Accelerating the growth of start-ups in the Smart City Entrepreneurial Ecosystem: *an empirical analysis of the Brainport Smart District (BSD) in Helmond, the Netherlands*

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Executive summary

Smart City has become one of the most popular topics in recent years due to the emergence of innovative digital technologies. According to the European Commission, Smart cities refer to cities that seek to improve the administration and efficiency of the urban environment through embedding Information and Communication Technology (ICT) into the traditional infrastructure and services (European Commission, n.d.; Timeus et al., 2020). Considering the environmental, social, and economic issues caused by rapid urbanisation in the past years, both international and national incumbents have introduced smart city initiatives to create a better, more innovative, and more sustainable living environment, such as Singapore, Dubai, and Amsterdam. The observation of Amsterdam proves that urban innovation led by innovative start-ups is the primary catalyst for developing smart cities. Therefore, special attention should be paid to innovative state-ups in the Smart City industry.

Start-ups have been active in an innovation system where every part is connected and linked by a network of relationships. In this study, the author defines this innovation system as Smart City Entrepreneurial Ecosystem (SCEE), where stakeholders in the Smart City industry are involved and interact with each other, including start-ups, government, industry players, knowledge and research institutions, citizens, etc. It is observed that start-ups have encountered the "valley of death" problem in their early development stage with limited commercial resources such as funding, unstable customers, brandings, etc. Additionally, it is difficult for them to communicate with the government to realise bottom-up innovation, and there are many regulatory setbacks for them due to the low agility of the government, making it difficult to react immediately towards the innovation in the market. Given these problems, it is imperative to research the SCEE and figure out how to help start-ups address these problems with the help of other actors in the ecosystem by establishing favourable interactions. Currently, little research has been done on the development and analysis of SCEE, and people know little about the collaboration and interaction between actors. Therefore, it is necessary to conduct research on the interactions between start-ups and other actors in the SCEE and obtain insights to guide practical work. The main research question in this study is "*How to develop and analyse the Smart City Entrepreneurial Ecosystem to accelerate the growth of start-ups?*"

The previous research claimed that there are six different dimensions of smart cities: smart economy, smart mobility, smart governance, smart environment, smart people, and smart living (Giffinger et al., 2010). Mitra et al. (2021) emphasised the significance of developing entrepreneurship in smart cities through the innovation created by start-ups. Six smart city ecosystem models are the mainstream models utilised in academia. Integrative Smart City Ecosystem Model proposed by Wirtz & Müller (2022) distinguishes six consecutive layers of a smart city ecosystem model, namely the physical infrastructure model, software infrastructure mode, service provision model,

interaction model, collaboration model, and governance model. Tripathi et al. (2019) demonstrate the critical elements of a general start-up ecosystem model, including entrepreneur, support factors, finance, demography, market, education, human capital, and technology. The adapted Hutchison's i-COA® framework adapted by Appio et al. (2019) introduces the "soft" layer and "hard" layer in the ecosystem model; the former includes collaboration ecosystems, applications, and life, while the latter consists of physical place and infrastructure. Mitra et al. (2022) created a Start-up Ecosystem in Smart Cities with four pillars: knowledge hub, public policy, entrepreneurship, and economy. Under the four pillars, there are the foundation, namely the support services and technology infrastructure. The N-helix model is frequently used as the structural foundation in the innovative knowledge-creation process. In this study, the Quadruple Helix Model is chosen to serve as the structure of the conceptual model of SCEE, which include four significant actors, government, academia, industry, and society.

To answer the research question, the author conducted a systematic literature review to develop a theoretical framework of SCEE, and a case study of Brainport Smart District was used to apply the theoretical framework to it. Brainport is an innovative district located in Helmond, the Netherlands, aiming to create a smart and sustainable future community. The SCEE of BSD can be developed with the theoretical framework with the obtained data from online resources and stakeholder interviews. To analyse the ecosystem of BSD, Social Network Analysis was employed to identify the network features, key actors, and key interactions of this ecosystem.

The conceptual model of SCEE is made up of two components, actors, and interactions. There are 16 different actors defined under the four categories. Government includes the international government, national government, provincial government, local government, local management team, and other public authorities. Academia contains universities, research institutions, and individual innovators or students. Industry consists of start-ups/SMEs (small and medium-sized enterprises), large tech enterprises, incubators & accelerators & intermediary innovative platforms, private investors, and software & hardware infrastructure providers. There are only two actors in society, users & consumers, and media. As for interactions, there are ten types of interactions derived from existing works of literature: governing & regulating, cooperation & partnership, financially supporting & investing, educating & training & advising & knowledge sharing, infrastructure supporting, selling & supplying, buying & consuming, marketing & promoting, innovation creating, intermediating & connecting & network building.

After applying the theoretical framework to BSD, there are 15 nodes and 33 edges in the ecosystem, where nodes indicate actors, and edges represent the interactions between actors. This network is relatively condensed since its diameter is 3, the average clustering coefficient is 0.622, and the average path length is 1.697, which means actors can reach each other in a short time and with little effort. Considering

the degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality, start-ups/SMEs, the local management team of BSD, users & consumers, and software & hardware infrastructure providers are the key players in the ecosystem due to their high value in these indicators. As for interactions, most interactions happened between start-ups and actors in the government and industry. And there is also a self-loop in the social network of the SCEE in BSD, which means that start-ups are interacting with other start-ups in the ecosystem.

Identifying key actors will be helpful for policymakers or other actors to make strategic decisions to improve the SCEE and create a better environment for start-ups to thrive and grow. The analysis of interactions provides guidance on how to improve the current interactions between start-ups and other actors and also points out what interactions are lacking in the ecosystem. This study not only fills in the knowledge gap in the development and analysis of SCEE and benefits scholars interested in this field but also can be adopted by policymakers and practitioners to improve the whole ecosystem and stimulate entrepreneurship and innovation in smart cities.

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Contents

1. Introduction

1.1 Background

According to the European Commission, Smart cities refer to cities that aim to improve the administration and efficiency of the urban environment through embedding Information and Communication Technology (ICT) into the traditional infrastructure and services (European Commission, n.d.; Timeus et al., 2020).

The United Nations predicts that 66% of the population worldwide will be living in urban areas in 2050, and currently, there are already 54% living in the cities; issues such as traffic congestion and increasing housing shortage have occurred accordingly (Bibri & Krogstie, 2020; Nam & Pardo, 2011; United Nations Environment Programme, 2018). With the increasing population, growing urbanisation rate and the rapid development of digital technologies, smart city has become one of the most popular topics in academia and industry (Nam & Pardo, 2011). In addition, modern cities are confronted with environmental challenges and resource crises, such as excessive greenhouse gas emissions, energy resource depletion, water pollution, etc. To help the urban environment acquire environmental, social, and economic benefits, international and national authorities have enacted multiple smart city initiatives to upgrade the ageing and deteriorating infrastructures, aiming to increase the living quality of citizens and make the urban environment more appealing and competitive in the global market (de Jong et al., 2015). For instance, the European Commission has enacted the “smart cities” initiative, applying innovation policies and technology to 18 multi-scale lighthouse projects in different dimensions, including sustainable urban mobility, sustainable urban environment, integrated infrastructures in the energy sector, etc (European Commission, n.d.). It has also built a Smart Cities Marketplace by integrating two platforms, namely “Marketplace of the European Innovation Partnership on Smart Cities and Communities (EIP-SCC Marketplace)” and the “Smart Cities Information System (SCIS)”. This platform is designed to promote collaboration between all the smart city actors, facilitating information exchange and the match of financing opportunities (Caragliu & del Bo, 2019). In another case, Singapore has introduced Smart Nation Singapore Initiatives to transform health, transport, urban living, government services and businesses with a focus on digital government, digital economy, and digital society (Smart Nation Singapore, n.d.). Dubai has been dedicated to transforming itself into a smarter and more sustainable city by upgrading six dimensions under the Smart Sustainable Cities (SSC) initiative, ranging from transportation, infrastructure, communications, economic services, and urban planning to electricity (The United Arab Emirates’ Government, 2021).

Noori, Hoppe, et al. (2020) stressed the importance of knowledge and innovation management in adding value and propelling the development of smart cities. Meijer & Thaens, Pierre et al. and Sørensen & Torfing (2016, 2013, 2011) defined urban

innovation as the process that makes substantial changes to the urban environment and addresses urban-related problems through producing and implementing innovative ideas and technologies. The emergence of a smart city is built upon urban innovation, which is mainly driven by innovative ideas and cutting-edge technologies developed by innovative start-ups. A place with many emerging start-ups represents a superior level of entrepreneurship, which creates more job positions, boosts regional economic prosperity, and addresses environmental challenges (Santos, 2017).

Start-ups refer to small and medium-sized enterprises (SMEs) delivering innovative products or services in their early-development stage with limited workforce and fundings. Smart city start-ups are the start-ups that are active in the smart city industry and contribute to smart economy, smart mobility, smart governance, smart environment, smart people, and smart living, the main components of a smart city (Giffinger et al., 2010). Considering innovative start-ups as the main driver for smart city development, many cities have enacted relevant incentive policies and programmes to stimulate urban innovation and nurture the entrepreneurial environment, thus accelerating the pace of smart city development with the increasing participation of start-ups. For instance, Amsterdam has served as a pioneer in engaging start-ups in creating a smart city as the winner of Europe's Capital of Innovation Award by the European Commission in 2016. According to the findings of Noori, Hoppe, et al. (2020), the main driver of Amsterdam Smart City is innovation, and its development path is described as "innocratic" (start-up and business-driven) with four different key features, namely competition, entrepreneurial, innovative, and bottom-up approach. In 2019, Amsterdam started the "Amsterdam Smart City" innovation platform, which intends to connect start-ups with all the other stakeholders (i.e., government, Venture Capital investors, institutional investors, and citizens) to transform their innovative ideas into pilot projects and shape the future of smart Amsterdam (Amsterdam Smart City, n.d.; FMDV, 2014). Moreover, the City of Amsterdam also introduced a public programme named "StartupAmsterdam" in 2015, an incubator for innovative start-ups and scale-ups to improve the sustainable and innovative performance of the city (StartupAmsterdam, n.d.). Also, in 2017, there was an accelerator programme named "Startupbootcamp Smart City & IoT Amsterdam", which is dedicated to addressing the smart city challenges through scaling and empowering the business of tech start-ups (Startupbootcamp, n.d.). The success of Amsterdam Smart City confirms the effectiveness of the innocratic development path in a smart city, which creates a participatory innovation environment enabling bottom-up innovation and encourages the business collaboration between start-ups and other actors in the Smart City Entrepreneurial Ecosystem (SCEE) (Capra, 2016; Noori, Hoppe, et al., 2020).

According to Bergek et al. (2008), an innovation system is a system with a configuration of parts that are interconnected and linked by a relationship network. Freeman et al. (1987) denote the innovation system as a network where both the public and private entities interact with each other and thus generate new

technologies during these joint activities. Since multiple actors are interacting with each other and creating innovative technologies in the SCEE, the author defines SCEE as a supporting innovation system with all the stakeholders in the smart city industry, including start-ups, government, venture capitalists, knowledge institutions, public organisations, citizens, etc.

1.2 Problem statement & research gaps

Considering what has been mentioned above, it is apparent that innovative ideas created by start-ups are the key to developing a smart city. However, it is observed that start-ups have encountered the "valley of death" problems in their early development stage, which will further impede their commercial expansion and the smart city development accordingly.

The problem "valley of death" frequently happens in the initial development stage of start-ups, which is the intervening phase between research and the new product development process (NPD) (Branscomb & Auerswald, 2001). As shown in Figure 1 below, the x-axis represents the development process of an innovative product, and the y-axis stands for the number of resources. In the discovery stage, there are plenty of research resources, while the commercialisation resources are limited. There are sufficient commercialisation resources but rare research resources in the mature commercialisation phase. The Valley of Death is the resource gap between opportunity discovery and product development. Currently, most of the start-ups in the smart city industry are still in the early discovery stage with limited commercialisation resources (i.e., public and private funding and incentive government policies) but plenty of research resources, which means that the technology innovation is developing ahead of the organisation innovation (managing the innovation for practical use) and policy innovation (creating an enabling environment for innovation evolving) in the smart city context (Nam & Pardo, 2011).

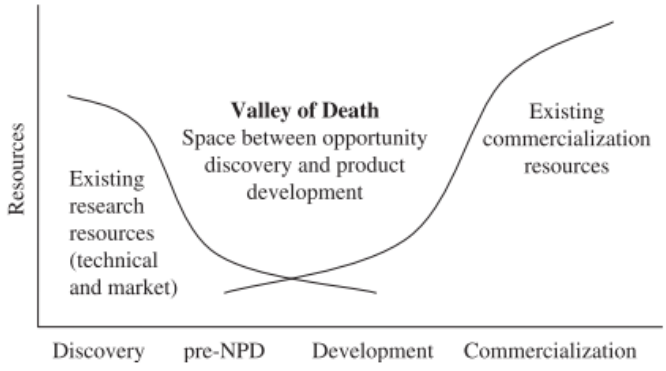

Figure 1 Valley of Death (Branscomb & Auerswald, 2001)

Noori et al. (2020) introduced the “readiness” of a smart city in their paper, pointing out that the development of a smart city is achieved through the integration of technological and non-technological factors. Therefore, whether a smart city is ready to be developed and function well is decided by technological readiness and socioeconomic readiness. Nevertheless, it is easy to find that start-ups have met many problems in the current SCEE, including a lack of communication with the government and top-down governance, insufficient funding from both the public and private sectors, and the different levels of organisational agility between business environment and the government, showing that the socioeconomic readiness of smart cities still needs improvement.

Firstly, the SCEE is a complicated network system with multiple stakeholders and numerous interconnections between them. However, this ecosystem has been rarely studied and has not been defined yet in academia, which makes it even more difficult for the government to have a clear overview of all the actors and their interactions within the ecosystem. Hence, the communal discourse between start-ups and government is likely to be inhibited, slowing the implementation of innovative ideas (Thuzar, 2011). Additionally, Nam & Pardo (2011) emphasised the importance of policy innovation, which prioritises the bottom-up collaboration between government and other stakeholders instead of the top-down public administration, transforming government from an initiator and commander to a facilitator and collaborator. However, Caragliu & del Bo. (2019) pointed out that the engagement of stakeholders and bottom-up design is lacking in practices, which contradicts the principle and goal of innovative smart city initiatives. Therefore, an innovative SCEE is needed to enable the engagement of start-ups in the design and decision-making process and thus realise bottom-up innovation (Joss et al., 2019).

Another problem start-up face is insufficient funding from both the public and private sectors. Although lots of capital have flowed into the smart city industry, most of them have gone into large-scale infrastructure projects rather than small-scale start-ups. Unlike large-scale smart infrastructures with steady and predictable revenues, the revenue of start-ups is uncertain, and the benefit of their technologies is challenging to monetise. Therefore, for risk-averse institutional and public investors, the high risk and uncertainty have prevented them from investing in small-scale start-ups. Even though there are many funding opportunities provided by venture capital investors and funding programmes initiated by the government, such as the Netherlands Enterprise Agency (RVO), only the outstanding start-ups satisfying the strict selection criteria can receive financial support.

Last but not least, the organisational agility level of the business environment is higher than that of the government, since the organisations in the business environment can respond immediately to emerging opportunities and adapt to the innovative transformation. However, due to the hierarchy and conservation of the government, it takes time for incumbents to implement regulatory changes to react to the

innovations. The whole decision-making process in the public authorities is longer and more tedious, and the engagement level of other stakeholders in the decision-making process is also relatively lower. Therefore, it is commonly seen that the current regulations enacted by the government are not applicable to the latest technologies or products in the business environment, which constrains the commercialisation of innovative services or products.

Currently, little research has been done on SCEE, especially the collaboration and interaction layer. In addition, the interactions between start-ups and other actors are not investigated in detail yet. Even though some researchers have studied the interaction patterns between stakeholders in the ecosystem, none of them has used Social Network theory to analyse the key actors, interactions, and network attributes of the ecosystem. Therefore, it is necessary to build a comprehensive SCEE theoretical framework that depicts the key actors and their interactions in the Smart City industry for quantitative and qualitative analysis. This theoretical framework can be utilised to promote the cooperation between start-ups and other stakeholders to co-address the problems and challenges start-ups are confronted with in the early development process, thus accelerating the growth of start-ups and urban innovation.

1.3 Research questions & structure

This study intends to help start-ups in the Smart City industry overcome the “valley of death” problem in their early development stage by improving the current environment of SCEE, which provides essential human capital, knowledge and expertise, resources, and regulatory help to facilitate start-ups’ growth through favourable interactions.

This research can be divided into two parts. First, the author aims to build a theoretical framework for SCEE with a focus on start-ups. Then, the author will apply this theoretical framework to the case of BSD to conduct an empirical analysis, defining the critical actors within the ecosystem, investigating the interaction patterns between them, analysing the characteristics of the ecosystem network, and proposing policy recommendations to help start-ups grow by establishing and sustaining the partnership with other actors.

With the help of a systematic literature review of the existing academic papers, an initial integrated theoretical framework can be created. Then, the author will gather necessary information through the internet and Interviewees to apply the SCEE framework to the BSD case and identify the major stakeholders and their interaction patterns. By analysing the BSD ecosystem using Social Network Analysis, the author will investigate the network attributes of the ecosystem, such as degree centrality, betweenness centrality, and closeness centrality. In the end, policy recommendation and strategic advice will be given for policymakers and practitioners to understand the innovative entrepreneurial environment in the Smart City industry better.

The main research question and sub-questions are demonstrated below:

1.3.1 Main question

How to develop and analyse the Smart City Entrepreneurial Ecosystem to accelerate the growth of start-ups?

1.3.2 Sub-questions

1) What does a theoretical framework for SCEE look like?
2) How can the theoretical framework be applied to analyse a real-life case to improve the interactions in SCEE to stimulate start-ups' growth?
3) What are the analytical results of applying the theoretical framework to the case of BSD?
4) How to accelerate the growth of start-ups in the SCEE with insights from the case study results of BSD?

The structure of this report is demonstrated as follows: Chapter 1 provides a background of this research, introducing the concept of smart cities and pointing out the current problems existing in the SCEE for start-ups. Also, the academic gaps related to ecosystem research and the research questions of this study are listed. Chapter 2 shows the whole process of conducting the systematic literature review, demonstrating the current literature related to Smart City ecosystem frameworks, significant actors, and their interactions. An adapted coding framework is given after synthesising the data extracted from these pieces of literature. In Chapter 3, the author presents the theoretical framework of SCEE. Chapter 4 explains the methodologies taken by the author to develop and analyse the SCEE of BSD. In Chapter 5, the findings of the BSD case study are shown. In the end, the author will reflect on the findings of this research and discuss its academic contribution and practical implication in Chapter 6 and deliver conclusions in Chapter 7.

2. Systematic literature review of Smart City Entrepreneurial Ecosystem

This chapter demonstrates the current academic work regarding the Smart City Entrepreneurial Ecosystem through a systematic literature review. The procedure for conducting a systematic literature review is explained first. Then, an introduction to the six dimensions of Smart City and entrepreneurship in Smart City are given. Five different Smart City ecosystem models in academia are demonstrated in Chapter 2.4, and the actors and interaction types in the Smart City Entrepreneurial Ecosystem are summarised in Chapter 2.5 and 2.6, respectively. In the end, an adapted coding framework of SCEE is proposed by synthesising information gained from the reviewed literature.

2.1 Systematic literature review procedure

Conducting a rigorous systematic literature review is essential in this research as building a theoretical framework for the ecosystem needs lots of information and data extracted from the existing academic references. This review aims to create a comprehensive theoretical framework of SCEE by finding, selecting, and synthesising data from relevant frameworks in the existing literature, making up for the deficiency of the current ecosystem framework. The detailed research questions are demonstrated as follows:

1) What do the existing Smart City ecosystem frameworks look like?
2) Who are the actors in the SCEE?
3) What are the types of interaction between different actors in the SCEE?

The author will follow the eight steps to implement a systematic literature review on SCEE and answer the research question.

1) Identify the research question
2) Develop and validate the review protocol
3) Conduct systematic searches – review the title
4) Screen for inclusion – review abstract
5) Assess quality – review full-text
6) Extract data
7) Analyse and synthesise data
8) Report the finding

Appendix 1 provides detailed information on the systematic literature review procedure, including major elements such as research questions, search strategies, inclusion criteria, quality assessment criteria, screening procedures, data extraction and synthesis strategies (Xiao & Watson, 2017).

To conduct data extraction and synthesis, the most important step, "framework synthesis" is employed to synthesise the obtained qualitative data. As shown in Figure 2, the synthesis stages run through the systematic literature review process, starting from familiarisation, framework selection, indexing, and charting to mapping & interaction. The first stage is to get familiarised with the literature relevant to the determined research aim and questions. Then, an initial conceptual model will be chosen to serve as the reference model to derive the categorising codes, which leads to the third step, indexing.

At the stage of indexing, the selected studies will be screened by titles, abstracts and full-texts, and data will be extracted according to the codes defined by the initial conceptual model (deductive coding). The original codes will be modified during this process, and new codes will be added iteratively as new evidence is gained from new studies (inductive coding). Since both the deductive and inductive coding approaches are utilised in this study, the coding approach in this study is hybrid coding. Data extracted from the eligible literature is sorted and recorded separately in a designed Excel spreadsheet and a Word document. The Excel spreadsheet is used to record the key information of different studies and assign them to different thematic categories, and the Word document will record the long sentences or paragraphs pertaining to different codes for data synthesis. The results of the data extraction are reviewed by the committee to guarantee the validity of the systematic literature review. In the end, the distilled interpretations from coded data are demonstrated in the charts, and a comprehensive theoretical framework of the SCEE is mapped (Brunton et al., 2020; Carroll et al., 2013; Dixon-Woods, 2011).

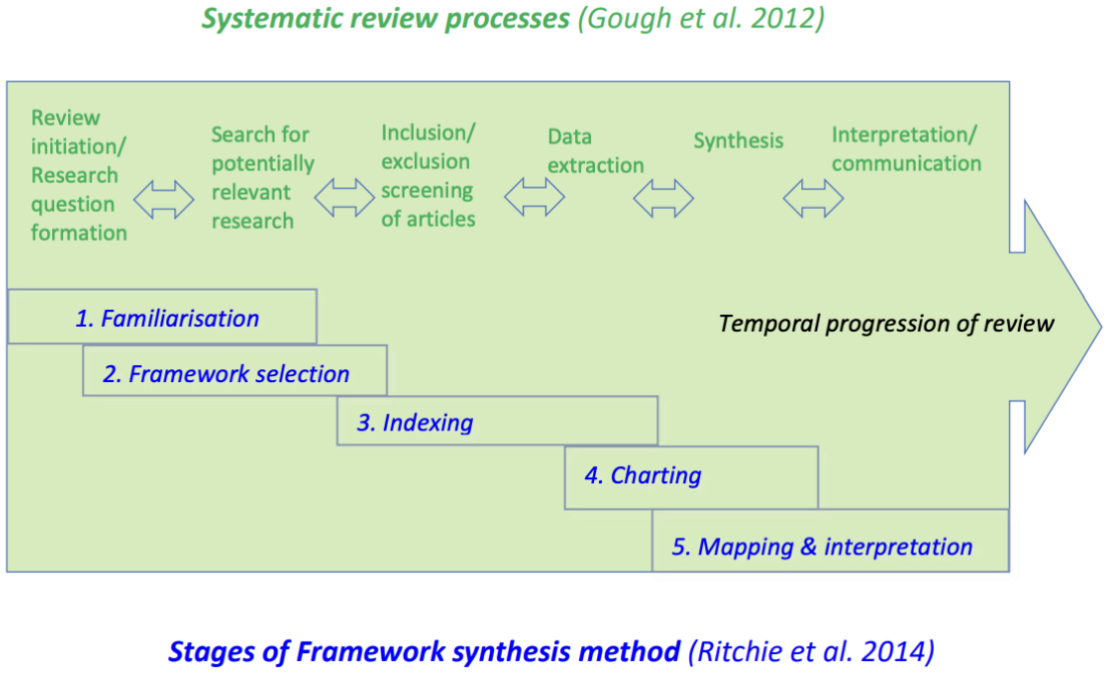

Figure 2 Framework synthesis stages corresponding to the systematic review process(Ritchie et al., 2013)

2.2 Introduction to Smart City

There are mainly six dimensions of a smart city based on the commonly used framework developed by Giffinger et al. (2010), including smart economy, smart mobility, smart governance, smart environment, smart people, and smart living.

Smart economy uses innovation and entrepreneurship to increase the productivity, efficiency and competitiveness of products and services, thus improving people's quality of life and boosting economic development (Lu et al., 2019).

Smart mobility plays a vital role in the smart city industry with the boom of electric vehicles (EV) and automatic vehicles (AV). The key to smart mobility is integrating ICT technology with the transportation management system and transportation infrastructure, making it more accessible, sustainable, and safe (Giffinger et al., 2010).

The features of smart governance consist of the active participation of citizens in the decision-making process and more transparent governance and policies, which could be realised by digital technologies (Sharif & Pokharel, 2022). The ideal product of smart governance could be an open and interactive platform that encourages active communication and collaboration between the government and other stakeholders (Smart Selangor Delivery Unit, 2016).

Smart environment refers to utilising innovation to preserve the natural environment and resources, leading to less pollution, better environmental protection, and more sustainable resource management (Giffinger et al., 2010).

Smart people will be the main contributor to the establishment of a smart city. In the concept of smart people, human capital (entity's ability and proficiency) and social capitals (relations among organizations) are of great significance (Sharif & Pokharel, 2022). Better human capital and social capital could be realized by improving educational resources and institutions, thus boosting innovation development.

Smart living focuses on improving the living quality of citizens through ICT technologies, which is the further outcome of smart economy (Apostol et al., 2015). According to Giffinger et al. (2010), the key factors of smart living include cultural facilities, health conditions, individual safety, housing quality, education facilities, and touristic and social cohesion.

2.3 Entrepreneurship in Smart City

Kummitha (2019) and Scornavacca et al. (2020) have conducted bibliometric analysis and cluster content analysis to systematically analyse the evolutionary trends in the Smart City research area, which concluded that despite there being much research in

the field of Smart City, only a small percentage of them concentrates on the entrepreneurship with 35 papers out of 479 papers until June 2017. Moreover, among the existing literature related to the entrepreneurial aspect of Smart City, little research dived into the favourable entrepreneurial conditions and the entrepreneurial ecosystem for Smart City development. Based on the categorisation and classification of Kummitha (2019) and Scornavacca et al. (2020), the prevailing research shaping the entrepreneurial environment of the Smart City is demonstrated as follows.

Mitra et al. (2021) have conducted research on entrepreneurship in smart cities, and they stressed that it is primary for the SCEE to provide early-stage enterprises with knowledge and resources to stimulate entrepreneurship in smart cities. The cities are where entrepreneurship is incubated, with lots of innovative ideas being developed, tested, and commercialised in living labs, incubators, and accelerators (Mitra et al., 2021). It is worth mentioning that entrepreneurship has a close bidirectional relationship with smart cities, as entrepreneurs introduce technologies to the market to accelerate the socio-technical transition of smart cities, and these technologies can, in turn generate and collect big data to help entrepreneurs gain data-based market insights and make the analytical decision (Kummitha, 2019; Mitra et al., 2021).

