,1250	0,0847	0,1291	0,1417	0,1227	0,1249	0,1269	0,1272	0,0897	0,1146	0,1205	0,1079	0,0922	0,1147	0,1136	0,1136	0,1219	0,1003	0,0970	0,1044	0,1000	0,0875	0,1059	0,1080	0,1103
	E23	Innovation pilots	#	22	0,1099	0,0951	0,0872	0,0890	0,0943	0,0910	0,1005	0,1002	0,0887	0,1181	0,1201	0,1192	0,1210	0,0760	0,1167	0,1311	0,1095	0,1127	0,1162	0,1205	0,1084	0,0847	0,1131	0,1014	0,0900	0,1080	0,1020	0,1022	0,1171	0,0955	0,0937	0,0978	0,0908	0,0793	0,0975	0,1087	0,1049
	E24	Innovation and tech events	#	23	0,1073	0,0984	0,0918	0,0906	0,0976	0,0957	0,1084	0,1066	0,0917	0,1236	0,1224	0,1215	0,1233	0,0740	0,1204	0,1368	0,1205	0,1208	0,1228	0,1273	0,1103	0,1139	0,0925	0,1106	0,0882	0,1053	0,1053	0,1069	0,1207	0,1015	0,0997	0,1039	0,0983	0,0849	0,1051	0,1090	0,1066
	E26	International Events	#	24	0,0954	0,0900	0,0854	0,0842	0,0891	0,0861	0,0979	0,0962	0,0839	0,1101	0,1092	0,1100	0,1071	0,0647	0,1046	0,1195	0,1021	0,1051	0,1070	0,1097	0,0955	0,0988	0,1071	0,0733	0,0812	0,0949	0,0907	0,0923	0,1049	0,0893	0,0876	0,0942	0,0848	0,0680	0,0893	0,0915	0,0891
	E29	Publication in Scientific Journals	#	25	0,0757	0,0723	0,0715	0,0702	0,0728	0,0703	0,0753	0,0766	0,0700	0,0920	0,0886	0,0910	0,0923	0,0606	0,0877	0,1035	0,0873	0,0913	0,0932	0,0939	0,0826	0,0857	0,0874	0,0821	0,0525	0,0898	0,0765	0,0767	0,0909	0,0806	0,0803	0,0775	0,0702	0,0609	0,0737	0,0774	0,0811
	E30	Intellectual Property	#	26	0,1055	0,0938	0,0873	0,0891	0,0944	0,0911	0,1021	0,0989	0,0888	0,1183	0,1188	0,1209	0,1182	0,0791	0,1200	0,1329	0,1127	0,1190	0,1180	0,1223	0,1087	0,1122	0,1118	0,1001	0,0963	0,0826	0,1023	0,0995	0,1174	0,0973	0,0954	0,1009	0,0880	0,0764	0,0961	0,0985	0,1067
	E31	Number of clustered companies	#	27	0,1181	0,1138	0,1069	0,1086	0,1160	0,1124	0,1192	0,1202	0,1066	0,1331	0,1287	0,1281	0,1284	0,0880	0,1247	0,1376	0,1152	0,1219	0,1224	0,1258	0,1082	0,1146	0,1161	0,1051	0,0905	0,1101	0,0879	0,1122	0,1236	0,1005	0,0987	0,1090	0,0958	0,0860	0,1078	0,1068	0,1104
	E32	Companies clusterization type	#	28	0,1127	0,1070	0,1018	0,1020	0,1076	0,1042	0,1137	0,1118	0,1030	0,1242	0,1230	0,1223	0,1226	0,0821	0,1177	0,1344	0,1115	0,1180	0,1184	0,1217	0,1060	0,1094	0,1137	0,1031	0,0878	0,1081	0,1086	0,0843	0,1210	0,0987	0,0970	0,1041	0,0910	0,0818	0,1027	0,1032	0,1054
SOCIAL	S2	Research, Tech and Innovation Centers	#	29	0,1182	0,1135	0,1079	0,1082	0,1142	0,1105	0,1206	0,1172	0,1092	0,1351	0,1337	0,1345	0,1349	0,0872	0,1283	0,1445	0,1217	0,1269	0,1260	0,1309	0,1144	0,1210	0,1271	0,1143	0,1025	0,1210	0,1153	0,1138	0,1028	0,1050	0,1032	0,1091	0,1015	0,0915	0,1137	0,1099	0,1151
	S3	Universities	#	30	0,1250	0,1200	0,1141	0,1144	0,1207	0,1154	0,1230	0,1254	0,1139	0,1443	0,1397	0,1389	0,1409	0,0850	0,1340	0,1511	0,1302	0,1356	0,1347	0,1398	0,1212	0,1279	0,1328	0,1224	0,1083	0,1247	0,1158	0,1188	0,1373	0,0883	0,1154	0,1170	0,1092	0,1000	0,1186	0,1194	0,1216
	S8	Higher Education Degree	%	31	0,1087	0,1014	0,0947	0,0951	0,1006	0,0987	0,1068	0,1079	0,0947	0,1278	0,1252	0,1244	0,1262	0,0753	0,1186	0,1365	0,1170	0,1174	0,1194	0,1224	0,1055	0,1106	0,1134	0,1059	0,0939	0,1094	0,1020	0,1021	0,1234	0,1043	0,0767	0,1052	0,0950	0,0831	0,0989	0,0997	0,1064
	S9	International Workers	%	32	0,0887	0,0837	0,0781	0,0783	0,0842	0,0800	0,0883	0,0880	0,0779	0,1010	0,0960	0,1029	0,0983	0,0659	0,0915	0,1084	0,0908	0,0935	0,0924	0,0950	0,0875	0,0891	0,0971	0,0899	0,0744	0,0884	0,0829	0,0844	0,0978	0,0821	0,0819	0,0653	0,0791	0,0676	0,0787	0,0837	0,0858
	S13	Social Activities	#	33	0,0927	0,0877	0,0834	0,0836	0,0883	0,0884	0,0939	0,0920	0,0832	0,1067	0,1030	0,1039	0,1054	0,0678	0,0999	0,1128	0,0944	0,0958	0,0948	0,0989	0,0897	0,0913	0,0994	0,0874	0,0713	0,0859	0,0836	0,0836	0,1002	0,0779	0,0807	0,0841	0,0627	0,0676	0,0855	0,0829	0,0894
	S20	Internships	#	34	0,0690	0,0661	0,0612	0,0629	0,0666	0,0629	0,0687	0,0669	0,0627	0,0885	0,0838	0,0832	0,0844	0,0530	0,0784	0,0903	0,0740	0,0775	0,0765	0,0799	0,0728	0,0742	0,0770	0,0680	0,0561	0,0663	0,0654	0,0656	0,0742	0,0625	0,0654	0,0666	0,0600	0,0423	0,0721	0,0711	0,0684
GOV	G1	District Budget	€	35	0,1118	0,1076	0,1040	0,0983	0,1083	0,1079	0,1144	0,1080	0,1022	0,1232	0,1176	0,1168	0,1202	0,0875	0,1123	0,1319	0,1166	0,1126	0,1160	0,1237	0,1052	0,1100	0,1188	0,1037	0,0854	0,1042	0,1048	0,1034	0,1170	0,0950	0,0946	0,0958	0,0978	0,0827	0,0821	0,1068	0,1016
	G2	District management team Professionals	#	36	0,1099	0,0982	0,0947	0,0920	0,1004	0,0986	0,1051	0,1046	0,0945	0,1212	0,1216	0,1193	0,1226	0,0816	0,1121	0,1298	0,1136	0,1154	0,1144	0,1190	0,1081	0,1116	0,1174	0,1025	0,0847	0,1044	0,0988	0,1033	0,1169	0,0951	0,0933	0,1004	0,0965	0,0847	0,1078	0,0811	0,1001
	G4	Indicators in Open Data	#	37	0,1091	0,0989	0,0955	0,0928	0,0996	0,0948	0,1042	0,1038	0,0924	0,1188	0,1192	0,1185	0,1202	0,0840	0,1157	0,1303	0,1068	0,1147	0,1166	0,1196	0,1044	0,1048	0,1090	0,1002	0,0887	0,1083	0,1025	0,1026	0,1176	0,0989	0,0971	0,0982	0,0942	0,0765	0,0965	0,1016	0,0810

