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Building Inclusive Smart Cities through Innovation Intermediaries

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Abstract: To be inclusive, smart cities should be built on Industry 4.0 technologies within a quadruple helix model involving governments, academia, industry, and citizens. Innovation intermediaries facilitating collaborative innovation could foster this model of smart city. This paper identifies digital innovation hubs (DIHs) as innovation intermediaries that can help build inclusive smart cities. A screening of DIHs in European and extra-European countries through desk research finds 48 DIHs linked to smart city projects or policies, of which 23 are involved in building inclusive smart cities and mostly addressing the areas of smart environment and government. This paper suggests a framework for boosting their functions as transformation leaders, knowledge brokers, and technical mediators to facilitate the use of Industry 4.0 technologies for building inclusive smart cities.

Keywords: smart city; IoT; big data; DIH; smart environment; blockchain

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1. Introduction

Over the past three decades, the concept of the "smart city" has evolved around different meanings, which have been shaped by culture, social needs, and policies, as well as the stage of development of the city. The definitions of what a smart city is are continuously changing from one city to another and between communities [1]. According to the European Commission, a smart city is a place where traditional networks and services are made more efficient using digital solutions to benefit its inhabitants and businesses [2].

The development of the smart city is closely connected with the phenomenon of Industry 4.0, in terms of mutual capacity for innovation, integration, and digital transition with tangible effects in the urban spatial distribution of goods and services [3]. Industry 4.0 enabling technologies, including the Internet of Things (IoT), cloud computing, big data analytics, autonomous robots, simulation, additive manufacturing, horizontal and vertical integration, digital twins, cyber–physical systems, cybersecurity, augmented and virtual reality, artificial intelligence, and blockchain technology, are shaping the development of inclusive smart cities.

Despite its various definitions, scholars and policymakers agree that smart city projects need to be built on a quadruple helix model (QHM) involving governments, industries, academia, and civil society. The QHM should be the principle for designing smart cities [4], placing citizens at the centre [5] along with the idea that "whatever the problem community is the answer" [6].

However, when cities are asked to operationalize QH collaboration, in most cases, they remain disillusioned with results that are hindered by practical and budgetary constraints, limited technical knowledge, uncertainty on how to allocate budget for these initiatives and, above all, unclear collaboration goals [7]. Thus, engagement and user-driven innovation methods are necessary to bring together stakeholders of the triple helix and increase citizens' participation in the co-creation processes of digital services of public interest [8].

To operationalize QH collaboration and contribute toward new engagement mechanisms, we argue that a QHM guided by innovation intermediaries can become the basis for building inclusive smart city projects, ensuring relevance to context and needs. Indeed, innovation intermediaries could act as connectors in innovation processes [9], creating and managing linkages among different partners [10,11] which include civil society [12].

As innovation intermediaries, we consider digital innovation hubs (DIHs) since these structures connect stakeholders for the digital transformation of small and medium-sized enterprises (SMEs) [13]. The RQs are the following:

RQ1. How do DIHs support the development of inclusive smart cities?
RQ2. Which Industry 4.0 technologies do these DIHs address?

Results, based on a desk research, show that just a few DIHs are focused on building smart cities involving citizens, and that these DIHs are both in European and extra-European countries. A variety of structures is identified with a prevalence of networking structures, universities, and research and technological organizations. The main activities involving citizens are built around living lab services that foster citizens' involvement in the co-design of smart city solutions. The main technologies used refer to the IoT and big data while blockchain seems to be emerging in the awareness and training activities of DIHs.

Based on the data collected, a research and policy agenda is drawn. The conclusions can be applied to drive industrial policies in boosting the connective activities of innovation intermediaries and help firms define new business models for designing and adopting advanced technologies within inclusive smart cities. The article is structured as follows. First, the role of Industry 4.0 technologies and innovation intermediaries in building inclusive smart cities is reviewed. Then, the methodology is illustrated, and the results are presented and discussed. Finally, conclusions are drawn.

2. Industry 4.0 Technologies for Inclusive Smart Cities

Smart cities and Industry 4.0 are two of the most relevant advancements in the urban and industrial landscape. Together, Industry 4.0 and smart cities are transforming the way we live and work and are ushering in a new era of efficiency, sustainability, and economic growth.

Smart cities are urban areas where digital technologies are used to enhance citizens' lives efficiently. The concept of smart cities refers to many aspects of cities' life that function together organically and become "smart", i.e., enhanced by technologies: mobility, environment, citizens, government, economy, and architecture [14]. Smart mobility involves the use of modern transport technologies to improve urban traffic, transport, and logistic systems. A smart environment takes care of natural resources. Smart citizens are holders of social and human capital and knowledge and co-create public life. Smart governments create strategies and policies which enable the co-production of public services democratically and transparently. A smart economy allows firms to organise their business processes within the larger context of the city. Smart architecture refers to devices working together through infrastructures for data processing, exchange, storage, and security.

All these aspects make use of innovative technologies that were created for the industry sector and were later applied to cities, enabling both smart factories and smart cities [15]. Such technologies are part of a general trend towards automation and data exchange in manufacturing technologies that are conventionally referred to as "Industry 4.0" [16]. Industry 4.0 is "a revolutionary industrial concept of the production process in manufacturing, focused on new technologies that interconnect machines and equipment with digital data into automatic and intelligent systems" [17] (p. 2).

The development of the smart city is closely connected with the phenomenon of Industry 4.0, in terms of mutual capacity for innovation, integration, and digital transition with tangible effects in the urban spatial distribution of goods and services [3]. The technologies that constitute the pillars of Industry 4.0 are the Internet of Things (IoT), cloud computing, big data analytics, autonomous robots, simulation, additive manufacturing, horizontal and vertical integration, digital twins, cyber–physical systems, cybersecurity [18], augmented and virtual reality [19], artificial intelligence [20], and blockchain technology [21]. An overview of these technologies and how they can be used in smart cities is given below and summarized in Table 1.

Table 1. Applications of Industry 4.0 technologies in smart cities.