In terms of Smart City entrepreneurial practices, Perng et al. (2018) primarily investigated how hackathons have promoted digital innovation, entrepreneurship, and start-up economy in the context of Smart City as a platform connecting programmers, entrepreneurs, investors, industry experts, etc. As an effective instrument, hackathons grant participants the opportunity to develop their innovative prototypes further, attract more investments and become a start-up company, reinforcing the ethos of entrepreneurial and urban innovation. By testing on a Smart City Living Lab in Amsterdam, Climate Street, Sauer (2012) assessed entrepreneurs' engagement level in bottom-up innovation and found that their participation and innovativeness were limited and prohibited.

Santos (2017) has provided valuable insights on the determinants of entrepreneurship in urban development, which can be used as guidelines to make smart city policy, thus enhancing the interactions between different stakeholders, and engaging more actors in the bottom-up design and decision-making process. Kraus et al. (2015) found the key factors that entrepreneurs consider necessary in exploiting entrepreneurial opportunities in Smart Cities, including business-led urban development, high-tech and creative industries, social and relational capital, government-led development and support, etc. It is also claimed in this paper that the government did not provide sufficient support in administration and financial subsidies, in which case innovative initiatives should be introduced by the government.

2.4 Smart City ecosystem models

2.4.1 Integrative Smart City Ecosystem Model

The Integrative Smart City Ecosystem Model was first proposed by Wirtz & Müller (2022), which demonstrates six consecutive layers of a smart city ecosystem after reviewing nine studies in relevant journals and reference books. This integrative model serves as an effective and credible guideline for other researchers to distinguish and classify various smart city ecosystem models and conduct further research.

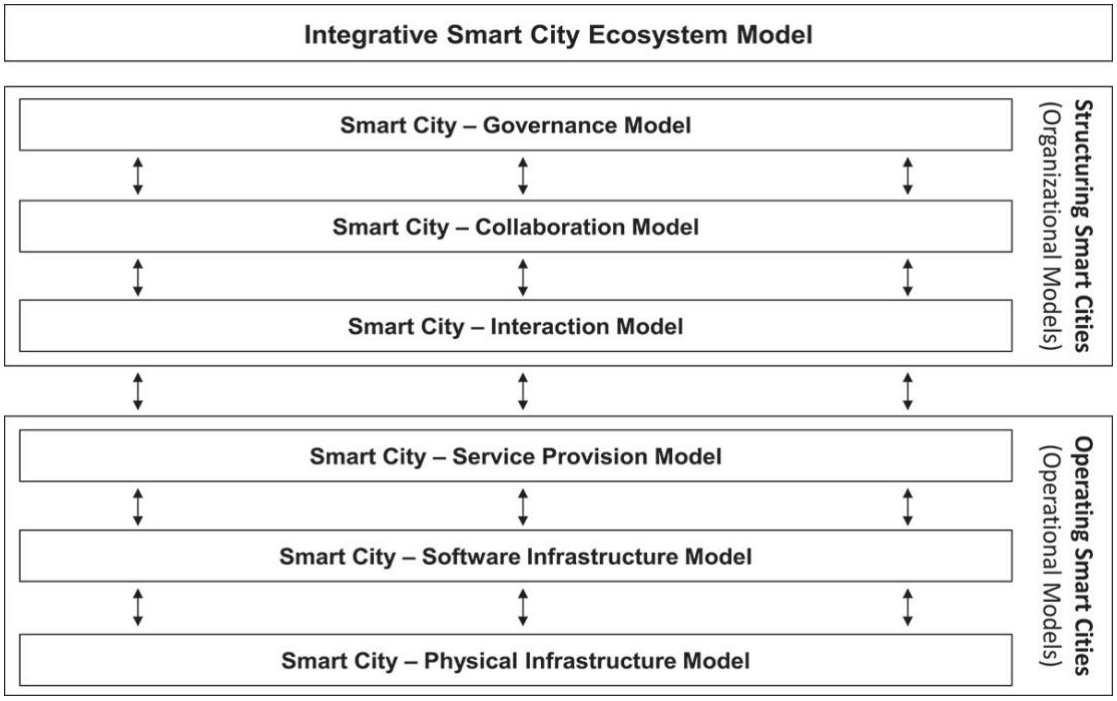

Figure 3 The Integrative Smart City Ecosystem Model and the elaborated sub-models (Wirtz & Müller, 2022)

The six layers are obtained from extracting, analysing, synthesising, and comparing the previous ecosystem schemes proposed by other scholars. On the one hand, the governance model, collaboration model and interaction model belong to the organizational models, which depict the collaborative structure of the smart city ecosystem. On the other hand, the service provision model, software infrastructure model, and physical infrastructure model pertain to operational models, the networks that smart city relies on to sustain their operation. Each layer of the integrative smart city ecosystem framework will be elaborated as follows.

On top of the Integrative Smart City Ecosystem Model is the governance model, which describes the regulatory procedures and measures taken by the authorities to boost cooperation between stakeholders and ensure the smooth running of smart city programs without malicious intervention. Below the governance model is the collaboration model. The collaboration model is of great importance as it indicates the main players and their interdependencies within the ecosystem, collaborating to

achieve value creation. The existence of the interaction model is to compensate for the deficiency of the collaboration model, elaborating the attributes and categories of the interplay between different actors Wirtz & Müller (2022).

When it comes to the operational models down below, the service provision model is defined as a digital platform offering public services (Mukti & Prambudia, 2018; Robert et al., 2017). As for software and hardware infrastructure, their pivotal function is supporting the data generation, storage, and processing cycle in the smart city context (Wirtz et al., 2019a). In the software infrastructure model, relevant software supports the data utilisation process during three different stages, from perception to communication and operation. On the contrary, the hardware infrastructure is the physical infrastructure that practically realises the above data logistic process, including data servers, Internet/Network infrastructure, and endpoints ICT devices.

2.4.2 General start-up ecosystem model

To build the SCEE framework, diving into the general start-up ecosystem model is inevitable, which serves as the starting point to explore the structure and key elements of the ecosystem. Numerous existent studies investigate the start-up ecosystem with different definitions, structures, and major elements. By employing a multi-vocal literature review, Tripathi et al. (2019) systematically reviewed 63 papers related to the start-up ecosystem, summarising the definition, key elements, and their influences on the start-up ecosystem. In the following paragraphs, the author will describe the general start-up ecosystem model with the systematic and detailed results obtained from the work of Tripathi et al. (2019).

In the biological world, an ecosystem is defined as a complex system where living beings interact with each other and other non-living elements (Ives & Carpenter, 2007). Likewise, a start-up ecosystem is a complicated community containing interdependent actors and other supporting components in a defined geographic region, contributing to new venture creation and entrepreneurship boom (Cohen, 2006). Despite the fact that there are diverse definitions of the start-up ecosystem, they share overlaps in using similar terminologies, such as stakeholders, supporting organization, infrastructure, network, and region (Tripathi et al., 2019).

After reviewing all the selected articles and implementing a word frequency query and thematic analysis, Tripathi et al. (2019) defined the principal elements and sub-elements of the start-up ecosystem, including entrepreneur, support factors, finance, demography, market, education, human capital, and technology as shown in Figure 4 below.

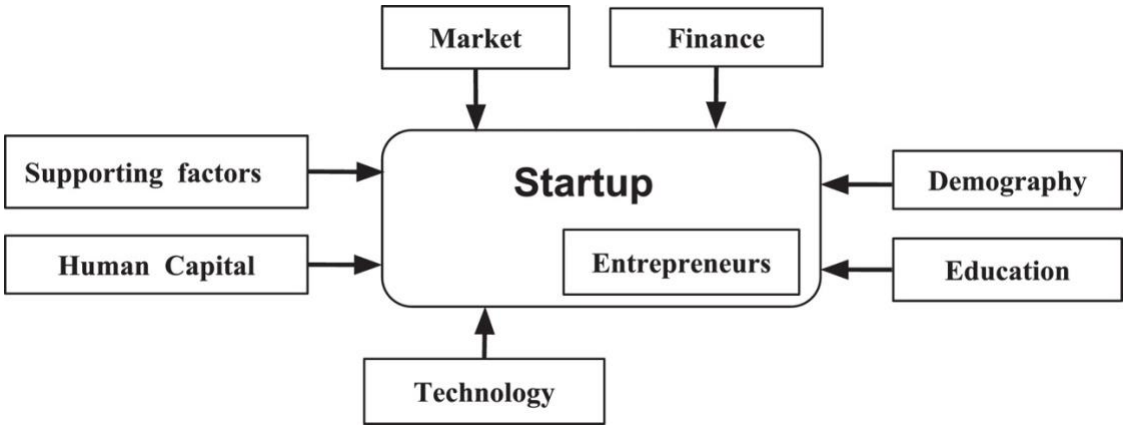

Figure 4 Key elements in a start-up ecosystem (Tripathi et al., 2019)

The entrepreneur is the first and primary element of the start-up ecosystem, representing the entities starting a new business venture, namely the start-up founders. The second main element is support factors, which contribute to the growth of start-ups. For instance, incubators, accelerators, and mentors provide mentorship, funding, and customer networks to entrepreneurs in the early development stage (Kulkarni, 2013; Libes, 2012; Pronovix, n.d.). Among these sub-elements of support factors, the government has been playing an indispensable role since it can promote new venture creation through designing favourable policies (PwC South Africa, 2015), simplifying legal procedures (Compass.com, 2016), collaborating with large enterprises, and offering financial support to start-ups or relevant parties (S.A., 2015).

In terms of funding, it is also an essential factor going through the life-cycle process of a start-up. Sub-elements, including established companies, venture capital, crowdfunding, bank, and government, are the diverse sources of both public and private investments in start-ups. As for the fourth main element, demography describes different demographic attributes of a start-up ecosystem, such as culture and language, Gross Domestic Product (GDP), and geography, which will shape and influence the start-up ecosystem in an in-directed way.

The fifth main element, the market, is the environment where the start-ups' products will be traded. Due to the difference in market size, the market can be divided into the local and global markets. Beyond these two elements, customers also significantly impact the market. Only when the products or services developed by start-ups are consistent with customers' needs will start-ups be able to sustain their competitiveness in the market. In addition, education, the sixth main element, determines the quality of the start-up ecosystem from two aspects. On the one hand, a good education environment will grant entrepreneurs the essential knowledge, mindset, and skills to develop their businesses (Farrel, 2014). On the other hand, knowledge institutions such as universities and research centres enable the knowledge flow from academia to industry; start-ups can utilise this kind of sharing knowledge to transform cutting-edge theoretical research into practical use.

The start-up ecosystem's last two main elements are human capital and technology. As mentioned before, the ecosystem consists of interdependent actors, which are the key drivers to innovative development through utilising innovative technology. The combination of human capital and technology is widely perceived in the start-up ecosystem, namely those high-tech start-ups. Human capital refers to all the stakeholders in the start-up ecosystem, such as educational institutions, accelerators & incubators, governments, and young talents. The sub-elements of technology are summarised, including education, established companies with strong R&D capability (i.e., IBM and Tesla), start-up founders, local industry, and innovation.

Table 1 Elements and sub-elements of a start-up ecosystem (Tripathi et al., 2019)

Elements	Sub-elements
Entrepreneur	Entrepreneur
Support Factors	Incubators, Accelerators, Co-Working Space, Events, Government, Legal Framework, Media, Mentors
Finance	Funding, Established Companies, Seed Investment, Venture Capital, Bank, Crowdfunding, Government
Demography	Cultural & Language, Gross Domestic Product, Geography, History, Society, Immigrants
Market	Market, Local Market, Global Market, Customer, Economic
Education	Education, Educational Institution, Accelerator & Incubator, Experience, Media, Family
Human Capital	Talent, Education, Accelerator & Incubator, Experience, Government, Young Talent, Policy
Technology	Technology, Education, Established Companies, Founders, Industry, Geography, Innovation, Product

The start-up ecosystem summarised by Tripathi et al. (2019) is the most comprehensive ecosystem framework in the current academia, which gives a holistic overview of the major elements and sub-elements of the ecosystem. This framework will be of great use to further develop the SCEE as an authoritative reference model. The only deficiency of this framework is that there are some overlaps of the sub-elements under different main elements, while they will be assigned to a specific category in the ecosystem framework proposed by the author in this study. For instance, the government has shown up under the category of “support factors”, “finance”, and “human capital” as a common sub-element in the start-up ecosystem designed by Tripathi et al. (2019), while it will be considered as an individual entity assigned to a specific category in the designed framework.

2.4.3 Adapted Hutchison's i-COA® framework

Hutchison et al. (2011) developed an i-COA (intelligent community open architecture) model to depict the intelligent Ukrainian communities, consisting of 5 layers: a place, infrastructure, collaboration ecosystem, applications, and life from bottom to up. The 5-level pyramid framework shown in Figure 5 is adapted by Appio et al. (2019) with a combination of the six dimensions of smart cities. This adapted conceptual model for Smart City Ecosystem proposed by Appio et al. (2019) consists of the "hard" layer (land and infrastructure) and "soft" layer (human and social capital) (Angelidou, 2014). In the "hard" layers, the first two levels, including physical place and infrastructure, serve as the base of the pyramid. In the "soft" layer, there are three other levels: collaboration ecosystems, i-Solutions (applications and solutions based on ICT), and life. On the third level, there is the collaboration ecosystem, which is relevant to initiatives regarding smart people and smart governance. Above the third level, smart living and smart economy strategies are highly intertwined with the fourth and fifth elements, namely i-Solutions and life.

The model proposed by Appio et al. (2019) offers a novel perspective to observe the smart city ecosystem, showing the "hard" (physical) and "soft" (social) components of the ecosystem. However, it did not explain each layer in detail, such as the stakeholders active in the collaboration ecosystems while concentrating on analysing and improving the smart city initiatives on six dimensions at each level to create a collaborative environment.

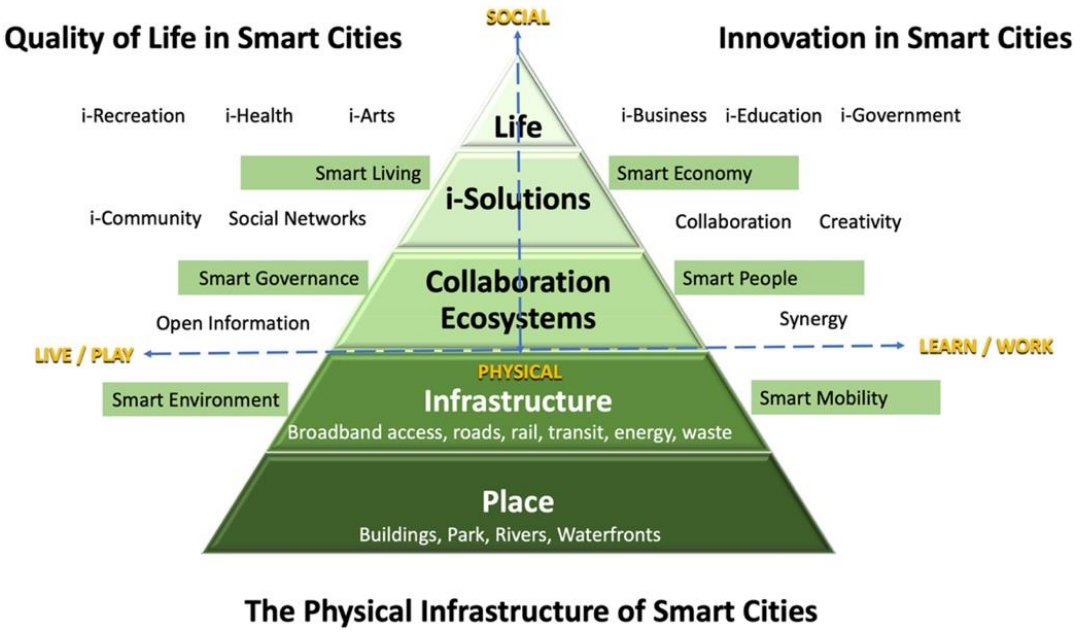

Figure 5 An adaptation of Hutchison's i-COA® framework highlighting Giffinger's smart city elements (Appio et al., 2019)

2.4.4 Smart City Start-up Ecosystem

Mitra et al. (2022) proposed a Start-up Ecosystem for Smart City, whose main pillars are support services, including knowledge hub, public policy, entrepreneurship, and economy, standing on a solid base of technology infrastructure. Like the 5-level pyramid framework developed by Hutchison et al. (2011), this model (see Figure 6) also contains the "hard" elements and the "soft" elements.

In terms of technology infrastructure, there are emerging and commonly used information and communication technology in the smart city industry (i.e., Cloud computing, Artificial Intelligence, Machine learning, and IoT/Sensors), serving as the bedrock of the support services.

Above the technology infrastructure, the four pillars are the most significant elements that support the architecture of the start-up ecosystem in smart cities. The first pillar is the knowledge hub, which entails sub-elements including innovation platforms, living labs, public participation, etc. As Ardito et al. (2019) and Hollands (2008) claim, knowledge plays an influential role in the smart city, propelling innovation development and economic prosperity. A city is where innovative knowledge and start-ups can be nurtured; thus, it is necessary to build a knowledge-based environment.

To make the city of tomorrow more efficient, sustainable, and effective and nourish the entrepreneurial culture, favourable public policy is a necessity, which is the second pillar of the start-up ecosystem. The sub-elements of public policy consist of regulation & compliances, collaboration, taxation structure, data protection (for data leakage), IPR (Intellectual property protection), and labour laws (for the workforce), etc. These sub-elements are the key to building a solid and collaborative network, promoting the commercialisation of the products and services of start-ups, and enabling the smooth running of businesses.

The third pillar, entrepreneurship, is closely related to start-ups and the most significant among the four pillars. It can create more employment opportunities, lead to healthy competition and an inclusive environment, and boost economic growth (Feld, 2012; Penco et al., 2020). Various actors are participating in entrepreneurship, such as financial services providers (i.e., venture fund agencies and investment bankers), support professionals (i.e., incubators, self-help groups, and universities) and start-ups.

It is known that the current economy will be transformed into a sustainable circular economy in the smart city development process; thus, the fourth pillar of the start-up ecosystem is the economy. Data availability facilitating opportunities can boost the economy by detecting potential business and investment opportunities with the help of big data. Human capital is the basis for creating innovative ideas, products, and

services, thus contributing to economic growth. Other sub-elements related to the economy include financial services, knowledge transfer, trade centres and logistics centres.

In general, this model is designed in the same way as Hutchison's i-COA® framework, with technology infrastructure serving as the "hard" part and support services serving as the "soft" part. The sub-elements under each pillar are chaotic, and there is no clear definition of their specific function and contribution to the start-up ecosystem.

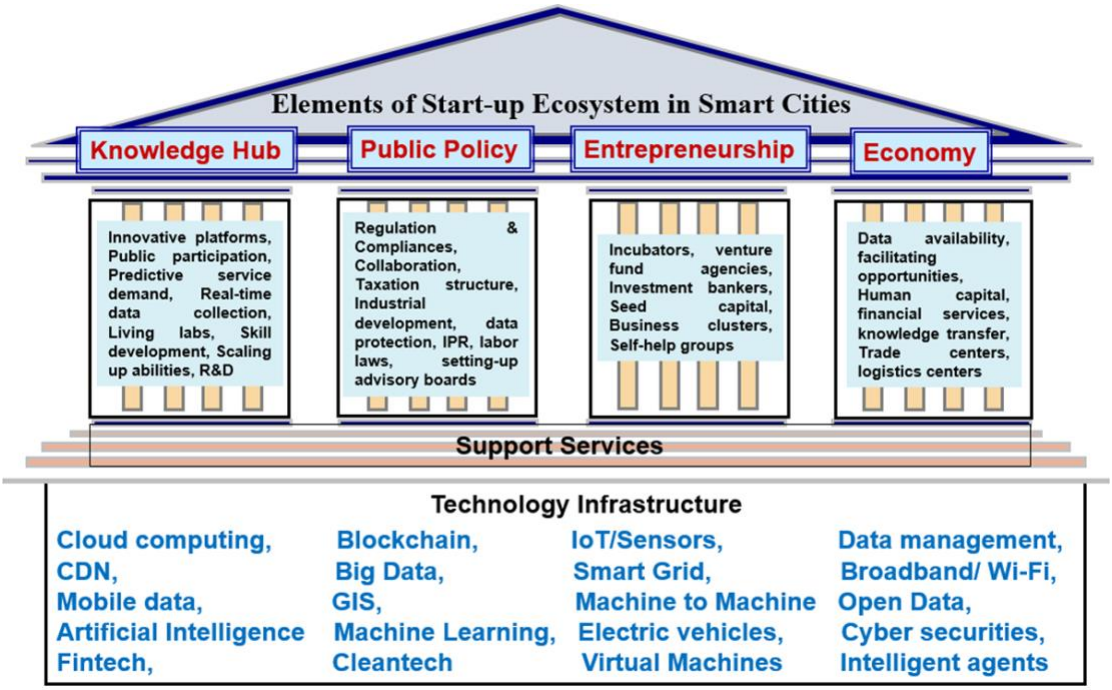

Figure 6 Elements of Start-up Ecosystem in Smart Cities (Mitra et al., 2022)

2.4.5 N-Helix model

Smart City is used as an urban living lab or an experimental environment to develop, implement and test innovative ideas (Vallance et al., 2020; Wirtz & Müller, 2022). To study the urban innovation ecosystem, “n-Helix” Models have been widely used in the innovative knowledge creation process as the structural foundation, including the Triple, Quadruple, and Quintuple Helix Models (Taratori et al., 2021a).

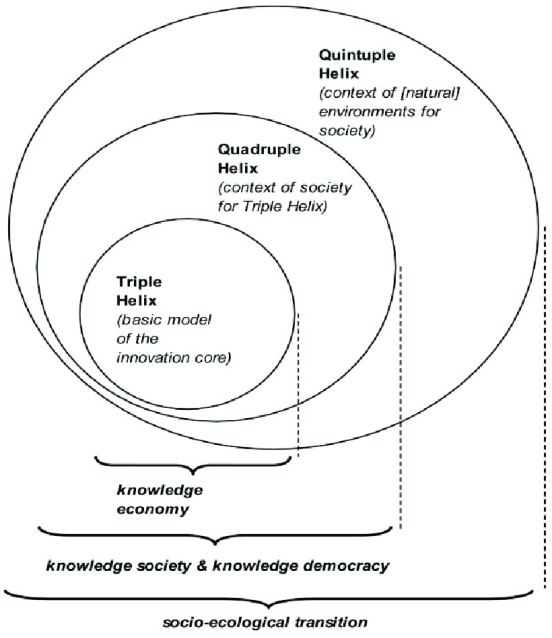

Figure 7 Triple, Quadruple, and Quintuple Helix Model (Appio et al., 2018)

"N-Helix" model defines the main components in the ecosystem and their relationships, displaying the complete knowledge emerging, distributing, and promoting process; thus, it is frequently used by policymakers to make strategic decisions by synergising opinions from diverse actors (Micek, 2020; Tura et al., 2019). In addition, McAdam & Debackere (2018) claimed that the "N-Helix" model is an effective tool for evaluating the interdependencies between different actors. Robaeyst et al. (2021) made a conceptualised model of the open innovation system, where the interactions between stakeholders on helical, organisational, and individual levels are depicted as lines between circles in Figure 8.

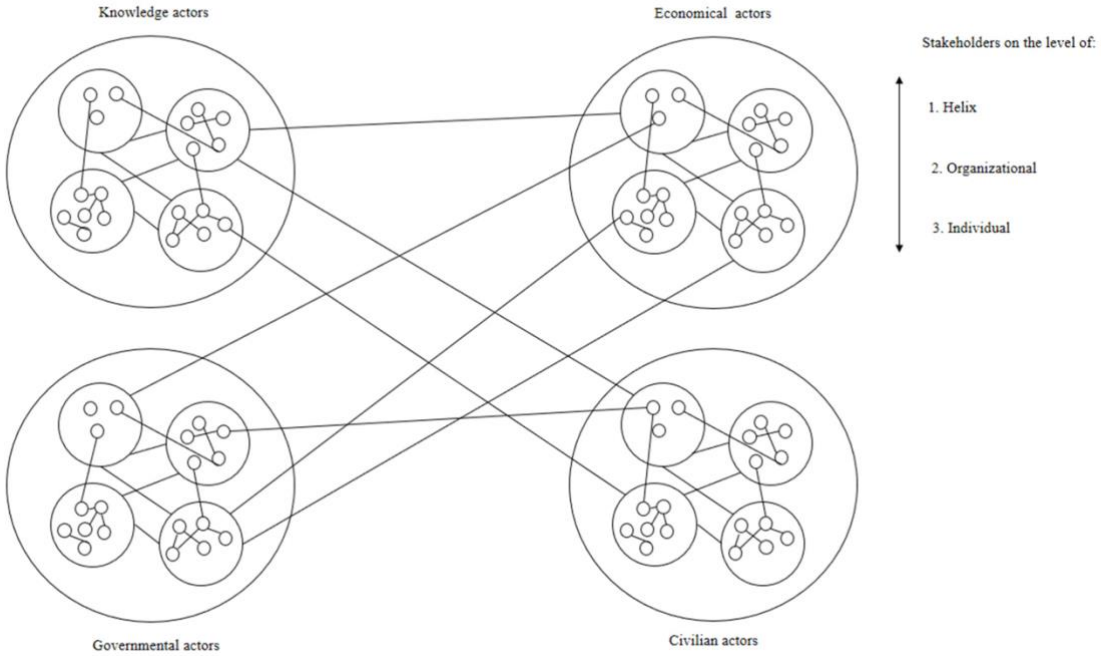

Figure 8 Conceptualization of the regional open innovation network. Stakeholders within the ecosystem exist on helical, organizational, and individual levels. The stakeholders in the network interact with one other on these three different levels (Robaeyst et al., 2021)

The triple Helix Model was first introduced to describe the open innovation ecosystem, consisting of universities, the industrial sector, and the government (Taratori et al., 2021a). Universities (or knowledge institution or academia) is where scientific and technological knowledge is delivered, and innovative ideas are created. The industrial sector (or business) includes all the players engaged in the smart city industry business. The government contains different levels of regulators to design policy and regulate the whole market.

Compared with Triple Helix Model, Quadruple Helix Model takes "society" into account. In society, there are many citizens who play an essential role in the urban innovation ecosystem since they are the users and consumers of innovative technologies and smart products. Beyond that, media facilitates innovation and knowledge generation, which is crucial in enhancing information circulation. The

evolution from Triple Helix Model to Quadruple Helix Model introduced the concept of culture and emphasised the importance of public awareness and participation (Schütz et al., 2019).

As for Quintuple Helix Model, the fifth component, “natural environment”, was added (see Figure 9). Under this circumstance, the concept of ecology and sustainability contributes to significant value. The way the natural environment interacts with the other four components is related to environmental and ecological issues, which will drive relevant research development and new knowledge creation (Taratori et al., 2021b).