Table 9-3: Power of Influence among Key Performance indicators in Innovation Districts

9.3. INTERPRETATION OF FINDINGS

This sub-section aims to communicate what the results mean in the context of this study and to contrast the findings with previous studies. For this goal, this module consists of four major components: (1) to discuss how the findings are related with the specific previous studies in performance indicators in IDs; (2) to discuss the main dimensions that must be considered to assess performance in IDs and the main KPI that compound this dimensions; (3) to discuss the different agents that interact in the ID with greater power of action over the indicators and (4) to discuss the level of influence among the indicators in each dimension if the ID.

9.3.1. Key Performance Indicators in Innovation Districts

Analysis of an organization's or administration's performance is a common method for ensuring that the administration is advancing in the intended direction (Caird, et al., 2016). When discussing Innovation Districts, the reasoning is similar, with the particularity that, if this type of district is one of the solutions to current social, economic, and territorial challenges, ensuring its good performance entails ensuring proper solutions to these challenges (Dameri, 2017). For this reason, the issue of innovation district indicators has garnered increasing scientific interest. Addressing to this interest, Yigitcanlar, 2020 and Adu-McVie, 2021, propose indicators for IDs as a set of conceptual attributes to classify Innovation Districts; they have elaborated a three-prong framework that includes: (a) classification by Function, which emphasises the essential functions of Innovation Districts; (b) classification by Feature, which stresses the shared characteristics of Innovation Districts; and (c) classification by Space-use, which focuses on the design, and plans of Innovation Districts, (Yigitcanlar et al., 2020; Adu-McVie et al., 2021). Even when this study helps for the classification of the IDs, according with its characteristics, it still does not provide a comprehensive framework for evaluating the performance. As opposed, the framework elaborated in this thesis confer this exhaustive perspective and focus the aim from the beginning in the performance assessment of IDs, which provides a set of indicators that no only cover all the dimension that an ID has, but also allows to identify the differential value that this urban areas of innovation pursue, and with it, to include it in the strategic plan that managers have to elaborate make to achieve their objectives.

By the other hand, Esmaeilpoorarabi and Kamruzzaman, adopt a different approach and analyse indicators in IDs to define the best characteristics to guarantee assertive emplacement selection of IDs (Esmaeilpoorarabi et al., 2017; Esmaeilpoorarabi & Kamruzzaman, 2018), proposing five research areas: (a) Context indicators, which emphasise regional and city qualities; (b) Form indicators, which emphasise spatial and physical aspects; (c) Function indicators, which emphasise uses-services and socioeconomic aspects; (d) Image indicators, which emphasise personal and perceptual aspects; and (e) Ambient indicators, which emphasise socio-equipment and socio-cultural aspects.

Other study centres indicators on specific elements of performance, such as wellbeing (Orii et al., 2020) or district development activities, such as transportation (Truong & Ta, 2020).

Although all these concepts may be linked to certain strategic choices that the district can make, such as the use of space, opting for a more urban or natural approaches, or the primary functions that the district chooses to concentrate on, such as having a primarily industrial or financial bent; the majority of these measures, however, belong to a specific starting point of the district development and do not enable for a study of evolution, which is required to assess management performance. Furthermore, in order to evaluate performance, more than one dimension is required, and all of them are interconnected and necessitate a comprehensive multidimensional vision. The framework created in this thesis offers this multidimensional character required to make choices not only when establishing a district, but also throughout its growth, allowing to evaluate these areas of urban innovation in all the domains that characterize and differentiate them. A specific approach like the ones elaborated in previous research could be important for the development of specific district activities, but it is not enough when it comes to a holistic performance assessment, which must be linked to the ultimate objectives pursued by these areas.

In more recent research Tan Yigitcanlar and Adu-McVie have expanded the application of their first proposal, classifying Innovation Districts with the set of indicators in context, feature, functions, and spaces use (Adu-McVie, et al., 2022) by applying it into Australian innovation districts. The research cluster 30 innovation districts from Southeast Queensland under three performance levels – i.e., desired, acceptable, and unsavoury – concerning their form, feature, and function characteristics. Although this work provides a framework for the classification of innovation districts, it does not provide Performance Indicators as metrics for the achievement of the goals of the district in all the domains (urban, economic, social and governance). The proposal elaborated in this thesis by compendium of articles, expand the knowledge achieved in this previous works since it not just introduces a wider view in four dimensions, but also analyses the interdependence between the indicators, facilitating this the decision-making process with a greater understanding of the impact of these decisions over all the variables involved. Additionally, this thesis proposes to identify the differential value of the indicators of Innovation Districts in front of other kind of districts, which also makes it possible to understand what value is offered, and how to prioritize it. This information cannot be found in previous studies.

9.3.2. Performance assessment in Innovation Districts requires urban, economic, social, and governance perspectives (Research sub-question i and ii)

Knowledge-based Urban Development Approach

The transformation of a district of innovation implies the activation of assets and agents in the urban, economic, social and governance dimensions, with a holistic approach between all of them (Pique, et al., 2019b).

Under the perspective of Knowledge-based Urban Development (Knight, 1995; Sarimin & Yigitcanlar, 2012), the cases examined through the opinions of the experts revealed that all KBUD dimensions (Urban, Economic, Social, and Governance) are required to evaluate performance in IDs, and as such, they shape this framework in Innovation District performance indicators. In this sense, all the dimensions were deemed necessary because they all contain indicators of relevance, validating the importance of considering all these perspectives when analysing Innovation District performance assessment. Additionally, since the actions are interconnected, it is necessary for decision-makers to have visibility and control over more variables in order to ensure the achievement of their goals.

In the following paragraph of this section, the four dimensions of the KBUD are analysed in detail.

- **Economic Dimension**

The Economic Dimension in Innovation Districts has been analysed in previous research, including the start-ups, companies and clusters (Pique, et al. 2019a; Pique, et al. 2019b), and the KBUD framework incorporates this dimension as one of the key dimensions for developing Knowledge Base Urban Development (Sarimin & Yigitcanlar, 2012). This thesis expands the previous scientific knowledge and go deeper into this economic dimension, identifying and validating with the opinion of the experts (using Fuzzy-Delphi methodology) the set of indicators of relevance.