Industry 4.0 Technology	**Possible Application in Smart Cities**
Internet of things	• Enable objects to become agents of data collection and monitoring. • Interconnect objects and devices in the smart factory, in the smart city, or between the smart factory and the smart city.
Big data analytics	• Analyse data to make informed decisions. • Efficient utilization of resources and assets.
Cloud, edge, and fog computing	• Store and process large amounts of data efficiently and cost-effectively.
Artificial intelligence	• Detect patterns in big data. • Predictive maintenance of assets.
Cyber–physical systems	• Connect the elements of smart cities enabled by Industry 4.0 technologies. • Minimize human intervention in processes to make them faster and reduce costs and human error.
Autonomous robots	• Improve traffic flow, accessibility and efficiency of transportation systems, road safety and city efficiency, while reducing emissions and energy consumption.
Digital twins	• Create replicas of assets and processes for analysis and simulation.
Simulation	• Simulate the functioning of assets and services before building their prototype. • Enable collaboration between stakeholders of a city for exploring different options for urban planning.
Additive manufacturing	• Create customised objects using innovative materials, enabling fast and cost-effective maintenance of assets and infrastructure.
Augmented reality	• Enrich the cities' urban environment with digital information placed above assets, buildings, and infrastructure. • Support emergency response in urban environments.
Virtual Reality	• Design and verify ideas within a virtual 3D space, saving time and resources.
Blockchain technology	• Increase data integrity and availability. • Solve the problem of data vulnerability in smart cities.

Source: Authors' elaboration.

The IoT has enabled objects to be connected to the internet, allowing them to collect and exchange data, as well as be sensed, identified, and controlled remotely. This has led to the emergence of Industry 4.0 and smart cities, as it has enabled firms and cities to turn objects into agents of data collection and monitoring, and in turn, has provided decision-makers with data to support their decisions and take action [15]. Examples of such objects include sensors, actuators, autonomous transport vehicles in factories, mobile phones, smart TVs, control systems in buildings, CCTV, and public transportation [22].

The IoT has enabled the collection and analysis of large amounts of data (i.e., big data) in both industries and smart cities. This data can be used to improve resource utilization, plan living and work spaces, create more efficient transportation systems, and provide faster services [23]. Cloud computing is an on-demand network that provides access to shared IT resources such as servers, storage, and applications [24]. However, due to the large amount of data generated by the IoT, edge and fog computing are becoming increasingly necessary [25]. Edge computing allows data analysis to be performed where the data is created, reducing latency [26], while fog computing acts as a mediator between the edge and the cloud, deciding which data should be sent to the cloud and which should remain local [22].

AI algorithms can process large amounts of data to detect patterns and features that would otherwise go unnoticed [27], allowing for the predictive maintenance of mechanical systems and components [28]. Cyber–physical systems (CPS) are a core concept of Industry 4.0 and can also be applied to smart cities. These systems monitor physical processes through a virtual copy of the physical world and can make decentralized decisions independently, eliminating the need for central process control [29]. CPS in smart cities connect various elements and allow them to co-direct actions and organize them organically [30], to minimize human intervention [31]. Autonomous robots connected to the IoT are enabled by CPS [32]. In smart cities, the mass adoption of autonomous vehicles as a mode of transportation could bring about a multitude of benefits, such as reduced emissions and energy consumption, improved traffic flow, increased accessibility and efficiency of transportation systems, increased road safety, and increased city efficiency [33].

Moreover, CPS would not be possible without the ability to create digital twins that are virtual replicas of processes and assets. Industries have taken advantage of this technology for simulation, monitoring, and control, but recently, urban designers have also become interested in its potential [34]. Digital twins can be used to create simulations that replicate the physical world in a virtual 2D or 3D model including machines, products, and humans. Companies can use digital twins to simulate cycle times, energy consumption, and ergonomic aspects of production [32]. Smart cities can use simulations to test changes to public transportation and find ways to reduce downtime or increase capacity [35] or simulate crowd evacuations [36]. Additionally, digital twins provide an environment where smart city practitioners can collaborate with urban planners, urban designers, and the public to explore different urban planning options [34,37].

Augmented Reality (AR) and Virtual Reality (VR) can be used to enhance the planning and prototyping process. AR is a technology that adds computer-generated enhancements to an existing reality, allowing users to interact with it. It can be used to provide digital information about assets, buildings, and infrastructure, and to support emergency response by displaying invisible emergency-related information [19]. VR is a computer-generated simulation of a real-life environment or situation, allowing users to experience it first-hand. It can be used to assess design ideas in real-time and within a 3D space during the design and planning phase, saving time and resources [38].

Once the planning phase is finished, objects and processes are created in the real world. Additive manufacturing technologies can be employed to make repairs to infrastructures and assets more efficient and cost-effective. These technologies allow for the rapid production of prototypes and complex structures, as well as lightweight parts [39]. Metal additive manufacturing is being used in conjunction with smart city infrastructures, such as embedded sensors and targeted structural reinforcement, resulting in less material waste and cost [40].

Nevertheless, the IoT and databases have enabled firms and smart cities to become more efficient but vulnerable to cyber-attacks [41]. Blockchain technology, which is a key component of Industry 4.0 [21], can help to increase data integrity and availability [1] and protect against data vulnerability [42]. As Nakamoto [43] first explained, a blockchain is an immutable database distributed to multiple nodes of a network and visible to stakeholders who are interested in reading the data contained in the database. Data immutability and visibility bring data transparency, which enables trust among stakeholders [44].

Finally, vertical and horizontal system integration are two strategies enabled by Industry 4.0 technologies that firms and smart cities can use to become more agile. Vertical integration refers to the integration of systems within the factory or smart city, while horizontal integration involves connecting with external parties through shared platforms [18]. This horizontal integration allows for automated value creation within the smart city [45].

