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Domestic and International Theoretical Evolution, Research Hotspots and Fronts of Design Innovation and Urban Innovation Ecosystem
-- A CiteSpace-Based Bibliometric Analysis (1999～2024)

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Abstract. The paper systematically examines domestic and international research trends on the urban innovation ecosystem and their relationship with design innovation from 1999 to 2024 based on CiteSpace bibliometrics analysis. With global economic modernization, technological innovation and institutional innovation have become critical for economic development, with design innovation gaining attention as a bridge connecting the two. By analyzing literature from the Web of Science and CNKI databases, the paper defines relevant concepts and reveals differences in the temporal distribution, hot topics, and research trends between Chinese and international studies. The study finds that international research started early and remains active, while domestic research has rapidly developed under the "mass entrepreneurship and innovation" initiative. Domestic scholars primarily focus on the theoretical exploration and application of ecosystems and innovation ecosystems, whereas international scholars emphasize the application of theoretical frameworks, policy formulation, and social innovation from the perspective of design studies. Design innovation is crucial in promoting collaboration among innovation entities, optimizing resource allocation, driving service innovation, and improving the innovation environment. This paper summarizes the current state of research both domestically and internationally, highlighting the importance of design innovation for future studies and providing valuable references and insights for scholars in related fields.

Keywords: Urban innovation ecosystem; design innovation; urban innovation; Citespace; visual knowledge map.

1. Background

Since the 20th century, a wealth of valuable research on innovation has emerged. With the continuous updating and optimization of innovation paradigms, scholars have drawn analogies between innovation and natural ecosystems and introduced the concept of innovation ecosystems. In the 21st century, innovation ecosystems have gradually become a research hotspot in innovation. The study of urban innovation ecosystems is a significant part of the research. It takes cities as units where urban innovation entities, resources, and environments interact to promote the exchange of materials, energy, and information. This leads to the networked dynamic evolution for innovation and forms an interdependent ecological organic system. In China, there has been considerable research on urban innovation systems, predominantly on economic management, urban planning, and geography. However, there is a lack of research on the designs. Investigating urban innovation ecosystems through design innovation theory, design innovation entities, and design innovation activities can significantly contribute to this field. It can also expand the scope of design studies from products and services to urban systems. Therefore, it is essential to review the research on design innovation and urban innovation ecosystems and learn the latest research trends domestically and internationally. This will provide further research opportunities for the design discipline in urban innovation. This paper employs Citespace, a Java-powered data analysis tool, to conduct quantitative analysis and data

interpretation of domestic and international literature based on research keywords, research timelines, publishing institutions, and authors. By examining the current research status, hotspots, and trends in design innovation and urban innovation ecosystems, this study aims to lay a foundation for further research in this area.

2. Definition

2.1. Ecosystem

In biology, an ecosystem is a non-equilibrium thermodynamic system. It describes an ecological community or assemblage and its specific physical environment, with the energy processing, distribution, and dissipation among the participants in the ecosystem and the resulting interdependencies. Ecosystems are scale-independent, meaning they can exist at any scale where there are organisms, a physical environment, and interactions between them. Therefore, the concept of the ecosystem has been broadly extended to various disciplines. For instance, an industrial ecosystem focuses on the flow of energy and materials among industrial organizations within a specific geographic area. Similarly, an urban ecosystem reviews the interdependencies among participants in the urban environment. In economics, ecosystem services are defined as the benefits humans derive from urban and biological ecosystems. Management science regards ecosystems as the flow of knowledge and value among multiple stakeholders in economic activities, leading to services, production and benefits. The interdisciplinary extensions of ecosystems are numerous, but they can generally be classified into three categories based on their core value flows: energy and material flow, knowledge flow, and value flow. As shown in Figure 1, the types of ecosystems and ecosystem concepts studied in this paper are logically categorized.

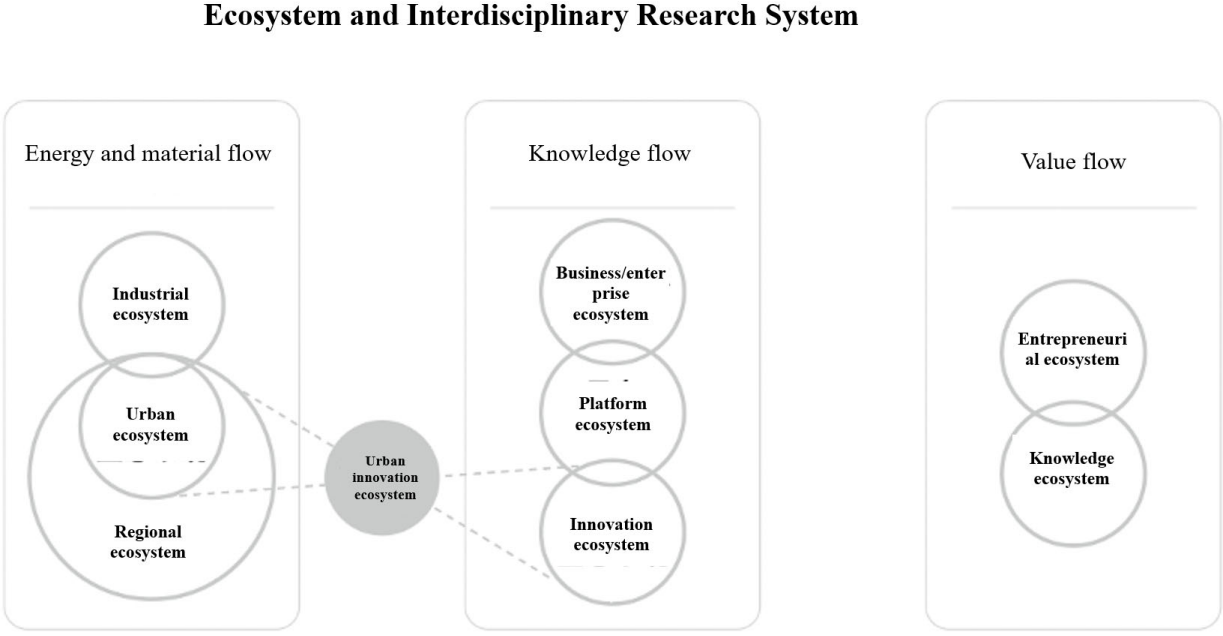

Figure 1. Cross-Research Relationship Diagram of Different Types of Ecosystems

2.2. Innovation ecosystem

Scholars studying strategic and organizational theory have incorporated innovation mechanisms into the concept of ecosystems. Adner (2006) first introduced the term "innovation ecosystem," defining it as "a collaborative arrangement in which firms combine their individual offerings into a coherent, customer-facing solution." Within this framework, an innovation ecosystem includes a focal firm, a set of upstream component suppliers, and downstream complements. These together support the focal firm in realizing its customer value proposition[1].

Building on Adner's initial definition, subsequent scholars have expanded and deepened the concept of innovation ecosystems. Carayannis and Campbell (2009) [1] described an innovation ecosystem as the aggregation of stocks and flows of human, social, intellectual, and financial capital, alongside the co-evolution, co-specialization, and co-selection of cultural and technological heritage and patterns. These systems explicitly demonstrate supply-driven characteristics (Adner, 2017; Adner & Kapoor, 2010; Hannah & Eisenhardt, 2018; Jacobides et al., 2018)[3][3][4][5]. However, compared to traditional supply chains, the value proposition of innovation ecosystems is more dependent on the availability of complementary products and services (Adner, 2017; Ceccagnoli, Forman, Huang, & Wu, 2012; Teece, 2018)[3] [7][8].