The results showed that this dimension was the one that contain the biggest number of indicators considered relevant and with the higher scores (19 indicators). Among the four indicators that received the highest scores in this dimension (jobs (E1), investment in startups (E18), companies (E4 and E5), and knowledge-based companies (E12)), it can be observed that there is an emerging need to identify and weight those indicators that demonstrate the distinctive characteristics of these types of districts. It implies, for instances, that it is not only interesting to know how many businesses are located in the area (E3), but also to know how many of them are knowledge-based ones (E12) (differential value). Even while private investment (E9) in firms is of interest, it is much more vital to know which kind of enterprises are being fostered, with a particular emphasis on startups (E19) (differential value). Consistent with the above, the number of Innovation Pilots (E23) was deemed an important indicator because it demonstrates the real activity of what an Innovation District is as a living lab, providing the ecosystem for developing prototypes in real environment. Additionally, it shows that the process of innovation works, that it impacts the territory and that it generates exchange of valuable experiences between agents, this is also aligned with the literature which mention that the intellectual production is the fuel of this knowledge-based economy (Yigitcanlar, 2011). Furthermore, the clustering of companies (E31) was considered a very effective strategy for developing an Innovation District and was therefore given a high score due to it sum up different agents of the same value chain. Furthermore, the presence of distinct clusters (E32) is incorporated into the district's strategy, directing the district's specialization (Differential Value). This reinforces the postulation of Storper and Venables 2004 that highlight the importance of face-to-face interactions, co-presence, and co-location

of individuals and enterprises within the same sector, locality, or region, which facilitates knowledge spill overs and the flow of tacit information in innovation ecosystems.

On the other hand, while the impact on the specific territory is of interest, Local Worker (E2) was not valued highly, even while it is considered relevant that employment be generated, but whether these jobs are occupied by local or foreign people, it is not considered a relevant criterion to assess performance in Innovation Districts, showing this the international tone that this urban areas of innovation pursue to reach it development and maturity, aligned to what was stated by Areas of Innovation Life Cycle Model (Pique et al., 2020). Relocated Companies (E6) have not been recognised as a meaningful indicator to assess performance, because whether new companies are generated or come from outside, the primary aspect is the presence of companies, and what counts is the quality of the company, whether generated or relocated. Furthermore, distinguishing between public (E8) and private investment (E9) is important because public money is needed in the early stages of development to build quality infrastructures in order to create conditions for private investment in the later stages of development. As a consequence, private investment is attracted to build the service layer over the infrastructure layer.

Organizations Using Digital Tools (E11) are now deemed fundamental, rather than a differentiating value, because all competing businesses use them, making it no longer a meaningful sign. For this reason, this indicator has not achieved the relevance required by experts. This could be because organisations that do not use digital tools are not actively engaged in the innovation process.

When addressing Companies with Quality Certifications (E13), it is important to note that they are regarded as a measure that is heavily reliant on national laws and standards. Despite the fact that worldwide standards exist and that each business must adjust to what the market needs in its sector, it is not viewed as a distinguishing element in assessing innovation performance.

In addition, while the findings indicate that an index that measures the number of incubators (E16) must exist, it is also important the output of them, as a consequence, despite the fact that this indicator was approved, Ventures Incubated (E17) got a slightly better score.

Furthermore, measuring the number of Start-ups (E19) it’s important but it also necessary to link it with the success of the new ventures. The Investment in Start-ups (E18) was considered extremely essential because it means investing in a business opportunity to grow and impacts in the creation of jobs and the space needed. Lastly, the turnover of start-ups (E20) was not considered important, with the understanding that, while the income of the business may be low in the early phases, it does not necessarily indicate a failing company.

- **Urban Dimension**

This dimension mainly seeks to convert the land and infrastructure and with it, to provide a platform to the economy, and on the other hand, offering amenities that improve quality of life and thus attract talent to the

district (Sarimin & Yigitcanlar, 2012). Previous research identified Urban Intervention area, Infrastructures, investment in Real Estate and construction of buildings as important factor for the district development in early stages (Pique et al. 2019a; Pique et al. 2019b). With this research, this dimension is analysed in depth, identifying the Key Performance Indicators in Urban development.

The set of indicators identified relevant by experts in this dimension locate this dimension in a second place, considering the number of indicators selected and their scores (9 indicators). When analysing the indicators nominated by experts, higher ratings were given to: Available Floor Space (U11), New Facilities (U14), Potential Floor (U2), Intervention Area (U1), and Degree of Occupancy (U15). The experts express something similar to what was mentioned in the economic field: while it is important to know how much space is available to build or to use as office in the district (Potential Floor (U2) and Available floor space (U11), respectively), it is more important to identify how much of this space is devoted to New Facilities (U14), which are places dedicated to special activities such as business incubators (E16) and other functions that distinguish the district from others and confer a differential value to the district. The facilities are regarded as the main source of development in these areas, hence monitoring them is of utmost significance. In addition, the measurement of New Facilities, which is a predictor of future customer and business potential, is seen as crucial. This is consistent with what the literature reveals, which states that the conditions and surroundings required for city growth associated with knowledge based on talent differ from those required for commodity-based manufacturing (Knight, 1995; Yigitcanlar, et al., 2008f), and that it is critical to provide environments and programmes to facilitate the concentration of creative industries integrated into a supportive social environment (Scott, 2000). This kind of providing draws knowledge-based enterprises, which replace conventional businesses in old industrial areas with huge urban clusters (Hutton, 2004), therefore boosting the concentration of highly qualified people (Florida, 2008).

When debating the indicator that measures the kilometres of Urbanized Street (U3), the findings revealed that it is viewed as a fundamental means rather than a goal, something that must be built into every area from the bottom up, with no extra value to assess performance. Similarly, the kilometres of Optical Fiber (U5) got a better score than the Connected Buildings indicator (U4), despite the fact that it is still deemed basic and is not weighted to evaluate performance. A similar situation occurs with the amount of Wi-Fi points indicator (U6), which was not recognised as pertinent either, because they are features that must be present at all times but do not impart a distinguishing character to the district.

In terms of investment, the experts prioritize the Real Estate Investment (U8) but not the differentiation between foreign investment (U7) or local investment, and it last one (U7) has not exceeded the cut-off level to differentiate between national and international investment.

The Occupancy Rate (U15) of the district's buildings was categorised as a further signal of importance for the urban component. This indicator ultimately gauges how appealing a region is to businesses and if installed capacity is being utilised effectively. At the same time, it can be used as a kind of effective promotion, since a high occupancy rate will make it more appealing to other businesses. Occupancy Rate

could activate the need of construction of new buildings, or if the district is full, the development of new locations.

When it comes to Constructed buildings (U9), this indicator was selected, expressing the square meters that could be offered to tenants, allowing companies or organizations to be settle in the innovation district in new well-equipped buildings. The New Locations (U12) indicator was qualified as highly important, even when it is complex of implementing. It means for instances, given the long-term nature of these initiatives, a static estimation at the outset is extremely difficult to deem accurate. Purchasing these locations for growth too early (by securing in a current land value) risks draining funds from other investments. And, running out of space, having a need to grow, and failing to prepare for it, is a costly mistake. As a consequence, the indicator New Locations is regarded as complicated, yet strategic significant.

Finally, the Green Zones (U13) indicator findings are examined, it can be said that are highly important in any area. However, the idea has become more naturalised, and based on the district's location, it may be more significant.

- **Social Dimension**

Sarimin & Yigitcanlar (2012) included the Social dimension in the KBUD framework in order to provide a holistic approach of the Knowledge Based Urban Development. Previous research included social indicators like housing, amenities and social activities (Pique et al. 2019b). With this thesis, a set of indicators is provided based on the previous literature review, the set of indicators of 22@ and Porto Digital, and the selection by experts using the Fuzzy Model Methodology.