This paragraph gave an overview of Industry 4.0 technologies and how they relate to smart cities. Recently, the concept of Industry 5.0 has been proposed to include social and environmental sustainability as desirable objectives to achieve along with economic development, in line with the UN's Sustainability Development Goals (SDGs) [14]. If applied to smart cities, Industry 5.0 could help to achieve many of the SDGs [15]. Indeed, technological innovation is linked positively to the reduction of CO_2 emissions [46], which could balance their increase given by economic development and urbanisation [47]

3. Call for an Intermediary-Driven Quadruple Helix Model for Smart City Development

Smart city solutions should be accepted by the urban community and based on ideas jointly elaborated with stakeholder groups and adapted to local development policies [4]. Therefore, the QHM based on the involvement of governments, academia, industry, and civil society should be the principle for designing smart cities [4,5]. The involvement of citizens can help build healthy and resilient communities that find solutions on their own and take control of their future, taking on big issues such as food, economics, education, leadership, and environmental challenges [48]. To reach this aim, cities need to move to knowledge-based development, just as organizations do [49]. Recalling the Japanese concept of *ba*, which refers to spaces as "interaction fields" encompassing not only physical places but also the relationships between people [50] playing a major role in knowledge creation [51], cities can be pictured as shared spaces for emerging relationships where knowledge is created [52]. Many projects have tried to build collaborative working environments that can benefit from sharing expertise and technologies, providing open-source tools to demonstrate the methodology of living labs in Europe [53]. Strong relations between smart cities and urban and regional development are receiving attention at the policy-making and implementation levels, providing ground for designing new policy frameworks that support QHM [54], as in the case of regional smart specialization strategies (S3).

However, when cities are asked to operationalize QH collaboration, they often remain disappointed with results that are hindered by practical and budgetary constraints, limited technical knowledge, uncertainty on how to allocate budget and, above all, unclear collaboration goals [7]. As seen in the previous paragraph, the user-centric innovation process in smart cities can be facilitated by Industry-4.0-enabling technologies which foster a modular approach to product and service development across firm boundaries [7]. Several technological interventions (e.g., smartphone apps and other digital platforms) have been used within urban infrastructures, but technology itself does not facilitate active citizenship and public engagement. Indeed, even if citizens participate and are engaged, this does not guarantee that they will take advantage of smartness. This will only happen if learning permeates the helices [55].

To achieve an effective exchange of knowledge, cities need to become favourable environments for collaboration and cocreation [56], and places where communities come together and commit to staying together long enough to discover ideas and issues that are significant [57].

This is possible by creating a culture where dialogue, trust, inclusiveness, confidence, and hope are promoted, and in which people feel and become part of the decision-making process [56].

The basis for an optimal model of urban management is knowledge properly disseminated and distributed, as a condition for acquiring interdisciplinary competencies [4]. Thus, ongoing work should focus on developing methods that fit existing government processes and tools and methodologies that support capacity building in these areas [7].

We argue that a key role in this sense could be held by innovation intermediaries, recognizing their connective function in innovation processes [9]. From a general standpoint, innovation intermediaries act as "match-making" between partners [11] by establishing and coordinating interactions between science, industry, and government [10], which can extend to civil society [12]. Innovation intermediaries are known as brokers [58], boundary spanners [59], and gatekeepers [60]. These are information gatherers and knowledge disseminators at the frontier of organizations and groups [61]. Often, they are defined as knowledge intermediaries recognizing their role in managing knowledge and the inevitable linkage existing between knowledge and innovation [62]. Their role becomes vital in the case of SMEs, which lack the necessary skills and financial resources to interpret knowledge and employ it for improving their innovation performance. With specific reference to SMEs, intermediaries can favour innovation initiation, network composition and innovation process management [58]. The ability of organizations to recognize, source and integrate key information or knowledge is important for their strategy, innovation, and performance over time. However, there is a lack of attention on the role of innovation intermediaries in smart city development. A general review of the literature was conducted on Scopus and Web of Science based on the keywords smart city along with intermediary, broker, gatekeeper, and boundary spanner, searched in the title, abstract, and keywords, and filtered to include only peer-reviewed research articles in English in the areas of management, economics, and social sciences. From an initial output of 32 articles, 16 articles were considered eligible since they discussed the role of innovation intermediaries in smart cities, as presented in Table 2.

Table 2. Intermediaries in smart cities.

Author (Year)	Method *	Applications	Technology	Intermediary	Key Roles
Borrás and Edler [63]	CS	n.i.	n.i.	State	• Facilitator • Lead-User and initiator • Enabler of social engagement • Gatekeeper
Ardito et al. [64]	CS	Buildings, elder people, mobility, energy, business processes, city government	ICT Big Data Analytics	University	• Knowledge intermediary, gatekeeper, provider and evaluator.
Schhurman et al. [65]	CS	Everyday life in city	Online platform	Living Labs	• Gatekeeper and selector of innovative ideas
Zhou et al. [66]	CS	Environment urban spaces for blind, social spaces renewal	Cloud, IoT devices, algorithmic modelling, dashboard	Community duty planners	• Connecting governments to communities • Developers of smart applications • Introducing bottom-up initiatives • Resource mobilizers
Calzada [67]	AR	Energy, mobility	ICT solutions platforms, apps, data commons	Entrepreneurs/ activists (fifth helix)	• Transformational intermediaries • Collaboration builders • Fulfilling stakeholders' ambitions bringing them together
Vallance et al. [68]	CS	Urban innovation	Digital platform	University-platform	• Guiding project facilitation activities • Interdisciplinary connector • Ensuring outcomes are meaningfully shaped by users
van Winder and Carvalho [69]	CS	Urban challenges	Apps, 3D printer	City-based, public intermediaries	• Initiators, moderators, influencers • Collecting and defining challenges • Co-developing solutions. • bridging mindsets • Dealing with tensions