Granstrand and Holgersson (2020)[10], through a thorough and systematic review, identified 21 definitions of innovation ecosystems and proposed a new definition: "An innovation ecosystem is the evolving set of actors, activities, and artifacts, and the institutions and relations, including complementary and substitute relations, that are important for the innovative performance of an actor or a population of actors. "

In a recent systematic literature review and thematic analysis, Klimas and Czakon (2022) [11]identified 34 specific types of innovation ecosystems and classified 50 distinct innovation ecosystem varieties into five broader categories based on 14 typological criteria: (1) life cycle, (2) structure, (3) innovation focus, (4) scope of activities, and (5) performance.

2.3. Regional innovation ecosystem

In the 1990s, based on the national innovation system analysis model, Cooke and Bechtel[12]proposed the concept of the "regional innovation system." The regional innovation ecosystem, within the field of social sciences, introduces the geographic concept of regions into the study of innovation management and regional economic development. It refers to the complex network structure of interactions, cooperation, and competition among various innovation-related entities within a specific geographic area. These entities may include businesses, startups, higher education institutions, research organizations, government departments, and other innovation-related organizations and individuals. The goal of this ecosystem is to promote innovation activities, knowledge sharing, and value creation, thereby driving economic growth and development in the region.

2.4. Urban innovation ecosystem

Currently, there is no universally accepted definition of an urban innovation ecosystem. Instead, this concept emerges from the innovation ecosystem perspective, defining "city" as the regional boundary. This gives rise to the "urban innovation ecosystem." It refers to the network of interactions among diverse organizations, institutions, and individuals within an urban area, aimed at promoting innovation, knowledge sharing, and economic prosperity. These ecosystems typically comprise businesses, startups, higher education institutions, research organizations, government departments, and residential communities. They all collaborate, compete, and create value to drive the city's innovative development and economic growth.

2.5. Design innovation ecosystem

While there is a considerable amount of research on innovation systems both domestically and internationally, studies specifically focused on design innovation ecosystems are relatively rare, particularly in terms of constructing models for these ecosystems. Bian Honglei (2009)[13] proposed the national industrial design innovation system, mainly elaborating on innovation by enterprises and innovation of the industrial design innovation system platform. He constructed the design innovation system from a macro perspective.

3. Research Methods and Data Sources

3.1. Research method

This paper utilizes Citespace software as a data analysis tool to conduct cluster analysis. We quantitatively analyze 448 Chinese papers and 195 English papers from the perspectives of keywords, publishing institutions, and authors. By examining keyword co-occurrence, this paper identifies the research hotspots of domestic and international research teams and sorts the research based on the timeline. Then through comparative analysis, the differences between domestic and foreign studies are studied, and the development direction of domestic team city innovation research is pointed out.

3.2. Data Sources

To ensure the credibility and persuasiveness of the collected data, Chinese literature was selected from the China Academic Journal Network Publishing Database of the China National Knowledge Infrastructure (CNKI). This paper used the keywords "design innovation," "urban innovation ecosystem," "social innovation," "regional innovation ecosystem," and "regional innovation system," retrieving 688 documents. From these, 448 high-quality journal articles from 1999 to 2024 were selected. International literature was selected from the Web of Science using the keywords "urban innovation ecosystem," "design innovation," "Regional Innovation Eco*," "Urban Innovation Eco*," "Regional Innovation System," and "Urban Innovation System." A total of 552 documents from 2000 to 2024 were retrieved.

4. Data Analysis and Processing

4.1. Difference in Time Distribution between Domestic and International Research Teams

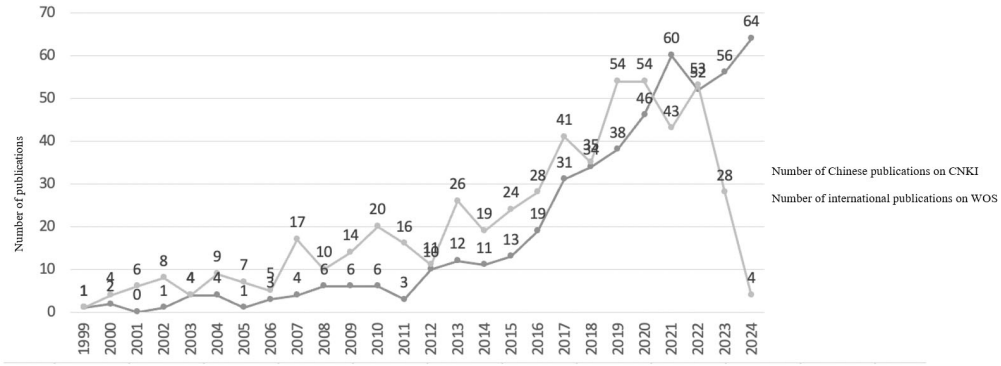

Figure 2. Temporal Distribution of Literature on Urban Innovation Ecosystem in China and Abroad

The summary of the published papers reflects the academic community's focus on a specific field. The more papers there are, the more active the related research is. As shown in Figure 1, the concept of innovation ecosystems emerged in international research around 1999, and the research has been quite active. The research showed an upward trend from 2017 to 2022, and a downward trend from 2022. Compared to international research, the study of urban innovation ecosystems by Chinese teams started later. Since 1999, some scholars have researched it, but the development has been slow in the early decade of the 21st century, with few studies published. Starting in 2012, related research entered a period of rapid development, with the number of core papers continuously rising and experiencing explosive growth, eventually surpassing the number of international publications. This is also related to changes in the structure of social demand in China. Since 2011, China's GDP per capita has exceeded $5,000, and investment demand gradually gave way to consumer demand, shifting from production-driven consumption to consumption-driven production. This requires a greater variety of products to satisfy consumption and thus promote further economic growth. Consequently, China

vigorously promoted the innovation-driven development strategy of "mass entrepreneurship and innovation." Since 2016, there has been another surge in related research, closely related to the country's release of the *National Innovation-Driven Development Strategy Outline*. It emphasizes that innovation is the primary driving force for development and integrates technological innovation with institutional innovation, management innovation, business model innovation, industry innovation, and cultural innovation. A new development engine is encouraged to cultivate new and innovation-driven economic growth points.

4.2. Difference in Research Hotspots between Domestic and International Teams

Keywords are a refined summary of the literature, and keyword co-occurrence analysis can reveal the research hotspots in the field. In this analysis, the importance of nodes is measured by their centrality, which is positively correlated with their importance in the entire literature data network. The size of a node depends on its frequency of occurrence in the literature. For domestic research, 83 keywords with a frequency higher than 2 were selected from the software Citespace through keyword statistics and analysis, resulting in a keyword co-occurrence map (see Figure 3).

The co-occurrence map of domestic hotspots (see Figure 3) includes 407 nodes, 695 connections, and a density of 0.0084, indicating a certain degree of correlation and interaction among domestic scholars' studies. However, the overall network connectivity and concentration are relatively low. In contrast, the co-occurrence map of international hotspots (see Figure 4) comprises 299 nodes, 918 connections, and a density of 0.0206, showing the correlation and strong interaction among foreign scholars' research, with a high research concentration.