When analysing the Social dimension that seeks to promote professional and personal development (Knight, 1995), 7 indicators were selected. The data in this dimension exhibits a similar scenario than the previous one; the difference worth of this kind of district in the social field rests in the presence of Research and Development Centres (S2) that enable the growth of technology and innovation, as well as the performance of qualified talent in these surroundings (differential value). This is why the associated indicators received the highest ratings (research, technology, and innovation centres (S2) as well as the percentage of professionals in possession of a higher education degree (S8)).

It is also noteworthy to examine how various indicators that were included in Districts of Innovation like 22@Barcelona and that the concept that they measure were pointed as relevant for the development of the knowledge cities in the literature review, such as housing, students in the district's universities, and citizens (Florida, 2002; Pancholi, et al., 2015b, Pancholi, et al., 2015a, Carrillo, 2006), have obtained scores lower than the threshold number of FDM and because of that they are not in the final list of KPIs. As previously said, the social component (Number of dwellings and other amenities that could be offered to increase the quality of life) is crucial in these instances for the recruitment and retention of talent, but experts were divided as to whether the resources to serve these social demands should be located within the innovation

area or nearby. Still, experts concur on the significance of these indicators, therefore their assessment within the district may be viewed as a way to monitor their development. The Social dimension reaches a third place in terms of numbers of indicators selected by experts but the significance of talent for these urban areas of innovation is more and more positively weighted in the literature, which may mean that it should be considered in more detail why if talent is increasingly determining in these areas, the aspects directly related to their quality of life are not weighted so heavily to evaluate performance in innovation districts.

- **Governance Dimension**

The Governance dimension has been analysed in previous research, studying the Management Bodies of the Districts (Pique et al., 2019b). This dimensions also appears in the Cases of 22@ and Porto Digital, emphasising the importance of the consciousness of all the dimensions, the relationship between them, and the need for orchestration of the agents that intervene in the Innovation District.

Being the main roles of the government leadership, generating environments and clear rules that favour exchange and promote participation (Sarimin & Yigitcanlar, 2012), value would be added by the development of direct or indirect measurement that can infer the progress of this role, and to enhance the cross-promotion function of governance. Within the Governance dimension 3 were indicators selected, the indicator with the highest score was District Management Team of Professionals (G2), which measures the number of professionals on the district's management team. Next came the quantification of the District Budget (G1) and the open data indicators (G3). The indicator District Management Team Professionals received one of the highest ratings of all the study. Even so, the governance dimension obtained very few indicators (relative to the other dimensions) but scored exceptionally well (impact). This may exemplify the importance of having a competent management team, but its actions are evaluated on the benefits obtained rather than measuring the actions taken. In other words, if measurement, control, and monitoring are viewed as the first steps in ensuring that an activity works as intended, it will be interesting to ensure first: that there is governance (G2), second, that the number of human resources dedicated to governance are competent and sufficient (in quantity) to meet the needs of the district (G2), and third, that the economic resources are sufficient (G1). Other performance outcomes of governance actions could be measured by the previously mentioned dimensions' indicators.

9.3.3. The Role of Agents implementing the Performance Indicators. (Research sub-questions iii)

Triple Helix Approach

Under the perspective of the Triple Helix concept (Etzkowitz and Leydesdorff, 2000), previous works have analysed the role of the University, Government, and Industry in the Ecosystems of Innovation (Pique et

al., 2018) and the role of Agents in Urban Areas of Innovation (Pique et al., 2019a; Pique et al., 2019b). This Thesis goes forward analysing the role of the agents in relation of performance indicators in Innovation District, investigating the leadership with greater power of action among the indicators of all the dimension. For instance, the government presents a greater role in the management and power of action over the activities that measure the indicators of the urban environment, or the industry that acquires a more leading role when it comes to economic variables. In this line, all the agents proposed by the Triple Helix theory have been validated as relevant for the performance indicators.

In the following paragraphs of this section, all the agents of the Quintuple Helix (Carayannis et al., 2012) and Cluster of innovation (Engel and Del-Palacio, 2009) theories are analysed in detail in relation of their role in the Performance indicators in Innovation Districts.

- **The Role of the Government**

According to the preponderance of the different actors in the development of an ID (Pique et al., 2019a; Pique et al., 2019b), it is observed that the government played a leading role at the beginning of the district's evolution route, particularly in urban planning, defining the Intervention Area (U1) and the Potential Floor (U2) and the development of infrastructures. Facilitating the legal processes for Constructing Buildings (U9) and clarifying the rules with transparency and legal stability to Real Estate Developers (U8). In more advanced phases, when there was a high degree of Construction Implementation (U16) and the level of Occupancy (U15) was elevated or other zones of the city needs for urban regeneration, the Government explored New Locations (U12). Additionally, the Government allowed the development of the district with amenities in order to become the area more attractive. This demonstrates that the government's power of action is predominant in the urban dimension. As opposed, Housing, Hotels and Residences for Students were important issues that have not passed the Fuzzy Delphi filter.

In the Economic Dimension, the Government introduced Tax Exemptions (E7), promoted the smart specialization thorough different types of Urban Cluster in the ID (E32), and encouraged the Clusterization of Companies (E31). In terms of the entrepreneurial ecosystem, Government participated by creating Incubators (E16), incubating new Ventures (E17), and providing urban labs for testbed of Innovation Pilots (E23).

The government was also the main driving agent for social development in the initial stages, therefore, actions undertaken were directed towards increasing and improving the number of Universities (S3) and Research and Tech Centre (S2) (Rapetti et al., 2022a). Also, providing New Facilities (U14) for the community and infrastructures for Universities (S3) (differential value).

In terms of the Governance, the Government allocated and mobilised resources for the development of the district (G1), creating organisations or units like 22@Barcelona or Núcleo Gestor do Porto Digital (NGPD)

with professionals dedicated to the management of the district (G2). Strategies of Open Data (G4) can stimulate the creation of new ventures in the district.

- **The Role of Universities**

Concerning the role played by academic institutions, the main contribution in the initial stages consisted of providing the right talent and technology to make the area attractive (Pique et al., 2018).

Universities (S3) related indicators are reflected in the social dimension and measured through a set of indicators that are relevant to provide talent, from internships (S20) to educated people with Higher Education Degree (S8) (differential value). The Number of Students didn't pass the threshold of the FDM (Rapetti et al. 2023). On the other hand, universities provided technology, coming also from Research and Technology Centres (S2) (differential value), writing Publications on Scientific Journals (E29) (differential value) and protecting new ideas and businesses with Patents and Intellectual Property (E30) (differential value).

Universities played a key role, promoting events of Innovation, Tech and Entrepreneurial events (E24) and providing facilities like Incubators (E16) in order to create startups (E17), helping them to find investment (E18) in order to grow (E20).

- **The Role of the Industry**

The industry came into play in all the dimensions of the ID. In the Urban Dimension (Pique et al., 2019b), Industry was in charge of the construction of buildings and infrastructure (U9, U16), acting as Real Estate Investors (U8).

As key player in the Economy, Companies (E3), Nationals (E4) or International (E5) fulfilled the offices with firms (U15) creating new Jobs (E1). Knowledge-based Companies (E12) were the differentiation (differential value) of Innovation Districts.

The industry participated in the Entrepreneurial Ecosystems which in turn, triggered the creation of startups (E19) (differential value), attracted venture investment (E18) (differential value), and contributed to corporate innovation and the establishment of a formalised ecosystem of innovation.

- **The Role of the Society**

Society, as a quadruple helix agent (Carayannis & Campbell, 2009), oversees cultural development and the organisation of social events (S13) beyond professional life. Involving local people and foreigners (S9) in these social activities was seen as critical factor to ensure success, therefore, their participation began to be

measured. This indicator is also important for determining if the design of housing and services was sufficient or whether further investment was necessary to fulfil demand.