Table 2. *Cont.*

Author (Year)	Method *	Applications	Technology	Intermediary	Key Roles
Hielkema and Hongisto [70]	CS	Transportation, health and welfare, environmental data, spatial information	Mobile applications, open data	Living lab (owned by municipality)	• Connectors • Orchestrator, providing support and feedback to parties. • Space for innovation and "rivalry"
Johnson et al. [71]	TP	Communication between citizens and governments	Sensors	Technology	• Mediating transactions between citizens and government
Ekman et al. [72]	CS	Renewable energy	Mobile apps, software solutions	Electricity aggregators	• Coordinators in the energy systems. • Knowledge brokers • Relieving and enabling actors in optimal value creation.
Karimikia et al. [73]	CS	Urban challenges	IoT, 5G, data analytic platforms, aug-mented/virtual reality	Organization of the management and development of cities' smart initiatives initiated by local authorities	• Political, cultural, social and technical boundary-spanning roles.
Kim [74]	CS	n.i.	n.i.	Self-funded civic organization	• Creating an alternative smart city making a path for poor areas.
Ojasalo and Kauppinen [75]	Expert In-terviews	n.i.	Open innovation platforms	Innovation intermediaries and open innovation platforms	• Facilitating collaborative innovation • Enabling involvement of user communities
Ojasalo and Tähtinen [76]	Interviews	n.i.	Open innovation platforms	Open innovation platforms	• Acting as an intermediary between a city and external actors by governing, sparring and collaborative relationships.
Rosen and Alvarez León [77]	TP	Urban land	Digital platforms	Digital platforms	• Acting as intermediaries between land use, industry technology and information.
Skjølsvold et al. [78]	Interviews	Transport	Electric vehicles	Housing boards	• Producing and resolving controversies. • Linking neighbourhood, policy and innovators, and technology developers' interests. • Institutionalizing ideals of equity, fair access and inclusive participation.

* CS = case study; AR = action research; TP = theoretical paper. Source: Authors' elaboration.

The selected articles, which are mainly based on case studies, show a wide range of different intermediaries from states, city-based intermediaries, universities, living labs and, to a certain extent, technology itself. Considering the possible identities of intermediaries, according to Zhou et al. [66], private actors should not be contemplated since conflicts of interest may become a valid concern. Thus, intermediary actors' work should ideally be funded by governments to maintain motivation and a certain degree of neutrality. According to Ojasolo and Tähtinen [76], the concepts of innovation intermediaries and innovation platforms are closely related since platforms facilitate and enable collaborative innovation between city and external actors, including private companies, third sectors organizations, research organizations, citizens, and other cities. Platforms may be owned by several cities. The presence of more owners provides more efficient, larger-scale learning and scaling of activities [75]. The model suggested by to Ojasolo and Tähtinen [76] includes three types of relationships between platforms and actors: governing based on coercive powers; sparring based on sharing knowledge; and collaborative innovation aimed at new solutions. Platforms can also be specific types of intermediaries related to land management with implications for smart cities in terms of cooperation over land and urban governance [77]. In another specific area such as electric vehicles, democratically elected neighbourhoods can also become intermediary actors [78]. In certain cases, the intermediary role can be fulfilled by groups or individuals who have a mastery of IT and a good grasp of urban knowledge and planning. Instead, Johnson et al. [71] acknowledge that the rise of modern smartphones and smart city technologies have further enabled and in certain cases moderated micro-transactions between citizens and governments.

Living labs are described as eligible intermediaries by both Schuurman et al. [65] and Hielkema and Hongisto [70]. In the case of Schuurman et al. [65], the living lab becomes a gatekeeper and selector of innovative ideas whose mission is to recruit specified panes of citizens. For Hielkema and Hongisto [70], living labs promote smart city development as well as the future of open data while supporting the policy goals of the government. More specifically, when public data is made open, living labs can enable value creation and become the centre of a network of related industries that all benefit from the development of smart applications. In general, the selected articles show that there are many functions that an intermediary can hold which go beyond a plain connectivity function. Indeed, intermediaries can also relieve actors from tasks that go beyond their capabilities and resources [72], initiate and influence knowledge sharing [69], mobilize resources, and even develop smart applications [66], and, finally, become a space for innovation [70]. Instead, Ardito et al. [64] suggest that universities can be at the core of building smart city ecosystems and be active in developing and maintaining key relationships within and across them. However, the authors acknowledge that this requires a change in the mindset of the top management of smart city projects and more efforts involving academics.

Specific characteristics of an intermediary are listed by Zhou et al. [66] when presenting the case of community development planners (CDP) who act as translators between governmental long-term policies and communities' short-term needs in the process of problem identification. According to the authors, intermediary actors for smart city development should share six features: familiarity with top-down governmental policies and long-term plans; a good grasp of urban knowledge for identifying bottom-up needs; ability to translate and combine the two logics of top-down and bottom-up; IT knowledge to technically connect the two approaches; openness to stakeholder diversity; and the capability to mobilize multiple resources for action. Among these features, IT knowledge is exclusively the purview of intermediary actors in smart city development. These articles explicitly acknowledge the need to further investigate the role of intermediaries to uncover how citizen-users are embedded in smart cities' emerging systems of relations [68]. Karimikia [73] instead, introduces a taxonomy of boundary spanning which includes four types of activities: political aimed at aligning different interests between actors; cultural by creating an environment where actors become acquainted with each other's knowledge and expertise; and technical by providing appropriate communication channels to facilitate information and knowledge flow across actors in activities that require multiple specialities and skills in developing smart city projects.

Going beyond the QHM, Calzada et al. [67] suggest the penta-helix model including the fifth helix of entrepreneurs and activists. Instead, Ekman et al. [72] argue that a smart city is a service ecosystem which requires an increased need for coordination and control since the creation of value involves several actors, activities, and resources. Thus, in this scenario, the knowledge broker role constitutes an example of the need to revise the understanding of actors in smart city transformations, suggesting that the "brokerage" function in such service ecosystems needs further attention by addressing how the brokerage function can support conceptualizations. More specifically, van Winden and Carvalho [69] start questioning how to evaluate the outputs of intermediaries beyond the number of contracts but also in terms of the accumulation of learning and experiences.

4. Methods

Considering the difficulties in operationalizing a QHM, the need to find engagement methods, and the limited number of studies on innovation intermediaries in smart city development, as well as the relevance of the topic, this paper aims to provide a first mapping of structures that could potentially fill this role. We selected DIHs that address smart city initiatives as eligible intermediaries.