Regarding research hotspot keywords, domestic scholars focus on theoretical exploration and empirical research related to concepts such as ecosystems, innovation ecosystems, urban agglomerations, and green innovation within the urban innovation ecosystem. Particularly, they emphasize innovation models of unicorn startups and have initiated research on innovation systems, institutions, and models relatively early, though the development is still immature. This is related to the early start of innovation research in China and the high entrepreneurial enthusiasm stimulated by the policy incentives of "mass entrepreneurship and innovation." However, the overall research is still primarily focused on the enterprise and urban application levels, with immature theoretical refinement at the institutional management level. Supported by innovation ecosystem theories, foreign scholars focus on theoretical frameworks in urban innovation ecosystems, such as regional policy formulation, corporate management strategies, and entrepreneurship methods. Notably, international design scholars are also using service design approaches, such as mind mapping, stakeholder analysis, and interdisciplinary collaborative design, to explore social innovation and sustainable development models in urban innovation systems. In contrast, there is almost no exploration of innovation ecosystems using design discipline tools among domestic design scholars.

Figure 3. Co-occurrence Map of Domestic Research Hotspots

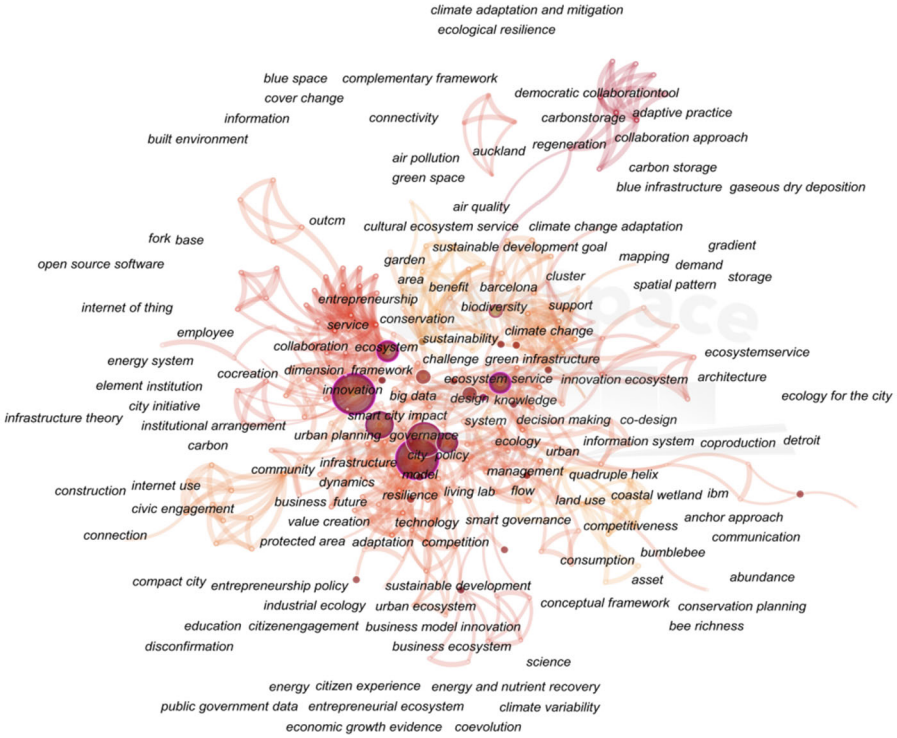

Figure 4. Co-occurrence Map of International Research Hotspots

Table 1. Keywords Frequency Statistics of Urban Innovation Ecosystem in Domestic and International Research

S/N	Domestic			International		
	keywords	Centrality	Frequency	Keywords	Centrality	Frequency
1	innovation	0.33	36	innovation	0.29	34
2	innovation ecosystem	0.13	25	city policy	0.3	34
3	eco-cities	0.19	23	governance	0.2	21
4	innovation ecology	0.12	15	ecosystem service	0.27	20
5	innovative cities	0.13	14	smart city	0.12	18
6	ecological civilization	0.09	12	ecosystem	0.2	15
7	city cluster	0.09	11	policy	0.14	14
8	ecosystem	0.06	10	design	0.09	11
9	ecological environment	0.07	10	biodiversity	0.17	11
10	smart city	0.07	9	framework	0.04	11
11	urban innovation	0.04	8	knowledge	0.06	10
12	resource-based city	0.04	7	challenge	0.07	10
13	innovation-driven	0.04	7	management	0.05	10
14	ecological efficiency	0.05	7	system	0.11	9
15	city	0.11	6	sustainability development	0.05	9
16	Shanghai	0.04	6	conservation	0.08	8
17	urban innovation ecosystem	0.03	6	resilience	0.04	7
18	sustainable development	0.03	5	model	0	6
19	institutional innovation	0.03	5	entrepreneurship policy	0.1	6
20	collaborative innovation	0.04	5	urban planning	0.04	6
21	innovation subject	0.03	4	innovation ecosystem	0.06	5
22	circular economy	0.01	4			
23	technological innovation	0.01	4			
24	innovation design	0	4			
25	innovation capability	0	4			
26	innovative development	0.02	4			
27	regional innovation	0.03	4			

Through the LLR algorithm to generate keyword clustering maps, we obtained clustering labels for literature keywords on urban innovation ecosystems, with 14 domestic and 11 foreign clustering labels. The modularity values (Q) of the clustering views are 0.7668 and 0.6617, respectively. Since Q>0.3 indicates effective clustering, these clustering data are valid and can form distinct structures for subsequent analysis. (See Figures 5 and 6 for details.) By ranking the average silhouette values (S) of various clusters in domestic and international studies in descending order and combining this with a co-occurrence analysis of keywords, the differences between the research focus of domestic and international scholars can be compared, as shown in Table 2.