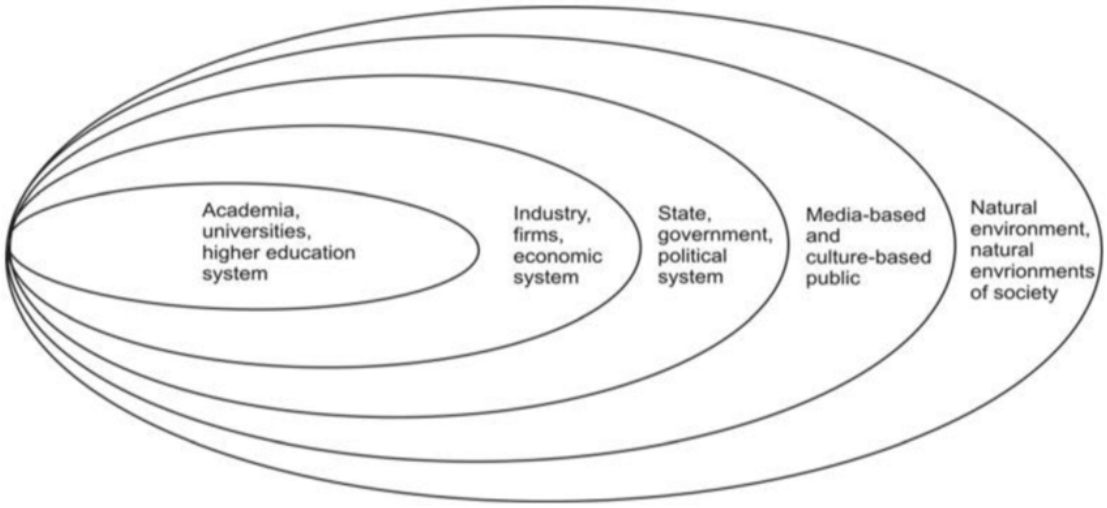

Figure 9 The sub-systems of Quintuple Helix Model (Taratori et al., 2021b)

2.5 Actors

Table 2 demonstrates the major stakeholders in the SCEE summarised by different studies. Similar to the Quadruple Helix Model, Sarma & Sunny (2017), Marrone & Hammerle (2018) and Tanda & de Marco (2021) all consider citizens, businesses, research institutions and government as the prominent four actors in the SCEE. Wirtz & Müller (2022), Wirtz et al. (2019), Oomens & Sadowski (2018) and Putra & van der Knaap (2018) provided a detailed category of stakeholders in their study. Moreover, all the actors mentioned in their research can be assigned under the four categories of the Quadruple Helix Model (i.e., government, academia, industry, and society). For instance, “Strategic Smart City Partners (ICT & platform providers)” are part of the “Industry”. Faber et al. (2018b) investigated the actors in the Smart City Mobility Business Ecosystem, and Mitra et al. (2021) and Tomor (2019) put particular emphasis on the entrepreneurial actors. The actors introduced by them are also part of the four pillars, and their results supplement the sub-categories of these four pillars, which will be elaborated on in the following paragraphs.

In terms of government, Sarma & Sunny (2017), Marrone & Hammerle (2018), and Tanda & de Marco (2021) indicated the participation of government incumbents in the SCEE as policymakers and bureaucrats without further explanation of the sub-actors. Whereas there are different sub-actors at different hierarchies in the government. Wirtz & Müller (2022) and Oomens & Sadowski (2018) introduced different levels of governmental actors, including the municipality, regional Government, and national government. In addition, Putra & van der Knaap (2018) and Tomor (2019) mentioned that public authorities and organisations were also active in the SCEE. For instance, Amsterdam Economic Board was dedicated to connecting large companies with Amsterdam Smart City and Amsterdam Municipality to build an open web-based platform (Putra & van der Knaap, 2018). In the case study conducted by Tomor (2019) in Utrecht, the Netherlands, the Regional Economic Developmental Agency, Energy Cooperation Association, and Housing Association were important participants in the Smart Solar Charging project/initiative. The local management team also played a significant role as programme managers to coordinate and manage the regional smart city projects (Tomor, 2019).

The knowledge institutions in academia can also be divided into different sub-categories, including universities and research institutions conducting research development activities and giving instrumental advice for legislation shaping and policymaking (Marrone & Hammerle, 2018). For instance, Amsterdam University of Applied Science launched smart city initiatives to address societal challenges through conducting research and implementing pilot projects in Amsterdam (Putra & van der Knaap, 2018). Under the category of society, citizens have been mentioned several times since they are the users/consumers of the innovative products and services provided by other stakeholders in SCEE (Tomor, 2019).

There are plenty of sub-actors under the category of industry. Firstly, large-scale companies are a vital part of driving urban innovation due to their cutting-edge technologies and dominant status in the market, such as ICT companies, sensor developers (Wirtz et al., 2019a), car manufacturers, parts suppliers (Faber et al. 2018b), etc. Likewise, start-ups and entrepreneurs are the source of innovation in the Smart City industry (Putra & van der Knaap, 2018; Sarma & Sunny, 2017a; Tomor, 2019). Under the Smart City context, incubators, accelerators, living labs and innovative platforms have emerged, such as Amsterdam Smart City, an open innovation platform that connects all the stakeholders in SCEE (Mitra et al., 2021; Putra & van der Knaap, 2018). Beyond that, Mitra et al. (2021) claimed that private investors such as venture fund agencies, investment bankers, and other financial institutions are the entities that provide financial support to the research & business activities in SCEE. The last important sub-actor is software infrastructure providers (i.e., ICT & platform providers, cloud providers, connectivity providers) and hardware infrastructure providers (i.e., commercial grid operators, logistics centres, road system providers) (Faber et al., 2018; Mitra et al., 2021; Wirtz et al., 2019b; Wirtz & Müller, 2022).

Table 2 Overview of the major stakeholders active in the SCEE

Nr	Actors	Reference
1	Agents (Entrepreneurs), Decision Makers (Policymakers and Bureaucrats), Framers (Technology Providers, Supplier Networks, Markets), Constituents (Citizens, Investors, Labour)	Sarma & Sunny (2017)
2	Citizens, Business, Research Organisations, Governments	Marrone & Hammerle (2018)
3	Private companies, Public Administration, Citizens, Academia	Tanda & de Marco (2021)
4	Citizens/Users (Customers), Industry/Companies (Private Sector Providers), Municipality/Public, Authorities (Public Administration), Research & Development (Developers), Strategic Smart City Partners (ICT & Platform Providers), Involved Smart City stakeholder groups	Wirtz & Müller (2022)
5	Education/Research Facilities, Government/Administration, Citizens, Industry (Private Providers: ICT Companies, Cloud Providers, Platform Hosts, Sensor Developers, Commercial Grid Operators), Public Providers (Agencies, Social Facilities, Public Suppliers, Statistical Authorities)	Wirtz et al. (2019)
6	National Government, Regional Government, Municipality, Knowledge Institute, Users, ICT Company, Platform Provider, Strategic Partners	Oomens & Sadowski (2018)
7	Data Provider, Car Manufacturer, Energy Supplier, Infrastructure Provider, Institute & Initiative, Insurance, Mobility Provider, Parts Supplier, Platform & Connectivity Provider, Public Institution, Technology Company	Faber et al. (2018b)
8	Government (Amsterdam Municipality, Amsterdam Economic Board, Chief Technology Office Amsterdam Municipality), Private Company (Large Companies, Start-Ups, Social Entrepreneurs), Education & Research System, Resident Representative, User Innovators, Citizen, Intermediaries, Amsterdam Smart City (ASC)	Putra & van der Knaap (2018)
9	Innovative Platforms, Living Labs, Incubators, Venture Fund Agencies, Investment Bankers, Self-Help Groups, Financial Institutions, Knowledge Institutions, Trade Centres, Logistics Centres	Mitra et al. (2021)
10	Citizens, Communities, Users/Consumers, Local Organisation (Schools, Service Providers), Large and Start-Up Companies, Government, Knowledge Institutes, Entrepreneurs, Public Organisations (Regional Economic Developmental Agency, Energy Cooperation Association, Housing Association)	Tomor (2019)

2.6 Interactions

Although there are some Smart City ecosystem models introducing the key elements and actors in the ecosystem, the interaction patterns between actors are not elaborated nor categorised in the existing ecosystem models. To complement this insufficiency, the author investigated other studies to discern the interaction types as demonstrated below.

Faber et al. (2018b) modelled and visualised the Smart City Mobility Business Ecosystems using a smart city initiative as a case study. In their research, they introduced six relationships between stakeholders in the mobility business ecosystem: cooperation, funds, membership, ownership, partial ownership and supplied, as demonstrated in Table 3.

Table 3 Relation types between entities in the smart mobility ecosystem (Faber et al., 2018)

Relation Types	Description
Cooperation	Entities collaborating towards shared services or products. The cooperation can be temporary or a long-term strategic one.
Funds	Granting of funds between two entities, usually during the initial start-up phase of one entity.
Membership	Entity is part of an initiative, institution or project.
Ownership	One entity having exclusive rights over another entity due to a legal belonging.
Partial Ownership	Several entities sharing the rights of another entity, the shares can be equal but also proportionate.
Supplied	One entity provides its service or product to another entity, which consumes it for its own service or product.

In the civic entrepreneurial ecosystem developed by Sarma & Sunny (2017a), the authors investigated the interactions between ecosystem actors by taking Kansas City as an example of a Smart City. In their findings, large-tech enterprises collaborate with local entrepreneurs to use their local experience and distribution channel, which is considered a strategic partnership. Some vendors provide infrastructural support, such as IoT system (Internet of Things), which connects ecosystem actors to big data and enable information and knowledge exchange between actors.

The internal alignment and networking relationships of actors for creating joint value in smart city projects were studied by Oomens & Sadowski (2018). Based on their results, the interacting way between participants consists of reporting, legislation, funding, consuming/buying, educating, knowledge sharing, infrastructural supporting and selling.

As a typical example of an urban innovation system, (Putra & van der Knaap, 2018) studied the web-based platform of Amsterdam, where actors interact with each other and exchange information. There are one-sided and bi-directional relationships between actors; the former indicates the one-way interaction initiated from actor A to actor B, and actor B does not take the initiative to connect with actor A, while the latter refers to the two-way connection between actor A and actor B.

According to Tomor (2019), the municipality has provided lots of support to accelerate the progress of the Smart Solar Charging project in Utrecht, the Netherlands, varying from financing, flexible/enabling rulemaking and licensing, networking, education, administrative support, and political lobbying.

2.7 Summary: adapted coding framework

With all the obtained literature on the aspect of Smart City ecosystem models, actors and interactions, an adapted coding framework is proposed. To synthesise all the coded information, the author utilised the "framework synthesis" and chose the Quadruple Helix Model as the *a priori* framework to determine the initial codes (i.e., government, academia, industry, society). In the end, a comprehensive coding framework with a full range of actors and interactions is demonstrated, including the initial codes and new codes.

2.7.1 Framework selection

In Chapter 2.4, the author introduced five different ecosystem frameworks. Primarily, the author introduced the Integrative Smart City Ecosystem Framework proposed by Wirtz & Müller (2022) as a guideline for investigating the ecosystems within the Smart City. This integrative model distinguishes six layers of a smart city ecosystem: the governance model, collaboration model, interaction model, service provision model, software model, and physical model (Wirtz & Müller, 2022). These six sub-models have been studied respectively or together by different researchers with different research focuses. The first three models belong to the organisational models, showing the collaborative structure of the smart city ecosystem, while the last three pertain to operational models, merely demonstrating the supporting infrastructure network of the ecosystem. The following four models will be either an organisation model, an operational model, or a combination of both.

As the essence of a SCEE is the same as the General Start-up Ecosystem Model, a group of actors interplaying with each other in a complex system, it is necessary to get familiar with this general model and understand its structure. In the General Start-up Ecosystem Model, there are eight key elements, ranging from human capital to demography and technology. Even though the general model gives an overview of the start-up ecosystem, it doesn't demonstrate key players and their interactions. There are also some overlaps between sub-elements. For instance, the sub-element "accelerator" has shown up both under the key element "support factors" and "education". In addition, other sub-elements such as "innovation" and "product" under the key element "technology" cannot be transformed as an actor in the designed ecosystem framework.

In the Adapted Hutchison's i-COA® framework, a 5-level pyramid framework is proposed by Hutchison et al. (2011), which is further developed by Appio et al. (2019)

by integrating six dimensions of Smart City with the original pyramid. The structure of this pyramid is consistent with the six layers of the Integrated Smart City Ecosystem Model, consisting of the "hard" layer (land and infrastructure) and the "soft" layer (human and social capital). Likewise, although this ecosystem model establishes a solid structure, it doesn't describe each layer in detail. For instance, in the third layer, "Collaboration Ecosystems", the active stakeholders and their collaboration is not itemised.

The fourth model is the Smart City Start-up Ecosystem proposed by Mitra et al. (2022), whose structure is very similar to the Adapted Hutchison's i-COA® framework, both possessing the "hard" infrastructure and "soft" support services. Above the physical infrastructure, four pillars support the Start-up Ecosystem in Smart Cities: knowledge hub, public policy, entrepreneurship, and economy. Under these four key elements, there are also several sub-elements. However, some sub-elements cannot be transformed as an actor like the sub-elements of the General Start-up Ecosystem Model, such as "data collection" under "knowledge hub" and "taxation structure" under public policy. Even though there is some social and human capital under "entrepreneurship", such as incubators, venture fund agencies and investment banks, they only represent a small group of stakeholders in the financial sector. Therefore, this ecosystem model is insufficient to serve as the initial reference model.

The last model is the Quadruple Helix Model, which consists of four different categories of actors (i.e., government, society, academic research, and business) and depicts their interactions. This model is frequently used in the knowledge creation and innovation development process, which is in accordance with the urban innovation taking place in smart cities. In this study, the author aims to investigate the interaction pattern between different start-ups and other actors; thus, the author has chosen the Quadruple Helix Model as an *a priori* framework to design the coding framework of actors and interactions.

2.7.2 Adapted coding framework

Once the *a priori* framework is chosen, the initial coding framework is used to code individual studies and obtain new codes. Looking at Figure 10, the SCEE framework applied to Quadruple Helix Model consists of two main components, namely actors and interactions. In Quadruple Helix Model, there are four different categories of actors (i.e., government, academia, industry, and society); thus, these four types of actors serve as the 2nd category codes in the coding scheme. However, the 2nd category codes are too general to describe multiple stakeholders active in the ecosystem. Additionally, the interaction patterns are not coded in the Quadruple Helix Model. In this case, the author replenished the coding scheme by processing the raw data obtained from the literature review.

In Chapter 2.5, the author has listed the actors of the ecosystem derived from existent studies, which serve as the raw data codes. In the beginning, these raw data codes were assigned under four *a priori* 2nd order category codes. Then, these raw data codes were inductively merged into several 1st order category codes. For instance, “technology company”, “large companies”, “data provider”, “energy supplier”, and “infrastructure provider” are part of the 2nd order category code “Industry”. The first two raw data codes can be merged into one 1st order category code as “Large-tech Enterprises”, and the rest raw data codes can be grouped into one 1st order category code as “Software & Hardware Infrastructure Providers”. In the end, sixteen different 1st order categories were acquired from the raw data codes and constituted the 2nd order category codes.

As for creating 1st order category codes of interaction patterns, the conceptualisation process is slightly different from actors since there are no initial codes of interaction patterns in the Quadruple Helix Model. Under this circumstance, the author utilised inductive coding to develop the 1st order category codes of interactions during the reviewing process. Ten types of interactions are derived from the existing literature.

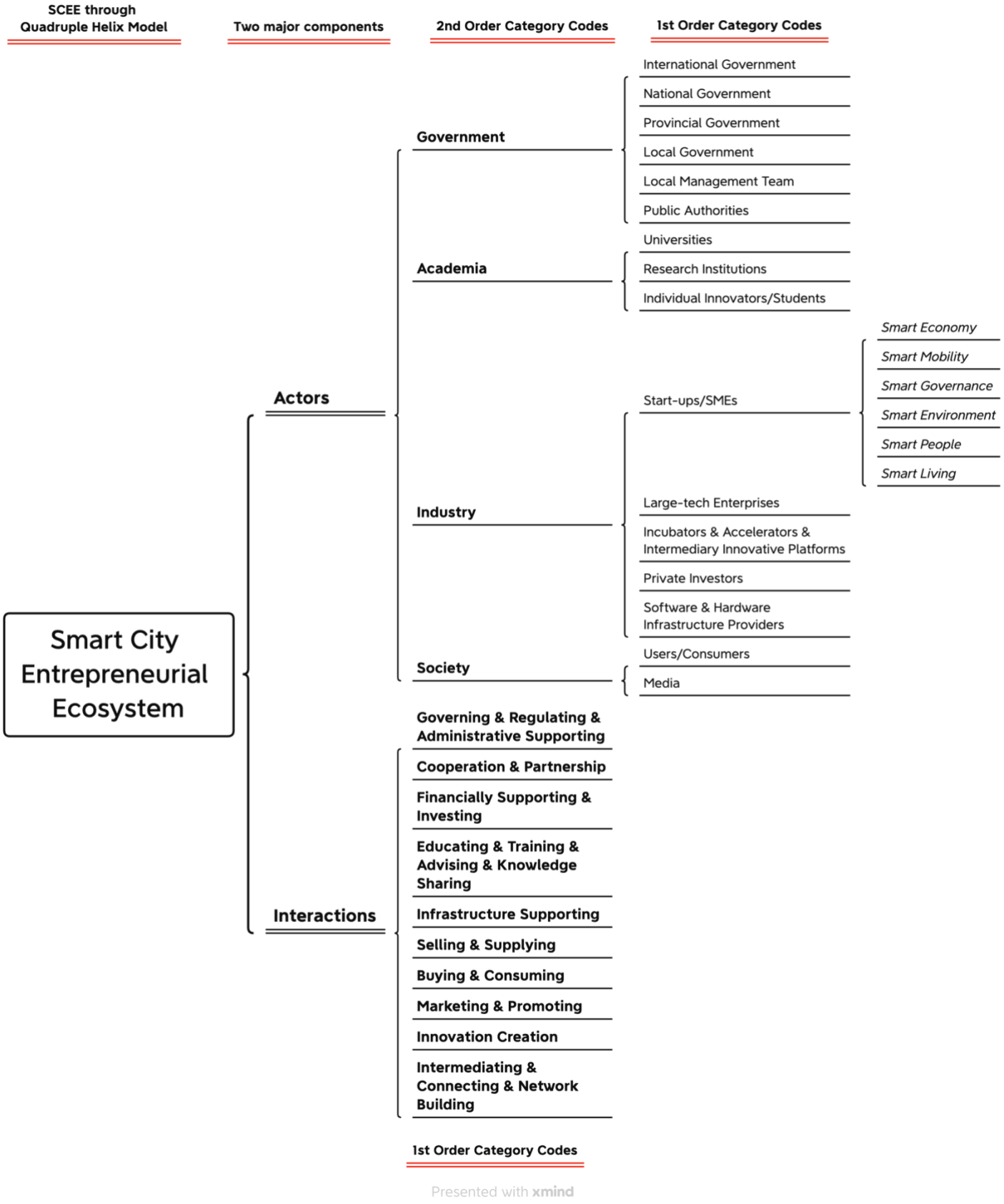

Figure 10 Final adapted coding framework of the Smart City Entrepreneurial Ecosystem

3. Theoretical framework of Smart City Entrepreneurial Ecosystem

The SCEE is a collaboration and interaction model that mainly consists of two components, namely stakeholders and their interrelations. Table 4 shows the categories and descriptions of stakeholders derived from the synthesis of relevant literature. The elements under the 2nd order category are decided by the Quadruple Helix Model, containing government, academia, industry, and society. The elements under the 1st order category are coded from raw data and constitute the elements of the 2nd order category.

In Table 5, categories and descriptions of interaction patterns are demonstrated, obtained through inductive coding in the systematic literature review process. There are ten kinds of interaction patterns summarised in this model, comprising governing & regulating, cooperation & partnership, financially supporting & investing, educating & training & consulting & knowledge sharing, infrastructure supporting, selling & supplying, buying & consuming, marketing & promoting, innovation creation, intermediating & connecting & network building.

3.1 Categories and descriptions of actors

There are four 2nd Order Category actors derived from the Quadruple Helix Model and sixteen 1st Order Category actors in the SCEE theoretical framework. Under government, different levels of administrative authorities are distinguished, from international government, national government, provincial government, Local Government, and local management team to public authorities. As for academia, universities and research institutions are included due to their contribution to innovative scientific activities. In addition, universities cultivate young talents with a strong passion for innovation and entrepreneurship and equip them with essential knowledge and thinking modes. The industry is where most of the actors in the SCEE are active, ranging from start-ups and large-tech companies bringing innovation, private investors providing funding, incubators and accelerators incubating innovative ideas, to software & hardware infrastructure providers sustaining the operation of society and business. The last key component, society, comprises individual creators, users/consumers, and media. Individual creators produce innovative services or products, and users/consumers consume them in turn. Media is an instrument employed more and more frequently to promote innovation.

Table 4 Categories and descriptions of stakeholders in the SCEE

Nr	2nd Order Category	1st Order Category	Descriptions
1	**Government**	International Government	Supranational, intergovernmental organisations that are established upon a treaty or a multilateral agreement consisting of more than two states (Putra & van der Knaap, 2018).
2		National Government	The highest regulatory institute in a country that is in charge of legislation and policymaking (Oomens & Sadowski, 2018).
3		Provincial Government	Provincial legislatures are responsible for the design and enaction of the province's policies/agenda and regulations, which only affect the residents in the province (Oomens & Sadowski, 2018).
4		Local Government/Municipality	Regional legislatures/municipalities are responsible for the design and enaction of the policies/agenda and regulations of the region/municipality, which only affect the residents in the region/municipality (Oomens & Sadowski, 2018; Putra & van der Knaap, 2018).
5		Local Management Team	The local authority administrates and is responsible for the development and implementation of smart city initiatives and projects.
6		Other Public Authorities	Other public authorities are other public organisations (except government) established by the legislature to perform administration and create common values and interests for the citizens, including government departments, public organisations, or government agencies (i.e., Public Economic Organisation, Public Entrepreneurship & Innovation Department, Building, Housing, and Infrastructure Department) (Putra & van der Knaap, 2018; Tomor, 2019; Wirtz et al., 2019b; Wirtz & Müller, 2022).

7	**Academia**	Universities	A university provides higher education and conductsresearch activities in multiple disciplines related to Smart City (Marrone & Hammerle, 2018; Putra & van der Knaap, 2018; Tomor, 2019; Wirtz et al., 2019b; Wirtz & Müller, 2022).
8		Research Institutions	An institute specialising in research development and application activities (Marrone & Hammerle, 2018; Wirtz & Müller, 2022).
9		Individual Innovators/Students	Individual or student who has innovative ideas which have the potential to be transformed into services or products to benefit society (Putra & van der Knaap, 2018).
10	**Industry**	Start-ups/SMEs (small and medium-sized enterprises)	Small and medium-sized enterprises delivering innovative products or services in their early-development stage with limited manpower and funding (Mitra et al., 2021; Putra & van der Knaap, 2018; Tomor, 2019).
11		Large-tech Enterprises	Large-scale companies that provide cutting-edge technologies and products with sufficient personnel and stable revenues (Faber et al., 2018; Putra & van der Knaap, 2018; Tomor, 2019).
12		Incubators & Accelerators & Intermediary Innovative Platforms	An intermediary agency/platform/programme provides essential help and supports for start-ups to grow and scale up, including funds, mentorship, office, social network building, etc (Mitra et al., 2021; Parjanen & Rantala, 2021; Putra & van der Knaap, 2018).
13		Private Investors	Private entities/organisations that grant financial support to start-ups in the way of loans, equity, and grant; common private investors comprise venture capital funds, banks, private equity firms, and venture arms of large companies (Mitra et al., 2021).

14		Software & Hardware Infrastructure Providers	An ICT entity that provides software infrastructure as a service or product, such as AWS (Amazon Web), provides cloud computing and cloud storage service (Oomens & Sadowski, 2018; Wirtz et al., 2019b; Wirtz & Müller, 2022).
			An entity that can provide hardware infrastructures (i.e., optic fibre, data centre) or physical infrastructures (i.e., energy grid, water supply system, road) (Faber et al., 2018; Mitra et al., 2021; Tomor, 2019).
15	**Society**	Users/Consumers	Entities who use and consume the services or products offered by another entity (Putra & van der Knaap, 2018; Sarma & Sunny, 2017a; Tanda & de Marco, 2021; Tomor, 2019).
16		Media	Any type of instrument that can realise transmission of data and information, including news, social, web, print and other forms of media.

3.2 Categories and descriptions of interaction patterns

There are ten common interaction patterns included in this SCEE theoretical framework, which describe most of the interrelations between actors in the ecosystem. Governing & regulating are major activities assigned to the government. Cooperation & partnership has been existing between many actors, such as the collaboration between different start-ups. Financially supporting & investing can be seen as the way how investors are involved in the ecosystem. Knowledge institutions provide educational resources to cultivate talents (smart people) to build the Smart City, equip them with the necessary knowledge, skills, and mindset, and share their knowledge to transform abstract research ideas into practical applications through smart city projects (educating & training & advising & knowledge sharing). In addition, living labs and open innovation platforms enable communication between citizens and other actors, and thus citizens can share their opinions and advice on ongoing initiatives and projects (educating & training & advising & knowledge sharing). The operation of a community and enterprise relies on the infrastructures and amenities provided by the software and hardware infrastructure providers (infrastructure supporting). Selling & supplying and buying & consuming are two interactions that occur simultaneously when there is a transaction. Sellers also utilise marketing & promoting to attract more consumers. Innovation creation is the source of new services and products and what start-ups do in the innovation system. Intermediating & connecting & network building is a newly emerged interaction pattern, mainly initiated by accelerators, incubators, and intermediary innovation platforms to connect start-ups with other ecosystem stakeholders.

Table 5 Categories and descriptions of interaction patterns in the SCEE

Nr	1st Order Categories	Abbr.	Description
1	Governing & Regulating & Administrative Supporting	Regulating	The superior party conduct administration, restrictions, and control upon another subordinate party (Oomens & Sadowski, 2018; Tomor, 2019).
2	Cooperation & Partnership	Cooperation	Entities build a collaborative partnership to achieve common goals (Faber et al., 2018; Oomens & Sadowski, 2018; Sarma & Sunny, 2017a).
3	Financially Supporting & Investing	Investing	One entity provides funding to another entity to support its business activities, normally through loans, grants, or equity investments (Faber et al., 2018; Oomens & Sadowski, 2018).
4	Educating & Training & Advising & Knowledge Sharing	Advising	Entities share knowledge and ideas with other parties to facilitate innovation development, cultivate talents having an entrepreneurial mindset, optimise functions of products/services, and promote communication between different stakeholders (Marrone & Hammerle, 2018; Tanda & de Marco, 2021).
5	Infrastructure Supporting	Infrastructure	Providing necessary infrastructures to support business operations or livings of other entities (Appio et al., 2018; Mitra et al., 2021; Oomens & Sadowski, 2018; Sarma & Sunny, 2017a).
6	Selling & Supplying	Supplying	Selling or supplying services or products to the users or consumers (Faber et al., 2018; Oomens & Sadowski, 2018).
7	Buying & Consuming	Consuming	Buying or consuming services or products provided by other entities (Oomens & Sadowski, 2018).
8	Marketing & Promoting	Marketing	Promoting services or products to attract potential consumers through online advertisement, public meetings, and social media promotion (Mitra et al., 2021; Putra & van der Knaap, 2018).
9	Innovation Creating	Creating	Creating innovative ideas that have the potential to be further developed into services or products for people (Mitra et al., 2021).
10	Intermediating & Connecting & Network Building	Connecting	Connecting different parties as a mediator to facilitate the collaborations between them and match the demands and supply (Mitra et al., 2021; Putra & van der Knaap, 2018; Tomor, 2019).