According to the European Commission's definition, DIHs are orchestrators that connect stakeholders of regional ecosystems to support the digital transformation of SMEs. These structures act as one-stop shops that make companies competitive with respect to their business/production processes, products, or services by adopting and developing digital technologies [79]. They are conceptualized as knowledge brokers that connect SMEs to a wide range of stakeholders by selecting, exchanging, and integrating knowledge, and by potentially following the knowledge appropriation stage [13]. DIHs are also encouraged to create a multi-layered innovation system that can be exploited at the regional, national, and European levels [80].

In order to understand how DIHs support the development of inclusive smart cities (RQ1) and which Industry 4.0 technologies they address (RQ2), a search was conducted on fully functioning DIHs from the European catalogue of Digital Innovation Hubs [81].

DIHs were filtered following three steps:

- Step 1. All DIHs registered as fully functioning in the European catalogue of DIHs were filtered by the keywords smart city and smart cities. On a total of 423 DIHs, filtering led to 53.
- Step 2. The DIHs' descriptions in the catalogue were analysed and cross-checked with the contents on their websites. Based on the information collected, the DIHs were classified into three categories: DIHs with examples of smart city projects that involve citizens (Category A); DIH including smart city as part of their mission activities, expertise, or projects but without examples of citizens' involvement (Category B); and DIHs only mentioning smart cities as part of the priorities of the national or regional policies to which they align (Category C). Five DIHs were excluded since no references to smart cities were found either in the catalogue or website.
- Step 3. The information of the 48 DIHs identified in the previous step was integrated with the S3 of the regions where the DIHs are located. In fact, according to the European Commission (2017), DIHs' activities should be in line with their regions' needs identified in regional innovation strategies. Moreover, DIHs are often called to actively participate in their policy design process [82]. The S3 prioritizes smart cities as drivers for regional innovation. The nature of this priority is linked to the European Innovation Partnership for Smart Cities and Communities, launched in 2012 by the European Commission and combining ICT, energy management, and transport management to generate innovative solutions to the environmental, societal, and health challenges facing European cities today.

Figure 1 shows the results of the screening of the 48 DIHs in both European and extra-European countries (Appendix A). We categorised the DIHs by three categories, namely A, B, C, as follows:

A. DIHs including smart city projects involving citizens (n = 23);
B. DIHs with no identified involvement of citizens in smart city (n = 17);
C. DIHs mentioning smart cities as part of the national or regional strategy to which they are aligned (n = 8).

The highest number of DIHs summing all the categories is reported in Spain, followed by Slovenia and Romania. Spain has also the highest number of "category A" DIHs.

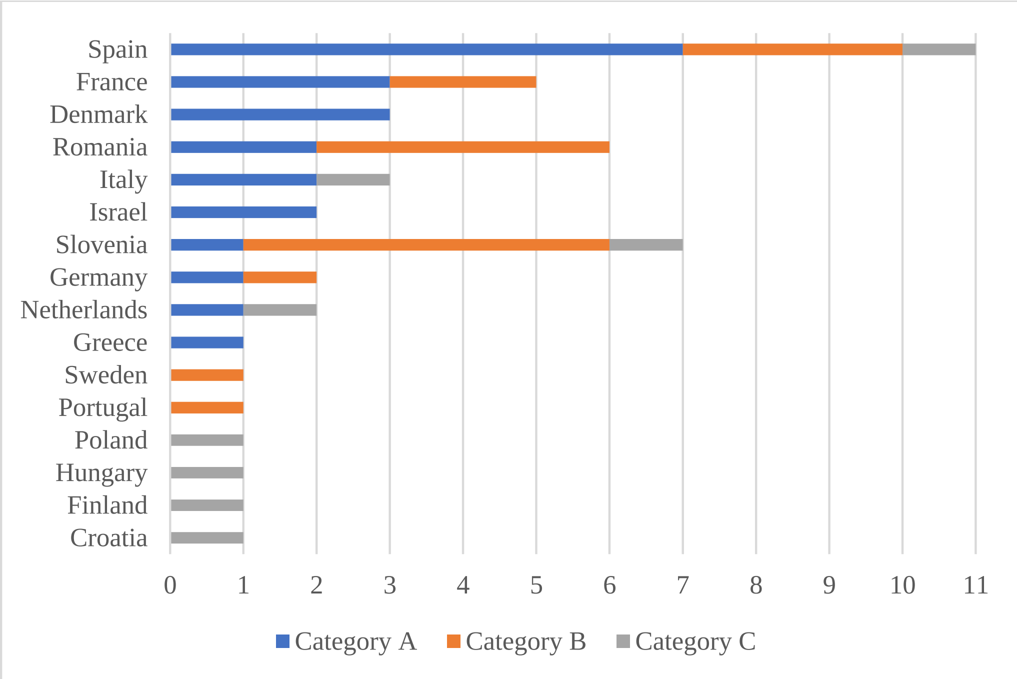

Figure 1. DIHs and smart cities initiatives. *Source: Authors' elaboration*.

The analysis of the structures reveals a variety of DIHs types, including networking structures (23), universities (7), RTOs (7), government-led (4), science parks (3), incubators (2), projects (1), and industrial associations (1).

Considering their S3, 13 DIHs are placed in regions whose S3 for the programming period 2014–2021 considers building smart cities as a priority, such as the Dytiki Ellada region in Greece, where smart cities are an integral part of the policy which aims to contribute to attractive, green, and competitive cities. Great attention to the matter is also recognized in the case of regions in Slovenia, where second highest number of DIHs is identified. In these regions, the S3 prioritises building smart cities and communities, recalling ICT systems projects in the areas of renewable energy sources, smart urbanisation, mobility safety, and healthcare. Similarly, in the region Skane Ian in Sweden, the S3 aims to build smart sustainable cities that solve cities' sustainable challenges, such as water, energy, mobility and information systems. Technologies for smart cities are mentioned in the S3 of Castilla y León in Spain. Remarkably, in Helsinki-Uusimaa in Finland, the S3 stresses the intention of building a citizens' city that can become a leader in public data. The themes include urban development, well-functioning everyday life, and the well-being of citizens considering urban planning, healthcare, transportation, and housing with a focus on social innovation.