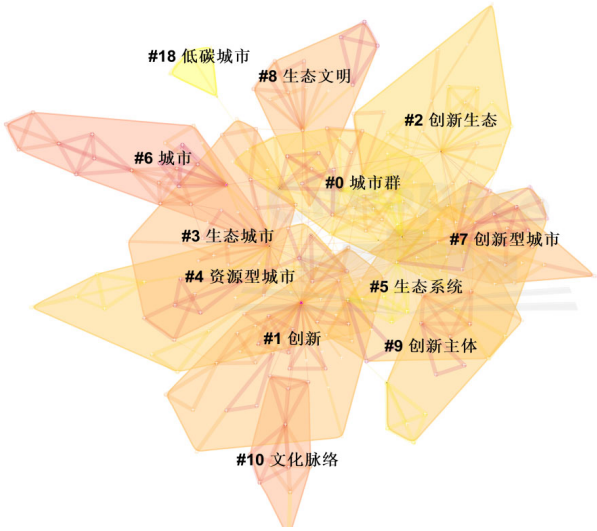

Figure 5. Cluster Map of Domestic Research Hotspots

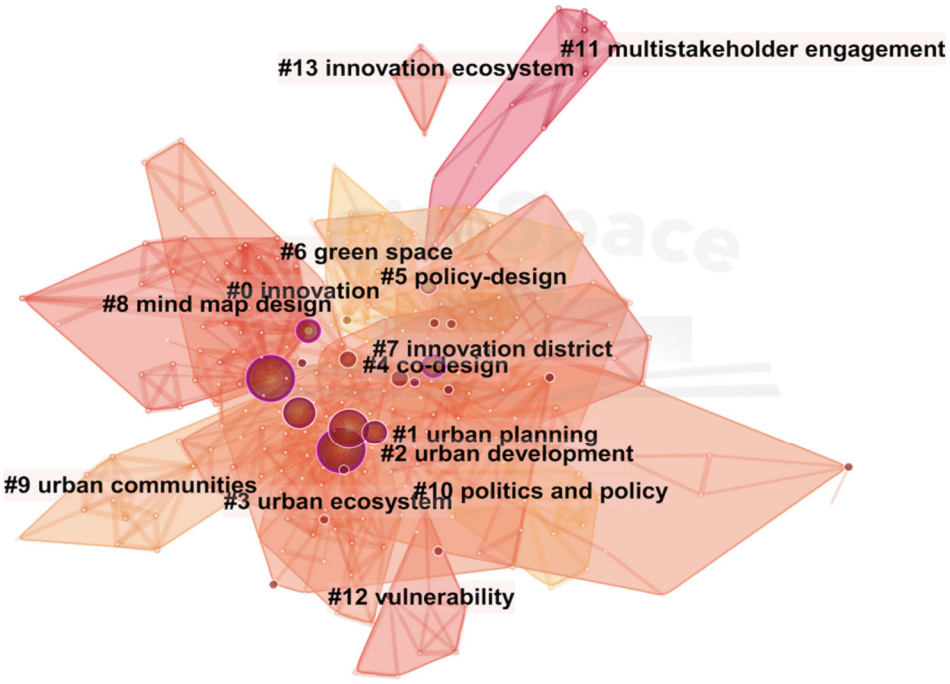

Figure 6. Cluster Map of International Research Hotspots

Table 2. Cluster Statistics for Keywords of Urban Innovation Ecosystem in Domestic and International Research

Domestic					International				
Cluster	Frequency	Silhouette value	Year	Co-word cluster	Cluster	Frequency	Silhouette value	Year	Co-word cluster
18	4	1	2023	low-carbon city	13#	4	1	2020	innovation ecosystem
10	11	0.978	2011	cultural texture	0#	35	0.972	2020	innovation
8	16	0.963	2011	ecological civilization	9#	14	0.955	2018	urban communities
6	22	0.955	2010	city	11#	12	0.954	2023	multistakehol der engagement
1	35	0.95	2013	innovation	8#	15	0.922	2017	mind map design
9	14	0.944	2014	innovation subject	10#	14	0.905	2016	politics and policy
0	39	0.921	2016	city cluster	2#	30	0.902	2018	urban development
5	24	0.905	2014	ecosystem	12#	9	0.901	2020	vulnerability
3	27	0.885	2012	eco-cities	6#	17	0.892	2015	sustainable innovation
4	25	0.86	2015	resource-dependent cities	3#	28	0.825	2017	urban ecosystem
7	19	0.853	2012	innovative cities	5#	25	0.818	2017	policy-design
2	28	0.851	2018	innovation ecology	4#	25	0.807	2016	co-design
/	/	/	/	/	1#	31	0.798	2018	urban planning
/	/	/	/	/	7#	17	0.782	2019	innovation district

5. Overview and Comparison of Domestic and International Researches

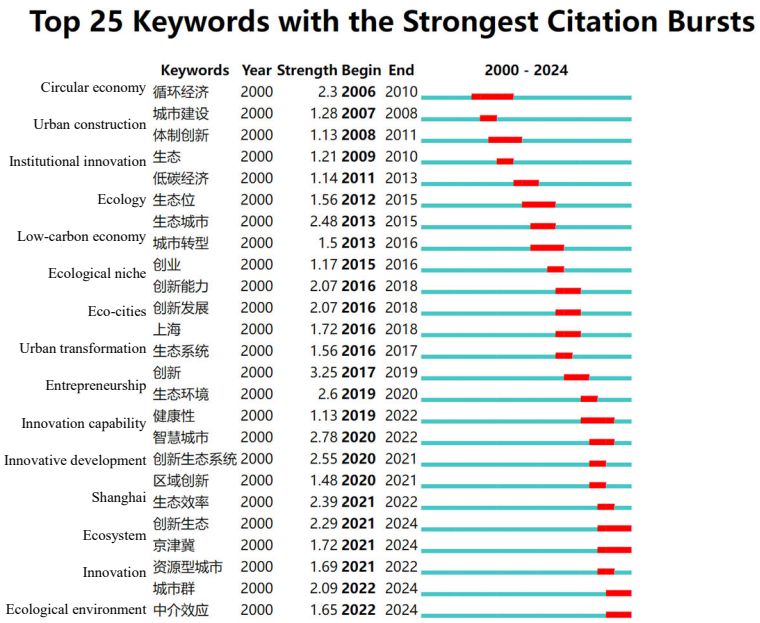

Figure 7. Map of Burst Keywords in the Domestic Research of Urban Innovation Ecosystems

Top 25 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	1960 - 2024
state	1960	3.16	2002	2007	
cluster	1960	7.45	2007	2012	
firm	1960	2.82	2007	2010	
competitiveness	1960	3.2	2008	2014	
network	1960	4.88	2009	2015	
performance	1960	3.39	2011	2014	
regional innovation system	1960	6.05	2013	2017	
organization	1960	4.02	2013	2016	
university	1960	3.07	2013	2016	
innovation system	1960	5.52	2014	2016	
economic geography	1960	4.53	2015	2017	
entrepreneurship	1960	2.93	2016	2017	
open innovation	1960	4.28	2017	2018	
pattern	1960	3.44	2018	2020	
patent	1960	3.2	2018	2020	
construction	1960	2.99	2018	2019	
sharing economy	1960	3.94	2019	2024	
migration	1960	3.7	2019	2020	
perspective	1960	3.47	2019	2024	
urban	1960	4.31	2020	2022	
challenge	1960	3.62	2020	2021	
smart city	1960	3.07	2020	2021	
innovation policy	1960	2.86	2020	2021	
empirical evidence	1960	3.6	2021	2022	
economic growth	1960	3.79	2022	2024	

Figure 8. Map of Burst Keywords in the International Research of Urban Innovation Ecosystems

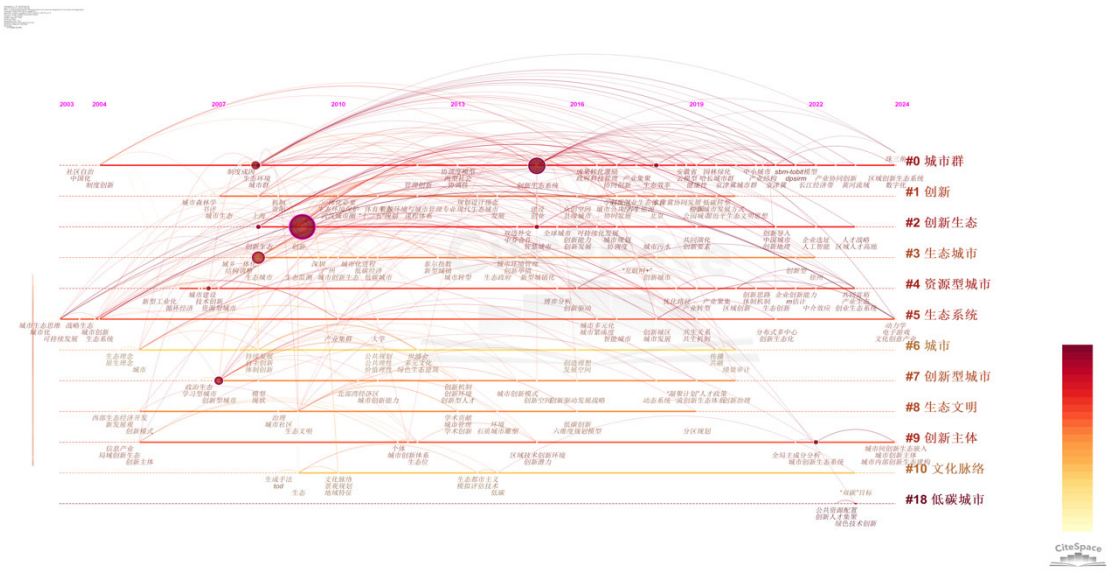

Figure 9. Cluster Timeline Map of Research Hotspots in the Domestic Research of Urban Innovation Ecosystems

