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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

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Districts (ID) stand out as the most favourable ecosystems to create economic, urban, social and governance solutions proactively and at the speed demanded by 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 (Esmailpoorabi 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 (Esmailpoorarabi et al., 2018a; Esmailpoorarabi 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" (Esmailpoorarabi 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 be 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.*)

N°	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.*)

N°	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 Bojadziew 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; Bojadziew and Bojadziew, 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 f_{α} as follows: $f_{\alpha}(x) \rightarrow [0, 1], \forall x \in A$. (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.)

$$f_{\alpha} = \begin{cases} \frac{x-p}{q-p}, p \leq x \leq q \\ \frac{r-x}{r-q}, q \leq x \leq r \\ 0 \end{cases} \tag{1}$$

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:

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

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

Stage 2: The fuzzy weights of indicator p_j are assigned as follows: $p_j = (p_j; q_j; r_j)$ where

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

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

$$r_j = \min(\text{Fuzzy-1}(r_{ij})) \text{ where } i = 1, 2, 3, \dots n \text{ and } j = 1, 2, 3, \dots m. \quad (5)$$

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

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

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

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.

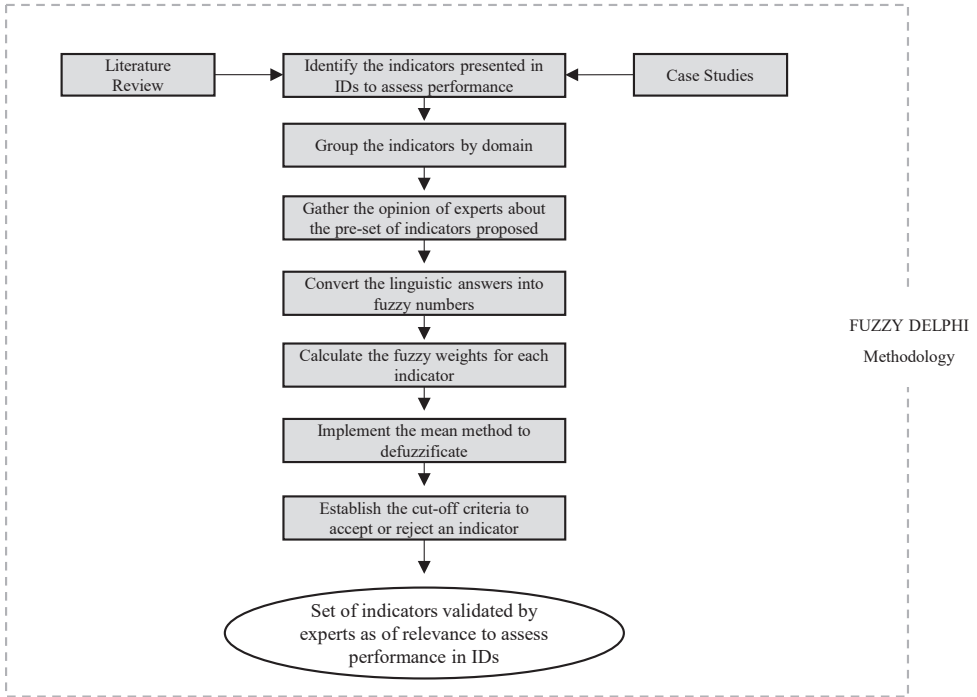


FIGURE 1 Fuzzy Delphi Methodological Process

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 $n \times n$ 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 k th 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

$$m = \min \left[\frac{1}{\max_i \sum_{i=1}^n a_{ij}}, \frac{1}{\max_j \sum_{j=1}^n a_{ij}} \right] \quad i, j \in \{1, 2, 3, \dots, m\} \tag{9}$$

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)

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

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:

$$r = [r_i]_{n \times 1} = \left[\sum_{j=1}^n t_{ij} \right]_{n \times 1} \quad (11)$$

$$c = [c_i]_{1 \times n} = \left[\sum_{i=1}^n t_{ij} \right]_{1 \times n} \quad (12)$$

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.