5. Findings

The two RQ questions are addressed in the following paragraphs considering how DIHs involve citizens in smart city development (RQ1) and which Industry 4.0 technologies they consider (R2).

5.1. Initiatives Involving Citizens in a QHM

DIHs included in category A involve citizens in three main kinds of activities which include living lab services, collection of data, and training.

The main way of DIHs to engage citizens is by providing living lab services. These structures operate in a real-life context with a user-centric approach that enables innovation, co-creation, and start-up development [83]. Three DIHs present themselves as living labs. These are the cases identified in the Netherland, Romania, and Israel. Specifically, in the case analysed in the Netherlands, the strategy department of the Municipality of Eindhoven asked the DIH to investigate what the future of living labs in Eindhoven could be. This led to three basic principles of municipal policy: being based on bottom-up development, stimulating economic growth, and becoming future-proof. Similarly, the case selected in Romania is defined as a testing and co-innovation structure. Through the living lab, technology partners, PA, and academic and research institutions have access to skills, methods, methodologies, know-how, tools and communities for co-creation, prototyping, and testing. The goal is to empower the users of its services and integrate them into the innovation process, motivating them to participate, putting the right tools in place to enable a bottom-up dialogue and translating ideas into sustainable commercial products or services. The DIH in Israel is presented as a living lab consortium which uses data and advanced technology to accelerate innovation through collaboration.

Further cases include DIHs providing living lab services, such as the second one identified in Israel which manages an AI Citizens Lab. This DIH, coordinated by the university, connects citizens, city leaders, and AI technology to help understand city leaders' and citizens' challenges, plan innovative city–citizen interactions, and improve the quality of life for everyone living in the city or visiting it. Similarly, a DIH in Denmark presented as a networking organization coordinated by the national government includes the IoT living lab as an example of services offered and specifies this service to facilitate testing and composition of smart city technologies. Other DIHs have the goal of building living labs as in the case of a public–private partnership coordinated by a networking organization in France. This DIH aims to create international bridges by building living labs where solutions can be tested. Similarly, the DIH coordinated by the regional government in Germany states that it will become a place of participation for companies and citizens alike. In another case in Denmark, the DIH, coordinated by the university, collaborates with the Danish living labs to ensure an efficient and sustainable green transition. Instead, a DIH presented as a joint venture created by entrepreneurs for entrepreneurs in France is a partner in Interreg projects that focus on smart city innovation and that explore innovative procurement and methods to work with businesses in developing data-based solutions in living labs and demonstrating the value of open data. Fab labs are considered by the Italian DIH, which is presented as a networking organization. The Fab labs are described as meeting places for people of all ages open to research and innovation.

Secondly, the involvement of citizens is mentioned as a way to collect and provide real-time data in a sample of DIHs in Spain. For instance, to provide real-time information on air quality to reinforce citizens' awareness of their right to clean air; analyse photographs received by citizens during snow events; enable citizens to file complaints or incidents; give their opinion on budgets; make proposals; and be always informed about the status of said actions. In this latter example, the city council has been offered a dashboard that allows monitoring of all the data provided by citizens. The main social innovation of this Citizen Line APP lies in the use of the data collected in terms of open data through learning and collaborative knowledge. Further examples are identified in the testing phase of innovative solutions, as in the case of testing the use of IoT and QR codes for improving recycling among citizens and monitoring waste in real time. In a further case in Spain, a network of low-cost sensors was installed to measure tropospheric ozone in private homes of volunteers from Spain, Italy, and Austria. The programme encourages collaboration between local communities, citizens, NGOs, and scientists to foster environmental awareness and social and political responsibility.

Other activities are related to the training stage and are identified in DIHs in Spain, Greece, and Italy. These training events are organized to build citizen-centric smart cities for administrators, technicians, and officials of local authorities. Similarly, workshops are coordinated in municipalities whose objective is to provide training to citizens, entrepreneurs, and professionals from the PA with visual means. Open-source platforms to train students and the elderly are used to engage citizens in smart cities.

The adoption of smart city solutions addresses specific services of the city. The main example of building an integrated solution refers to a project of e-city coordinated by a Spanish science park, which aims to become the first urban space to implement a circular city paradigm in a real environment that will be eco-efficient, renewable, innovative, and digital by 2027. The project will develop an urban infrastructure with sensors to allow the creation of a city platform that provides services for citizens and information to improve efficiency. Digital platforms will integrate services such as smart street lighting. These platforms will be able to cover many areas, including operational processes, logistics, air quality, and even connected vehicles for traffic management. Assistance is needed to bring experts from different disciplines and different regions together and to make them cooperate on smart system-enabled products and services for urban areas.

5.2. Industry 4.0 Technologies Addressed by DIHs

The IoT and big data analytics are the main Industry 4.0 technologies recalled by DIHs. For example, a DIH in Israel coordinated by the university provides its living lab service for projects regarding the use of the IoT to collect data that are then analysed to provide services to the community. Some of the projects this DIH is involved are about monitoring water quality in real-time to ensure public health and safety, the use of acoustic sensors for leak detection, and the analysis of systems from the field of agriculture and examining their effectiveness in urban gardening for water saving. A Danish DIH, which is also coordinated by the university, offers access to a wide range of energy data collected in real-time and a living lab that demonstrates how electricity and heat, energy-efficient buildings, and electric transport can be integrated into an intelligent, flexible, and optimized energy system in smart cities.

Other specific cases refer to the use of NFC (near-field communication) and QR code tags. This is the case of a DIH in France that is involved in a pilot project inviting travellers to read a section of works from the digital library with NFC tags and QR codes placed in buses and the metro, and a project based on NFC linked to a participatory platform for interactive communication to realize further projects and applications.