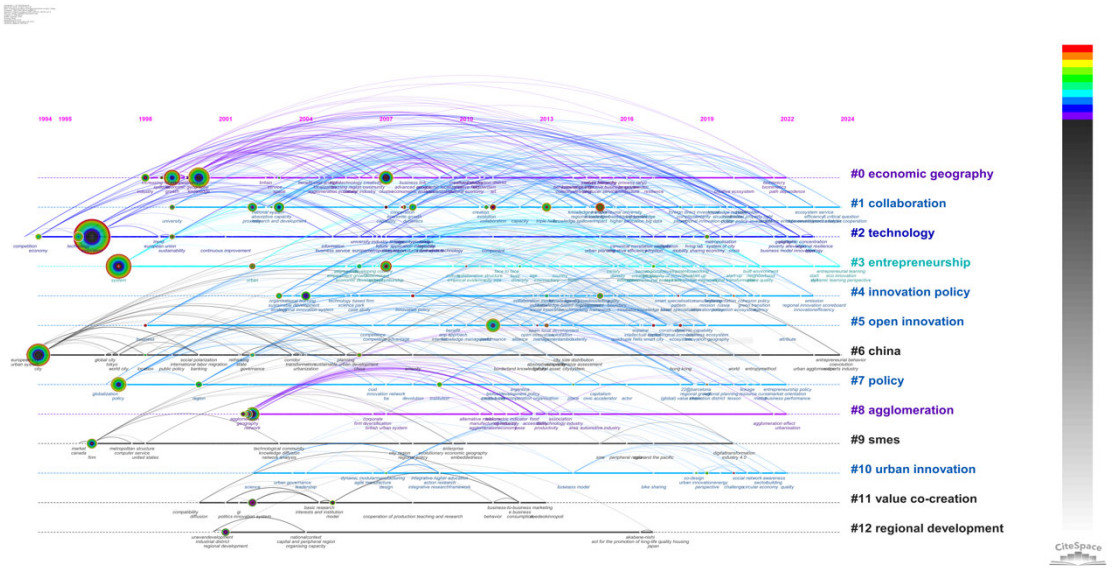

Figure 10. Cluster Timeline Map of Research Hotspots in the International Research of Urban Innovation Ecosystems

Through a comprehensive analysis of keywords, the research hotspots in urban innovation ecosystems are illustrated through a timeline, showcasing their evolutionary trajectory. Keyword clustering reflects the subdivision of research directions. Figure 7 reveals the beginnings, developmental process, and frontier changes in domestic and international research, presenting the multi-stage subdivisions of urban innovation ecosystem studies.

5.1. Domestic Research Overview

Research on innovation ecosystems in China began in 2003, focusing initially on sustainable urban development. This research then has evolved from theoretical exploration to applied studies, from studies on individual regions to those on urban clusters, and from evaluation models to empirical testing. Based on the previous analysis of publications, the research can be divided into three main directions: macro theoretical framework research, evaluation model research, and studies in other extended fields. The first two directions are the primary research focuses for urban innovation ecosystems. Research on macro theoretical frameworks dominated from 2003 to 2017, while research on evaluation models has been predominant since 2017. Research on other related fields has been conducted alongside the main studies.

5.1.1. Research on macro theoretical frameworks (2003-2014)

After the rapid development of Chinese cities in the 1990s, traditional industrial models led to environmental degradation and increased costs, making urban transformation a focal point. The academic community began exploring urban innovation ecosystems, proposing theoretical frameworks and practical paths for the transformation of resource-based cities, aiming to fundamentally address urban development issues. Li Changan (2003)[14] pointed out that the causes of urban diseases in China stem from traditional development models, and that a sustainable development view is key to building an innovative urban ecosystem to avoid these problems. Sui Yinghui (2004)[15] proposed that an urban innovation system is a self-organizing innovation system with unique technological, economic, and social structures, and an interdependent strategic ecosystem, which influences the city's innovative capacity and the formation of urban innovation clusters. Scholars such as Liu Yi (2006)[16] proposed developing a circular economy to facilitate the new industrialization of resource-dependent cities. Many studies find that establishing an urban innovation ecosystem is the cornerstone of urban development transformation and the implementation of the national innovation strategy. Research on urban innovation ecosystems then enter the phase of practical exploration. Long Ruyin (2007)[17] proposed strategies for selecting technological innovation paths for resource-dependent cities under a circular economy system to build sustainable and innovative cities. Xu Zhengquan (2008)[18] introduced the point-line-plane model for constructing innovative cities. Wen Xiaocai (2008)[19] and Li Shoulin[20] proposed policy and institutional adjustment strategies from the perspectives of building sustainable innovation regions and accelerating urban-rural integration, and industrial restructuring respectively. Zhu Jun (2009)[21] emphasized the balance between the human material environment, the ecological environment, and urban construction and development as the key to urban innovative development. Chen Liang (2014)[22] and Su Zhanghong (2013)[23] studied urban innovation development from the perspectives of planning and landscape design. Lu Xiaocheng (2013)[24] offered strategies for development concepts, spatial patterns, industrial structures, production methods, and lifestyles to achieve a low-carbon economy. During this stage, the exploration of the theoretical framework also progressed. Wang Dongjing (2012)[25] introduced ecological niche theory into urban innovation research, identifying obstacles to ecological development and proposing targeted strategies. Wang Zhimin (2017)[26] drew lessons from Silicon Valley to develop institutional frameworks for international innovation hub cities. Wu Ying (2017)[27] took Shanghai as an example and offered recommendations for building innovation systems from horizontal and vertical dimensions.

5.1.2. Research on evaluation model (2017-2024)

In recent years, research on evaluation models and metrics has become a hotspot. Scholars primarily use empirical methods, applying various calculation models to single or multiple urban clusters to validate these evaluation models. The research is further divided into dynamic evaluation models, innovation metrics evaluation models, and framework models.

1) Research on dynamic evaluation model

Liu Haoxuan (2018)[28] introduced an ecological environment perspective to construct a dynamic evaluation system for innovative cities. Zhang Yongkai (2018)[29] proposed the framework and evaluation system for urban innovation ecosystems based on the innovation ecosystem framework and evaluation system. Zhang applied the analytic hierarchy process to analyze Beijing and Shanghai comparatively and provided optimization suggestions. Xu Jun (2020)[30] identified four driving factors for the innovation ecosystem of resource-dependent cities from an ecological perspective: innovation subjects, innovation content, innovation resources, and innovation environment. Xu analyzed the four stages of the urban evolution process, revealing the framework and realization mechanism of the innovation ecosystem for these cities.