$$\alpha = \frac{\sum_{i=1}^n \sum_{j=1}^n [t_{ij}]}{N} \quad (13)$$

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

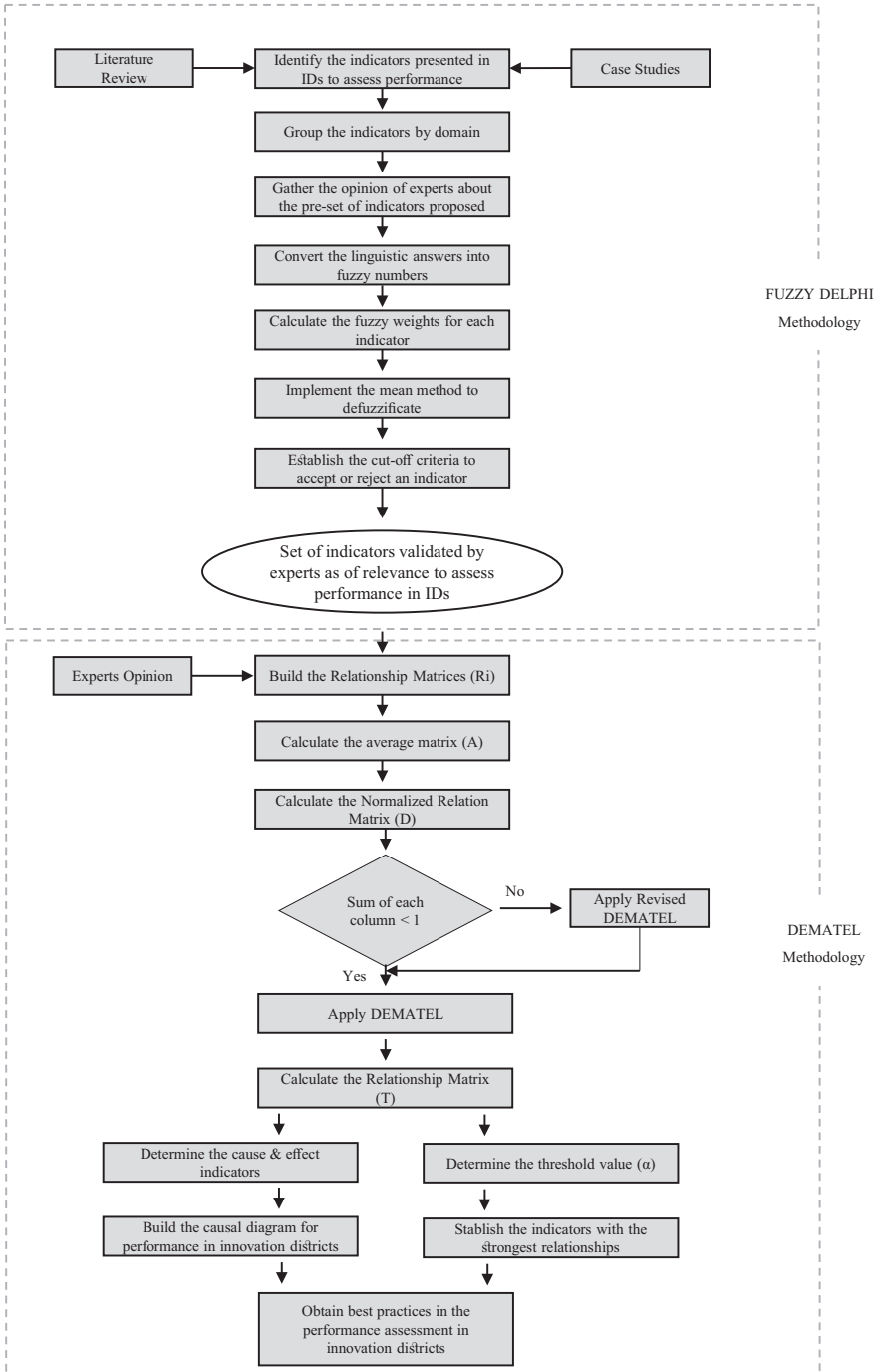


FIGURE 2 Fuzzy Delphi and DEMATEL Methodological Processes (Own Elaboration)

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	0.6433590711	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 Investment	Eur	0.1	0.587023392	0.9	0.539007797 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	0.664128598	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	0.53739919 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	0.668262402 Accepted
34 E18	Investment in Start-ups	Eur	0.3	0.845193974	0.9	0.681731325 Accepted
35 E19	Start-Ups	#	0.3	0.804792061	0.9	0.668262402 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	0.516966661 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	0.510061599	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 Accepted
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	0.65526796	0.88611111	0.58138562

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	INFLUENCE AREA																				
		U1	U2	U3	U4	U5	U6	U7	U8	U9	U10	U11	U12	U13	U14	U15	U16	U17	U18	U19	U20	
U1	Innovation Area	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U2	Potential Floor	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U3	Completed Buildings	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U4	Available Floor Space	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U5	New Facilities	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U6	Occupancy Rate	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U7	Contribution to Real Estate	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U8	Jobs	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U9	International Companies	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U10	National Companies	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U11	Private Investment in Companies	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U12	Knowledge-based Companies	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U13	Incubators	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U14	Ventures Incubated	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U15	Investment Start-Ups	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U16	Turnover Start-Ups	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U17	International Events	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U18	Publications	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U19	Number of Children Companies	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U20	Universities	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U21	Higher Education Degree	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U22	Social Activities	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U23	International Workshops	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U24	Team Management	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	
U25	Indicators in Open Data	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	

TABLE 9 Cause, Effect indicators & Threshold number

AREA		INDICATOR	Unit	Ri	Ci	Ri + Ci	Ri - Ci	Identify	Threshold FACTOR
U R B A N	U1	Intervention Area	sqm	3,75	4,07	7,82	- 0,32	Effect	0,1061
	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	
E C O N O M I C	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		
S O C I A L	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	
G O V	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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