Other DIHs address open data platforms. For example, a DIH in Denmark is involved with other partners in accelerating the development of Danish leadership in data-driven solutions in the energy field. The platform collects a wide range of energy data (e.g., heating systems and electric consumption); then, a sample of DIHs use the FIWARE platform (four DHIs, three of which are part of the network of FIWARE). The FIWARE is an open-source initiative that works towards building a set of standards to develop smart applications for different domains such as smart cities, smart ports, smart logistics, smart factories, and others. The FIWARE network is looking into using FIWARE technology with blockchain in smart cities. Furthermore, another 13 DIHs are involved in activities regarding blockchain technology that, even if not mentioned in smart city projects, hold potential implications for their development. These activities relate mainly to raising awareness, training, the presence of blockchain experts among the partners and researchers of the DIHs, and projects that specifically involve blockchain. Interestingly, among these initiatives, a network alliance in Romania organizes hackathons for using blockchain beyond cryptocurrency, such as agrifood traceability, whose principles become useful when they are applied to several services offered by smart cities.

6. Discussion

The results of the study show that the topic of innovation intermediaries for building inclusive smart cities is still in its infancy, but it needs to be addressed to overcome challenges in ensuring an effective QHM design in urban design and management. Considering the case of DIHs, just a few of these innovation intermediaries are actively involving citizens in developing smart city solutions. These DIHs mainly act as living labs, becoming spaces for innovation [70] that enable the co-creation of innovative solutions with citizens. Their goal is to empower users and integrate them into the innovation process, motivating them to participate, putting the right tools in place to enable a bottom-up dialogue, and translating ideas into commercial products or services. Further activities relate to collecting data from citizens and providing training to a wide range of stakeholders including citizens, entrepreneurs, and professionals from the PA. The main examples of smart city solutions coordinated by DIHs are found in the areas of smart environment and government.

This range of activities sees DIHs as knowledge brokers among several stakeholders, not only selecting and exchanging knowledge but also following the appropriation stage since they also follow the commercialization stage of products and services [13]. Furthermore, their participation in European projects and international seminars outlines their role as gatekeepers [60] that establish connections that go beyond national borders.

Interestingly, the topic of open data is explicitly addressed by a group of DIHs integrating the findings of Hielkema and Hongisto [70], according to whom, when public data is made open, intermediaries can enable value creation and become the centre of a network of related industries that all benefit from the development of smart applications.

As for the technologies addressed by DIHs, a leading role is placed on IoT and big data analytics. DIHs are increasingly giving attention to blockchain-based solutions, which are still in an exploratory phase, so the DIHs' activities related to blockchain are mainly raising awareness and training. However, some projects, especially those in the agri-food sector, show that there will be some concrete applications in the next years which will also apply to smart cities. DIHs in regions with a focus on building inclusive smart cities are expected to take on further developments. This is to ensure that all services of cities are addressed in an integrated manner, as current initiatives are limited to certain areas such as waste, clean air, and government. A framework has been proposed to enhance the role of DIHs in constructing inclusive smart cities making use of Industry 4.0 technologies.

Figure 2 suggests that DIHs located at the core of QHM should be able to fulfil three essential roles, requiring interdisciplinary abilities to guarantee an optimal urban design and management model, with knowledge being effectively shared and spread [4]. Specifically, as *transformation leaders*, they should help QH stakeholders abandon traditional and closed models, drive change, enable active engagement, and be global carriers of best practices. As *knowledge brokers*, they should reduce knowledge distance among QH stakeholders, bring together human and financial resources, develop principles for project facilitation, and be orchestrators that support and provide feedback to different parties. Finally, as *technical mediators*, DIHs should be able to offer support services, even relieving actors from tasks that go beyond their capabilities or resources, facilitate the management of Industry 4.0 knowledge between parties, create a space where the benefits are tangible, and match short- and long-term objectives. These functions should favour the development of inclusive smart cities connected through Industry 4.0 technologies and generating and using open data for effectiveness and efficiency in smart environment, mobility, government, citizens, architecture, and economy.

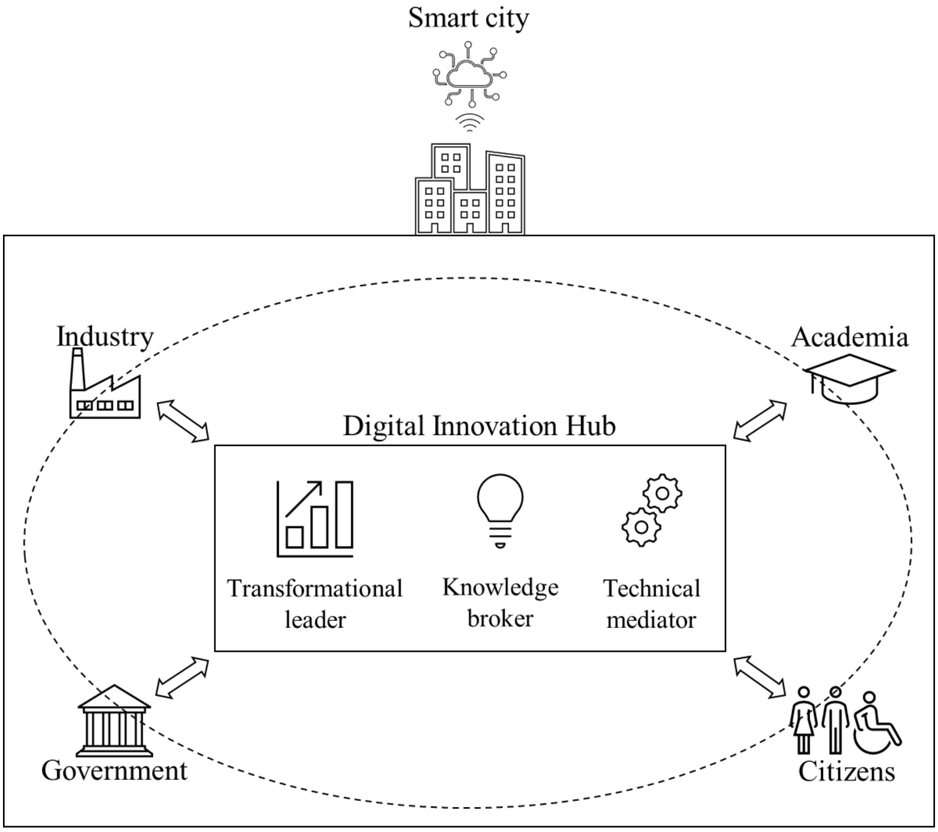

Figure 2. DIHs contribution to building inclusive smart cities. *Source: Authors' elaboration*.