Bai Ou (2021)[31] proposed a dynamic capability analysis framework for the innovation ecosystem of smart cities by studying three smart city cases in Zhejiang Province, adding a new direction to the research on smart city innovation.

Many scholars have enriched the theoretical research on the innovation ecosystem of resource-dependent cities. Wu Yingkai (2021)[32] proposed the dynamic evolution process and its driving mechanisms of the innovation ecosystem of resource-dependent cities. Yang Xiuli (2022)[33] used the system dynamics long-term evolution analysis to study Daqing City in Heilongjiang Province, identifying the causes of urban economic fragility from both micro and macro levels. Based on this, Yang proposed the construction mechanism, system dynamic mechanism, and operation mechanism of the innovation ecosystem for resource-dependent cities.

Han Gengjun (2020)[34] took the Beijing-Tianjin-Hebei urban agglomeration as the research object and proposed principles and core contents for constructing an innovation ecosystem from the perspective of regional resource integration and integrated development. Many scholars have measured the ecological efficiency of urban agglomerations using undesired output models and refined the influencing factors through the Tobit model. Zhang Qiufeng (2022) [35] measured the ecological efficiency of 99 cities in Beijing-Tianjin-Hebei, Yangtze River Delta, Pearl River Delta, Middle Yangtze River, and Chengdu-Chongqing urban agglomerations from 2010 to 2019 through the super-efficiency SBM model considering undesirable outputs. Zhang revealed the evolution patterns of ecological efficiency in these five urban agglomerations and identified the influencing factors of ecological efficiency through the Tobit model. Liu Yunqiang (2018)[36] used a non-radial, non-angular DEA model considering undesirable outputs to measure the ecological efficiency of urban agglomerations in the Yangtze River Economic Belt from 2005 to 2015. Liu empirically analyzed the impact of green technological innovation on ecological efficiency and the associative effect of industrial agglomeration and green technological innovation on ecological efficiency through the Tobit model.

2) Evaluation model of innovation indicator

Duan Jinjun (2017)[37] used a maturity calculation model to conduct empirical evaluations of Shanghai, Hangzhou, Shenzhen and 13 cities in Jiangsu. Zhu Ying (2019)[38] used a system coupling coordination model to evaluate the coupling of innovation elements in 23 Chinese technological innovation cities. Shi Zhusheng (2019)[39] used the cloud model to quantitatively analyze the health level of innovation ecosystem development in 16 prefecture-level cities in Anhui Province and optimized the evaluation index system for urban innovation ecosystems. Yan Jingyi (2021)[40] used the DICE analysis framework followed by the knowledge ecosystem to optimize and reconstruct the three-level evaluation index for evaluating innovation in nine national high-tech zones in small and

medium-sized cities. Lyu Xiaojing (2021)[41] calculated the vitality index of the Beijing-Tianjin-Hebei regional innovation ecosystem through an improved entropy-weight TOPSIS model and obstacle degree model and identified the obstacle factors. Hua Yue (2021)[42] used a generalized difference-in-differences model to study the impact of goal-oriented innovation policies on the ecological efficiency of 188 prefecture-level and above cities in China. Hua concluded that structural effects and green technology effects are the main channels through which innovative cities promote urban ecological efficiency. Peng Dinghong (2022)[43] proposed the DPSIRM framework evaluation index system for urban innovation ecosystems and conducted case studies in five cities in the Yangtze River Economic Belt. Cai Hong (2022) [44]constructed an evaluation index system for urban innovation ecosystems, comprising five dimensions and 20 indicators, including innovation environment, innovation investment, innovation dynamics, development trends, and openness. Cai carried out a cluster analysis of 919 key cities nationwide and proposed four recommendations: improving the quality of the innovation environment, establishing a full ecological innovation system, fostering urban innovation dynamics, and promoting cross-regional innovation system synergy. Liu Xielin (2022)[45] developed a three-tiered evaluation index system encompassing urban innovation subjects, internal urban innovation ecosystem construction, and intercity innovation ecosystem integration. Through the stepped and equal-weighted method, Liu determined the weights of each indicator to evaluate 11 Comprehensive Innovation Reform Pilot Zones. Liu Xielin (2024)[46] evaluated the competitiveness of innovation ecosystems in 100 cities from 2015 to 2019 based on the self-developed three-tiered evaluation index system and identified corresponding issues. The aforementioned studies focus on the overall evaluation indices. Additionally, some scholars have studied individual evaluation indices, such as the relationship between spatial spillovers and innovation ecosystems, and innovation resilience. Luo Nengsheng (2018)[47] expanded the convex common frontier to a non-convex common frontier from the perspective of spatial spillover decomposition, using an improved data envelopment analysis model to measure the ecological efficiency of 191 prefecture-level and above cities in China from 2003 to 2015, and researched the high-level pressure and low-level suction mechanisms of urban innovation spatial spillovers in enhancing ecological efficiency. Chen Chaofan (2021)[48] examined the impact of innovation on ecological efficiency and multidimensional heterogeneous honesty in 260 cities from 2007 to 2016 through the spatial econometric model from the perspective of urban spatial association and spillovers. Chen also calculated the spatial spillover distance boundary of innovation, providing quantitative references for enhancing regional innovation cooperation. Liu Jing (2022)[49] established a resilience calculation model to assess the resistance and recovery capabilities of urban innovation ecosystems when faced with external shocks. Liu selected 19 cities as case studies for model validation.

3) Innovation ecological framework model

Lu Chao (2016)[50] constructed a theoretical path for innovation-driven urban development from three aspects (strategic orientation, core content, and key approaches) and applied this path to evaluate the issues in Shanghai's innovative construction city from 2006 to 2014. Ye Tanglin (2024) [51] focused on an innovation ecosystem centered on R&D-intermediary-application, and built a collaborative innovation network for the Beijing-Tianjin-Hebei and Pearl River Delta urban agglomerations, comparing their characteristics and differences. Zhang Ke (2021)[52], using a "platform-function-place" research framework, clarified the process and characteristics of spatial functionalization and placemaking in innovation districts. Zhou Lei (2022)[53], taking Cornell Tech in New York as an example, proposed that science and engineering universities play a role in bearing and empowering human, economic, physical, and network assets in the urban innovation ecosystem, thus contributing to its construction. Yang Boxu (2023)[54], based on innovation ecosystem and innovation geography theories, constructed a theoretical model of "industrialization-urbanization-innovation polarization." Through this model, Yang deeply analyzed the historical changes and issues in urbanization development in China, proposing four strategic guidelines: creating urban dislocation development based on ecological niches, fostering innovation clusters through industrial clusters,

accelerating integrated innovation with digital technology, and leveraging urban advantages to counteract the siphoning effect.

5.1.3. Studies in other extended fields

As scholars delve deeper into the study of urban innovation ecosystems, some have continued to expand its connotations and extensions, examining the impact of intellectual property on the construction of innovation ecosystems, as well as the enhancement brought about by collaborative innovation in science and technology services, green technology innovation, and low-carbon pilot policies.