4. Methodology

4.1 Research design

This study employs three methods to answer each sub-research question, namely systematic literature review, case study, and Social Network Analysis (SNA). The former two are qualitative methods, and the last one is a quantitative method. To obtain a theoretical framework for SCEE, the author has first conducted a systematic literature review of the relevant academic literature (see Chapter 2).

After that, a case study will be conducted, where the theoretical framework will be applied to the Brainport Smart District, and its ecosystem will be analysed using the SNA. The essential data required for building the ecosystem of BSD are derived from online public resources and stakeholder interviews.

In the end, the Smart City Entrepreneurial Ecosystem of BSD is analysed quantitatively using the SNA, unveiling the key players and network features of this complicated system.

4.2 Case study

After analysing and synthesising the data in the systematic literature review procedure, the theoretical framework of the SCEE is established, and a case study is conducted on BSD to exemplify and illuminate the theoretical framework in a real-life context. As an effective research technique widely used in academia, a case study is an ideal tool that provides holistic, multi-faceted, and in-depth insights into a complex issue in a real-life setting (Crowe et al., 2011; Tellis, 1997).

In this study, an illustrative case study approach is chosen, which elaborates on one or two cases to explain the situation or topic to readers unfamiliar with it (Epler, 2019). In other words, BSD is utilised to interpret the Smart City Entrepreneurial Ecosystem theoretical framework in a real-life context by using common language so that readers will have a better understanding of this theoretical framework and know how to apply it to their situations since every step is explained in detail.

To apply the theoretical framework on BSD, essential data is acquired through stakeholder interviews, online resources, and public documentation. After that, SNA is employed to analyse the SCEE framework of BSD in a quantitative way, whose results provide a theoretical foundation for BSD to realise self-reflection and self-improvement and thus facilitate the growth of innovation and entrepreneurship. In addition, readers can compare their analytical results on their cases with the results of BSD to validate the effectiveness of their results.

4.2.1 Case selection

Brainport Smart District is chosen as an illustrative case to explain the theoretical framework of SCEE, instruct readers on how to employ the theoretical framework in their own situations, and provide analytical insights for formulating optimising strategies. The selection criteria of the study case and the reason why BSD is chosen in this study are explained below.

The first requirement of the selected case is smartness and innovation. Since this research studies the entrepreneurial ecosystem in the Smart City industry, the chosen case should adopt cutting-edge technologies and innovative ideas in the development and operation process. A traditional entrepreneurial ecosystem without any innovative implication is not considered in the case study. As for BSD, it intends to build the neighbourhood of the future and become the smartest district in the world, which makes it satisfy the first requirement.

Additionally, the level of entrepreneurship and the involvement of start-ups are also crucial in case selection since the main objective of this study is to help start-ups grow in the entrepreneurial ecosystem. Limited participation of start-ups in an ecosystem will not lead to reliable and valid analytical results. The main reason to choose BSD is that it introduces the “co-creation” concept, which encourages collaboration between multiple stakeholders, including start-ups, government, citizens, and knowledge institutions. In addition, the companies that participate in the building of BSD are mainly innovative small and medium-sized enterprises (SMEs), showing a start-up driven trend. Thus, it is ideal for the author to apply the theoretical Smart City Entrepreneurial Ecosystem framework to BSD.

The size of the ecosystem is also an essential factor in the study case selection. The case study will be too complicated to conduct if the ecosystem is too large, with thousands of actors and interactions. If the ecosystem is too small with a limited number of actors and interactions, it is hard to derive valuable insights and convince the readers. Therefore, a medium-scale ecosystem like BSD with an appropriate number of sub-actors (20 - 50) and initial interactions (80 -150) is preferred.

Also, the popularity of the case in previous research is considered. If it has been researched a lot by other researchers, such as Amsterdam, Vienna, and Copenhagen, it is recommended to use some cases that have not been researched frequently. It is also worth mentioning that the Netherlands ranks 14th among the global start-up ecosystem but the 1st in the European Union area, as announced in the 2022 Global Start-up Ecosystem Report (GSER) (Startup Genome, 2022). Therefore, an empirical study on Smart City Entrepreneurial Ecosystem conducted in the Netherlands can produce valuable and generalised lessons that can be useful in other European ecosystems. Since Amsterdam has been studied a lot by researchers as one of the smart city good practices in the world, the newly emerged smart district BSD is

recommended to be investigated to explore further the entrepreneurial ecosystem of Smart Cities in the early development stage.

4.2.2 Data collection

There are mainly three data sources in this case study. These data will be used for implementing the SNA on the SCEE framework of BSD.

1) Semi-structured stakeholder interviews

Stakeholder interviews will be conducted to gather necessary information from stakeholders active in the BSD project. There are six interviewees attending the interviews; three of them work in the start-ups involved in the BSD development, and the others are the incumbents working for the administration organisations, including the Municipality of Helmond and Brainport Smart District Foundation (BSDF).

- Interviewee A is the co-founder of company A. Company A is a building company producing sustainable modular wooden houses.
- Interviewee B co-founded company B, an innovation centre for agriculture and sustainability. Innovative technologies are used in their smart farm to achieve self-sufficiency in agricultural products.
- Interviewee C works in the commercial department of company C. This company is dedicated to eliminating particulate matter and air pollutants through its products and strategic solutions.
- Interviewee D is working at the municipality of Helmond and a board member at BSDF.
- Interviewee E is a programme manager working at the BSDF, mainly responsible for the digitalisation of the whole district.
- Interviewee F is the director working at the BSDF and is in charge of internal financial and organisational management.

2) Public documents

There are some public documents published by the government, which can be found on the official website of the EU government, national government, provincial government, Local Government, and the local management team. These documents provide reliable and formal information regarding public funding, zoning plan, local masterplan, quality evaluation criteria, etc.

3) Online websites & Media platforms

Online websites and other media platforms, including LinkedIn, Twitter, Facebook, and TikTok, grant people access to public information. For instance, the marketing team of BSDF updates the latest news of BSD on its official website and other public social media platforms periodically.

It is worth mentioning that another company, Team CASA, is also involved in the ecosystem as a research object in terms of start-ups/SMEs, while no interview is conducted with any members of Team CASA; all the information of Team CASA is obtained through online resources. Team CASA is a start-up made up of more than thirty students aiming to build comfortable, affordable, sustainable, and alternative buildings, which has designed and built the CASA 1.0 residential projects in BSD.

4.3 Data analysis: Social Network Analysis

Social network analysis is employed in this study as the foundation to model the SCEE. An effective software called "Gephi" is adopted to analyse and visualise the whole Smart City Entrepreneurship Ecosystem with the empirical data of BSD, which provides results on network features, key nodes, and key edges with quantitative indicators.

SNA theory is famous because of Stanley Milgram's findings on "six degrees of separations" (Powell & Hopkins, 2015). In the social network, people and organisations are considered nodes, and multiple interactions between them serve as edges (Powell & Hopkins, 2015; Stokman, 2001; Vaughan, 2005). SNA has been widely used to study social phenomena and address social problems due to its useful indicator analysis, such as degree centrality, betweenness centrality, and closeness centrality, which are conducive to providing helpful information regarding the interior structure of the social system, the mutual interaction between actors, and the function and effect of each actor (An et al., 2015). Since the SCEE is a complicated system with a large number of actors intertwined with each other and this study will mainly investigate the collaboration and interaction between actors, SNA will be a useful tool to sort out the complex interactions, identify the most influential actors and interactions with quantitative indicators. Moreover, the analysis of the interior structure of the social network provides insights further to evaluate the compactness and clustering capability of SCEE. In addition, the network diagram offers a straightforward visualisation of the ecosystem, making it easier to demonstrate the characteristics of interconnected edges and indicating the most influential nodes (Powell & Hopkins, 2015). Compared with plain words and complex dataset, a visualised ecosystem is more accessible for the users and increases their awareness of the characteristics of the ecosystem. With a better perception of the ecosystem, it is easier for the users to use the derived insights to make public policy and strategic decisions.

4.3.1 Constructing the social network of SCEE in BSD

To build the social network of SCEE in BSD, it is primary to establish a matrix containing the nodes and edges. The stakeholders of BSD summarised in the coding schemes are denoted as nodes, and their interactions are considered as edges. The boundary of this social network is constrained within the Brainport Smart District; thus, only actors

and interactions relevant to BSD's design, development, and operating process will be considered. For instance, this study will not consider the interactions between start-ups and other governments and industry partners outside the scope of BSD. Under this circumstance, the analysis of BSD is of great use in improving its current situation. Otherwise, redundant actors and their behaviours will intervene in the clear structure of the social network, which may make it too complicated for incumbents to find the crux of problems and generate optimising strategies.

Looking at the matrix in Table 6, A_1 denotes actor 1 (i.e., national government) under category A (i.e., government), and X_{12} represents the interactions between A_1 and A_2. As for the value of the cell, it stands for different types of interactions between actors. For example, the value of X_{14} is 1, 2, 3, revealing that there are three different types of interactions between A_1 and A_4, and the total weight of the outflow from A_1 to A_4 is 3.0. It is worth mentioning that X_{12} is different from X_{21}, as the former indicates the resource flowing from A_1 to A_2 (outflow from A_1) while the latter represents the flow from A_2 to A1 (outflow from A_2). For instance, the bank can give financial support to start-ups, while start-ups cannot financially support the bank.

Table 6 Matrix of the social network of SCEE

NR		1	2	3	4	5	6	7	8	9	10	11	12	13	14
		A1	A2	A3	A4	A5	B1	B2	C1	C2	C3	C4	C5	D1	D2
1	A1	X11=0	X12=1	X13=2	X14=1,2,3	X15=4	X16=5	X17=6	X18=7	X19=1,2,3,4					
2	A2		0												
3	A3			0											
4	A4				0										
5	A5					0									
6	B1						0								
7	B2							0							
8	C1								0						
9	C2									0					
#	C3										0				
#	C4											0			
#	C5												0		
#	D1													0	
#	D2														0

To input this matrix into Gephi, it must be split into the node and edge lists. At first, the node list (shown in Table 7) is required, consisting of all the ecosystem's actors. As for the edge list, the value of the cell in the matrix needs to be adjusted before putting it into the edge list (shown in Table 8). For instance, the value of $X_{1,4}$ is 1, 2, 3, and its weight is 3.0, indicating that there are three edges pointing from A_1 to A_4. Although there are three different types of edges from A_1 to A_4, as shown in the matrix, they are combined as one edge with a weight of 3.0 in the edge list.

Table 7 Node list of the social network of SCEE

Nr	Label	Category
1	A_1 (i.e., National Government)	Government
2	A_2	Government
3	A_3	Government
4	A_4	Government
5	…	Academia
6	…	Industry
7	…	Society

Table 8 Edge list of the social network of SCEE

Nr	Source	Target	Label (Type of interactions)	Weight
1	A1	A2	1 (i.e., Financially support)	1
2	A1	A3	2 (i.e., Governing)	1
3	A1	A4	1,2,3	3
4	…	…	…	…

Figure 11 below is an example of the visualised social network of SCEE created by Gephi based on the author's assumptions on the interactions between actors, where the nodes represent actors and edges refer to the interactions between them. The thickness of the edges is determined by the weight of each edge. The colour of the edges is the same as their initiators. For instance, the edges pointing from Regional Management Team to other nodes are all red, the same as the node Regional Management Team.

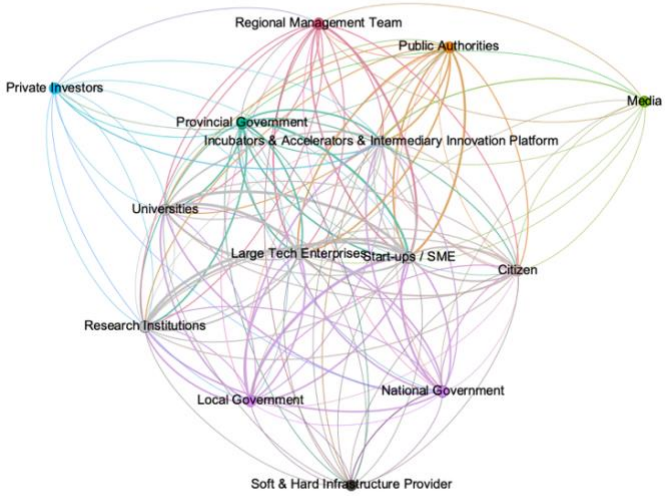

Figure 11 An example of the visualised social network of SCEE created by Gephi

4.3.2 Indicators for the measurement of SCEE

With the information obtained from the case study, we constructed the directed weighted network represented by the set,

$$G= (N, X) \qquad (1)$$

so that G is the social network of SCEE, the nodes set $N_{ij}=\{n_{ij}\}$ represents actors, and the edges set $\{x_{ij}\}$ denotes the inter-relationship between different actors.

In this study, the representative indicators of the social network theory are utilised, and they are defined and computed as follows (the calculation process will proceed automatically in Gephi):

a) The average clustering coefficient and average path length

The clustering coefficient of a node quantifies the cohesion and connectedness of its neighbouring nodes. The average clustering coefficient is the mean value of all nodes' clustering coefficient, which represents the clustering property of the whole network, and is defined as (Xu, 2010):

$$c_i = \frac{1}{n}\left(\frac{\sum_j \sum_k w_{ij} w_{jk} w_{ki}}{\sum_j w_{ij} \sum_j w_{ji} - \sum_j w_{ij} w_{ji}}\right) \qquad (2)$$

Where n is the number of nodes, j and k are the neighbouring nodes of i, and w_{ij} represents the weight of the edge from node i to node j.

On the other hand, the average path length measures the average level of the minimum distance between all possible pairs of nodes in the network, and is computed as:

$$PL = \frac{1}{n(n-1)} \sum_{i \neq j} l_{ij} \qquad (3)$$

where $l_{i,j}$ is shortest path length between node i and j.

b) The weighted in-degree and weighted out-degree

The weighted in-degree and weighted out-degree represent the inflows and outflows of nodes, and their values are determined by the weight of directed edges. The formula is:

$$M_i^{in} = \sum_j w_{ji} \qquad (4)$$

$$M_i^{out} = \sum_j w_{ij} \qquad (5)$$

c) Betweenness centrality

Betweenness centrality is a useful tool to detect the mediating ability of nodes in the network, which is calculated as follows (Opsahl et al., 2010):

$$K_j = \frac{\sum_i \sum_k n_{ijk}}{n_{ik}} \qquad (6)$$

where n_{ijk} is the number of edges that link node *i* and node *k* by node *j*, and n_{ik} is the number of binary shortest paths between node *i* and node *k*.

d) Closeness centrality

The closeness centrality of sector *i* is the inverse of the sum of shortest distances from node *i* to its neighbours, which decides the central ability of node *i*. (L. C. Freeman, 1978) defined this indicator as:

$$CC(i) = \frac{1}{\sum_j^n l_{ij}} \qquad (7)$$

e) Eigenvector centrality

In terms of eigenvector centrality, it is widely used to identify the central ability of a node by investigating the status and function of its connecting nodes. Similar to (Bonacich & Lloyd, 2015), the value of eigenvector centrality is expressed as:

$$\boldsymbol{c_i} = \lambda^{-1} \sum_{j=1}^{n} A_{ij} c_j \qquad (8)$$

where c_j is noted as the vector of centralities, A_{ij} is the adjacency matrix that illustrates the relations between nodes, and $\boldsymbol{c_i}$ is the eigenvector corresponding to the eigenvalue λ of *A*.

4.4 Reliability and validity

To ensure the reliability of this study, a systematic literature review protocol and interview protocol were designed, which give detailed descriptions of the whole data-gathering process from literature and interviews. In addition, these two protocols were assessed and confirmed by the supervisors, including the search query in the systematic literature review protocol and the interview questions in the interview protocol. The systematic literature review and interviews were conducted according to the procedures and requirements in the protocols to guarantee data consistency.

In terms of face validity and item validity, on the one hand, this study adopted stakeholder interviews to obtain necessary information, including actors and interactions in BSD and did qualitative analysis based on the interviews. On the other

hand, SNA was utilised to analyse the SCEE, and all the individual indicators (items) of SNA were used to detect structural features and identify the key actors and interactions in the SCEE of BSD. Therefore, these two methodologies analysed what it is supposed to and answered the research question and realised the research aim, namely improving the environment of SCEE and facilitating favourable interactions between start-ups and other actors in SCEE.

As for data validity, the interview data obtained through stakeholder interviews were cross-checked through public online resources, such as the official website of BSD, the LinkedIn page of start-ups, and other social media channels. For instance, detailed information regarding the funding and grants from government to start-ups is published online, which confirms the information provided by interviewees during the interview. The validation of the interview data was also conducted with other interviewees. For instance, the start-up founder may be uncertain about a relevant regulation or public policy, which was confirmed and elaborated on by the interviewees working in the government. In addition, to compensate for the insufficiency of the data gathered from interviews, the author collected additional qualitative data from online resources to ensure a complete picture of the SCEE of the study case.

To avoid bias in case selection, the author has designed the case selection criteria, including the level of innovation, involvement of entrepreneurs and start-ups, ecosystem size, and popularity of the case in academia. The selection criteria serve as a guidance for the author to choose the most appropriate case to conduct the research and thus derive more generalised lessons from the results that can be applied to other cases.

5. Case study results on Brainport Smart District

5.1 Background

Brainport Smart District is an innovative district located in Helmond, the Netherlands, which aims to create a smarter, safer, and more sustainable working and living environment for future residents. Involving the four parties of the Quadruple Helix Model (i.e., government, academia, society, and industry) in the co-creation process, BSD is serving as an "urban living labs" where the innovative ideas, products and services from different stakeholders can be tested through pilot projects. There are eight different programmes covering a wide range designed by the BSDF, namely Circular District, Participation, Social and Safe District, Healthy District, Digital District, Mobile District, District with Energy and District with Water (*Official Website of Brainport Smart District*, 2022).

BSD is still in the early development process with an ambition to build 1,500 new houses for different groups of people in the next ten years in this mix-used smart and sustainable community, where business premises and natural reserves are surrounded. Currently, there are 52 temporary houses built by mHome, which are made of modular units with circular and biological building materials. In the business challenges launched by BSD, many entrepreneurs and start-ups have been attracted to test their innovative solutions and conduct experiments on the land of BSD.

Figure 12 Eight programme lines and urban vision of Brainport Smart District

5.2 Overall network features

This study establishes a social network for the SCEE of BSD with the available data from online public resources and stakeholder interviews. As shown in Figure 13, each node in the network represents a group of actors in the SCEE of BSD, and each line denotes the interaction between them incurred by the development of BSD. There are 15 nodes and 33 edges in the social network of SCEE. Nodes with the same colour pertain to the same 1st order category (i.e., government, academia, society, and industry), and the colour of each edge is the same as its sourcing node. In other words, if the edge is directed from the government to academia, its colour is the same as the

government. There are different sizes for the nodes and edges. The larger the node is, the larger impact it will bring; the thicker the line is, the more interactions it contains (Shi et al., 2017).

Although there are many sub-actors belonging to the 2nd order category of actors, the author chose to investigate the interactions between different groups of actors rather than between the individual actors. For instance, the interactions between Start-up A and Start-up B with other actors are integrated as the interactions between "Start-ups/SMEs" and other groups of actors (i.e., National Government, Provincial Government). The reason is that there is a limited number of interactions between individual actors with other actors, making it difficult for the author to extract valuable insights and compare the characteristics of nodes (i.e., weighted in-degree and weighted out-degree) and interactions. Only when the individual actors are grouped together with other individual actors of the same 2nd order category will it be feasible for the author to find out which groups of actors play an influential role in the whole network. It is also worth mentioning that this study intends to find out the impacts of a group of actors under the same 2nd order category instead of the impact of an individual actor in the BSD.

As for the edges, 80 edges were distilled from the available information at the beginning. Then, the duplicate edges were deleted, and 74 edges were left. In addition, the parallel edges between nodes were combined, and thus there are 33 lines between different actors. For example, there are two different types of interaction between "National Government" and "Local Management Team", namely "Governing & Regulating" and "Financially Supporting & Investing", with a weight of 1.0 respectively. Since Gephi can only recognise one edge between a pair of nodes, these two parallel edges have to be integrated as one edge pointing from "National Government" to "Local Management Team" with a weight of 2.0.

In terms of the features of the SCEE network, the weighted average degree of the whole network is 4.867, which means that each node connects to 4.8 actors on average. The diameter of the network is 3, indicating that the largest length of connections between two nodes is three steps. It is observed that the average clustering coefficient of this network is 0.622, and its average path length is 1.697, and both results reveal that the actors in this network are tightly intertwined with each other. The former means that around 62.2% of the neighbouring nodes of one node are mutually linked, while the latter shows that the interactions between actors take approximately 1.697 steps.

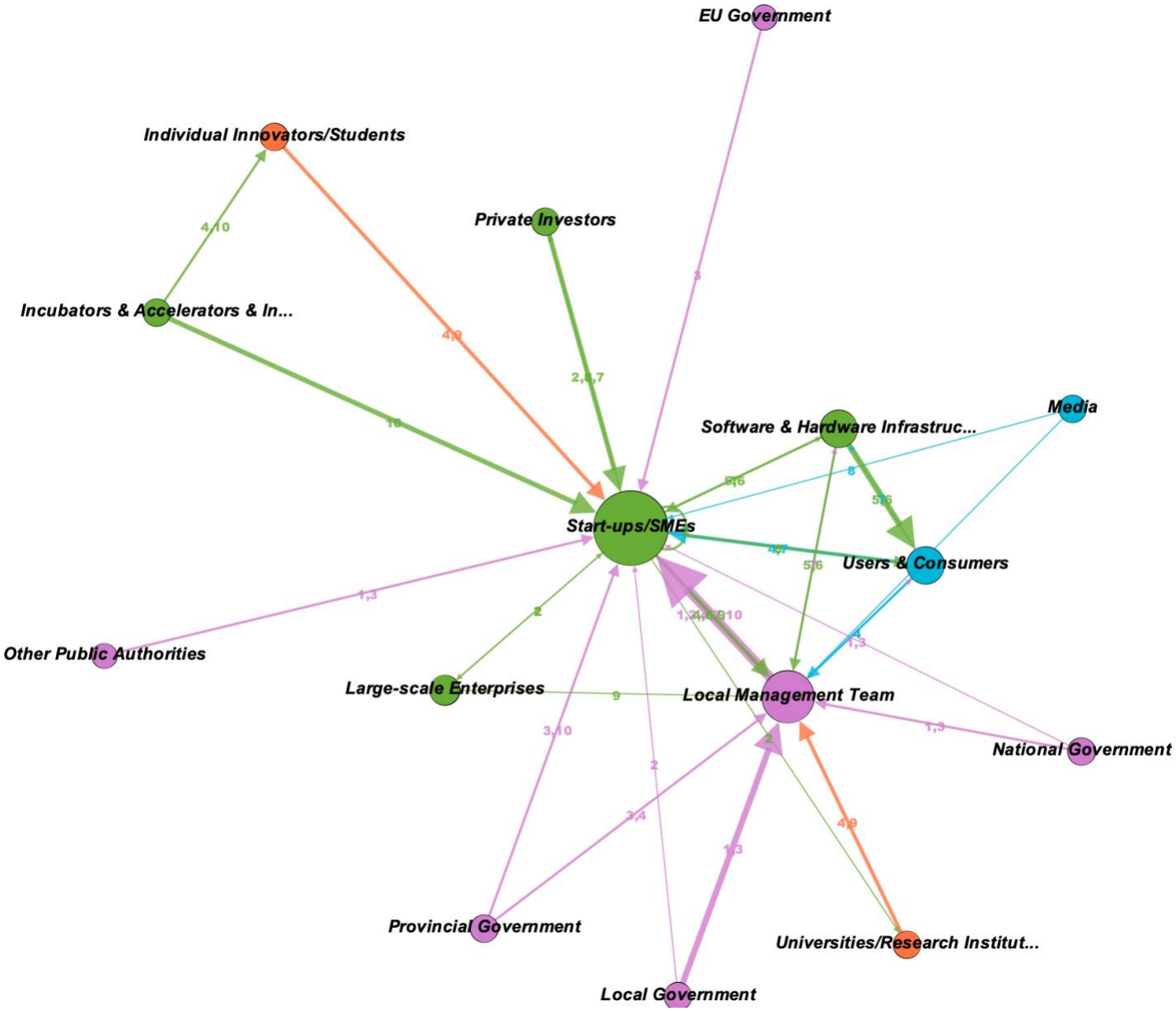

Figure 13 Visualised social network of the SCEE of BSD

(Type of interaction, 1: Governing & Regulating, 2: Cooperation & Partnership, 3: Financially Supporting & Investing, 4: Educating & Training & Advising & Knowledge Sharing, 5: Infrastructure Supporting, 6: Selling & Supplying, 7: Buying & Consuming, 8: Marketing & Promoting, 9: Innovation Creating, 10: Intermediation & Connecting & Network Building)

5.3 Actors

5.3.1 Overview of the actors in the SCEE of BSD

With the help of the theoretical framework of SCEE presented in Chapter 3, relevant actors in the development process of BSD are assigned under different 2nd order and 1st order Categories of actors. Slight changes are made to align with the practical situation of BSD. For instance, "large-tech companies" is adjusted to "large-scale companies" since not only "large-tech companies" such as Philips and ASML will be engaged in the development and operation stage of BSD but also "large-scale companies" such as construction contractors and architectural design companies have contributed a lot to the urban planning and infrastructure construction in BSD to make it more accessible and user-friendly. In addition, "universities" and "research institutions" are integrated as one actor named "universities & research institutions". Table 9 demonstrates the results of the stakeholders of BSD, and the detailed information of each actor is demonstrated in Appendix 3.

There are seven different parties under the category of "Government", namely The European Union (international government), Government of the Netherlands (national government), Province of Noord-Brabant (provincial government), Municipality of Helmond (local government), BSDF (local management team), and Netherlands Enterprise Agency and Ministry of Agriculture, Nature, and Food Quality (other public authorities). Among them, the BSDF funded in 2018 is the local management team that has direct control and administration over BSD, consisting of five board members from the Municipality of Helmond, Eindhoven University of Technology (TU/e), Brainport Development, Province of Noord-Brabant, and Tilburg University (*Official Website of Brainport Smart District*, 2022). There is also a BSD team subordinating to the BSDF, where there are program managers and other staff devoted to the development and operation of BSD.

Under the category of "Academia", Eindhoven University of Technology and Tilburg University (Universities) are not only the board members of BSDF but also engage in testing innovative ideas, advising on decision-making, evaluating the start-ups and projects, and connecting different stakeholders in BSD. TNO (The Netherlands Organisation for Applied Scientific Research) participates in innovative projects in BSD as a research institution. Additionally, students and individual innovators contribute to BSD by applying their innovative ideas to practical projects and sharing their opinions on communication events hosted by BSDF.

In "Society", there are the residents of BSD living and working in this area and other media platforms, which encourages the information flow and innovative development. For instance, New York Times published an article about the emergence of Brainport Smart District. The official website and newsletter of BSD inform interested groups of the latest updates in BSD. Social media platforms such as Facebook, TikTok, Instagram

and LinkedIn are utilised by BSDF and start-ups to promote and advertise the innovative district and innovative products.