Although Talent is mentioned in the literature as a key resource of the Knowledge Based Economy (Florida, 2002), the experts prioritise other indicators instead of Students in District Universities (S6), Students of Primary and Secondary Schools (S7) and Students of Long-Life Learning Programs (S12) or Professional Woman in the Districts (S17). The indicator that measures the number of Citizens (S1) didn't pass the filter of FDM neither.

- **The Role of the Environment**

As a demand side of the Quintuple Helix, the Environment (Carayannis, et al., 2012) connects with the sustainability of the district. In the case of 22@, the indicator Green Zone (U13) was detected, but didn't pass the threshold of the FDM. In the case of Porto Digital (Rapetti et al., 2022b), the indicator Renovated Building (U10) was identified, but didn't get enough recognition from the experts. At the end, as the data of the analysis comes from the literature review and the activity of the cases from 2000 until 2020, the movement of sustainability promoted by United Nations with the Sustainable Development Goals (UN-General-Assembly, 2015) was not included as performance indicators in 22@ and Porto Digital. IASP included in the World Conference 2022 (IASP, 2022) this dimension as debate for the practitioners of Science Parks and Innovation Districts. No indicators of Sustainability are included in the final list of Performance Indicators of this study.

Clusters of Innovation

This study also serves to provide new evidence of the role of the component of the clusters of innovation (COI) theory (Engel, et al., 2018) in the Performance Indicators of ID. Innovation Districts, as part of city, behave as a COI.

- **Core Components**

If we look at the core components of a COI (Engel, 2022), they are all covered, with specific indicators to capture their breadth and depth:

  - Major corporations and entrepreneurs are active actors throughout the lifetime of the ID. Specifically, big organizations are incorporated in a set of indicators in the economic dimension as Companies (E3), International Companies (E4), National Companies (E5) and Knowledge-Based Companies (E12).
  - Entrepreneurs are measured in startups associated indicators as number of Incubators (E16), number of new Startups incubated (E17), Investment in Startups (E18), Number of Startups (E19), and Turnover of Startups (E20).

- Venture capital indicators are always active in the economic dimension. See, for example, private investment in companies (E9) and investment in startups (E18).

- **Supporting Components**

Regarding supporting components beyond Government and University (explained before), COI needs:

- Supporting professionals, such as attorneys and accountants specialising in entrepreneurial matters, specific indicators in this case was not identify, but professional in possession of higher education degree (S8) could represent this requirement.
- Professional managers of startups are indirectly related with Professionals in the district who work for national and international corporations (E3, E4, E5).

- **Hybrid Components**

COIs are also distinguished by their hybrid components (Engel, 2022). These elements have manifested as described below:

- Incubators (E16), Clusters (E31 and E32) are specific indicators to measure the presence of such hybrid components.
- Corporate Venturing Capital (CVC) and Business Angels: the indicators found do not differentiate between private investment (E9) in terms of CVC, Venture Capital and Business Angel investors.
- Public VC: public investment in companies includes grants as well, which impedes a more detail information on public VC. No indicators in this issue pass the Fuzzy Delphi filter.
- Service organisations and corporate foundations: there are no metrics that capture information on these types of groups (often charities and a mix of governments and significant corporations) that provide general assistance for the innovation process.

- **Behaviours among the Components**

Finally, COIs integrate a set of behaviours between the components (Engel & Del-Palacio, 2009). These behaviours are nearly all prevalent in IDs and can be captured by some of the proposed framework's indicators:

- Entrepreneurial process: innovation pilots (E23) is the unique indicator that offers some insight into the subject. Although there are indicators related to infrastructures that support entrepreneurship (such as Incubators – E16), indicators that capture more specific information for this category, such as the number of serial entrepreneurs, the number of failed projects, and

the number of grants awarded, were not identified (and from these the successful ones and the failed ones).

- High mobility of resources: A) People: no indicators connected to workforce turnover or others were discovered. B) Capital: Success rates of private investment (volume, number, series) and grants received could provide more information on the mobility of resources. C) Technology: Regarding technology mobility, several indicators such as Innovation and Tech events (E24) outside the usual Tech Transfer from Deep Tech Research (E29) incorporated in Intellectual Property (E30).
- Alignment of interests: The participation of multiple ecosystem actors is difficult to measure and does not appear in any one metric. Variation in the budgets allocated by government, industry, and academic institutions for actions to create innovation ecosystems is a metric that would be useful for establishing interest.
- Global perspective: International firms (E4), international events (E26), and international workers (S9) are a few of the indicators that demonstrate the ID's focus on global participation. In the case of the metric foreign direct investment (U7) didn't pass the FDM filter.
- Global linkages: no indicator was discovered that addresses more formal ties, such as number of collaborative international projects, memorandums of understanding with international organisations, soft-landing plans.

9.3.4. Relationships between indicators are essential information for the prioritisation of actions (Research sub-questions iv)

Regarding the level of impact between indicators in each dimension (urban, economic, social and governance), it is essential to consider how a change made to one indicator might affect (increase or degrade) the measure of another indicator. Which may also be employed in the opposite direction, it means, to utilise this interdependencies knowledge in advanced to make a decision over one action, knowing that it would eventually benefit another.

In paper 2 were analysed the stages where the indicators are activated as a first approach. The paper 3 upgrade this view analysing the interconnections between the indicators and their interrelations as a deeper understanding of the activation of the indicators in relation with the others. The discussion focusses on this last concept understanding that these connections also incorporate the evolution of the districts but with a more conclusive approach.

In the following paragraphs the four KBUD dimensions (Knight, 1995; Sarimin & Yigitcanlar, 2012) are analysed in detail.

- **Urban Dimension**

When considering the urban dimension, it was possible to see that it provides in majority *cause indicators*. The strongest *cause indicators* in this dimension are the Real Estate Investment (U8) and the Construction Implementation Degree (U16), which primarily affects the indicators that measures the number of Jobs (E1) and the number of Knowledge-based companies (E12) which have direct effects on economic activity. Beyond the role of real estate investment in stimulating the economy, it is essential to note that since the focus in these Innovation Districts, in the urban dimension, is on the development of hard factors to attract knowledge-based businesses (E12), new ventures (E17), and trained individuals (S8); ultimately, real estate investment is indirectly related to the attraction and retention of qualified individuals. This "*cause indicators*" trend is followed by the Potential Floor indicator (U2), which defines the area available for building linked directly to the Constructed Building indicator. Additionally, the Available Floor Space (U11) may be observed a consequence of the Constructed Building and the New Locations (U12) and concurrently affect the Occupancy. This places the indicator that assesses the district's expansion potential (New Locations (U12)) in a dual position. All of this validate what was express in previous research, which postulate that the urban layer is the base that create the conditions to enterprises and services to grow and that offer the quality of services required for the qualified talent to choose to stay and settle in a region (Pareja-Eastaway & Pique, 2011), which in the end subscribes the connection between the urban sphere and the economic and social ambits.

- **Economic Dimension**

The preponderance of indicators of economic dimension are *effect indicators*. Jobs (E1), private investment (E9), and knowledge-based companies (E12) are the most influenced by others. In the case of Jobs, is mostly influenced by the creation of startups (E19) and the number of universities (S3), it can then be expected that if the innovation district seeks to increase the number of Jobs (E1), a good strategy can pursue to work on the number of startups (E19) and qualified personnel (S3) it generates.