Zheng Shuzhao (2016)[55] analyzed the construction of urban innovation capability and innovation ecosystems from the perspective of intellectual property. Li Jiannan (2018)[56] defined the basic framework of a smart city green innovation system model, including the urban infrastructure layer, green city layer, connectivity layer, instrumentation layer, open integration layer, application layer, and innovation layer. Jiang Hong (2020)[57], taking the Harbin-Changchun urban agglomeration as an example, proposed a mechanism for a collaborative innovation ecosystem in science and technology services based on coordinated innovation and innovation ecosystem theories. Du Man (2022)[58] used a super-efficiency SBM-DEA model considering undesirable outputs to measure the ecological efficiency of 270 prefecture-level and above cities in China from 2003 to 2019, and used the spatial econometric model and threshold regression model to analyze the impact of green technology innovation on urban ecological efficiency.

Deng Rongrong (2022)[59] used a spatial difference-in-differences model to evaluate the local and spatial spillover effects of low-carbon pilot policies on the ecological efficiency of 209 cities from 2007 to 2019. Deng concluded that these policies, acting as an intermediary mechanism, promoted the ecological efficiency of pilot cities through technological innovation effects and industrial structure effects.

5.2. International Research Overview

Research on urban innovation ecosystems abroad began in 1992, with research directions mainly divided into three categories: (1) Studies that consider the city as the premise of the innovation system, with the assumption that innovation is concentrated in the urban core. (2) Studies that expand the boundaries of urban innovation research to the urban periphery and even rural areas, arguing that innovation not only occurs in cities but that rural and other non-resource-concentrated areas also have the soil for innovation and their own development advantages. (3) In the field of design, scholars have conducted extensive practical research on urban innovation systems from the perspectives of social innovation, service design, and urban planning.

5.2.1. Research on urban innovation ecosystems from the perspective of urban innovation geography

Since 1994, foreign scholars have begun to study the ways of urban transformation and development from the perspective of urban systems. They compared urban development to corporate development to construct urban innovation system theories, analyzing problems encountered in the urban development process, building solution models, and assessing urban value. Additionally, urban research has been refined to evaluate and systematically study innovation within urban enterprises, with enterprises as evaluation units to reflect the innovation development of cities. Lichtenberger, E (1994)[60] pointed out that European cities will form cross-border metropolitan clusters, such as "megacities" and "sunbelt" cities, which will develop as enterprise models. Kraetke (2007)[61] analyzed major European metropolitan areas and emphasized the different sectors and development paths of knowledge-intensive economies in European urban agglomeration and metropolitan regions. These related studies mark the beginning of research on cities as innovation systems. Subsequently, scholars introduced research methods from economics, management, and other disciplines into innovation geography. Nijkamp (2013)[62] adopted a systematic strategic approach to transform

urban megatrends and challenges into research and policy concerns for Europe. He proposed that, from a typological perspective, the analytical frameworks used for these research and policy responses in Europe are built around four interrelated pillars (cornerstones). Qian H (2013)[63] developed and tested a three-stage structural model for regional entrepreneurial systems based on data from metropolitan areas in the United States, finding that entrepreneurial absorption is a significant driver of entrepreneurial activity, and high-tech and cultural diversity contribute to the vitality of regional entrepreneurial systems. Martin Ron (2018)[64] pointed out that evolutionary economic geography, particularly the concept of path dependence, explains the diversity of urban economic trajectories. Within this framework, four stages of path-dependent development of new technologies or industrial sectors in urban economies were identified, each characterized by the nature of the urban innovation system, interactions, and knowledge absorption capacity.

Additionally, some scholars have refined urban research to the enterprise level, using the study and systematic evaluation of enterprise innovation development to reflect urban innovation and propose relevant enhancement suggestions. Cohen B (2015)[65] studied the innovation structures of purpose-driven enterprises in cities. He drew from sustainability and territorial development literatures and the complexity science view of entrepreneurship to establish units, laws of interaction, boundaries, and system states of purpose-driven urban entrepreneurship across three geospatial layers, and elaborate a complexity model comprising sources of opportunities, context, and venturing process. GC de Zubielqui et al. (2015)[66] examined the modes of knowledge transfer between actors in the innovation system through a survey of 1,226 SMEs. The case studies found that SMEs generally use "generic" university-industry knowledge transfer pathways (e.g. published research results) rather than university-industry cooperation with high "relational" involvement. Belitski M (2016)[67] analyzed data on 187 cities in 15 European countries from 1999 to 2009 to examine how urban creativity, entrepreneurship, and the macro environment interact and influence urban economic development using a creativity filter and dynamic analysis.

Some scholars conducted theoretical and empirical research on the design and implementation of innovation policies. Laranja (2008)[68], based on theoretical perspectives from science, technology and innovation (STI) policy, discussed the theories on spatial dynamics and territorial relationships, studied the associated policy instruments or policy-mixes, and proposed how STI policies can be effectively designed and implemented. Since 1992, foreign scholars researched urban innovation policies, primarily focusing on regional policies and globalization policies. Starting in 2003, they focused on sustainable innovation policies and innovation policy systems. Sanger, MB (1992)[69] analyzed more than 25 successful innovation cases, revealing that innovation depends upon evolutionary tinkering with existing practices, from a process of trial and error and experimental learning, with innovators recombining old elements in new ways. He suggested evaluating policies in innovation development, emphasizing that public administrators need to embody entrepreneurial spirit, take risks, be action-oriented, and minimize bureaucratic and political obstacles. He also proposed corresponding training recommendations. Williams, R (1996)[70] reviewed the growing body of research that explores "the social shaping of technology" (SST). The research criticized traditional conceptions of technology from a range of disciplinary backgrounds such as the linear model of innovation. It suggested that SST offers a deeper understanding and also potentially broadens the technology policy agenda. Cooke, P (1997)[71] explored the importance of regional innovation systems. Taking an evolutionary economics standpoint, the study specified the concepts of region, innovation and system as the prelude to an extended discussion of the importance of financial capacity, institutionalized learning and productive culture to systemic innovation. The study concluded by advocating the strengthening of regional-level capacities for promoting both systemic learning and interactive innovation. Kuhlmann (2003)[72], based on the relationship between politics and innovation systems, speculated about the future governance of innovation policies encompassing centralized, decentralized, and intermediary hybrid models, trying to pave the way for empirical analysis. Kaiser, R (2004)[73] proposed an Open Method of Coordination (OMC) for innovation policy within multi-level governance systems, exploring the national and policy diversity in Austria,

Germany, the Netherlands, and Sweden.Sternberg R (2010)[74] adopted an institutional perspective and compared the cluster policies of North Carolina and Bavaria to link the differences in the design and implementation of cluster policies to characteristics of the national institutional environment, as well as to regional specifics and path dependencies. Study results emphasized the importance of considering institutional contexts when adjusting cluster policies to specific circumstances. Edler, J (2018)[75] provided comprehensive and in-depth guidance for policymakers on the definition, theoretical rationales, design, implementation, and governance of innovation policies. Grillitsch, M (2019)[76] reviewed the orientation toward grand societal challenges that can be seen as a new wave or paradigm for innovation policy (system innovation policy) aiming at system-wide transformation. Building on insights from transition studies, the study grouped the challenges into four domains: directionality, experimentation, demand articulation, and policy coordination and learning and related challenges within the four domains to three generic features of innovation systems. The study also conducted a case study on the strategic innovation programs, a policy initiative by Vinnova, Sweden's Innovation Agency, to analyze the design, implementation and evaluation approaches of system innovation policy. Tuckerman (2023)[77], through critical discourse analysis and corpus linguistics research on UK innovation policy, found that although there was some inclusion of key environmental and societal words, these were predominately secondary to economic themes, signaling a business "as usual" approach to innovation policy.