The last and largest sector is “Industry”, where start-ups, large-scale enterprises, incubators & accelerators & intermediary innovative platforms, private investors, and software & hardware infrastructure providers are all included. Three start-ups are interviewed in this study, namely company A, company B, and company C. Team CASA is also included as an important start-up in the early development stage of BSD. Company X indicates other start-ups in BSD that are not interviewed. As for large-scale companies, Philips, ASML, and VDL Group show a strong interest in being involved in the development and operation stage of BSD due to their long-term dominant status and strategic partnership with the Brainport Eindhoven region, seeking innovative business and residential communities for their own employees. There are also other large-scale enterprises developing the built environment of BSD. UN Studio designed the urban vision master plan to create a smart, sustainable, circular, and inclusive district. Eindhoven construction company Hurks helped a student team from TU/e to realise their innovative ideas and build the CASA 1.0 houses. Incubators & accelerators & intermediary innovative platforms contain four different platforms, namely Brainport Smart District Online Innovation Marketplace, TU/e Smart Cities Innovation Space, Food Tech Brainport and Brandevoort LAB, which connect various stakeholders in the SCEE of BSD and provide a testing ground for the creation and test of innovation ideas. In terms of private investors, there is no large consortium containing banks, private equity funds and venture capital funds but small-scale private investors. For instance, the housing association Woonbedrijf has invested in a real estate project named CASA 1.0 for social rental housing. Healthcare institutions and recreational property providers are also the targeted clients of building start-ups in BSD, who will purchase the newly built houses in BSD and operate them for a long time. In addition to these investors in the real estate industry, the commercial bank Rabobank in the Netherlands is active in providing funding for various SMEs in different sectors. There are four different types of software & hardware infrastructure providers offering amenities for the residents and users in BSD, ranging from ground infrastructure (Baas B.V.), smart grid (Spectral), road system (KWS), and optic fibre (telecom company). The former three companies constitute a consortium to develop the essential infrastructure of BSD.

Table 9 Relevant stakeholders in the SCEE of BSD

2nd Order Categories	1st Order Categories	Actors	2nd Order Categories	1st Order Categories	Actors
Government	EU Government	The European Union	**Industry**	Start-ups/SMEs (small and medium-sized enterprises)	Company A
	National Government	Government of the Netherlands			Company B
	Provincial Government	Province of North Brabant			Company C
	Local Government	Municipality of Helmond			Team CASA and Company X
	Local Management Team	BSDF		Large-scale Enterprises	Local large-tech companies: ASML, Philips, VDL Group, etc
	Other Public Authorities	Ministry of Economic Affairs and Climate			Urban Vision Designer: UN Studio
		Netherlands Enterprise Agency (RVO)			Construction Company: Hurks
		Ministry of Agriculture, Nature, and Food Quality		Incubators & Accelerators & Intermediary Innovation Platforms	Brainport Smart District Online Innovation Marketplace
					TU/e Smart Cities Innovation Space
					Food Tech Brainport

Academia	Universities/Research Institutions	Eindhoven University of Technology			Brandevoort LAB
		Tilburg University		Private Investors	Housing associations: Woonbedrijf
	Universities/Research Institutions	TNO			Healthcare Institutions
	Individual Innovators/Students	Students from TU/e			Recreational Property Providers
		Students from the Hague University of Applied Science			Cooperative Bank: Rabobank
Society	Users & Consumers	Residents of Brainport Smart District		Software & Hardware Infrastructure Providers	Ground Infrastructure Provider: Baas B.V.
	Media	Journals: New York Times			Smart Grid Provider: Spectral
		Official Website of Brainport Smart District, Brainport Development, Municipality of Helmond			Road Construction Contractor: KWS
		Social Media Platform: Facebook, TikTok, Instagram, LinkedIn			Telecom Company/Optic Fibre Provider

5.3.2 Key actors based on centrality indicators

1) Degree Centrality

In SNA, degree centrality is frequently utilised to measure the influence and importance of nodes, which could be differentiated as weighted in-degree and weighted out-degree. Figure 14 presents the weighted in-degree and weighted out-degree of each actor in the BSD. The weighted in-degree and weighted out-degree represent the inflows and outflows of nodes (actors), and their values are determined by the sum of the weight of directed edges (interactions). Under the context of SCEE, an actor with a large weighted out-degree plays a critical role in transferring its own knowledge and resources to other actors (outflow). In contrast, an actor with a large weighted in-degree receives considerable resources from others (inflow).

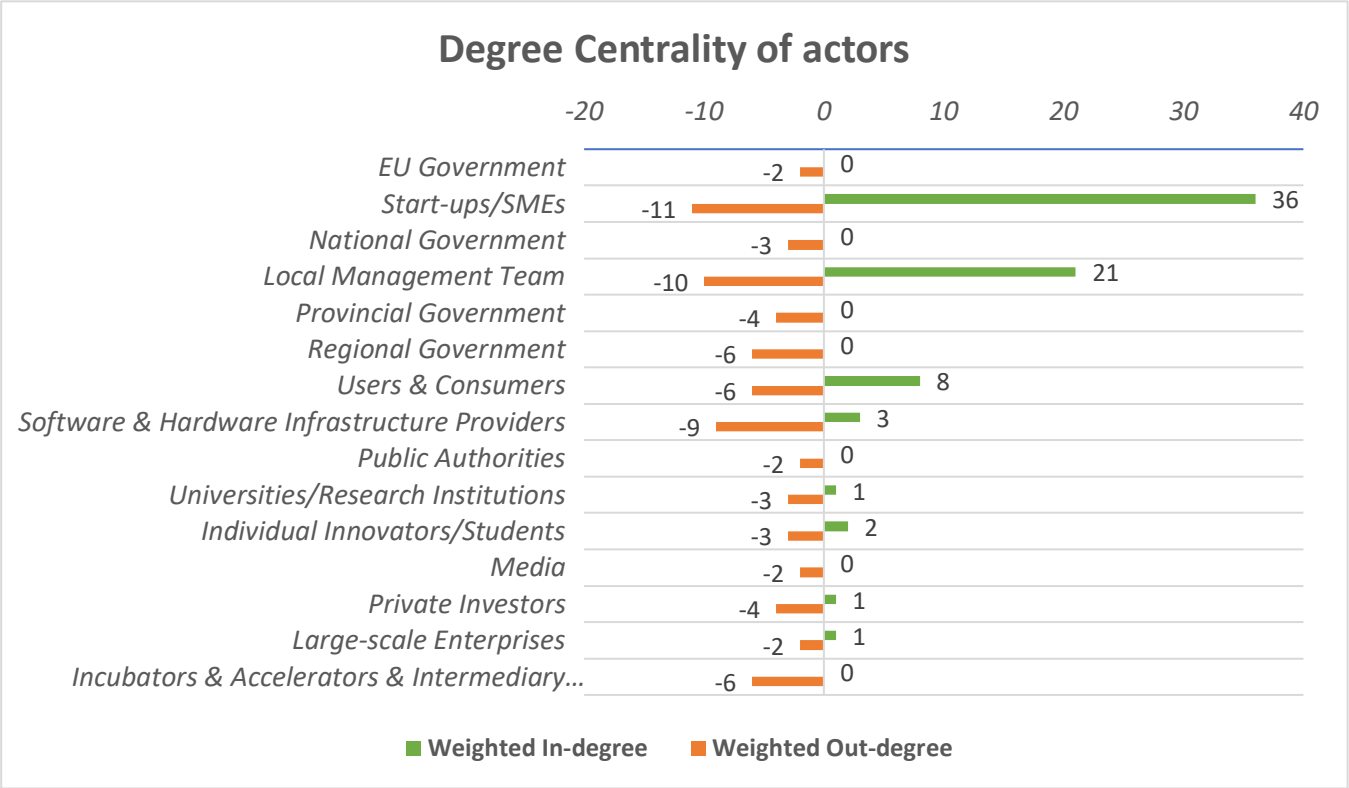

Figure 14 Degree centrality of actors in the BSD

Figure 15 demonstrates the weighted in-degree of actors, where the size and colour of nodes are determined by their weighted in-degree. The larger the node is, the darker the node's colour is, and the higher value of weighted in-degree it possesses. Start-ups/SMEs rank first with the highest weighted in-degree at 36. The local management team of BSD follows with a weighted in-degree at 21, which means that start-ups/SMEs and BSDF have received lots of proactive interactions from other actors, mostly knowledge and resources necessary for the growth of start-ups and the development of BSD. The users & consumers in BSD rank third with a value of 8, which can be explained by the services, products, and amenities provided by other actors in the SCEE.

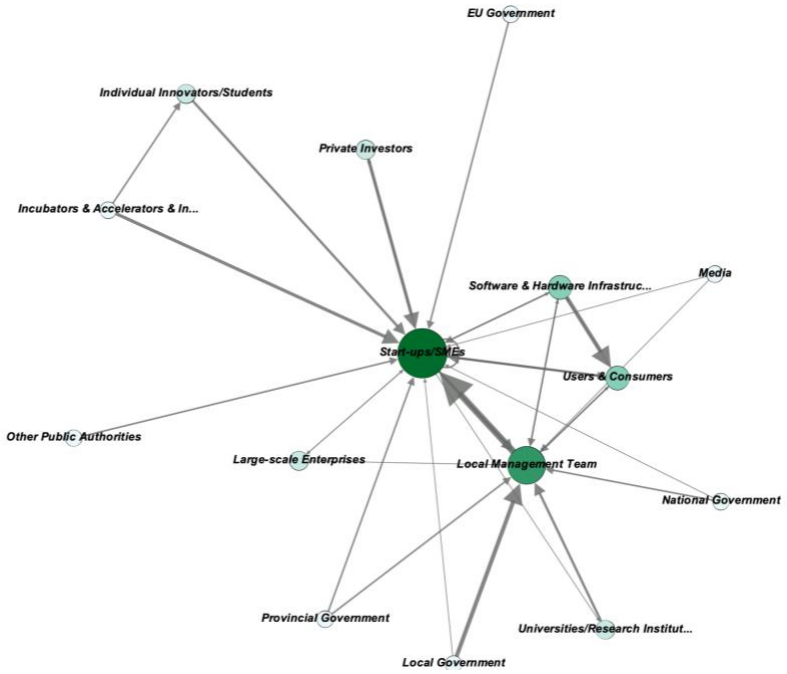

Figure 15 Weighted in-degree of nodes (actors) in the SCEE of BSD

From the perspective weighted out-degree, the top three actors taking initiative actions towards other actors are start-ups/SMEs, the local management team of BSD, and software & hardware infrastructure providers (see Figure 16). Specifically, these three actors mainly consume their own resources to either directly or indirectly supply other actors. For instance, start-ups provide innovative services and products to residents of BSD, the local management team hosted a business challenge to involve start-ups in the building process, and software & hardware infrastructure providers make the energy, water, and fibre network available for the whole district.

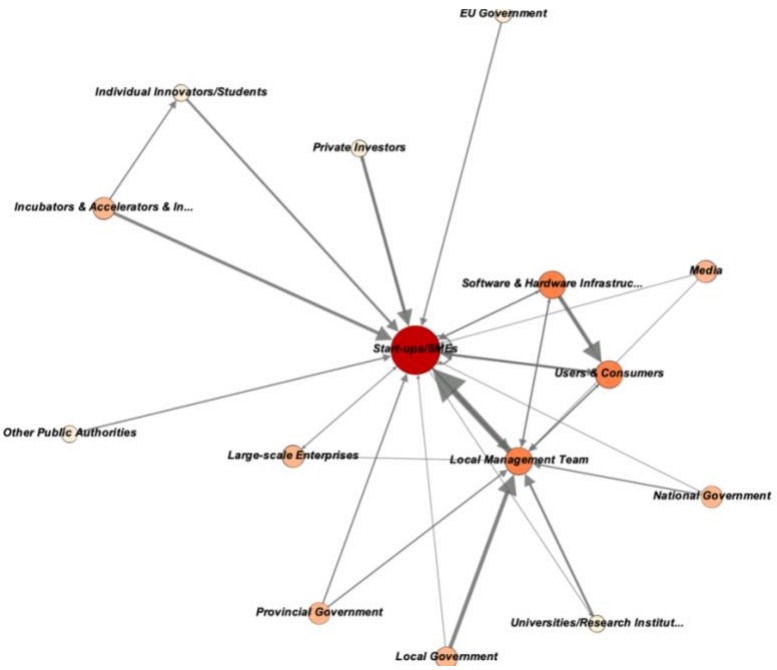

Figure 16 Weighted out-degree of nodes (actors) in the SCEE of BSD

2) Betweenness Centrality, Closeness Centrality, and Eigenvector Centrality

Besides degree centrality, three other different types of centralities are helpful to detect influential actors in the SCEE, namely closeness centrality, betweenness centrality and eigenvector centrality, as presented in Table 10.

Table 10 Closeness Centrality, Betweenness Centrality, and Eigenvector Centrality of actors

Nr	Actors	Betweenness Centrality	Closeness Centrality	Eigenvector Centrality
1	EU Government	0	0.538	0
2	Start-ups/SMEs	59	1	1
3	National Government	0	0.583	0
4	Local Management Team	10	0.667	0.777
5	Provincial Government	0	0.583	0
6	Local Government	0	0.583	0
7	Users & Consumers	0	0.667	0.655
8	Software & Hardware Infrastructure Providers	0	0.667	0.655
9	Other Public Authorities	0	0.538	0
10	Universities/Research Institutions	0	0.462	0.276
11	Individual Innovators/Students	0	0.538	0.003
12	Media	0	0.583	0
13	Private Investors	0	0.545	0.276
14	Large-scale Enterprises	0	0.6	0.276
15	Incubators & Accelerators & Intermediary Innovation Platform	0	0.571	0

A node serving as the intermediary between different nodes possesses high betweenness centrality. Similar to the previous figures, a node with a brighter colour and a larger size has a higher value for these centrality indicators. As shown in Figure 17, start-ups/SMEs and local management team of BSD are the key mediating nodes that connect all the other actors in the ecosystem, which can be explained by the fact that the whole ecosystem is built around the development of BSD with innovations from start-ups.

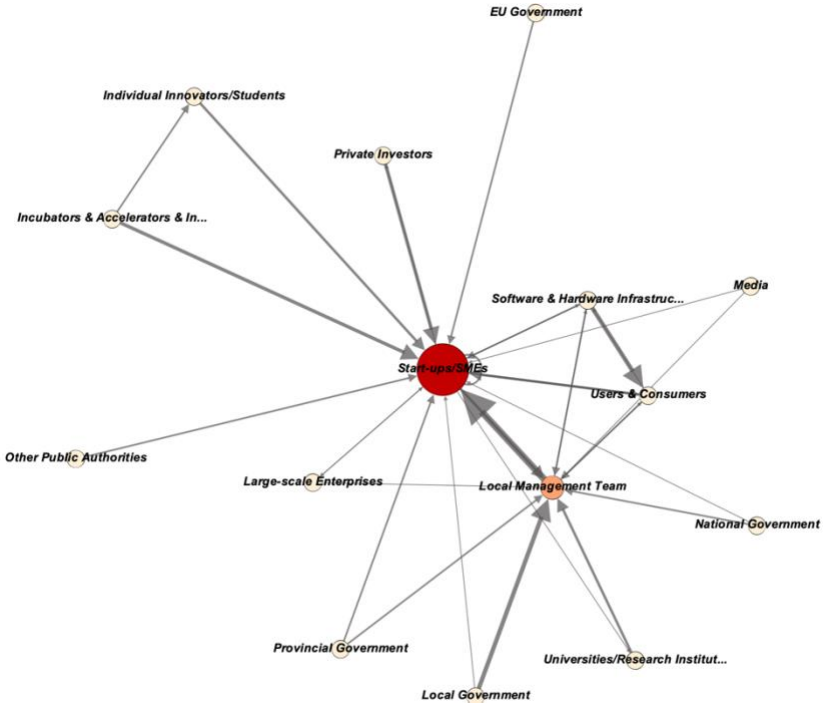

Figure 17 Betweenness centrality of actors in the SCEE of BSD

Nodes in the most central position of the network demonstrate high closeness centrality since they can reach any other nodes within a short distance. They are closely connected with other vertices and can deliver information and resources to their partners and even the whole network with minimal time and cost. Start-ups/SMEs still rank first in terms of closeness centrality. The local management team, users & consumers and software & hardware infrastructure providers are also of great importance, with the second highest value of closeness centrality at 0.667.

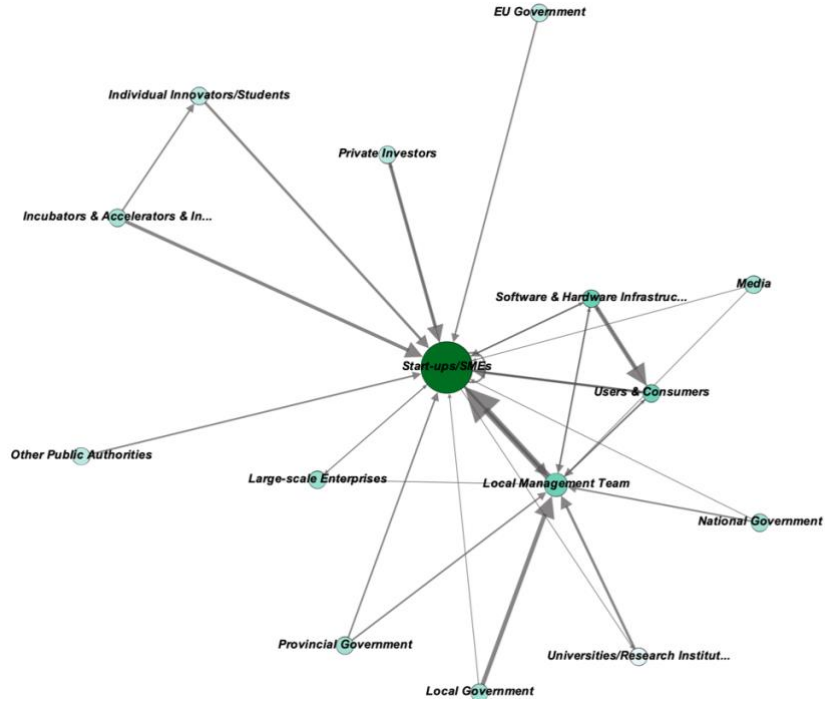

Figure 18 Closeness centrality of actors in in the SCEE of BSD

Concerning the eigenvector centrality, nodes connected to “star neighbour nodes” possess a high value. The more important their neighbour nodes are, the higher the value of the eigenvector centrality of those nodes. Start-ups/SMEs, the local management team, users & consumers, and software & hardware infrastructure providers are the top listed actors. Once they experience variation, they will immediately influence their neighbouring central actors, and the impact will extend to other actors linked to those prominent actors and then the whole network in a short time.

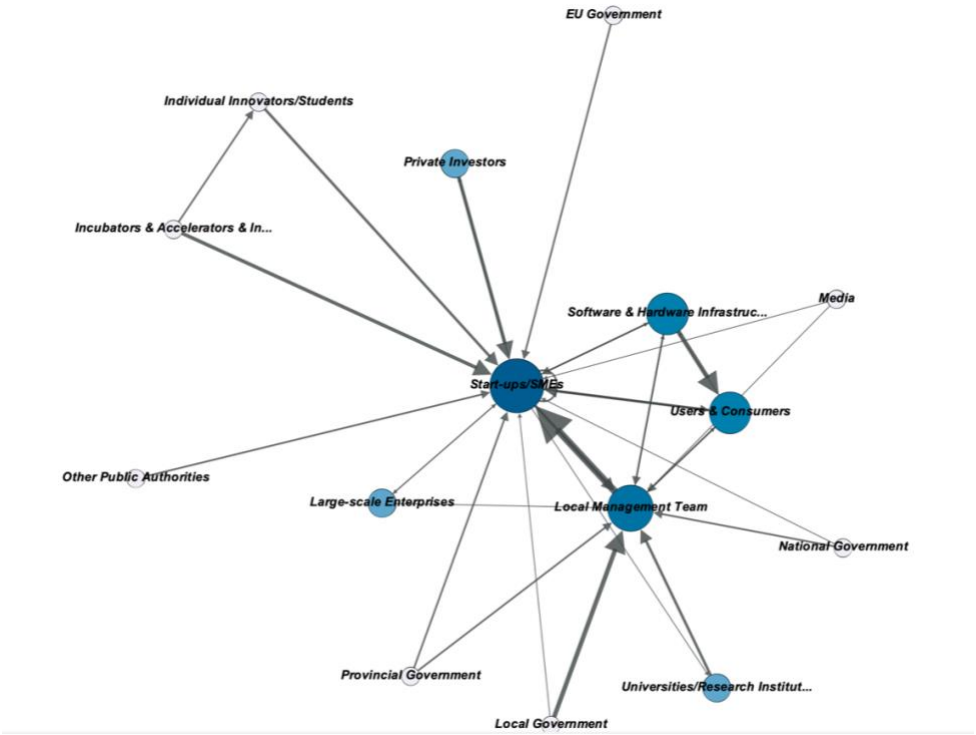

Figure 19 Eigenvector centrality of actors in in the SCEE of BSD

5.4 Interactions between actors

5.4.1 Overview of the interactions in the SCEE of BSD

Table 18 in Appendix 4 provides detailed information regarding every interaction between actors in the SCEE of BSD, which is extracted from the online public resources and stakeholder interviews. Actors from government and industry are the major players in the SCEE who have the most proactive interactions with the other two players (academia and society).

Regarding actors belonging to the government, EU government, national government, provincial government, local government, and public authorities are mainly interacting with start-ups and the local management team of BSD through governing and regulating and providing financial support. For instance, the national government granted funding and made special approval on the permit of company B (Interviewee B, personal communication, 2022). According to interview D, the national government also provides the opportunity for the local management team to pursue the National Growth Funding, which is called National Groeifonds in Dutch (Interviewee D, personal communication, 2022). As for the local management team of BSD, it has direct interactions with users & consumers, start-ups/SMEs, and software & hardware infrastructure providers. With users & consumers, the local management team of BSD shared the latest information about BSD and answered the questions from citizens through online events. Also, the local management team relies on the software & hardware infrastructure providers, such as establishing its public internet connectivity network with the help of a telecom company. The most intensive interactions that the local management team has are with start-ups, containing eight different interactions in total. For instance, the BSD Foundation designed the Q-book to clarify the quality standard start-ups should obey, held five business challenges to attract more start-ups in the development process of BSD, shared necessary information about BSD through different channels, and hosted networking events to connect entrepreneurs to other stakeholders in BSD (*Official Website of Brainport Smart District*, 2022).

As regards actors in the industry, start-ups/SMEs initiated eleven interactions with other actors in the SCEE of BSD, mainly collaborating with other actors or supplying their innovative products or services to others. Large-scale enterprises such as telecom company, energy company, and water company provided infrastructure to the local management team of BSD to make BSD an accessible place to live and work. It is also observed that large-scale construction enterprises help start-ups with construction work and transform their innovative ideas into real smart houses. As for incubators & accelerators & intermediary innovation platforms, they mainly connected to start-ups/SMEs and individual innovators/students to help them grow, introducing them to a commercial network, giving specialised advice, and removing the barrier to cross-border collaboration. Private investors provided financial support to start-ups through loans or grants in the case of BSD. The last actor in the industry,

software & hardware infrastructure providers, supply the local management team, users & consumers, and start-ups/SMEs with the necessary infrastructure.

University and research institutions are working closely with the local management team of BSD, sharing their expertise, and creating innovations in the test environment. For instance, the five board members of the BSDF include two professors from Eindhoven University of Technology and Tilburg University, respectively. They are engaged in designing the quality book for evaluating start-ups and recommending different programmes. In addition to professors, students also contribute a lot to start-ups as individual innovators. For instance, the residential building project CASA 1.0 was built based on the idea and technology developed by a student from Eindhoven University of Technology. More than one interviewee mentioned that they are working together with students to conduct research or get inspired.

In the sector of society, users & consumers are actively interacting with other actors. For instance, many citizens are involved in the city council and other events hosted by the local management team of BSD to co-develop residential products. The first resident of BSD is also a pioneer who helped with the design of the urban vision plan and programme lines, dedicatedly. In addition, users & consumers are the customers consuming the products supplied by start-ups, and they are willing to give their opinions and feedback to help start-ups optimise their products and services. In terms of media, another player in society, it helps with extending the publicity of BSD by introducing it in the international journal, such as New York Times. In addition, social media platforms, including LinkedIn, Facebook and TikTok, are used by start-ups to attract more potential customers (Interviewee B, personal communication, 2022).

Table 11 Overview of the interactions between actors in BSD

Nr	Source	Target	Categories of the source	Type of Interaction	Weight
1	EU Government	Start-ups/SMEs	Government	Investing	2
2	National Government	Local Management Team	Government	Regulating, Investing	2
3	National Government	Start-ups/SMEs	Government	Regulating, Investing	2
4	Provincial Government	Local Management Team	Government	Investing, Advising	2
5	Provincial Government	Start-ups/SMEs	Government	Investing, Connecting	2
6	Local Government	Local Management Team	Government	Regulating, Investing	5
7	Local Government	Start-ups/SMEs	Government	Cooperation	1
8	Local Management Team	Users & Consumers	Government	Advising	1
9	Local Management Team	Start-ups/SMEs	Government	Regulating, Cooperation, Advising, Consuming, Connecting	8
10	Local Management Team	Software & Hardware Infrastructure Providers	Government	Consuming	1
11	Public Authorities	Start-ups/SMEs	Government	Regulating, Investing	2
12	Universities/Research Institutions	Local Management Team	Academia	Advising, Creating	3

13	Individual Innovators/Students	Start-ups/SMEs	Academia	Advising, Creating	3
14	Users & Consumers	Local Management Team	Society	Advising	2
15	Users & Consumers	Start-ups/SMEs	Society	Advising, Consuming	3
16	Users & Consumers	Software & Hardware Infrastructure Providers	Society	Consuming	1
17	Media	Local Management Team	Society	Marketing	1
18	Media	Start-ups/SMEs	Society	Marketing	1
19	Start-ups/SMEs	Users & Consumers	Industry	Supplying	2
20	Start-ups/SMEs	Local Management Team	Industry	Advising, Supplying, Creating	3
21	Start-ups/SMEs	Universities/Research Institutions	Industry	Cooperation	1
22	Start-ups/SMEs	Start-ups/SMEs	Industry	Cooperation	2
23	Start-ups/SMEs	Private Investors	Industry	Supplying	1
24	Start-ups/SMEs	Large-scale Enterprises	Industry	Cooperation	1
25	Start-ups/SMEs	Software & Hardware Infrastructure Providers	Industry	Consuming	1

26	Large-scale Enterprises	Local Management Team	Industry	Creating	1
27	Large-scale Enterprises	Start-ups/SMEs	Industry	Cooperation	1
28	Incubators & Accelerators & Intermediary Innovation Platform	Start-ups/SMEs	Industry	Connecting	4
29	Incubators & Accelerators & Intermediary Innovation Platform	Individual Innovators/Students	Industry	Advising, Connecting	2
30	Private Investors	Start-ups/SMEs	Industry	Cooperation, Investing, Consuming	4
31	Software & Hardware Infrastructure Providers	Local Management Team	Industry	Infrastructure, Supplying	2
32	Software & Hardware Infrastructure Providers	Users & Consumers	Industry	Infrastructure, Supplying	5
33	Software & Hardware Infrastructure Providers	Start-ups/SMEs	Industry	Infrastructure, Supplying	2

5.4.2 Interactions between start-ups and other actors

As demonstrated in Table 11, there are 33 interactions between actors in the SCEE of BSD. Among them, most of the interactions are between start-ups and actors in government and industry. The section below elaborately describes interactions between start-ups and actors in the other four pillars, namely government, academia, society, and industry.