By the other side, private investment is directly and substantially connected with the number of Knowledge-based enterprises (E12), incubators (E16), universities (S3), and startups (E19). Indicating that the private investment will rise if any of the others are increased.

Additionally, Incubators (E16), Incubated ventures (E17), and Startups Investment (E18) are the ones that are mostly considered *causes* of other *indicators*. This is explained by the fact that the greater the number of incubators, incubated ventures, and investment in startups, the greater the number of startups and private investment in the district's businesses.

All of this provides evidence that support the Clusters of Innovation (COI) Statements which proposes that the emergence of rapidly expanding startups is significantly spurred by the behaviours of COI components (Engel & Del-Palacio, 2009), where the disruptive market potential of new business models held by

dynamic entrepreneurs is funded by venture capitalists and/or major corporations in a win-win situation. Relevant players, such as the government, universities, management (professional managers of startups), and professions (high qualified personnel from Universities), play an enabling support role for the interaction of the core components (Engel & Del-Palacio, 2009; Engel & del-Palacio, 2011; Engel, 2015).

On the other hand, the Number of Clustered Firms (E31) and the Number of Cluster Types (E32) are factors in the attractiveness of companies to the district, therefore, if the cluster is already mature, the district will be more appealing to new corporates to come. Again, here the COI theory is reinforced when state that the interaction between companies of the same sector or between other clusters allow them to benefit from shared ideas and information as well as the movement of people and resources, so creating a beneficial environment and new opportunities that attracts other firms to the district, and with this the connection and influence of the cluster over the number of companies (E12). Additionally, in this (Global) Network of COIs, interactions can range from ephemeral contacts to more enduring bonds anchored in contracts and formal partnerships, or, in a more extreme form, two COIs can function in a completely integrated way (Engel & Del-Palacio, 2009; Engel & del-Palacio, 2011).

Finally, in the case of turnover of Startups (E20), according to the data, it can be considered a strong *cause* of other indicators such as Jobs (E1) and Investment in Startups (E18). This could be explained by the fact that the greater the return on investment of a business (startups), the greater the number of jobs it could generate, and additionally, these businesses are more attractive to investors.

- **Social Dimension**

The majority of social dimension indicators are *effect indicators*, with the exception of universities (S3) and higher education degrees (S8), which influence the number of employment (E1) since they are the source of educated people. This underlines the talent as a primary resource of knowledge-based economy (Carrillo, 2006) and the role of universities as the source of this talent (Pique et al. 2018).

On the other hand, the Research, Technology and Innovation Centre (S2) has a higher level of both *effect and cause factors*, as it promotes knowledge-based businesses (E12) and intellectual property (E30) and is the result of the decision of Universities (S3) and International Companies (E4) to locate their innovation centres in the district (S2). In this case, this validation reinforces the R&D&I Centres as source of the Technology as one of the key resources of the Ecosystems of Innovation (Engel and Del-Palacio 2009) and on the other hand, it emphasises how this Centres are anchors agglomerations that attract other Centres, Universities and Companies to the IDs (Pique et al., 2019b).

- **Governance Dimension**

Indicators of the governance dimension are mostly *cause indicators* because they give the District Budget (G1) and District Management Team Professionals (G2) necessary for the district's development. It

underlines the importance of a management team with a budget that could coordinate and activate the agents of the ID (Pique et al., 2019a). This professional team is responsible not only for executing their own budget but also for encouraging the agents of the district to work with a common purpose. They influence mostly economic indicators such as Jobs (E1), Companies (E3), Private Investment (E9) and Knowledge-based companies (E12). This governance dimension evolves during the development of the ID, from promoters of the IDs managers, up to the creation of a Triple Helix Governance in the District of the Self-Orchestration of the Innovation Districts (Pique et al. 2021).

10. CONTRIBUTIONS

The present work seeks to address the gaps identify in the literature and provides significant contributions as:

1. **Holistic framework of 37 performance indicators in Innovation Districts is developed.** First, this thesis extends the limited research on the understanding of performance assessment in Innovation Districts, by developing a holistic framework of 37 performance indicators in the four main dimension of the KBUD (Urban, Economic, Social and Governance), validated by a panel of experts through Fuzzy Delphi methodology (Rapetti, Pareja-Eastaway, Pique and Grimaldi, 2022; Rapetti, Pique, Figlioli and Berbegal-Mirabent, 2022; Rapetti, Pique, Etzkowitz, Miralles and Duran, 2023). This answers the gap to define the key dimensions to assess performance of an ID in order to have a comprehensive perspective (Research sub-question ii) and stablish a set of indicators suitable to assess performance in these dimensions (Research sub-questions i) (Table 9.1).

2. **The different agents of the Triple Helix and Clusters of innovation have an impact over the performance indicators in Innovation District.**
   Second, the main agents (Academy, Government, Industry-New Ventures, Investors, Corporates-) have a direct power of action (level of influence) over the indicators analysed (Table 9.2). And insightful information to learn about the role of each one in order to contribute to the understanding of IDs performance is provided (Rapetti, Pareja-Eastaway, Pique and Grimaldi, 2022; Rapetti, Pique, Figlioli and Berbegal-Mirabent, 2022). This answers the gap to analyse the main agents with power of influence over the activities measured by the indicators (Research sub-questions iii).

3. **Relationships among performance indicators in Innovation Districts and cause/effect classification is established.**
   Third, the relationship between the Performance Indicators in Innovation Districts was proposed and validated by a panel of experts through DEMATEL methodology. The conditions of the indicators as cause or effect of others were stablished and analysed (Rapetti, Pique, Etzkowitz, Miralles and Duran, 2023) (Table 9.2 and 9.3). And the indicators that confer the differential value to these IDs were identified. This answers the gap to study the relationships between the indicators to analyse the level of impact between them (Research sub-questions iv).

4. **Two study cases of performance indicators (22@Barcelona and Porto Digital).**
   Four, the first two papers of this work contribute to empirical literature with two study cases and a in deep analysis of key performance indicators (Rapetti, Pareja-Eastaway, Pique and Grimaldi, 2022; Rapetti, Pique, Figlioli and Berbegal-Mirabent, 2022).

11. CONCLUSIONS, LIMITATIONS AND FUTURE LINES

11.1. CONCLUSIONS

Innovation Districts (IDs) are unique ecosystems development initiatives applied in urban environments that have significant influence in aspects other than district economic growth – via entrepreneurship, education, and innovation programmes – such as the social and urban dimensions. Both policymakers and academics have shown interest in IDs aimed to transform deteriorated areas into thriving centres.

By providing specialised facilities and infrastructures, these knowledge-intensive districts promote the concentration of creative enterprises integrated into a supporting social context. This draws knowledge-based industries, which replace traditional businesses in old industrial areas of large urban clusters, hence increasing the concentration of bright talent.

These multidimensional Innovation Districts are composed of a complex web of interconnected agents, each district with its own distinct strengths and weaknesses that must constantly adapt to new situations, creating the ongoing challenge of developing new strategies. Understanding how an ID can evolve and grow based on these agents is the beginning point for the ID to achieve its vision and goals, which can be accomplished by improving its strategy. Developing a strategy, enables determining where and when to invest, defining a unified plan across all agents and activities, and uncovering new possibilities for development and progress.

Evaluating an ID's major agents and activities is the first step in creating a strategy for long-term success and building a collection of interconnected metrics is the appropriated action to do so. Indicators reveal how an ID is changing and progressing towards a particular goal.