5.2.2. Innovation ecosystems in rural areas on the urban periphery

Since 2010, research on urban innovation systems in foreign countries has expanded from viewing the city as the primary focus to including the urban periphery. This perspective suggests that innovation output can also occur in the periphery of urban innovation clusters, with innovation activities emerging from the interconnections between urban and rural areas. Some studies even argue that the innovation capability and output proportion of rural areas can surpass those of cities. Arne Isaksen (2010)[78], based on representative samples of knowledge-intensive firms in Norway, analyzed the innovation output, innovation partners, knowledge sources, and localization of sources and partners for knowledge-intensive firms in three types of regions: large urban regions, small urban regions and rural areas. The study found that the small urban regions and the rural regions have a higher share of innovating, knowledge-intensive firms than the large urban regions, which may partly be explained by a much higher rate of public funding of innovation activity in the first two regional types. Shearmur (2012)[79] argued that innovation generation, marketing, and promotion can be separated from innovation zones, unrestricted by specific geographical and social environments, and can occur outside urban regions. Escalona-Orcao A I (2016)[80] identified 761 municipalities that could host creative clusters within an initial area of study of 7367 non-metropolitan municipalities with fewer than 50,000 inhabitants. He connected the concepts of clusters and creative activities with urban environments to evaluate the innovation clusters and innovative activities. Baskaran S (2016)[81] interviewed 271 young people from rural, semi-urban, and urban areas in Kenya, Tanzania, India, and Nicaragua to study the significance and fundamental principles of innovation as perceived by the rapidly growing youth population in developing countries, explaining how cultural mechanisms and public environments favor innovative solutions to individual or community needs. Xu Z (2019)[82] conducted a case study on Guildford's digital gaming industry based on secondary data and linked the literature on ecosystems with peripheral region studies in creating a conceptual framework for developing entrepreneurial ecosystems in peripheral places. Eder (2019)[83] conducted a systematic literature review of the work on innovation in the periphery from 1960 to 2016 and found an increasing number of studies suggesting that the innovation capacity of peripheral areas in innovation clusters has been consistently overlooked.

5.2.3. Research on urban innovation systems from social innovation in design, urban planning, and architecture

Design innovation boosts technological and organizational innovation, while design studies have continually explored innovative thinking, models, and systems. In recent years, as a new interdisciplinary field encompassing science, engineering, and humanities, design disciplines abroad

have expanded their research focus from products, services, policies, and industries to urban innovation systems. However, most of this research uses service design from a social innovation perspective, focusing on practical studies of innovative communities, innovation service platforms, service systems, and urban innovation laboratories, while theoretical research remains relatively limited.

Fasoli, A (2017)[84] analyzed the new collaborative design and production processes emerging from the Roma Makers Infrastructure initiated in Rome, Italy. The study focused on how a self-generating network of knowledge based on a peer-to-peer system can be a key agent to enhance civic engagement for urban development. Monna, V (2017)[85] researched community-centered design and material-driven design, aiming to define new scenarios regarding the relationships between local communities, urban spaces, waste, and meaning. Galluzzo, L (2019)[86] described the urban innovation reshaping project in the Martesana district of Milan. With a relatively fragmented socio-cultural structure, the design of service systems through social innovation linked different community institutions to form an innovation ecosystem.

6. Significance of Design Innovation in Building Mechanisms for Urban Innovation Ecosystems

6.1. Promoting Synergy between Innovation Subjects and Enhancing System Efficiency

Design thinking emphasizes the importance of teamwork and interdisciplinary collaboration, aligning well with the building of urban innovation ecosystems. The innovation subjects within an urban innovation ecosystem include enterprises, higher education institutions, research organizations, government departments, and residential communities. Design innovation fosters synergy among these diverse innovation subjects through interdisciplinary and cross-sector collaboration. By establishing design innovation platforms, different innovation subjects can share design resources, exchange design concepts, and collaboratively solve innovation challenges, forming a cohesive innovation force. This synergy helps enhance the overall efficiency and competitiveness of the innovation ecosystem.

6.2. Optimizing the Allocation and Utilization of Innovation Resources to Promote Multidisciplinary Integration

Innovation resources within an urban innovation ecosystem include talent, capital, technology, and information. Design innovation can optimize the allocation and utilization of these resources by introducing innovative design concepts and methods. For instance, cultivating design thinking and design models can stimulate the innovation potential and creativity of talents, design-driven R&D models can reduce innovation risks and improve efficiency, and design-oriented market strategies can accurately identify user needs and expand market space. These optimization measures help enhance the utilization efficiency and value-creation capacity of innovation resources. Moreover, design thinking, as an interdisciplinary mindset and methodology, emphasizes user-centric principles, iterative experimentation, and teamwork, offering a new perspective for theoretical research in urban innovation ecosystems. By incorporating design thinking, traditional research focused on singular dimensions such as technology, economics, or management can be expanded to include comprehensive studies in sociology, psychology, anthropology, and environmental science. This multidisciplinary approach aids in a more comprehensive understanding of the complexity and dynamism of urban innovation ecosystems, advancing theoretical research and development.

6.3. Strengthening Human-Oriented Approaches to Enhance the Sustainable Competitiveness of Innovation Systems

The core of design thinking is human-oriented, prioritizing user needs and guiding innovation activities through deep user research and insights. Introducing design thinking into the theoretical study of urban innovation ecosystems can significantly enhance the extent and depth of user

engagement. Design tools and methods such as user personas, scenario simulations, and prototype testing can be used to more accurately grasp the needs and expectations of urban residents, providing more precise foundations for policy-making, urban planning, and public services. This user-centered research orientation helps to build a more humanized and sustainable urban innovation ecosystem. Moreover, the core objective of urban innovation ecosystems is to enhance innovation performance and competitive advantage. Design innovation can enhance innovation performance and competitiveness by optimizing product functionality, improving user experience, and promoting social innovation. For instance, design-driven product innovation can create products with differentiated competitive advantages; design-oriented service innovation can offer more personalized and convenient service experiences; design-led social innovation can promote comprehensive progress and development in urban society. These enhancement measures help to strengthen the overall competitiveness and sustainable development capability of urban innovation ecosystems.

6.4. Promoting Service Innovation and Enriching the Content of Innovation

Design thinking is particularly prominent in the field of service design. By using tools such as user journey maps and service blueprints, it systematically plans and optimizes service processes to enhance user experience. In theoretical research on urban innovation ecosystems, incorporating service design thinking can drive the in-depth development of service innovation and enrich the content of innovation. Through service models and products driven by design innovation, such as smart city services and shared economy platforms, users can receive more convenient, efficient, and personalized service experiences. Such service innovation improves the quality of life for urban residents and contributes to the structural optimization and upgrading of the urban economy.

6.5. Improving Innovation Environment and Promoting the Construction of Innovation Ecology

The innovation environment within urban innovation ecosystems includes policy, cultural, and social environments. Design innovation can improve these environments by changing lifestyles and consumption patterns. For instance, green design and circular design can promote environmental awareness and drive sustainable urban development; service design and user experience design can improve residents' quality of life and social welfare; cultural and social innovation can enrich the cultural fabric and foster cultural diversity. These improvements help create a more conducive external environment and atmosphere for innovation.

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