1) Start-ups and Government

As can be seen from Figure 20, the government initiated various interactions towards start-ups compared with other sectors. In Figure 20, the size of a node is determined by its weighted degree, and the thickness of the edge is determined by its weight. For the EU government, it launched a project called “Connect SME”, which is a programme under the European Regional Development Fund (Interreg Vlaanderen-Nederland). BSD is selected as a living lab for start-ups to demonstrate and develop their innovative ideas in a testing ground. The European Regional Development Fund not only connects start-ups with living labs to introduce innovative technologies to the market but also provides subsidies for start-ups in promoting smartness, greenness, and inclusiveness in Flanders and the South of the Netherlands. Interviewee B and interviewee D mentioned that the EU government had provided financial support to their company through a combination of grants and loans. The national government, on the one hand, enacts the rules that start-ups should obey; on the other hand, it provides some funding that start-ups can use, such as innovation credit and Dutch Good Growth Fund. In the early development stage of company B, it was constrained by the regulations at that time, which prevented it to obtain a permit to operate the smart farm. After several rounds of negotiation, the national government made special treatment to this company and approved the permit.

According to interviewee A and B, the provincial government offered funding for company B to expand its business and has organised several social events to connect stakeholders in the innovative industry and facilitate collaboration between them. Concerning the local government, the largest node in Figure 20, the Municipality of Helmond, is trying its best to remove the regulatory barriers for start-ups. It has turned to the national government to ask for special approval and treatment on the innovative start-ups in BSD. The local management team, namely the BSDF, is the actor that has interacted most with start-ups, who have five different types of interactions and initiated eight interactions towards start-ups in total. The BSDF manages the selection process through a quality manual (Q-book), which is used to evaluate the projects provided by start-ups. Also, it hosted live broadcasts and online events and organised a business network (Business Challenge Wave) where qualified start-ups are selected and allowed to find new connections. Since BSD collaborated with start-ups to build the smart community, such as the sustainable buildings and smart farms offered by company A and B, BSDF offered to help start-ups facilitate their proposal and development process. Some public authorities, such as the Ministry of

Agriculture, Nature, and Food Quality, regulate the products of company B, while others, such as the Netherlands Enterprise Agency, provide national funding for company C to conduct scientific research.

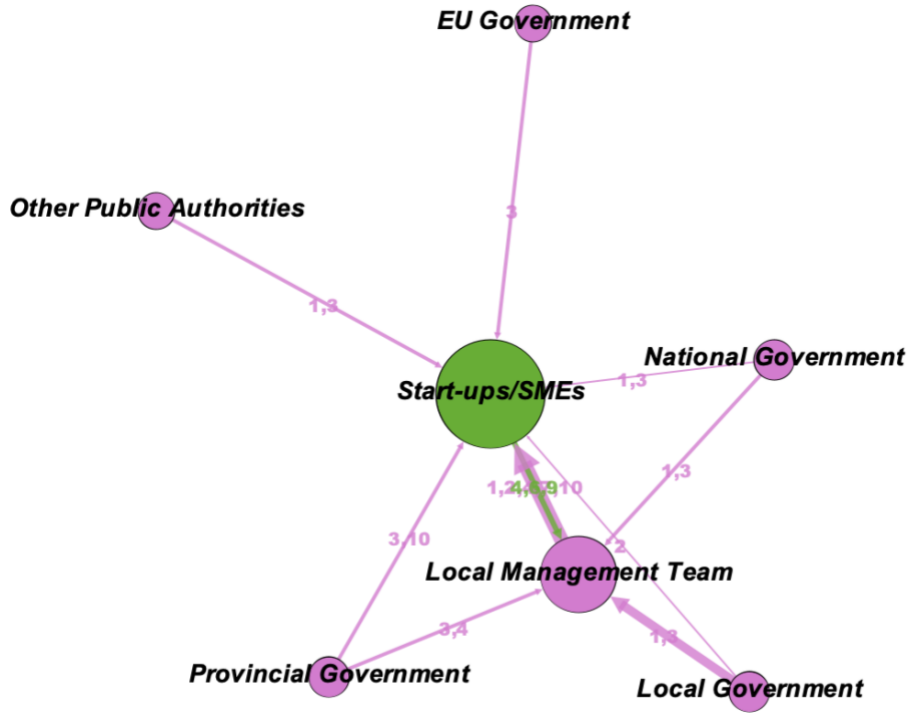

Figure 20 Social network of Interactions between start-ups and actors in government
(Type of interaction, 1: Governing & Regulating & Administrative Supporting, 2: Cooperation & Partnership, 3: Financially Supporting & Investing, 4: Educating & Training & Advising & Knowledge Sharing, 5: Infrastructure Supporting, 6: Selling & Supplying, 7: Buying & Consuming, 8: Marketing & Promoting, 9: Innovation Creating, 10: Intermediation & Connecting & Network Building)

Table 12 interactions between start-ups and actors in government

Nr	Source	Target	Type of Interaction	Weight
1	EU Government	Start-ups/SMEs	Investing	2
2	National Government	Start-ups/SMEs	Regulating, Investing	2
3	Provincial Government	Start-ups/SMEs	Investing, Connecting	2
4	Local Government	Start-ups/SMEs	Cooperation	1
5	Local Management Team	Start-ups/SMEs	Regulating, Cooperation, Advising, Consuming, Connecting	8
6	Public Authorities	Start-ups/SMEs	Regulating, Investing	2
7	Start-ups/SMEs	Local Management Team	Advising, Supplying, Creating	3

The above-mentioned interactions are proactive interactions from governmental actors to start-ups, and there are also three proactive interactions from start-ups to other actors (see Table 12). For the local management team of BSD, start-ups have contributed a lot by participating in the business challenge of BSD, thus collaborating with BSDF to co-create a smart, sustainable, and inclusive living and working future district with their innovative solutions and projects. For instance, company C was selected as a potential partner in Business Challenge Wave 5 of BSD, which can eliminate the particulate matter in the air and thus bring a healthy and clean living environment for the residents.

2) Start-ups and Academia

Figure 21 below shows the interactions between start-ups and actors in academia, which are much less compared with that of the government with a total weight of 4.0 (see Table 13). In the sector of "Academia", individual innovators/students contributed a lot to start-ups. The students from Eindhoven University have formed a team and developed innovative technologies to construct the first house (CASA 1.0) in BSD, which is to become sustainable, reusable, and affordable for lower-income people. In addition, students from the Hague University of Applied Science conducted research on the target market and joined the seminar with company B to help it pursue commercial opportunities. Also, company C mentioned their collaboration with PhD students at the Eindhoven University of Technology, which accelerates the research & development process of their innovative solutions.

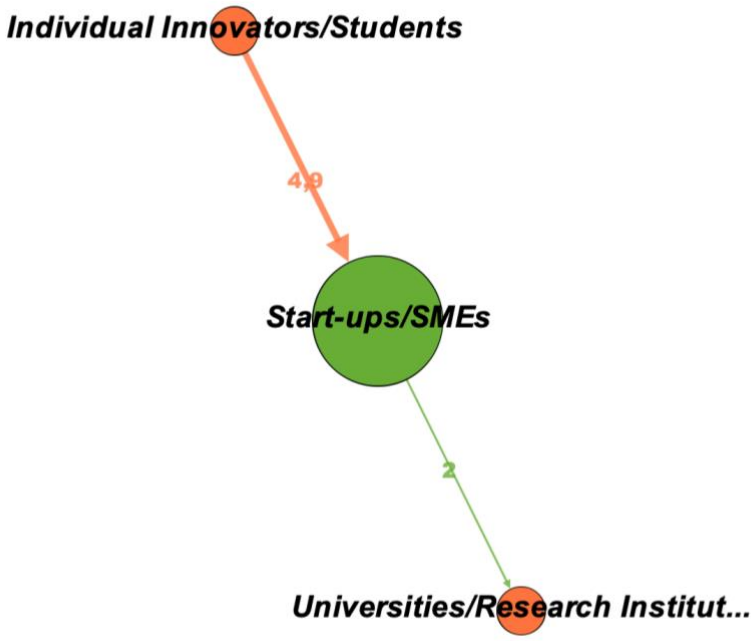

Figure 21 Social network of Interactions between start-ups and actors in academia

(Type of interaction, 1: Governing & Regulating, 2: Cooperation & Partnership, 3: Financially Supporting & Investing, 4: Educating & Training & Advising & Knowledge Sharing, 5: Infrastructure Supporting, 6: Selling & Supplying, 7: Buying & Consuming, 8: Marketing & Promoting, 9: Innovation Creating, 10: Intermediation & Connecting & Network Building)

Table 13 interactions between start-ups and actors in academia

Nr	Source	Target	Type of Interaction	Weight
1	Individual Innovators/Students	Start-ups/SMEs	Advising, Creating	3
2	Start-ups/SMEs	Universities/Research Institutions	Cooperation	1

3) Start-ups and Society

In terms of "Society", the users & consumers are the main consumers who are paying for or consuming the products from start-ups, such as the residential buildings, the smart farm, and the good-quality air in BSD. Also, they are assisting start-ups to improve their products or services by being part of the user council, where the demands and feedback from citizens are reflected by entrepreneurs. Another important actor in society is the media, which acts as the most effective promoting and advertising tool for start-ups to increase their publicity and attract more potential consumers and investors accordingly. In the end, the proactive interaction from start-ups to users & consumers is mainly about a supply and demand relationship, namely, start-ups producing innovative products and services for the consumers.

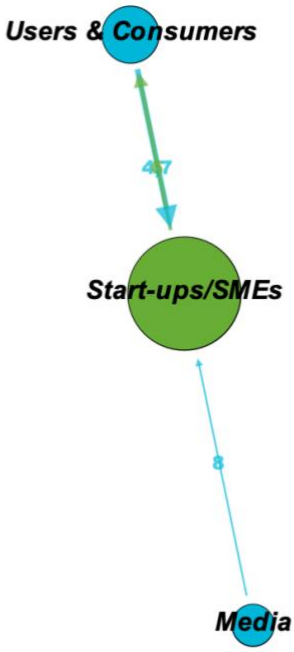

Figure 22 Social network of Interactions between start-ups and actors in society
(Type of interaction, 1: Governing & Regulating, 2: Cooperation & Partnership, 3: Financially Supporting & Investing, 4: Educating & Training & Advising & Knowledge Sharing, 5: Infrastructure Supporting, 6: Selling & Supplying, 7: Buying & Consuming, 8: Marketing & Promoting, 9: Innovation Creating, 10: Intermediation & Connecting & Network Building)

Table 14 interactions between start-ups and actors in society

Nr	Source	Target	Type of Interaction	Weight
1	Users & Consumers	Start-ups/SMEs	Advising, Consuming	3
2	Media	Start-ups/SMEs	Marketing	1
3	Start-ups/SMEs	Users & Consumers	Supplying	2

4) Start-ups and Industry

As presented in Figure 23, there are also various interactions between start-ups and other actors in the industry. To begin with, when it comes to proactive interactions towards start-ups, a large-scale construction enterprise, “Hurks”, collaborated with the student team CASA to build sustainable houses designed by them. Incubators & accelerators & intermediary innovation platforms have been playing an intermediating agent to connect start-ups with other stakeholders in the ecosystem through establishing an information exchange platform. BSD has developed an online innovation marketplace to enable start-ups to demonstrate their innovative projects, where the business supply and demand in the market can be matched. The major partner in BSDF, Eindhoven University of Technology, is also running the Smart Cities Innovation Space. This innovation hub mainly connects student innovators and entrepreneurs to other stakeholders (i.e., researchers, companies, and societal organisations) to cope with innovation challenges faced by the industry and society. In addition, the living lab “Brandevoort” involves residents of the present Brandevoort district in the development process of BSD, where residents can express their demands and opinions to start-ups and participate in developing, testing, and evaluating innovative concepts. Interviewee B stated that they came across the BSD project at an event hosted by Food Tech Brainport, which is a foundation in Helmond that connects the food processing industry to entrepreneurs, innovators, and potential investors.

As for private investors, they either invested in the project and operated it, or gave the grant to help start-ups grow. For instance, the housing association ‘Woonbedrijf’ has invested in a building project named CASA 1.0 and will use it for social rental housing (*Official Website of Brainport Smart District*, 2022). Rabobank granted company B a cheque to further expand its business in their smart farm (Interviewee B, personal communication, 2022). In the end, the operation of digital start-ups’ products relies on the fibre network provided by the telecom company. For instance, the smart lamp with sensors needs the fibre network to realise data transmission.

In terms of the proactive interactions from start-ups to other actors in the industry, company a is seeking partnerships with large-scale companies to establish its manufacturing system and supply chain, according to interviewee A. For private investors such as the housing associations, start-ups supply residential housing

projects to them. In addition, start-ups are also the consumers of the infrastructure provided by software & hardware infrastructure providers, such as cloud services, IoT platforms, fibre networks, etc.

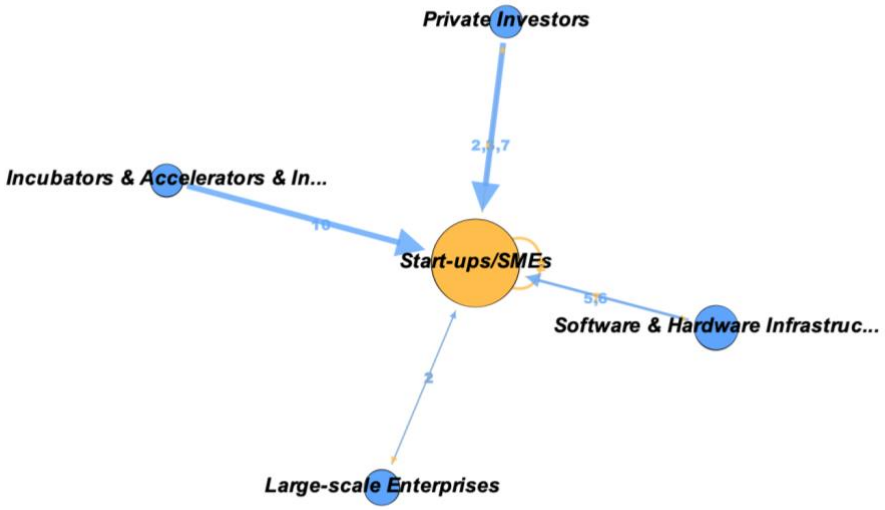

Figure 23 Social network of Interactions between start-ups and actors in industry
(Type of interaction, 1: Governing & Regulating, 2: Cooperation & Partnership, 3: Financially Supporting & Investing, 4: Educating & Training & Advising & Knowledge Sharing, 5: Infrastructure Supporting, 6: Selling & Supplying, 7: Buying & Consuming, 8: Marketing & Promoting, 9: Innovation Creating, 10: Intermediation & Connecting & Network Building)

Table 15 interactions between start-ups and actors in industry

Nr	Source	Target	Type of Interaction	Weight
1	Large-scale Enterprises	Start-ups/SMEs	Cooperation	1
2	Incubators & Accelerators & Intermediary Innovation Platforms	Start-ups/SMEs	Connecting	4
3	Private Investors	Start-ups/SMEs	Cooperation, Investing, Consuming	4
4	Software & Hardware Infrastructure Providers	Start-ups/SMEs	Infrastructure, Supplying	2
5	Start-ups/SMEs	Large-scale Enterprises	Cooperation	2
6	Start-ups/SMEs	Private Investors	Supplying	1
7	Start-ups/SMEs	Software & Hardware Infrastructure Providers	Consuming	1
8	Start-ups/SMEs	Start-ups/SMEs	Cooperation	2

There are also interactions between start-ups and start-ups, which is demonstrated as a self-loop in Figure 23. Most of the interaction type between them is cooperation and partnership. In the SCEE of BSD, company A is collaborating with another start-up they encountered in the networking event hosted by BSDF. They intend to combine their products and technologies to provide a better and more sustainable building product for the residents in BSD. Additionally, company B is utilising the farming robots developed by another start-up, which increases productivity and saves manual work in their smart farms.

5.5 Key findings

In the social network of the SCEE in BSD, there are 15 nodes and 33 edges. The weighted average degree of the whole network is 4.867, and its diameter is 3. The average clustering coefficient is 0.622, and the average path length is 1.697. These indicators prove the “small world” characteristic of this network; most of the nodes are interlinked and can reach each other within a short time and distance.

Regarding the key nodes, start-ups/SMEs are the most influential actors in the social network due to their high value in degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality. Additionally, the local management team of BSD, users & consumers, and software & hardware infrastructure providers are the key players with substantial impacts in the SCEE, which are the top listed actors following start-ups/SMEs in terms of the four centrality indicators of SNA.

As for the interaction between actors in the SCEE, most of the interactions happened between start-ups and other actors. Among them, start-ups have interacted more with the actors in the government and industry. The government regulates the market, provides financial support to start-ups, and connects start-ups to other stakeholders in the ecosystem. Beyond that, actors in industry collaborate with start-ups in product research & development, offer funding for start-ups by loans or grants, provide the necessary software & hardware infrastructure, and serve as an intermediary platform to build the commercial network of start-ups. In contrast, the interactions between start-ups and actors in academia and society are much less. In the case of BSD, university students bring innovation and inspiration to start-ups. Citizens from the society are engaged in the city council to give feedback on the products and services of start-ups and express their demands. It is also worth mentioning that there is also a self-loop in the social network of SCEE, which indicates the collaboration between start-ups in business and technology development.

6. Discussion

With the help of a systematic literature review, this study has proposed a theoretical framework for Smart City Entrepreneurial Ecosystem (SCEE) and applied it to the case of BSD Helmond for social network analysis, which results can be used for improving the current ecosystem and boost the growth of start-ups in this ecosystem.

The following chapter will demonstrate the reflection on the case study results of BSD in Chapter 6.1. In addition, the discussion about the academic contribution and the practical implication of the results are elaborated in Chapter 6.2 and 6.3.

6.1 Reflection on the case study results

6.1.1 Reflection on the overall network features

The theoretical framework of SCEE consists of actors and their interactions. There are 15 different actors under four categories (i.e., Government, Academia, Society, and Industry), and ten different types of interactions depicting the interrelationships between actors. After applying this theoretical framework with the gathered data to the empirical case of BSD, the social network theory was utilised to build and analyse the ecosystem of BSD. The SCEE of BSD comprises 15 groups of actors and 74 interactions between them, while in the visualised social network the 74 interactions were integrated and depicted as 33 edges due to the existence of parallel interactions between the same pair of actors.

The whole network of the SCEE in BSD is very condensed since its weighted average degree of the whole network is 4.867, and the diameter is 3, meaning every actor has around five interactions approximately on average and the largest distance between actors in the network is merely three edges. In addition, the average clustering coefficient is 0.622 and the average path length is 1.697, which demonstrates that most of the actors in the network are clustered and can connect each with an average of 1.697 steps. These network characteristics of the ecosystem prove its potential to connect all the stakeholders in the ecosystem and validate the effectiveness and efficiency of optimising the critical actors, whose spill-over effect will influence the connectivity of the whole ecosystem.

6.1.2 Reflection on the key actors

When it comes to the key actors, start-ups/SMEs are the most influential actor in the ecosystem due to their high degree centrality, betweenness centrality, closeness centrality and eigenvector centrality. Its weighted out-degree is 11 and weighted in-degree is 36, indicating that the four studied start-ups in this research have 47 interactions with other groups of actors in total. Its highest betweenness centrality, closeness centrality and eigenvector centrality also prove that start-ups/SMEs are acting as an intermediary agent between other actors, reaching other actors within a short distance, and connecting to "star actors" in the ecosystem. These features of start-ups in this case study can be explained by the "smartness" and "innovation" of BSD. Since BSD is dedicated to building a smart city district in a high-tech innovative region and is open to developing and testing new projects in their living lab, many start-ups have been attracted to implement pilot projects in this testing ground through business challenges launched by BSDF. The above results reveal the prominent status of start-ups in SCEE and confirm the priority to boost the growth of start-ups to achieve urban innovation.

Besides start-ups/SMEs, there are three other actors that perform well in terms of centrality ability, including the local management team of BSD (BSDF), users & consumers, and software & hardware infrastructure providers. The local management team ranks only second to start-ups/SMEs in every centrality assessment, which demonstrates that it is an important actor in the SCEE of BSD that can influence the whole ecosystem and start-ups/SMEs by taking certain measures. Likewise, users & consumers are also taking a central position in the whole ecosystem because they are the final entities living in the smart community and using and consuming all the products and services included in it. Without users & consumers, the value chain in the SCEE will collapse and start-ups/SMEs will not be able to sustain their business operations and get payback. As for software & hardware infrastructure providers, their influences are embodied in the infrastructure that sustains the whole community and the life of residents. Whether the district itself, users & consumers or start-ups are dependent on the software infrastructure (i.e., the air quality monitoring platform, IoT platform) and hardware infrastructure (i.e., fibre network, road system, smart grid.

The identification of key actors in the SCEE of BSD confirms the significance of this study again, highlighting the prominent status of start-ups/SMEs in promoting urban innovation and creating smart cities. In addition, the other three key actors identified a direction to improve the connectivity of the whole ecosystem and reinforce the linkage between start-ups and other actors. For instance, a more intimate connection between start-ups and the local management team (BSDF) can lead to further connections between start-ups and other actors. The reason behind this is that the local management team has a strong intermediating capability to connect start-ups to its "star neighbour actors" with the least time and cost, such as the national government.

6.1.3 Reflection on the key interactions

1) Interactions between start-ups and government

Actors in the government have been interacting most with start-ups in the SCEE of BSD, and there are six different types of interactions, including government and regulation, cooperation and partnership, financially supporting and investing, advising and knowledge sharing, buying and consuming, and intermediation, connecting, and network building.

Both the national government and other public authorities have regulatory power over start-ups. The business operation process of start-ups and their products are within their supervision. The national government is the central government that enacts all the rules and regulations in the Netherlands. For specific administrations, a specific public authority is responsible for granting permits on start-ups' experimental projects or innovative products, such as the road test for autonomous vehicles. Despite that the Ministry of Agriculture, Nature, and Food Quality has granted the permit for company B to develop and test innovative technologies in their smart farm, it took them seven years to obtain the operating permit. This phenomenon is related to the low level of organisational agility of the government, which means that the government is not able to take action timely and respond to the fast-changing business world and emerging innovative technologies. Since the Ministry of Agriculture, Nature, and Food Quality is not familiar with the new-type farm created by company B, it took a long time for them to conduct the research and understand the technologies, risks, and benefits of this smart farm. Since most of the products of start-ups are created out of innovation and have never occurred before, the current regulations are outdated and may not apply to start-ups and their products. For instance, there is no regulation until now addressing whether it is legal to use robots in smart farms for commercial interests since robots are not even widely applicable yet. That is the reason why the local government (i.e., the Municipality of Helmond) is doing political lobbying with the national government to seek law and regulation changes so that start-ups can encounter fewer political regulatory restrictions when developing their products and expanding their business. However, the whole process still takes a long time due to the complicated application procedures and complex hierarchy systems within governmental organisations. In this case, more efforts from the national government and public authorities (i.e., Netherlands Enterprise Agency, Ministry of Agriculture, Nature, and Food Quality, Ministry of Housing, Spatial Planning and the Environment, and Ministry of Infrastructure and Water Management) are needed to create a more innovation-friendly regulatory environment.

With regard to financial support, the government is playing an important role in providing funding for start-ups. From the perspective of the national government, currently, there is no sufficient funding going into the start-ups in BSD. Although the local management team of BSD (i.e., the BSDF) is applying for a National Growth Fund ("Nationaal Groeifonds" in Dutch; translation by the author) from the national

government of the Netherlands, the decision of the proposal has not been made yet at the time of writing this report. Even if this funding for BSD is approved by the national government, most of the money will flow into infrastructure development and subsidies for the social housing organisations in BSD. Start-ups in BSD have not been considered as one of the entities that can make use of this funding. Both interviewee B and interviewee C mentioned that their companies have received funding from the Netherlands Enterprise Agency ("Rijksdienst voor Ondernemend" in Dutch) and the Province of Noord-Brabant to support their further development. Whereas this is not sufficient for start-ups to expand their business and implement research activities. "We fund ourselves because most of the funding comes from the revenues of our other companies", as claimed by both interviewee A and interviewee B. Nevertheless, not many start-ups have multiple sources of income and usually start everything from zero.

Regarding building the connection between start-ups and other actors, the Province of Noord-Brabant has performed well in this aspect. According to interviewee A, the provincial government has shown strong interest in promoting the development of sustainable and circular building; it has organised several programmes, meetings, and webinars to gather the stakeholders working in this field, including start-ups, technical talents, investors, etc. The Province of Noord-Brabant is acting as a bridge to link stakeholders active in the sustainable building industry, which makes it much easier for people working in this innovative industry to find and communicate with their counterparts. As for the local management team of BSD, namely BSDF, it has launched five business challenges to attract the participation of innovative organisations. These selected organisations are considered a member of the Business Network of BSD, where they can find new connections and partners in this network. However, interviewee C claimed that there were only a few discussions with the local management team after they attended business challenge #5. In addition, they have not had any opportunity to communicate with other actors in the Business Network of BSD. One of the possible reasons is that the development process of BSD is very long, and that it has not started the construction yet with only around 60 houses built there currently, while the business challenge has already started three years ago to select qualified innovative organisations. Therefore, the interaction between start-ups with BSDF and other business partners in the Business Network has been postponed. Nevertheless, building connection with other stakeholders in the early development stage is important for start-ups since they need to find partners and investors to accelerate their business and go through the "Valley of Death" stage.

2) Interactions between start-ups and academia

Even though TU/e and Tilburg have been involved in the BSD development by serving as experts, they mainly interacted with the local management team of BSD, such as designing the Q-book and evaluating state-ups in the business challenge. However, the interactions between start-ups and the actors in academia, especially universities and research institutions, are very limited. The only three directed edges from

academia to start-ups are initiated by individual innovators and students, either creating innovative technologies and products or researching and giving advice on the business development of start-ups. As for the interaction directed from start-ups to academia, there is only one collaborative relationship between company C and the Eindhoven University of Technology. They created the innovative idea together, used expertise and tools to elaborate on it and apply it in a real-life context. This collaboration has lasted for more than five years between company C and Eindhoven University of Technology (TU/e) because many employees at company C once studied at TU/e and this brings collaboration space and opportunities. However, company A and company B both mentioned that there is no contact with TU/e and Tilburg University, two board members of the BSDF. Therefore, the above-mentioned results verify the fact that there is no sufficient interaction between start-ups and universities and research institutions.