Indicators within Innovation Districts have been the subject of scientific research. Nonetheless, such research focuses on more fundamental aspects of the field, such as: classification, best emplacement, and singular characteristic of performance as transport or well-being. But lacking to date in the research literature is a holistic framework for analysing the performance indicators in all the dimensions of an Innovation District.

This thesis provides a holistic framework for assessing the performance of Innovation Districts, therefore contributing to the reduction of the knowledge gap. It has been founded on the conceptual frameworks of the Knowledge-Based Urban Development paradigm, the Triple Helix model, the theory of Clusters of Innovation, the Lifecycle Model of an Innovation Area, and the Performance indicators underpinning. In addition, supplementary insights from the Quadruple and Quintuple Helix Models have been demonstrated to contribute to the comprehension of these cases.

Using the Case Study approach, two international Innovation Districts reference cases have been analysed. This initial set of indicators was upgraded with the literature review and validated with Fuzzy Delphi and DEMATEL methodologies, resulting in several conclusions:

First, it has been possible to establish a framework with a multidimensional perspective composed of 4 dimensions: “Urban", "Economic", "Social" and "Governance", with 37 indicators: 9 belonging to Urban dimension, 19 to Economic dimension and 6 and 3 to Social and Governance respectively. The economic component proved to be the most important, both in terms of score and quantity of approved indicators, however the Government dimension generated few accepted measures they have been highly scored. The Urban and Social dimensions attained intermediate levels in terms of both the quantity of indicators and the ratings and provide the basic measures that contribute to fulfil the holistic approach. Among all the indicators with high scores, it is evident that there is an emerging need to identify and weigh those indicators that demonstrate the unique qualities of these sorts of urban areas of innovation (ID). In other words, indicators that form the identity of these locations and confer differential value on them.

Second, it has been possible to express the interdependencies between each dimension's indicators. Pointing out the fact that it is crucial to evaluate how a change in one indicator may impact (raise or decrease) the measurement of another indicator. Upon examining the urban component, it became apparent that it provided a majority of *cause indications*. The strongest cause indicators in this dimension are Real Estate Investment (U8) and Construction Implementation Degree (U16), which largely influences the indicator measuring the number of Jobs (E1) and the number of Knowledge-based firms (E12) and has direct impacts on economic activity. The majority of economic dimension indicators are *effect indicators*. Among the strongest correlations, we can find that Jobs (E1), Private Investment (E9), and Knowledge-based Companies (E12) are the most influenced by others. In the case of Jobs, the formation of startups (E19) and the number of universities (S3) have the greatest impact over the number of workers (E1). The amount of Knowledge-based Companies (E12), Incubators (E16), Universities (S3), and Startups (E19) has a direct and strong relationship with the Private Investment (E9). The biggest part of social dimension indicators are *effect indicators*, with the exception of Universities (S3) and Higher Education Degree (S8), which influence employment (E1) as the source of educated individuals. The Research, Technology, and Innovation Centre (S2) has a higher level of both *effect and cause* factors, as it promotes Knowledge-based Companies (E12) and the Intellectual Property (E30) and is the result of Universities (S3) and International Companies (E4).

Third, regarding the agents in relation with the indicators found, it can be deduced that several agents operate with different action of power over the indicators in each dimension, but all of them are required to generate urban, economic, and social transformation. The Role of the Government is key in the urban dimension, defining the Intervention Area (U1) and the Potential Floor (U2), and allowing the Construction of Buildings (U9) with the Investment of the Real Estate Developers (U8). Also, the Government can impulse New Locations (U12) depending on the level of Construction Implementation (U16) and the degree of Occupancy (U15) or the need for urban revitalization in other zones. In the economic dimension, the Government can generate Tax Exemptions (E7), promote Urban Clusters (E32) (E31), provide urban labs for Innovation Pilots (E23) and activate the entrepreneurial ecosystem with Incubators (E16) which generates new Ventures (E17). The government can act by promoting the landing of universities (S3) and

Research and Tech Centre (S2) in the ID and developing New Facilities (U14) in the social dimension. Government also should allocate resources for the district (G1), create hybrid organizations for the district management (G2) and develop Strategies of Open Data (G4). Regarding the role played by Universities, the main contribution is the provision of the right talent and technology, to make the zone more attractive. The impact of Universities (S3) is measured through a set of indicators that are relevant for providing Talent for internships (S20) or people educated with Higher Education Degree (S8) in the ID. On the other hand, University is providing technology, that also comes from Research and Technology Centres (S2), writing Publications on Scientific Journals (E29) and protecting new ideas and businesses with Patents and Intellectual Property (E30). Universities also play a key role, promoting Tech and Entrepreneurial events (E24) and providing facilities like Incubators (E16) in order to create New Ventures (E17), helping them to find investment (E18) in order to increase turnover (E20). The Role of the Industry came into play in all the dimensions. In the urban dimension, Industry is in charge of the Construction of Buildings (U9) and its degree of implementation (U16), acting as Real Estate Investors (U8). As key player in the Economy, Companies (E3), Nationals (E4) or Internationals (E5) will fill the offices with firms (U15) creating Jobs (E1). Knowledge-based Companies (E12) will be the differentiating factor of Innovation Districts. These companies contribute to innovation ecosystems by interacting with Startups (E19) and venture capital investment (E18). In the case of Civil Society, its role focuses on cultural development and the organisation of extra-professional social activities (S13). Involving people, local and international (S9) was seen as critical to ensuring engagement; therefore, their participation began to be measured and it was also seen as a strategy to monitor if the planning of housing and services was enough or required further investment to meet demand.

For all the research, we have written three articles that accomplish the requirements for a Thesis by Compendium of Publications.

11.1.1. CONCLUSIONS OF THE RESEARCH QUESTION

This subsection seeks to summarize and group all the research sub questions so that their conclusion is clear.

Research Question: How can Innovation Districts be assessed on their performance?

The evaluation of the performance in Innovation Districts requires a holistic perspective in Urban, Economic, Social and Governance dimensions. For this purpose, it is necessary to analyse and establish a set of indicators in each of these dimensions, as well as the relationship between them and the main agents with power of action, to ensure the achievement of the objectives established for the development of the innovation district. This work has analysed a set of relevant indicators in two internationally recognized case studies and has selected the most outstanding indicators recognized by experts using the Fuzzy Delphi method. Finally, with the objective of analysing the dependencies between the indicators, the DEMATEL method has been applied to examine the cause-effect relationships. The responses to the research sub-questions are detailed below to give the detail required by the original question.

i. *Research sub question i: What are the key performance indicators for Innovation Districts?*
   Applying the Fuzzy Delphi Method, it was feasible to create a framework with a multidimensional viewpoint comprised of four dimensions: "Urban", "Economic", "Social", and "Governance", with 37 indicators: 9 for the Urban dimension, 19 for the Economic dimension, and 6 and 3 for the Social and Governance dimensions, respectively. The economic component proved to be the most significant, both in terms of score and number of recognised indicators, while the government dimension produced few accepted measures that were highly valued. The Urban and Social aspects achieved intermediate levels in terms of both the number of indicators and the ratings, and they offer the fundamental measurements that contribute to the holistic approach's fulfilment. Table 9.1 shows the indicators for each dimension.

ii. *Research sub question ii: How can the KBUD theory help to clarify the key dimensions of the performance assessment process in Innovation Districts?*
   The transformation of an innovation district necessitates the activation of assets and agents in the urban, economic, social, and governance dimensions, with a holistic approach among all of them (Pique et al., 2019b).
   According to the Knowledge-based Urban Development (KBUD) perspective (Knight, 1995; Sarimin & Yigitcanlar, 2012), the cases examined through expert opinions revealed that all KBUD dimensions (Urban, Economic, Social, and Governance) are required to evaluate performance in IDs, and as such, they shape this framework in Innovation District performance indicators. In this regard, all dimensions were judged important since they all include relevant indicators, proving the need of taking into account all of these viewpoints when assessing

Innovation District performance evaluation. Furthermore, because the activities are interrelated, decision-makers must have awareness and control over additional factors in order to fulfil their objectives.

iii. *Research sub question iii: Does the Triple Helix Model (University-Industry-Government) and Clusters of Innovation help to understand the main agents with power of action over the activities/concepts that the indicator measures?*

From the perspective of the Triple Helix concept (Etzkowitz and Leydesdorff, 2000), previous work examined the role of the University, Government, and Industry in the Ecosystems of Innovation (Pique et al., 2018) and the role of Agents in Urban Areas of Innovation (Pique et al., 2019a; Pique et al., 2019b.) This Thesis advances study by investigating the leadership with more power of action among the indicators of all dimensions with their actions and activities in the Innovation District.