7. Conclusions

This paper sheds light on the role of DIHs as innovation intermediaries that support the development of inclusive smart cities based on Industry 4.0 technologies within a QHM.

The results of a desk research of DIHs in European and extra-European countries show that 23 out of 48 are involved in projects building inclusive smart cities. These DIHs mainly provide living lab services to co-create and test solutions with citizens. IoT and big data analytics are the main technologies addressed, especially for initiatives aimed at building smart environments and governance. A growing role of blockchain-based solutions is expected, considering the attention given by the selected DIHs to the potential of this technology.

These findings, matched with the review of the literature on innovation intermediaries, led to the design of a framework to exploit their role in the context of a QHM, picturing them as transformation leaders, knowledge brokers, and technical mediators.

The results of the study have implications for managers, policymakers, and future research. First, DIHs as technical mediators in the context of smart cities should address all Industry 4.0 technologies, not only the IoT and big data, and support firms in revising their business models. Second, DIHs as transformational leaders and knowledge brokers should plan how to structure inclusive and integrated smart cities, connecting smart environment, government, mobility, economy, architecture, and citizens, making use of open data and of their national and international network of relationships. Third, firms should seek the support of DIHs to contribute actively to building inclusive smart cities, putting their skills, competencies, and technologies at the service of the QHM. Finally, policymakers should formalize and support a European and extra-European network of DIHs focused on smart cities to exchange knowledge and best practices. In this sense, brokerage and networking events can be organized to enable DIHs and their QH stakeholders to identify suitable possibilities for collaborations. Financial incentives are required to enable DIHs to test smart city solutions based on novel Industry 4.0 technologies, including blockchain.

Nevertheless, this study faces limitations due to the selection of keywords both in the literature review and the catalogue of DIHs that may have excluded other cases of innovation intermediaries and DIHs involved in smart city projects and initiatives. Furthermore, the analysis of the S3 was based on the last programming period, since not all regions have published their S3 for 2021–2027.

Three research directions can be identified to overcome these limitations. First, more in-depth case studies based on primary data comparing the experiences of the DIHs are needed. These should aim at understanding how initiatives and Industry 4.0 technologies were selected by DIHs, and at evaluating the role of DIHs as transformational leaders, knowledge brokers, and technical mediators, identifying and comparing their tasks. Second, expert interviews may support the understanding of the challenges and solutions for building inclusive smart cities based on Industry 4.0 technologies, and how the role of innovation intermediaries can be exploited in a context of open data. Third, it would be of interest to understand if there are characteristics of DIHs that can explain their involvement in smart cities projects. To this aim, a qualitative comparative analysis could help identify the conditions explaining certain outputs among DIHs.

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Appendix A. List of DIHs

DIH	Category	NUTS0 Name	NUTS2 Code	NUTS2 Name
DIH1	A	Denmark	DK04	Midtjylland
DIH2	A	Denmark	DK01	Hovedstaden
DIH3	A	Denmark	DK04	Midtjylland
DIH4	A	France	FR30	Nord–Pas-de-Calais (NUTS 2013)
DIH5	A	France	FR22	Picardie (NUTS 2013)
DIH6	A	Greece	EL63	Dytiki Ellada
DIH7	A	Israel	n.a	n.a
DIH8	A	Italy	ITF3	Campania
DIH9	A	Italy	ITI2	Umbria
DIH10	A	Netherlands	NL41	Noord-Brabant
DIH11	A	Romania	RO11	Nord-Vest
DIH12	A	Romania	RO32	Bucuresti–Ilfov
DIH13	A	Slovenia	SI04	Zahodna Slovenija
DIH14	A	Spain	ES51	Cataluña
DIH15	A	Spain	ES52	Comunidad Valenciana
DIH16	A	Spain	ES43	Extremadura
DIH17	A	Spain	ES61	Andalucía
DIH18	A	Spain	ES13	Cantabria
DIH19	A	Spain	ES61	Andalucía
DIH20	A	Spain	ES21	País Vasco

DIH	Category	NUTS0 Name	NUTS2 Code	NUTS2 Name
DIH21	A	France	FR71	Rhône-Alpes (NUTS 2013)
DIH22	A	Israel	n.a	n.a
DIH23	A	Germany	DE91	Braunschweig
DIH24	B	France	FR10	Île de France
DIH25	B	France	FR82	Provence-Alpes-Côte d'Azur (NUTS 2013)
DIH26	B	Portugal	PT30	Região Autónoma da Madeira (PT)
DIH27	B	Romania	RO32	Bucuresti–Ilfov
DIH28	B	Slovenia	SI04	Zahodna Slovenija
DIH29	B	Slovenia	SI04	Zahodna Slovenija
DIH30	B	Slovenia	SI03	Vzhodna Slovenija
DIH31	B	Slovenia	SI04	Zahodna Slovenija
DIH32	B	Slovenia	SI03	Vzhodna Slovenija
DIH33	B	Spain	ES30	Comunidad de Madrid
DIH34	B	Spain	ES41	Castilla y León
DIH35	B	Romania	RO12	Centru
DIH36	B	Romania	RO21	Nord-Est
DIH37	B	Romania	RO32	Bucuresti–Ilfov
DIH38	B	Spain	ES30	Comunidad de Madrid
DIH39	B	Sweden	SE22	South Sweden
DIH40	B	Germany	DED5	Leipzig
DIH41	C	Hungary	HU10	Közép-Magyarország (NUTS 2013)
DIH42	C	Croatia	HR03	Jadranska Hrvatska
DIH43	C	Italy	ITH5	Emilia-Romagna
DIH44	C	Netherlands	NL41	Noord-Brabant
DIH45	C	Poland	PL12	Mazowieckie (NUTS 2013)
DIH46	C	Slovenia	SI03	Vzhodna Slovenija
DIH47	C	Spain	ES51	Cataluña
DIH48	C	Finland	FI1B	Helsinki-Uusimaa

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