3) Interactions between start-ups and society

Most of the interactions start-ups have with the actors in society are with users & consumers. Among the three interactions users & consumers initiated towards start-ups, two are the consuming behaviour (consuming the products offered by start-ups), and only one is sharing their demands and opinions with start-ups at the BSD User Council. Even though there is a User Council open for all the stakeholders in BSD to communicate with the current or future residents, it is not effectively used by start-ups. All the companies interviewed in this study denoted that they did not participate in the User Council frequently or had never been to the User Council since their project will not start until at least three years later. Currently, it seems that the first residents have only collaborated with the local management team of BSD by attending the internal meetings and getting engaged in the early planning of BSD but seldom interacted with those entrepreneurs. In addition, even though there is a BSD online marketplace demonstrating the projects of start-ups in BSD, this platform only connects start-ups with investors without having a proper connection between start-ups and consumers. This lack of communication is considered a serious barrier for company B as mentioned by interviewee B. Due to the product features of company B, it is necessary for them to know about the demands and requirements of consumers. An online platform or a mobile application could be a feasible solution to communicate with consumers and realise online shopping. However, this proposal is confronted with many obstacles, such as the incomplete infrastructure system in BSD and the concerns regarding data privacy.

As for the interaction with media, there is one interaction company B had with online media channels. By utilising Facebook, TikTok, and their own official website, company B has updated the latest videos and posts about its production process, adopted innovative technologies, and goods for sale, which is conducive to its market promotion and advertising.

4) Interactions between start-ups and industry

The interaction types of start-ups with different actors in the industry can be varied. Start-ups are collaborating with other start-ups in the industry. For instance, both company A and company B stated that their collaboration with other start-ups makes up for their insufficiency in a certain field, such as the knowledge gap for specific technologies or a local market. This symbiosis between start-ups combines their resources to create better products and earns them a more competitive status in the market.

Large-scale enterprises can also be good partners for start-ups to realise their innovation. However, there is only one start-up, the Team CASA, which collaborated with a large Eindhoven construction company (i.e., "Hurks") to perform the construction work of CASA 1.0. As for other interviewed companies, company A and B both expressed their willingness to collaborate with large-scale companies to further expand their business. Nevertheless, interviewee B expressed concern about finding a suitable large-scale enterprise partner because the hierarchy in the company prevents communication between start-ups and enterprises. Also, they are concerned about being acquired by a large-scale company while they are seeking a collaboration, which contradicts their intention. Company C has established a partnership with many multinational companies, but not the projects within BSD.

The group of incubators & accelerators & intermediary innovation platforms has contributed a lot in connecting stakeholders in the SCEE of BSD. Four different platforms, the online innovation marketplace of BSD, the "TU/e Smart Cities Innovation Space", "Food Tech Brainport", and "Brandevoort LAB", have created a platform for innovation creation, cross-border collaboration, and knowledge exchange. Among them, only the online innovation marketplace is the local platform of BSD, while the latter three platforms are the platforms at the regional level (i.e., Brainport Eindhoven area) or provincial level (i.e., Province of North Brabant). Since BSD is part of the Brainport area, and subordinates to the Province of North Brabant, it has also benefited from these high-level platforms. As for its local platform, the online innovation marketplace of BSD only demonstrates the information of each innovative project and connects entrepreneurs with investors, performing less well in connecting different stakeholders in the ecosystem to realise resource and information exchange.

Private investors have not been very active in the early development stage of a start-up and also BSD. In the results regarding interactions between start-ups and investors, one of them is the housing cooperation that invests, holds, and operates the housing project CASA 1.0. Another one is a commercial bank in the Netherlands, Rabobank, which granted a cheque to company B for developing its smart farm in BSD. For the other two interviewed companies, they have not received any investments from private investors for their projects in BSD and most of the funding comes from the profits of their companies' business. The reason why private investors are reluctant to

offer funding to start-ups is that there are so many risks embodied in their innovative projects, such as immature technologies and uncertain profitability, and few consumers. Those risk-averse private investors, such as commercial banks, are not interested in this kind of risky investment. However, venture capital funds are specialised in finding potentially profitable start-ups and are willing to share risks with start-ups. From the perspective of start-ups, they are also more inclined to receive investments from venture capital funds instead of commercial banks since the former can share the risks with them while the former requires the payback of capital and interests.

6.2 Academic contribution

Currently, little research has been done on SCEE, especially the collaboration and interaction layer. In addition, the interactions between start-ups and other actors are not investigated in detail yet. Even though some researchers have studied the interaction patterns between stakeholders in the ecosystem, none of them has used SNA to analyse the key actors, interactions, and network attributes of the ecosystem. Therefore, it is necessary to build a comprehensive SCEE theoretical framework that depicts the key actors and their interactions in the Smart City industry for quantitative and qualitative analysis.

Primarily, the theoretical framework proposed in this study adds to the growing body of research regarding Smart City ecosystems. Currently, little research has proposed a comprehensive theoretical framework of SCEE with a focus on the collaboration and interaction behaviours among actors. According to the Integrative Smart City Ecosystem Framework proposed by Wirtz & Müller (2022), there are two types of smart city ecosystem models: organisational models (i.e., governance model, collaboration model, interaction model) and operational models (i.e., service provision model, software model, and physical model). Among the other four smart city ecosystem models studied in this research, some are either organisational models, operational models, or a combination of both. For instance, the General Start-up Ecosystem Model synthesised by Tripathi et al. (2019) merely summarised the key elements in a start-up ecosystem without any descriptions of the key actors and their interactions. Hutchison's i-COA® framework adapted by Appio et al. (2018) showed the five-level pyramid of the smart city ecosystem, which consists of both the collaboration ecosystems (organisational model) and software and physical infrastructure (operational model). Nevertheless, further information in terms of the collaboration ecosystems is not given in this study. Another Smart City Start-up Ecosystem Model proposed by Mitra et al. (2021) is also a combination of organisational and operational models, since it considers the software infrastructures as the foundation and knowledge hub, public policy, entrepreneurship, and economy as the four pillars of Smart City Start-up Ecosystem. However, the interactions between the stakeholders of the four pillars are not discussed. As for the last N-Helix Models, the triple, quadruple, and quintuple helix models are organisational models

with a focus on collaboration and interaction between actors. Even though the quadruple helix model is an organisational model, it only demonstrates a broad category of actors (i.e., government, academia, industry, and society) without a detailed classification and interpretation of the sub-actors, and the interactions between actors are also not categorised.

Compared with the above-mentioned smart city ecosystem models, the theoretical framework designed in this study fills the knowledge gap regarding SCEE and provides a comprehensive and reliable theoretical reference model for more research to be conducted in this aspect. By using the Quadruple Helix Model as the *a priori* framework, the author nominated sixteen 2nd Order Category sub-actors under the four 1st Order Category actors (i.e., government, academia, industry, and society), which provides a detailed but abstract insight into who are the major players in the SCEE. Additionally, since none of the extant literature has classified the types of interaction between actors in the SCEE, ten interaction patterns are formulated in the SCEE theoretical framework, which can be used as a theoretical basis for other researchers to continue further study.

Although some studies have investigated interactions between actors in the SCEE, they either investigated the interactions in the ecosystem in a holistic way (Oomens & Sadowski, 2018), or focused on the impacts of specific actors, such as government (Ferraris et al., 2020), living labs or open innovation platforms (Bifulco et al., 2017; Parjanen & Rantala, 2021; Putra & van der Knaap, 2018), knowledge institutions (Ardito et al., 2019). However, few of them detected the role of start-ups in the SCEE, and there is no research studying how start-ups can accelerate their growth in the SCEE with favourable interactions with other actors in the ecosystem. Nevertheless, this study explicitly investigates the role of start-ups in SCEE after building the complete SCEE and derives qualitative insights from the interactions between start-ups and other actors.

In addition to the systematic literature review and stakeholder interview, SNA is employed to conduct quantitative analysis on the SCEE, identifying the key actors, interactions, and network features of the SCEE, which is an innovative method in the research regarding Smart City ecosystems. Literature review, case study and expert interviews have been utilised before to build and analyse the smart city ecosystem qualitatively, while SNA is the first time to be used in analysing SCEE as a quantitative tool. For instance, Wirtz & Müller (2022) modelled the Integrative Collaborative Ecosystem for Smart Cities through a comparative analysis of the Smart City ecosystem frameworks in previous studies. Putra & van der Knaap (2018) explored the actor interaction and the function of an open web-based platform by implementing a case study on Amsterdam Smart City. To define the key constituents of a start-up ecosystem and build a relevant framework to promote collaborative entrepreneurship, Mitra et al. (2021) gained initial insights and opinions through focus group discussions with twenty experts. Compared with these previous studies, this study combines

qualitative and quantitative analysis; qualitative information is used to interpret the indicators of SNA, and SNA can visualise a large amount of initial qualitative information through a node-edge graph.

6.3 Practical implication and policy recommendation

This study has proposed a comprehensive theoretical framework of SCEE and used BSD to demonstrate how to apply the framework to a real-life case, analysing and visualising it with social network analysis. Since the interrelations between actors in the social network are considered crucial in creating and capturing value for urban innovation, it is necessary to sort out and visualise numerous interactions within the SCEE, which provides a better perception of the ecosystem for the policymakers and practitioners to identify the focal actors and interactions they should take action on (Faber et al., 2018). The findings of this study have several important implications for future practice. The analytical results on the actors, interactions, and network attributes of SCEE are not only useful for the development of BSD, but also applicable to the SCEE of other regions to kindle entrepreneurship prosperity and urban innovation development. In the following pages, the author will present policy recommendations for the government and strategic suggestions for start-up practitioners to create a better entrepreneurial ecosystem and promote the growth of start-ups.

As mentioned in the problem statement in Chapter 1.2, there is a lack of communication between start-ups and the government due to top-down governance. After analysing the case study results of BSD, the author observed that the connections between start-ups and actors in academia, society, and industry also need to be strengthened. Interviewees claimed that the current collaboration with universities and knowledge institutions is limited, most of which are with students and individual innovators. They expected to communicate and collaborate more with professionals in academia in conducting research activities and developing innovative ideas and products. As for the interactions between start-ups and citizens, the user council is not fully exploited by start-ups to learn the demands and feedback from citizens. In terms of the large-scale companies in the industry, start-ups find it difficult to connect and build a partnership with them due to the internal hierarchy in the large-scale company.

Since the local government of BSD, namely BSDF, is the most influential actor in the SCEE only second to start-ups and has direct contact with start-ups, it is suggested that BSDF should take actions to strengthen the linkages between start-ups and other stakeholders (i.e., municipality, universities and research institutions, users & consumers, private investors, large-scale enterprise, and other start-ups). Primarily, it is suggested that a local innovation platform like “Amsterdam Smart City” can theoretically be developed in BSD, which removes the barriers for start-ups to access the government and find partnerships, funding, and potential customers. Amsterdam

Smart City is an open innovation platform that not only provides working space for start-ups but also meeting opportunities for innovation professionals to meet, interact and collaborate through both online and offline events, challenges, and projects. Although there are four innovation platforms involved in the SCEE of BSD, “TU/e Smart Cities Innovation Space”, “Food Tech Brainport”, and “Brandevoort LAB” are innovation platforms at the provincial (Province of North Brabant) or regional level (Brainport Eindhoven area) without a focus on BSD. Only the online innovation marketplace of BSD is the local platform of BSD, while its function is limited to project demonstration and connecting start-ups with investors.

Therefore, BSDF should collaborate with the Municipality of Helmond to build a local intermediary innovation platform, which not only attracts the participation of start-ups, but also officers in government, citizens in society, investors, and large-scale companies in the industry. The gathering of different stakeholders promotes communication between actors, bringing resources, opportunities, challenges, and partnerships for start-ups. In addition, the platform makes it easier for start-ups to gather commercial resources including talent and expertise, potential customers, branding, funding, etc, which helps address the “valley of death” problem for them in the early development stage. For instance, considering that there are many large enterprises in the entire Brainport Eindhoven area, such as ASML and Philips, the local intermediary innovation platform can promote collaboration between start-ups and large-scale companies. Under this circumstance, start-ups can employ the resources from large companies in product development, expand their brand publicity, share their solid customer base, and play in a larger market. Simultaneously, large-scale companies can utilise the innovative technologies from start-ups to optimise their products, which is a win-win situation.

Another problem existing in the SCEE affecting the business expansion of start-ups, especially in the sector of government, is the low level of organisational agility of the national government and other public authorities. With the fast development pace of innovation, the regulations designed and enacted by the national government and other public authorities (i.e., Ministry of Agriculture, Nature, and Food Quality, Ministry of Housing, Spatial Planning and the Environment, and Ministry of Infrastructure and Water Management) may be outdated and not applicable for the innovative products and services provided by start-ups. For instance, some regulations on traditional vehicles are not applicable to autonomous vehicles. To conduct a road test, a special permit needs to be issued by the relevant public authority. Even though these public incumbents agree to revise the laws and regulations to keep pace with the innovation development, the whole process takes a long time due to the hierarchy within the government and will intervene in the development of start-ups. Therefore, a suggestion for the national government and other public is to increase the level of organisational agility and reaction speed and make necessary regulatory changes according to the latest technologies and innovative projects, which will remove the administrative barriers and obstacles for start-ups to grow faster and substantially.

Last but not least, one crucial problem for start-ups to develop their business is insufficient funding. As for the public investors, such as the government and other public authorities, the National Government of Netherlands, Province of North Brabant, and Netherlands Enterprise Agency have provided grants for start-ups to expand their business, which is encouraged to continue. However, more financial support should come from the local government. (i.e., Municipality of Helmond) and the local management team (i.e., BSDF), at least in the early development stage. For instance, the Municipality of Rotterdam compensated the feasibility study fee for start-ups in the development stage of an innovative project. As for private investors, since institutional investors are risk-averse and consider the risks of investing in start-ups too high, it is recommended for start-ups to participate in the innovation challenges hosted by venture capital funds or large commercial banks to gain funding or grants for business expansion.

Finally, start-ups are encouraged to utilise social media to increase the publicity of their products and attract more consumers; TikTok, Facebook, Instagram, and the official website have been proven as effective promotion and marketing way in this study. Not only the government should organise intermediary innovation platforms and social events (i.e., networking events, and User Council), start-ups should participate more in these social programs to seek developing opportunities.

7. Conclusion

In the section that follows, the answer to the research questions the limitations to study and future agenda are concluded.

7.1 Answers to the research questions

1) What does a theoretical framework for SCEE look like?

After conducting a systematic literature review on the existent works of literature, an integrated theoretical framework of SCEE is proposed following the structure of the Quadruple Helix Model. The theoretical framework of SCEE demonstrates major actors and their interaction patterns in the ecosystem. There are sixteen groups of actors under four different categories, namely "Government" (i.e., international government, national government, provincial government, local government, local management team, other public authorities), "Academia" (i.e., universities, research institutions, individual innovators/students), "Society" (i.e., users/consumers, media), and "Industry" (i.e., start-ups/SMEs, large-tech enterprises, incubators & accelerators & intermediary innovation platforms).

In addition, ten common interactions patterns in the ecosystem are summarised, including governing & regulating, cooperation & partnership, financially supporting & investing, educating & training & advising & knowledge sharing, infrastructure supporting, selling & supplying, buying & consuming, marketing & promoting, innovation creating, and intermediating & connecting & network building.

2) How the theoretical framework can be applied to analyse a real-life case?

In this study, the theoretical framework of SCEE has been applied to Brainport Smart District, which is an innovative district located in Helmond, the Netherlands, aiming to create a smarter, safer, and more sustainable working and living environment for future residents. The process of applying the theoretical framework to the case of BSD contains three steps. The first step is to gather information regarding the actors and their interactions through online public resources (i.e., public official websites, public documents, media) and stakeholder interviews. Six interviews were conducted with stakeholders active in BSD development, either of them is a start-up founder or incumbent working for the local management team of BSD (i.e., BSDF) or the Municipality of Helmond. Then, the obtained qualitative information is distilled, processed, and categorised based on the categories of actors and interactions defined in the theoretical framework. During this process, actors are transformed into nodes and the interactions between actors are transformed into edges between nodes to build the social network of SCEE. Finally, the derived node list and edge list from the last step are imported into the software "Gephi", which can calculate the quantitative indicators and visualise the social network of SCEE. The results of the quantitative

indicators are used for analysing network features and identifying key actors and interactions. The visualisation of the SCEE enables a holistic perception and a better understanding of the ecosystem, making it easier for policymakers and practitioners to take strategic measures upon certain actors or interactions, i.e., connecting start-ups more with users and consumers.

3) What are the qualitative and quantitative results of the BSD case from the theoretical framework analysis and Social Network Analysis?

This social network built upon the SCEE of BSD consists of 15 nodes (actors) and 33 integrated edges (interactions). In the beginning, there are 74 individual interactions distilled from the qualitative information obtained through online resources and stakeholder interviews. Since some interactions are parallel interactions between the same pair of nodes, they are combined as one interaction and the number of individual interactions constitutes the weight of the combined interaction. For instance, if there are five individual interactions between the international government and national government, then the weight of the combined parallel interactions is 5.0.

As for the quantitative results of the social network of BSD, the weighted average degree of the whole network is 4.867, and the diameter is 3, which means that every actor in the SCEE of BSD has 4.867 interactions with other actors on average, and the largest distance between two actors in the ecosystem is only three edges. In addition, the average clustering coefficient of this network is 0.622 and the average path length is 1.697. The former indicates that 62.2% of the neighbouring nodes of one node are connected and clustered on average, and the latter demonstrates that average it takes 1.697 edges for one node to reach another. All the results above have confirmed the “small world” characteristics of the SCEE of BSD, which means that actors are tightly connected with each other. By imposing measures on certain actors, the influence will go through the whole ecosystem due to the spill-over effect.

In terms of the SNA analysis on actors, start-ups/SMEs, the local management team, users and consumers, and software and hardware infrastructure providers are the key actors in the social network with high degree centrality, betweenness centrality, closeness centrality, and eigenvector centrality. Start-ups/SMEs possess the highest weighted in-degree (resource inflows) and out-degree (resource outflows), which means that they have interacted most with other actors in the ecosystem. The value of weighted in-degree and out-degree is determined by the sum of the weight of directed edges (interactions). The high weight in-degree and out-degree indicate that there are many resources flowing into start-ups (inflows) from other actors and flowing out of start-ups (outflows) to other actors through interactions. In addition to start-ups, the local management team, users and consumers, and software and hardware infrastructures are also playing a crucial role in the SCEE since they are serving as the intermediary agent (betweenness centrality), easily accessing other

actors (closeness centrality), and connecting to “star actors” in the ecosystem (eigenvector centrality).

Regarding the quantitative and qualitative results on interactions, most of the interactions happened between start-ups and actors in government and industry. The EU government, the National government of the Netherlands, and the Province of North Brabant have offered financial support to start-ups by means of loans and grants, such as the European Regional Development Fund, innovation credit, and the Dutch Good Growth Fund. In addition, the National Government, and other public authorities (i.e., Netherlands Enterprise Agency, Ministry of Agriculture, Nature, and Food Quality, Ministry of Housing, Spatial Planning and the Environment, and Ministry of Infrastructure and Water Management) are the regulatory entities that enact laws and regulations to regulate the business and development activities of start-ups. The Province of North Brabant has organised social events to build connections between different actors in the ecosystem and facilitate their collaboration. The local government (Municipality of Helmond) local government of BSD (BSDF) are collaborating with start-ups participating in BSD development and helping them address regulatory, financial, and societal problems. Start-ups also bring about their innovative ideas and projects to build the future community, BSD, in return.

When it comes to the interaction with actors in the industry, the interaction types can be varied. Large-scale companies are collaborating with start-ups, utilising their own resources (i.e., manufacturing systems and supply chains) to help start-ups realise their innovative ideas or projects. Incubators, accelerators, and intermediary innovation platforms have established a communication platform to connect different stakeholders in the SCEE and boost potential partnerships and collaboration. Additionally, private investors invest in innovative projects or offer grants to support the research and development activities of start-ups. There is also a self-loop, which means that there are interactions between a start-up with other start-ups in the ecosystem. One of the common interaction ways is to collaborate to combine their products or technologies to provide better and more innovative products.

The interactions between start-ups and actors in academia and society are very limited. Students from TU/e have developed the first sustainable residential house (CASA 1.0) in BSD and the Hague University of Applied Science helped company B to explore market opportunities through webinars and brainstorming. Consumers and users are the main consumers of the products and services provided by start-ups in society. Start-ups have turned to social media platforms, such as Facebook, TikTok, and Instagram, to increase the publicity of their products.

4) How to accelerate the growth of start-ups in Smart Cities with insights from the analytical results of the BSD case?

To accelerate the growth of start-ups in the Smart City, the case study results from BSD Helmond highlighted three aspects of recommendation for policymakers and practitioners in the SCEE. Firstly, since there is a lack of communication between start-ups and governmental actors and the analytical results on BSD reveal that the connections between start-ups and certain actors in academia, society, and industry should be strengthened, it is suggested to develop a local intermediary innovation platform. Although there are intermediary innovation platforms including "TU/e Smart Cities Innovation Space", "Food Tech Brainport", and "Brandevoort LAB", these innovation platforms at the provincial (i.e., Province of North Brabant) or regional level (i.e., Brainport Eindhoven area) without a focus on BSD. The current innovation platform of BSD, namely the online innovation marketplace of BSD, possesses limited functions such as project demonstration. Under this circumstance, a new well-functioned local innovation platform should be built in BSD led by the local management team (i.e., BSDF) and the local government (i.e., Municipality of Helmond), which can gather different stakeholders, promote their communication, and facilitate information and resource exchange between actors, bringing resources, opportunities, challenges, and partnerships especially for the development of start-ups, addressing the "valley of death" problem.

Also, it is observed that the low level of organisational agility of the regulatory actors (i.e., National Government of the Netherlands, Ministry of Agriculture, Nature, and Food Quality, Ministry of Housing, Spatial Planning, and the Environment) have restricted the development speed of start-ups. With the fast development of innovation, some of the regulations designed and enacted by them may not apply to the innovative products or business processes of start-ups. Even if these regulatory organisations agree to make regulatory changes to keep pace with the innovative development, the whole process will take a long time due to the hierarchy within the government. The outdated regulations and the low level of organisational agility have prevented start-ups from expanding fast and substantially. Therefore, a suggestion for the government and other regulatory public authorities is to make changes to the laws and regulations and increase the level of organisational agility, thus removing the policy barriers of start-ups.

Moreover, it is suggested that the national government (i.e., the National Government of the Netherlands), provincial government (i.e., Province of North Brabant) and other public authorities (i.e., Netherlands Enterprise Agency have provided grants for start-ups to expand their business) should continue their financial support for start-ups through public funding. However, the local government. (i.e., Municipality of Helmond) and the local management team (i.e., BSDF) are encouraged to increase their financial support for start-ups, at least in their early development stage.

When it comes to the suggestions for start-up practitioners, innovation challenges hosted by venture capital funds and large commercial banks are encouraged for them to participate to earn funding or grants. In addition, the social events of intermediary platforms can be a good opportunity to seek partnership opportunities and potential investment. In the end, social media is recommended to be employed by start-ups as a marketing and promotion tool to attract more potential customers, such as TikTok, Facebook, and Instagram.

5) Answer to the main research question

The main research question of this study is:

"How to develop and analyse the Smart City Entrepreneurial Ecosystem to accelerate the growth of start-ups?"

Insights from answers to the research sub-questions are used and interpreted to answer the main research question. The development and analysis of the Smart City Entrepreneurial Ecosystem are realised through the systematic literature review and social network analysis. Systematic literature review is a reliable tool to give a holistic overview of the existent studies on SCEE. SNA not only enables the visualisation of the ecosystem, showing the complicated interactions between different actors, but also provides results of quantitative indicators to unveil the network features of SCEE and its key actors and interactions.

This study sheds new light on the collaboration and interaction layer of the smart city ecosystem and dives into the interactions between start-ups and other actors specifically. These results fill the gap in academia since this study proposed the first comprehensive theoretical framework depicting the actors and their interactions in SCEE, which can be applied in the real-life context. More importantly, the findings provide a better perception of the SCEE for policymakers and practitioners, showing the key actors and key interactions in the visualised social network, which offers a theoretical foundation for strategic decision-making and policymaking; thus, promoting collaboration and favourable interactions between start-ups and other actors and boosting the boom of entrepreneurship and innovation in the SCEE. In addition, the theoretical framework and analytical results of BSD can serve as a reference for other studies. Researchers and practitioners can model and establish their own SCEE with the theoretical framework proposed in this study, analyse it with SNA, and obtain practical insights from the SCEE to address certain problems or challenges. The analytical results can also be compared with the results of BSD to confirm the validity of the results.

7.2 Limitations to study

As for the developed theoretical framework, it consists of two main components: actors, and interactions. However, it didn't include other elements in the SCEE and their impacts or relations with the SCEE, such as politics, finance, demography, market, and technology. Only the interaction layer and collaboration layer of the Smart City ecosystem are discussed in this study.

Another limitation of this study is that BSD Helmond is currently in the early development stage and is still under construction. Hence, only a small number of actors compose the whole ecosystem, and the potential actors in the future are not included in this study. Therefore, compared with other mature SCEEs in other regions, such as Amsterdam, Singapore, and Copenhagen, the dataset of BSD is relatively small, and it has simpler interactions between actors. Further research might explore the mature SCEE, where new insights might be derived with more actors and more complicated interactions.

When modelling the SCEE with social network analysis, this research used groups of actors (i.e., start-ups/SMEs) as node instead of individual actors (i.e., company A). Therefore, the specific influence of a particular actor cannot be clearly presented in this study. In addition, the analytical results of BSD obtained from SNA are not further discussed and validated with the experts and practitioners in BSD due to the time limit. If a validation interview could be arranged, not only the validity of SNA results can be confirmed, but also a better interpretation of results and more policy recommendations can be derived.

7.3 Future agenda / further research

A theoretical framework with more information on other elements (factors) in the SCEE will add value to the current works since this study mainly focuses on the structural dimension of SCEE and investigates the interaction and collaboration between stakeholders. By analysing the impacts of elements on the SCEE, more valuable insights can be gained on how to improve the SCEE from different perspectives rather than merely concentrating on optimising the interaction and collaboration between actors.

Moreover, a further study could develop and analyse the SCEE of a larger region with more actors and more complicated interactions. New types of actors and interactions might occur in the SCEE, but the theoretical framework developed in this study provides a theoretical basis for researchers and practitioners to develop their own SCEE. They can make slight changes to make the theoretical framework adapt to their own cases, or even add new categories of actors and interactions to the current theoretical framework.

Further studies could be conducted to investigate the influence of a specific actor by pointing to the specific actor as a node, such as Amsterdam Smart City, the intermediary innovation platform in Amsterdam. The research could be on the interactions between Amsterdam Smart City with other groups of actors, or with other individual actors, which is determined by the research aim of the study. Granularity can be adjusted based on different requirements. Also, a second round of interviews can be conducted with experts to confirm the validity of the results of SNA in thture study.

In the end, the theoretical framework proposed in this study is not only useful for boosting entrepreneurship and start-up growth in the urban context, but also for improving the services and quality of smart districts or cities and helping the Municipality of Helmond to develop strategic public policies using analytical insights obtained in the ecosystem framework.

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Appendix 1 – Systematic Literature Review Procedure

1. Background

1.1 Review rationale

This review protocol is designed for the thesis work of Yuxin Dai, which seeks to build a conceptual SCEE (SCEE) framework for further practical implications on the case of Brainport Smart District.