The Role of the Government is key in the urban dimension, defining the Intervention Area and the Potential Floor, and allowing the Construction of Buildings with the Investment of the Real Estate Developers.

Regarding the role played by Universities, the main contribution is the provision of the right talent and technology, to make the zone more attractive.

The industry came into play in all the dimensions of the ID. As key player in the Economy fulfilled the offices with firms creating new Jobs and participated in the Entrepreneurial Ecosystems which in turn, triggered the creation of startups, attracted venture investment, and contributed to corporate innovation and the establishment of a formalised ecosystem of innovation.

iv. *Research sub question iv: What kinds of linkages or interdependencies exist between these indicators? And how does one indicator's action effect or have an impact on another?*

Applying DEMATEL method, a cause-and-effect relationships was developed among the indicators selected, providing an understanding if the mutual influence of the indicators. And it has been possible to express the interdependencies (cause/effect) between each dimension's indicators. Pointing out the fact that it is crucial to evaluate how a change in one indicator may impact (raise or decrease) the measurement of another indicator. Table 9.2 and 9.3 show the linkages resulted for each dimension and indicator.

11.2. LIMITATIONS AND FUTURE LINES

This thesis has advanced scientific knowledge by providing a comprehensive set of Key Performance Indicators for Innovation Districts (IDs) in the Urban, Economic, Social, and Governance dimensions, as well as their relationship. After an in-depth literature review analysing what science has to say about Performance Indicators in IDs, a case study approach was implemented, examining two global reference Innovation Districts (22@Barcelona and Porto Digital) in order to propose a preliminary framework for assessing performance in IDs. Then, using the Fuzzy Delphi and DEMATEL methodologies, a panel of experts was able to select a set of thirty-seven indicators as the most relevant to assess the performance in IDs, the level and direction of influence among the indicators and the differential value conferred by these urban areas of innovation.

Although this thesis gives valuable insights into the study of Innovation Districts, we have found some limitations and restrictions, which reflect future research directions.

First, this thesis has worked using the case study methodology implemented in two cases, 22@Barcelona and Porto Digital, for extracting the first set of performance indicators in innovation districts. Even when they are international references of knowledge based urban transformation, more cases could be analysed in order to compare with the indicators found. Further research lines could increase the number of cases by analysing the set of indicators for all of them and comparing the ones that were applied to assess performance.

Second, 22@Barcelona and Porto Digital were brownfield transformation cases, which means old urban areas transformed into new Innovation Districts. Future research lines could analyse greenfield transformations, projects that are starting from scratch, in order to understand what performance indicators are needed in this kind of transformation, studying the comparison between brownfield and greenfield.

Third, this thesis has provided a set of performance indicators and their interdependencies in Innovation Districts, using FUZZY DELPHY and DEMATEL Methodologies. Future works could investigate the application of other theories, like the Theory of System Dynamics, in order to understand the behaviour of complex systems through identifying and simulating the dynamic structure that underlies comportment.

Fourth, this research provides a set of indicators, but does not study how to gather the data to calculate the indicators. Future lines might explore how to generate and collect the information for the measurements that the proposed indicators would assess. In this vein, it will be useful that future research provide guidelines of how the information will be collected, where this data is, when it can be collected, and who can be the provider. It will also help to verify the applicability of this set of indicators, understanding applicability in this case, as something that can be used, and the biggest challenge for its implementation and use lies in obtaining the data to calculate the indicators.

Fifth, this work sheds light on the relationships between the indicators and their moment of activation, analysing the case of Porto Digital. Future research lines can analyse in depth, by adding more cases or

quantitative methods, the moment when every performance indicator is necessary in the Innovation District lifecycle evolution.

Sixth, this research has provided a framework for analysing performance indicators of Innovation Districts independently. There is a challenge in comparing different Innovation Districts, for instance, with different sizes or starting points, just based on the indicators provided in this thesis. Future research lines could provide a mechanism for comparison between IDs by establishing ratios and classifications between the indicators that allow performance comparisons between districts.

Seventh, performance indicators are the result of the activities of agents that provide outputs and outcomes to the innovation districts. This research has identified the agents with more power of action in every performance indicator. Future lines could analyse what kinds of activities could be developed in order to impact performance indicators, and in this vein, comparing the activities that can impact one specific performance indicator, what actions are more effective and efficient for the achievement of the goals of this specific indicator, in order to evaluate all the performance indicators of all the Innovation District.

Eighth, this research has been conducted using the KBUD and TH for analysing and classifying IDs futures research lines can analyse other frameworks and perspectives in order to help to evaluate the performance indicators in IDs.

Lastly, Innovation Districts are inserted in cities with specific local, regional and national contexts. Future research could complement this thesis with an analysis of the legal, political, social, economic and environmental frameworks and how this context impacts the performance indicators of the Innovation District's development. In this vein, the relation of the performance indicators of Innovation Districts with the Local, Regional, National and Global Innovation Index could be the subject of extended research in order to correlate the performance indicators of Innovation Districts with their Cities, Regions or Nations.

12. REFERENCES

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13. ACRONYMS

22@Barcelona - The brand of the Innovation District of Barcelona
AOI - Areas of Innovation
BRL – Brazilian Real
DEMATEL - Decision-Making Trial and Evaluation Laboratory
DM – Delphi Method
CESAR - Advanced Studies and Systems Centre of Recife
CEO – Chief Executive Officer
CI - Informatics Centre
COI - Clusters of Innovation
CVC - Corporate Venture Capital
ESG - Environmental, Social & Governance
FDM – Fuzzy Delphi Method
GOV - Government
IASP - International Association of Science Parks and Areas of Innovation
IDs - Innovation Districts
IE – Innovation Ecosystem
ICT - Information and Communication Technologies
IND – Industry
IRM - Influential Relationship Map
IT - Information Technology
JESB – Journal of Evolutionary Studies of Business
KBUD - Knowledge Based Urban Development
KPI – Key Performance Indicator
M&A - Merger and Acquisition
MCDM - Multi-Criteria Decision Making
MPGM - Modification Metropolitan Master Plan of Barcelona
NGPD - Porto Digital Management Nucleus
PD – Porto Digital
R&D&I – Research, Development, and Innovation
SME - Small and Medium Enterprises
SQM – Square Meters
SDG – Sustainable Development Goals
TH – Triple Helix
TCI - Global Network of Clusters
UFPE - Federal University of Pernambuco
UN – United Nations
UNI - University
VC – Venture Capital