Although the smart city has been a popular topic in academia, the SCEE has not been widely researched yet compared with other topics (Hajikhani, 2020; Kummitha, 2019; Mitra et al., 2022). Among the current works, the civic innovation entrepreneurial ecosystem built by Sarma & Sunny (2017) is the latest and most comprehensive model so far in academia, while there still exist some insufficiencies to be made up. Despite that this model defines the key actors and their interdependency pattern within the ecosystem, such as agents (entrepreneurs), decision-makers (policymakers and bureaucrats), framers (technology providers, supplier networks, markets), and constituents (citizens, investors, labour), this conceptual model is still very simple and doesn't depict the complicated and intertwined connections between numerous actors in this ecosystem. In this systematic literature review, the author will build a comprehensive theoretical framework of the SCEE and explain the structure, actors, and interrelations between them.

1.2 Objectives and review questions

This review aims to build a comprehensive conceptual SCEE framework through finding, selecting, and integrating the relevant frameworks in the existing literature, making up for the deficiency of the current ecosystem framework. The detailed research questions are demonstrated as follows:

1) What do existent Smart City ecosystem frameworks look like?
2) Who are the actors in the SCEE?
3) What are the interaction patterns between different actors in the SCEE?

2. Search strategy

The main search strategy in this study is automated searching on electric bibliographic databases by using search terms. The author will search and analyse the literature from two electric databases between 2012 to 2022, namely Web of Science and Scopus. During the search process, more and more search terms and synonyms will be gathered to add to the search query, which is an iteration process. The selected search terms will be grouped or separated in the search engine to search them in the topic, abstract, and keywords of papers.

The search query used by the author demonstrates as follows:

TITLE-ABS-KEY (("smart city" OR "smart cities") AND ("ecosystem" OR "platform*" OR "community" OR "communities" OR "environment") AND ("innovation*" OR "innovative" OR "business" OR "entrepreneurial" OR "entrepreneurship" OR "start*up*")) AND DOCTYPE (ar OR re) AND PUBYEAR > 2009 AND PUBYEAR < 2023*

In addition to automated searches, reference searches will also be employed as ancillary searching equipment. After the initial automated searches, the author will check the reference lists of the most relevant literature specifically and conduct the backward chain searching manually.

3. Selection criteria & quality assessment

After the automatic and manual search, the obtained papers need to be screened by title, abstract and full text respectively and their quality will be assessed by giving different rates. Only the papers that are eligible after the screening of the title, abstract and the whole context will be qualified for data extraction and synthesis.

There are three steps to the selection of entitled studies. Firstly, the titles of the papers will be reviewed during the systematic search process. Then, the author will review the abstract of the selected papers based on the inclusion and exclusion criteria. In the end, the author will go through the whole context of the papers after the screening of the abstract. The inclusion and exclusion criteria are demonstrated as follows:

1) Include all research that is relevant to the models (structures), actors, and interactions of the SCEE.
2) Exclude the papers whose full texts are not available.
3) Exclude the papers that are not written in English.
4) Exclude duplicated studies.

Study quality assessment is used for evaluating the eligibility of selected papers by reviewing their full texts. Each paper is granted different ratings ranging from 0 to 5 as shown in figure 15. The more related to the SCEE, the more key elements it includes and interprets (i.e., ecosystem models, actors, interaction), and the higher the score of this paper will be.

Nr	Title	Screened by whole paper	Rate	Quadruple Helix Model	Ecosystem Model	Actors	Interaction	Governance / Leadership / PPP	Citizen / Society	Etrepreneurship / Start-ups	Knowledge institution	Living labs / Collaborative platforms	Notes
18	Entrepreneurial ecosystem and well-being in European smart cities: a comparative perspective	TRUE	4		TRUE					TRUE			
21	The City as Startup Machine: The Urban Underpinnings of Modern Entrepreneurship	TRUE	3							TRUE			
23	The importance of internal alignment in smart city initiatives: An ecosystem approach	TRUE	5		TRUE	TRUE	TRUE						Amsterdam c
26	Urban Innovation System and the Role of an Open Web-based Platform: The Case of Amsterdam Smart City	TRUE	5		TRUE	TRUE	TRUE						Detailed ecos
27	Smart Cities: A Review and Analysis of Stakeholders' Literature	TRUE	4			TRUE							Start-up com
28	Smart City Leaders, Champions, and Entrepreneurs-The People Part of Vibrant Smart Cities	TRUE	3		TRUE					TRUE			
32	Integrating Open Innovation Platforms in Public Sector Decision Making: Empirical Results from Smart City Research	TRUE	3		TRUE	TRUE	TRUE					TRUE	actor and inte
34	Cities as Collaborative Innovation Platforms	TRUE	3		TRUE			TRUE	TRUE			TRUE	
38	Insigma's Technological Innovation Ecosystem for Implementing the Strategy of Green Smart City	TRUE	5		TRUE								
40	What factors drive policy transfer in smart city development? Insights from a Delphi study	TRUE	5					TRUE					Provide policy
42	Municipal innovation and sustainability readiness: Results from a study of mediterranean cities	TRUE	3										Barriers and

Figure 24 Excel form of quality assessment with initial codes of key elements

In the end, the author excluded all the articles with a score below 3, and eventually, 36 articles were chosen for data extraction and synthesis (see Table 14).

Table 16 Screening results of selected papers

Screening results				
Nr	**Date**	**Selection methods**	**Database**	**Selected Articles**
1	08-08-2022	Articles screened by titles	Scopus and Web of Science	146
2	18-08-2022	Articles screened by abstracts	Scopus and Web of Science	104
3	21-08-2022	Articles screened by whole contexts	Scopus and Web of Science	36

4. Data extraction & Synthesis

In this study, the author will use the framework synthesis to synthesise the obtained qualitative data. The way of data extraction will be in accordance with the way of data synthesis.

Data extracted from the eligible literature will be sorted and recorded in a designed Excel spreadsheet and a Word document separately. The Excel spreadsheet is used to record the key information and label the codes on different studies (as shown in Figure 14), while the Word document will note down the long paragraphs pertaining to different codes for data analysis and synthesis. The results of the data extraction will be reviewed by the committee to guarantee the validity of the systematic literature review.

To conduct the data synthesis, the author will choose an existing conceptual model as *a priori* framework to determine the initial codes and then complement the coding

framework when new evidence emerges during the reviewing process (Dixon-Woods, 2011). In this case, the final adapted framework will consist of both the adjusted factors and new factors.

5. Study limitations

This study will use *a priori* framework as a reference model to structure the coding framework, thus the developed theoretical framework may be restrained in the narrow scope and existing mindset of this *priori* framework and miss out on key insights.

6. Reporting

The target audience will be policymakers, start-ups, researchers, and other interested groups around SCEE. Also, the literature review in this study can be utilised by other researchers to further conduct their research in this area. The whole paper will be published in the database of TU Delft as the master thesis of Yuxin Dai.

Appendix 2 – Interview Protocol

Each interview lasts for 60 minutes, and it is a semi-structural interview. In addition to the fixed questions shown below, the interviewer will ask questions based on the discussion with the interviewee. Some fixed research questions will be adjusted based on the identity of the interviewee. The whole interview process and prepared interview questions are demonstrated as follows.

1. Welcome and introduction
    a) The interviewer will welcome the guest and appreciate his/her participation first.
    b) Then, an introduction about the interviewer and the research project is explained, including the research title, research questions and research aim.

2. Introduction of the interviewee
   The interviewer will guide the interviewee to introduce himself/herself, and also provide information about the company/organisation he/she is working for.
    a) Could you please introduce yourself and your company/the organisation you are working for?
    b) What does your company/organisation do at BSD?

3. Have you ever heard of Smart City Ecosystem, start-up ecosystem, Smart City Entrepreneurial Ecosystem? What key elements do you think this ecosystem has?
    a) If the interviewee knows little about these terminologies, the interviewer should explain them to the interviewee.

4. In the Smart City Entrepreneurial Ecosystem I designed, there are mainly four different actors, government, industry, citizen, and academia, can you denominate some actors that you have interacted or contacted with?

5. Which groups of actors that you have been collaborating with the most? Which one gives you the most support?

6. How do you interact with government? Are there are incentive instruments from the government? Are there any barriers caused by the government?

7. How do you interact with the actors in academia, such universities, research institutions, and students?

8. How do you interact with the citizens?

9. How do you interact with actors in industry?
    a) Does your company/organisation have any interactions with start-ups?

b) Does your company/organisation get any fundings from private investors? How do you finance your projects?
c) Have you ever participated in the events of incubators, accelerators, and intermediary innovation platforms? What kind of help do you receive from them?
d) Does your company/organisation collaborate with large-scale enterprises?
e) What do hardware & software infrastructure providers do from your perspective? Do you have any interactions with them?

10. What kind of challenges and problems that you encounter when developing your projects/company?

11. Where do you see BSD in the next coming 5-10 years?

12. Do you have any suggestions for the theoretical framework or for the whole research?

13. Thanks the interviewee for joining this interview.

Appendix 3 – Actors in BSD (Node List)

Table 17 Detailed information of the actors in BSD

2nd Order Categories	1st Order Categories	Actors	Descriptions
Government	EU Government	The European Commission	The Commission is the sole EU institution tabling laws for adoption by the Parliament and the Council that: protect the interests of the EU and its citizens on issues that can't be dealt with effectively at national level; get technical details right by consulting experts and the public
	National Government	Government of the Netherlands	The King and the ministers together make up the Government of the Netherlands. The ministers and state secretaries are responsible for the day-to-day business of government.
	Provincial Government	Province of Noord-Brabant	The Province of Noord-Brabant represents the administrative layer between the national government and the local municipalities. The provincial administration takes initiatives on an economic, social, and cultural level and coordinates actions. The provincial administration of Brabant is primarily concerned with spatial development, accessibility and mobility for the region, regional economic policy, culture and regional identity.
	Local Government	Municipality of Helmond	Municipality of Helmond only carries out tasks that directly affect residents in Helmond, which include land-use planning, public

			housing, management and maintenance of local roads, waste management and social security.
	Local Management Team	BSDF	BSDF was founded in 2018 and is responsible for the development and administration of BSD, including municipality of Helmond, European Regional Development Fund.
	Other Public Authorities	Ministry of Economic Affairs and Climate	This ministry is committed to creating a favourable and excellent business environment for entrepreneurship by providing spaces for entrepreneurs to innovate and grow. It also encourages cooperation between research institutes and business.
		Netherlands Enterprise Agency (RVO)	Netherlands Enterprise Agency is an executive body of the Ministry of Economic Affairs and Climate, with a special focus on providing services and help to entrepreneurs start and enlarge their businesses through its financial supports and business network.
		Ministry of Agriculture, Nature, and Food Quality	The Ministry of Agriculture, Nature, and Food Quality is in charge of the farming, horticulture, and fishing sectors.
Academia	Universities & Research Institutions	Eindhoven University of Technology	A research university located in Eindhoven with specialisation in technology and engineering.
		Tilburg University	A research university located in Tilburg with specialisation in disciplines in economy, law, and social studies.
		TNO	The Netherlands Organisation for Applied Scientific Research
		Students from TU/e	Students that are active in Team CASA.

	Individual Innovators/Students	Students from the Hague University of Applied Science	Students that participated in the brainstorm session with Company B.
Industry	Start-ups/SMEs (small and medium-sized enterprises)	Company A	Company A is a building company producing sustainable modular wooden houses.
		Company B	Company B is an innovation centre for agriculture and sustainability; innovative technologies are used in their smart farm to achieve self-sufficiency in agricultural products.
		Company C	Company C is dedicated to eliminating particulate matter and air pollutants through its products and strategic solutions.
		Team CASA	Team CASA is a start-up with more than thirty students with different backgrounds. This student team aims to build comfortable, affordable, sustainable, and alternative buildings to accelerate energy transition.
		Company X	Other start-ups that are not interviewed but have interactions with other actors in the SCEE of BSD.
	Large-scale Enterprises	ASML, Philips, VDL Group, etc	These large-tech companies are located in the Brainport Eindhoven area, showing strong interests to settle in the office building and residential buildings of BSD.
		Urban Vision Designer: UN Studio	UN Studio is an international architectural design studio in the Netherlands with specialization in architecture, urban development, and infrastructure projects.
		Construction Company: Hurks	Hurks is a construction company in the Netherlands that do the develop, build, and maintain work.
		Brainport Smart District Online Innovation Marketplace	This online marketplace is developed by a Helmond company named COMP-IT-AUT. This platform demonstrates the innovative

			projects and services in Helmond and facilitate the match between supply and demand.
	Incubators & Accelerators & Intermediary Innovation Platform	TU/e Smart Cities Innovation Space	TU/e Smart Cities Innovation Space is an open community with a special focus on innovation challenges and student entrepreneurship, where students, researchers, industry, and societal organisations can collaborate and co-address the practical issues.
		Food Tech Brainport	Food Tech Brainport is a societal organisation that connects technology providers, food processing companies, and universities to the food processing industry with its own network.
		Brandevoort LAB	Brandevoort LAB is a living lab for the life in the future, where all the stakeholders collaborate to test innovative concepts and products to build a better living environment.
	Private Investors	Housing associations: Woonbedrijf	Woonbedrijf is a social housing association that develops and operates affordable residential houses to provide them to lower-income parties.
		Healthcare Institutions	Healthcare institutions intend to buy the houses developed in BSD and use them for senior nursing homes.
		Recreational Property Providers	Investors who intend to buy the houses developed in BSD and transform them to recreational properties.
		Rabobank	Rabobank is a commercial bank with headquarters in the Netherlands.
	Software & Hardware Infrastructure Providers	Ground Infrastructure Provider: Baas B.V.	Baas BV is an infrastructure contractor specialising in the construction of underground infrastructure (i.e., gas, water, and internet) and electric systems.

		Smart Grid Provider: Spectral	Spectral is a technology company that develops smart grids with its integrated platform, which can connect the energy consumers and producers.
		Road Construction Contractor: KWS	KWS is a road construction contractor.
		Telecom Company	Optic Fibre Provider
Society	Users & Consumers	Residents of BSD	The current and future residents of BSD.
	Media	Journal: New York Times	The New York Times is an American daily newspaper based in New York City with worldwide readers.
		Official Website of BSD	The public official website of BSD running by BSDF to update the latest news about the development of BSD.
		Social Media Platforms	Facebook, Instagram, LinkedIn

Appendix 4 – Interactions between Actors in BSD (Edge List)

Table 18 Detailed information of the interactions between actors in BSD

(Type of interaction, 1: Governing & Regulating, 2: Cooperation & Partnership, 3: Financially Supporting & Investing, 4: Educating & Training & Advising & Knowledge Sharing, 5: Infrastructure Supporting, 6: Selling & Supplying, 7: Buying & Consuming, 8: Marketing & Promoting, 9: Innovation Creating, 10: Intermediation & Connecting & Network Building)

Nr	Source	Target	Categories of the source	Type of Interaction	Weight	Descriptions	Reference
1	EU Government	Start-ups/SMEs	Government	Investing	1	Connect SME is a programme under Interreg Vlaanren-Nederland (a European Regional Development Fund (ERDF)) provides financial supports to start-ups and introduce them to the market for more opportunities	BSD website
2	EU Government	Start-ups/SMEs	Government	Investing	1	Interview B: The EU government funded company B (partly grant and partly loan). Interview D: There are some fundings start-ups can apply from the EU government.	Interview B/Interview D
3	National Government	Local Management Team	Government	Regulating	1	National Government enacts regulations to manage the municipality.	Interview D

4	National Government	Local Management Team	Government	Investing	1	There is a national growth fund (Nationaal Groeifonds) that BSD is applying for subsidy its infrastructure construction (e.g., water system, road system).	Interview D
5	National Government	Start-ups/SMEs	Government	Regulating	1	Interview B: The National Government regulates the rules of operating a farm and made special approval on the permit of company B. Interview D: National Government enacts regulations to manage start-ups.	Interview B/Interview D
6	National Government	Start-ups/SMEs	Government	Investing	1	Interview B: The national government funded the company B (partly grant and partly loan). Interview D: There are some fundings start-ups can apply from the national government.	Interview B/Interview D
7	Provincial Government	Local Management Team	Government	Advising	1	The provincial government officer is part of the board of BSD foundation and advises on the development of BSD.	Interview D
8	Provincial Government	Local Management Team	Government	Investing	1	Provincial government offers subsidies to BSD team as working capital.	Interview F
9	Provincial Government	Start-ups/SMEs	Government	Investing	1	The provincial government funded the company B (partly grant and partly loan).	Interview B

10	Provincial Government	Start-ups/SMEs	Government	Connecting	1	The provincial government has organised many networking events for start-ups in circular buildings to connect with each other.	Interview A
11	Local Government	Local Management Team	Government	Regulating	1	Municipality designs the zoning plan of BSD.	Interview D
12	Local Government	Local Management Team	Government	Investing	3	Municipality of Helmond is responsible for funding and development of the road system, part of water system and part of energy system at BSD.	Interview F
13	Local Government	Local Management Team	Government	Investing	1	Municipality offers subsidies to BSD team as working capital.	Interview F
14	Local Government	Start-ups/SMEs	Government	Cooperation	1	Municipality is helping start-ups to pursue regulation changes from the national government.	Interview D
15	Local Management Team	Users & Consumers	Government	Advising	1	A live broadcast was hosted by the BSD team to answer questions from citizens.	BSD website
16	Local Management Team	Start-ups/SMEs	Government	Regulating	1	BSD Foundation designed a quality manual (Q-Book) to describe the expected quality standard that all the projects and proposals should satisfy.	BSD website
17	Local Management Team	Start-ups/SMEs	Government	Advising	1	A live broadcast was hosted by the BSD team to answer questions from start-ups.	BSD website

18	Local Management Team	Start-ups/SMEs	Government	Advising	1	BSD team hosted a meeting with attendees from different parties, introducing the concept of BSD and providing a place for stakeholders to network.	BSD website
19	Local Management Team	Start-ups/SMEs	Government	Connecting	1	BSD team hosted a meeting with attendees from different parties, introducing the concept of BSD and providing a place for stakeholders to network.	BSD website
20	Local Management Team	Start-ups/SMEs	Government	Connecting	1	Innovation challenge 5 is a market (business network) of innovative organizations that can find new connections here.	BSD website
21	Local Management Team	Start-ups/SMEs	Government	Cooperation	1	5 Innovation challenges were hosted by BSD team, where start-ups are selected for the building of BSD. BSD team collaborate with start-up.	BSD website
22	Local Management Team	Start-ups/SMEs	Government	Cooperation	1	People from BSD team helps company A to facilitate their proposal and development process.	Interview A
23	Local Management Team	Start-ups/SMEs	Government	Consuming	1	Company C improves the air quality for BSD from the infrastructural and urban environment side with its products. BSD consumes its products.	Interview C

24	Local Management Team	Software & Hardware Infrastructure Providers	Government	Consuming	1	BSD relies on the fibre network provider to use the public connectivity network to connect all the public devices.	Interview E
25	Public Authorities	Start-ups/SMEs	Government	Regulating	1	The Ministry of Agriculture accepted company B as an innovation centre where innovations on agriculture are developed and tested.	Interview B
26	Public Authorities	Start-ups/SMEs	Government	Investing	1	RVO (Netherlands Enterprise Agency) provides national funding for company C for their research.	Interview C
27	Universities/Research Institutions	Local Management Team	Academia	Advising	1	The board member at the BSD Foundation from Tilburg University advises on the participation programme of BSD to encourage participation of different parties.	Interview F
28	Universities/Research Institutions	Local Management Team	Academia	Advising	1	TU Eindhoven is engaged in designing the Q-book and evaluating start-ups for business challenges.	Interview D
29	Universities/Research Institutions	Local Management Team	Academia	Creating	1	A lot of research ideas from universities are tested on BSD.	Interview D
30	Individual Innovators/Students	Start-ups/SMEs	Academia	Creating	1	TU/e student Team CASA designs and develops a housing concept in BSD.	BSD website

31	Individual Innovators/Students	Start-ups/SMEs	Academia	Advising	1	Students at the Hague University of Applied Science conducted research on company B to seek development opportunities for it.	Interview B
32	Individual Innovators/Students	Start-ups/SMEs	Academia	Creating	1	Company C works together with PhD students from Eindhoven University of Technology to do research on their products.	Interview C
33	Users & Consumers	Local Management Team	Society	Advising	1	First Resident Andy helped develop urban vision, brochures and 8 program lines.	BSD website
34	Users & Consumers	Local Management Team	Society	Advising	1	Wij zijn IN (We are IN) is a concept introduced by BSD team to include the ideas and insights of future residents in developing the residential product.	BSD website
35	Users & Consumers	Start-ups/SMEs	Society	Consuming	1	Citizens have the chance to attend the participation program and live the first mHome houses. Users rents the CASA 1.0 houses.	BSD website
36	Users & Consumers	Start-ups/SMEs	Society	Advising	1	Residents in the BSD User Council will give feedback to the innovation projects of start-ups to help them improve their products and services.	BSD website
37	Users & Consumers	Start-ups/SMEs	Society	Consuming	1	Local residents consume agricultural products from company B	Interview B

38	Users & Consumers	Software & Hardware Infrastructure Providers	Society	Consuming	1	Inhabitants use the fibre network by giving a subscription fee to the telecom providers.	Interview E
39	Media	Local Management Team	Society	Marketing	1	New York Times reported BSD to increase its publicity.	BSD website
40	Media	Start-ups/SMEs	Society	Marketing	1	Company B updated their production and advertising videos on Facebook and TikTok to attract more potential consumers.	Interview B
41	Start-ups/SMEs	Users & Consumers	Industry	Supplying	1	mHome offers 52 houses for residents. Housing corporation Woonbedrijf, Team CASA and the Eindhoven construction company Hurks collaborated to build CASA 1.0. Team CASA offers 3 social rental homes for citizens.	BSD website
42	Start-ups/SMEs	Users & Consumers	Industry	Supplying	1	Company B produces agricultural products for local residents.	Interview B
43	Start-ups/SMEs	Local Management Team	Industry	Creating	1	Start-ups provide innovative ideas to BSD through 5 innovation challenges.	BSD website

44	Start-ups/SMEs	Local Management Team	Industry	Supplying	1	Company C improves the air quality for BSD from the infrastructural and urban environment side with its products.	Interview C
45	Start-ups/SMEs	Local Management Team	Industry	Advising	1	Company C provides some strategies for the BSD team to improve air quality.	Interview C
46	Start-ups/SMEs	Universities/Research Institutions	Industry	Cooperation	1	Company C collaborates with Eindhoven University of Technology to develop an air monitoring platform.	Interview C
47	Start-ups/SMEs	Start-ups/SMEs	Industry	Cooperation	1	Company A collaborates with other start-ups to combine their technologies/products to make new products. Company A builds powerhouse, and another start-up is working on power.	Interview A
48	Start-ups/SMEs	Start-ups/SMEs	Industry	Cooperation	1	Company X developed farming robots for company B.	Interview B
49	Start-ups/SMEs	Private Investors	Industry	Supplying	1	Company A sells its houses to housing association, healthcare institutions, and private investors interested in recreational housing.	Interview A
50	Start-ups/SMEs	Large-scale Enterprises	Industry	Cooperation	1	Company A establishes partnership with producers of timber housing.	Interview A

51	Start-ups/SMEs	Software & Hardware Infrastructure Providers	Industry	Consuming	1	Start-ups uses the fibre network of fibre network providers to sustain the operation of their products and services.	Interview E
52	Large-scale Enterprises	Local Management Team	Industry	Creating	1	UN Studio designs the urban vision of BSD.	BSD website
53	Large-scale Enterprises	Start-ups/SMEs	Industry	Cooperation	1	Eindhoven construction company Hurks build the CASA 1.0.	BSD website
54	Incubators & Accelerators & Intermediary Innovation Platforms	Start-ups/SMEs	Industry	Connecting	1	Online innovation marketplace enables the match between supply and demand	BSD website
55	Incubators & Accelerators & Intermediary Innovation Platforms	Start-ups/SMEs	Industry	Connecting	1	At the TU/e Smart Cities Innovation Space, teachers will deliver essential knowledge to other actors in terms of system thinking, interdisciplinary cooperation and entrepreneurial attitude.	BSD website
56	Incubators & Accelerators & Intermediary Innovation Platforms	Start-ups/SMEs	Industry	Connecting	1	Food Tech Brainport is a foundation in Helmond that helps start-ups to grow, whose network connected the BSD project to company B.	Interview B

57	Incubators & Accelerators & Intermediary Innovation Platforms	Start-ups/SMEs	Industry	Connecting	1	The living lab "Brandevoort LAB" connects start-ups to other actors in the ecosystem (e.g., government, citizens, knowledge institutions and businesses).	Interview D
58	Incubators & Accelerators & Intermediary Innovation Platforms	Individual Innovators/Students	Industry	Advising	1	TU/e Smart Cities Innovation Space is an innovation hub that gathers students, researchers, governments, and companies. Students can engage in the social innovation project through this platform.	BSD website
59	Incubators & Accelerators & Intermediary Innovation Platforms	Individual Innovators/Students	Industry	Connecting	1	At the TU/e Smart Cities Innovation Space, teachers will deliver essential knowledge to other actors in terms of system thinking, interdisciplinary cooperation and entrepreneurial attitude.	BSD website
60	Private Investors	Start-ups/SMEs	Industry	Cooperation	1	Housing corporation Woonbedrijf established partnership with team CASA and invested in CASA 1.0 and holds the property.	BSD website
61	Private Investors	Start-ups/SMEs	Industry	Investing	1	Housing corporation Woonbedrijf invested in CASA 1.0 and holds the property to provide affordable houses for the social parties.	BSD website

62	Private Investors	Start-ups/SMEs	Industry	Consuming	1	Company A sells its houses to social housing association, healthcare institutions, and investors interested in recreational housing.	Interview A
63	Private Investors	Start-ups/SMEs	Industry	Investing	1	Rabobank granted Company B a cheque for developing the farm in BSD. (Rabobank Food Forward Track)	Interview B
64	Software & Hardware Infrastructure Providers	Local Management Team	Industry	Infrastructure	1	Fibre network provider creates a public connectivity network for BSD to connect all the public devices.	Interview E
65	Software & Hardware Infrastructure Providers	Local Management Team	Industry	Supplying	1	Fibre network provider creates a public connectivity network for BSD to connect all the public devices.	Interview E
66	Software & Hardware Infrastructure Providers	Users & Consumers	Industry	Infrastructure	1	The telecom companies will provide fibre network to residents through fibre to X project (fibre to everything).	Interview E/Interview F
67	Software & Hardware Infrastructure Providers	Users & Consumers	Industry	Supplying	1	The telecom companies will provide fibre network to residents through fibre to X project (fibre to everything).	Interview E/Interview F

68	Software & Hardware Infrastructure Providers	Users & Consumers	Industry	Infrastructure	1	Baas B.V. provides underground infrastructures and electrical systems (e.g., distribution network for electricity, gas, drinking water, and internet).	BSD website
69	Software & Hardware Infrastructure Providers	Users & Consumers	Industry	Infrastructure	1	Spectral provides smart grid to connect energy producers and consumers at BSD.	Interview F & BSD website
70	Software & Hardware Infrastructure Providers	Users & Consumers	Industry	Infrastructure	1	KWS is responsible for the road system construction at BSD.	Interview F & BSD website
71	Software & Hardware Infrastructure Providers	Start-ups/SMEs	Industry	Infrastructure	1	Fibre network provider provides the ICT facilities necessary for start-ups.	Interview E
72	Software & Hardware Infrastructure Providers	Start-ups/SMEs	Industry	Supplying	1	Fibre network provider provides the ICT facilities necessary for start-ups.	Interview E