Spatiotemporal Evolution of Makerspace Locations under Government, University, and Private-Enterprise Leadership: Spatial Mechanisms through the Innovation Helix Model

WEN Jun, CHEN Liuyan, ZHANG Minggang, CAO Aozhuo, SHEN Ping, BI Linglan

Abstract. Makerspaces expanded rapidly under China's "Mass Entrepreneurship and Innovation" initiative, but many now face closure, restructuring, or strategic repositioning. As collaboration among government, industry, universities, and research institutions becomes a central driver of regional innovation, examining makerspaces through the lens of their principal operators—government, universities, and private enterprises—is essential for strengthening regional innovation and developing new quality productive forces. Drawing on the innovation helix model and combining quantitative spatial analysis with qualitative interviews, this study investigates the spatiotemporal evolution of makerspaces in Chengdu, a major innovation hub. The findings show that government-led makerspaces have shifted from the urban core toward peripheral districts as their operation becomes more market-oriented and as outer districts seek innovation-driven growth. University-led makerspaces have expanded from locations near campuses to industrial development zones and government–university cooperation areas under the combined influence of internal demand for technology application and external government attraction policies. Private-enterprise-led makerspaces, driven by profitability and industrial policy, have become increasingly specialized by industry and have moved from policy-favored areas toward industrial development zones. Based on the clustering patterns and evolutionary challenges of the three types, the study proposes policy and planning recommendations to enhance regional innovation capacity.

Keywords: innovation; makerspaces; triple helix model; spatial distribution; government; market; university.

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Amid a new round of scientific, technological, and industrial transformation, China has called for the development of "new quality productive forces" and the accelerated conversion and application of scientific and technological achievements. In this context, makerspaces—important carriers of innovation—deserve renewed attention because they respond directly to the needs of industrial upgrading and the cultivation of new quality productive forces [1]. China launched the "Mass Entrepreneurship and Innovation" initiative in 2014. As low-cost and accessible entrepreneurial service platforms, makerspaces integrated resources for micro and small enterprises and individual innovators and expanded rapidly under favorable policy conditions [2]. More recently, however, some makerspaces have entered a "wave of closures" because of weak incubation capacity, depleted funding, or inappropriate location choices [3-4]. These problems vary by operating actor. Some government-led makerspaces are highly dependent on policy support and lack sustainable revenue-generating capacity [5], while certain privately operated makerspaces have closed because of unclear positioning and broken cash flows [6]. It is therefore necessary to examine how makerspaces led by different actors changed during phases of expansion and transition, and to identify their clustering patterns and pathways toward sustainable development.

The concept of the makerspace originated in Western contexts, where such spaces are often operated by private firms [7] and where location decisions are shaped by market access, the innovation environment, and rental costs [7-9]. In China, makerspaces provide innovation services but also perform functions related to economic restructuring and social service provision; government-led makerspaces, in particular, often serve as demonstrative and catalytic projects [10]. Consequently, Chinese studies of makerspace location also emphasize public financial support, research and development investment, and the industrial environment [11-13]. Because the operating models of makerspaces differ by leading actor, their spatial preferences are also likely to differ. Yet few studies have systematically compared their locations by actor type. This study therefore applies the triple helix framework and classifies makerspaces according to three helices—government, universities, and enterprises [14]—to investigate their spatial evolution.

Makerspaces are both physical platforms for innovation and intermediary service organizations. They connect innovation activities undertaken by government, the market, and universities and have accordingly been conceptualized as a fourth helix in an extended innovation model [15]. Existing location studies have largely emphasized their role as spatial carriers and used quantitative techniques to examine physical distribution, including multi-distance spatial cluster analysis [16] and nearest-neighbor indices [17]. Far fewer studies have qualitatively examined location change from the functional perspective of innovation intermediation. Taking Chengdu—home to one of China's first national demonstration bases for mass entrepreneurship and innovation—as a case, this study integrates quantitative and qualitative methods within an innovation helix framework to explain the evolving geography of three types of makerspaces, support their sustainable development, and identify new spatial approaches to fostering new quality productive forces.

1 Theoretical Framework: From the Triple Helix to the Quadruple Helix

Makerspaces are major platforms for innovation and entrepreneurship, and their activities commonly involve the three actor groups identified in the triple helix model: government, universities, and enterprises [18]. The triple helix explains the new university–industry–government relationship that emerged in knowledge-based economies [19-20]. The model's two principal theorists emphasized different dimensions. Etzkowitz's neo-institutional approach focuses on cross-actor networks and interaction, whereas Leydesdorff's neo-evolutionary mechanism emphasizes functional exchange among actors, including government's regulatory role, universities' knowledge-production role, and enterprises' wealth-creation role [21]. Their triple helix model is characterized by overlapping institutional spheres, actors partially assuming one another's roles, and hybrid organizations—such as university spin-offs and government laboratories—emerging in the areas of overlap [19-20].

As innovation systems have diversified, the triple helix has been extended into several versions of the quadruple helix according to regional differences in innovation actors. Scholars represented by Carayannis emphasize the values and participation of civil society and introduce the public as a fourth helix [22]. By contrast, researchers such as Yang Jinghua and colleagues [23] and Jin Xiaoming [15] regard science and technology intermediaries as bridges for communication and financing among the three helices. Because these intermediaries provide innovation services, they are introduced as the fourth helix.

Makerspaces have a dual character. Spatially, they are platforms that accommodate innovation activities; functionally, they operate as intermediary service organizations and constitute a fourth helix participating in innovation. Their effectiveness as intermediaries depends on their operating actor. When government, universities, or enterprises take the lead, makerspaces exhibit different objectives and comparative advantages and, consequently, different location preferences. This study therefore combines the overlapping framework of the triple helix [20] with the functional roles of four actors in the intermediary-oriented quadruple helix [15] to develop an innovation helix framework for analyzing makerspaces.

Within this framework, each of the three principal actors combines with the makerspace intermediary to form a distinct actor-led type. Government supplies policy support and an innovation environment; universities provide knowledge, technology, and talent; enterprises serve as the principal agents of market application; and makerspaces connect the three through innovation services. Each type therefore emphasizes a different service logic. Government-led makerspaces specialize in rapid policy response, pilot demonstration, and the cultivation of an innovation climate [19], while also implementing targeted support programs. University-led makerspaces are distinguished by talent and technology, prioritize the commercialization of research outcomes [15], and also respond to student employment needs. Enterprise-led makerspaces are characterized by market allocation, rely on profitability for continued operation, and extend industrial chains and organizational scale.

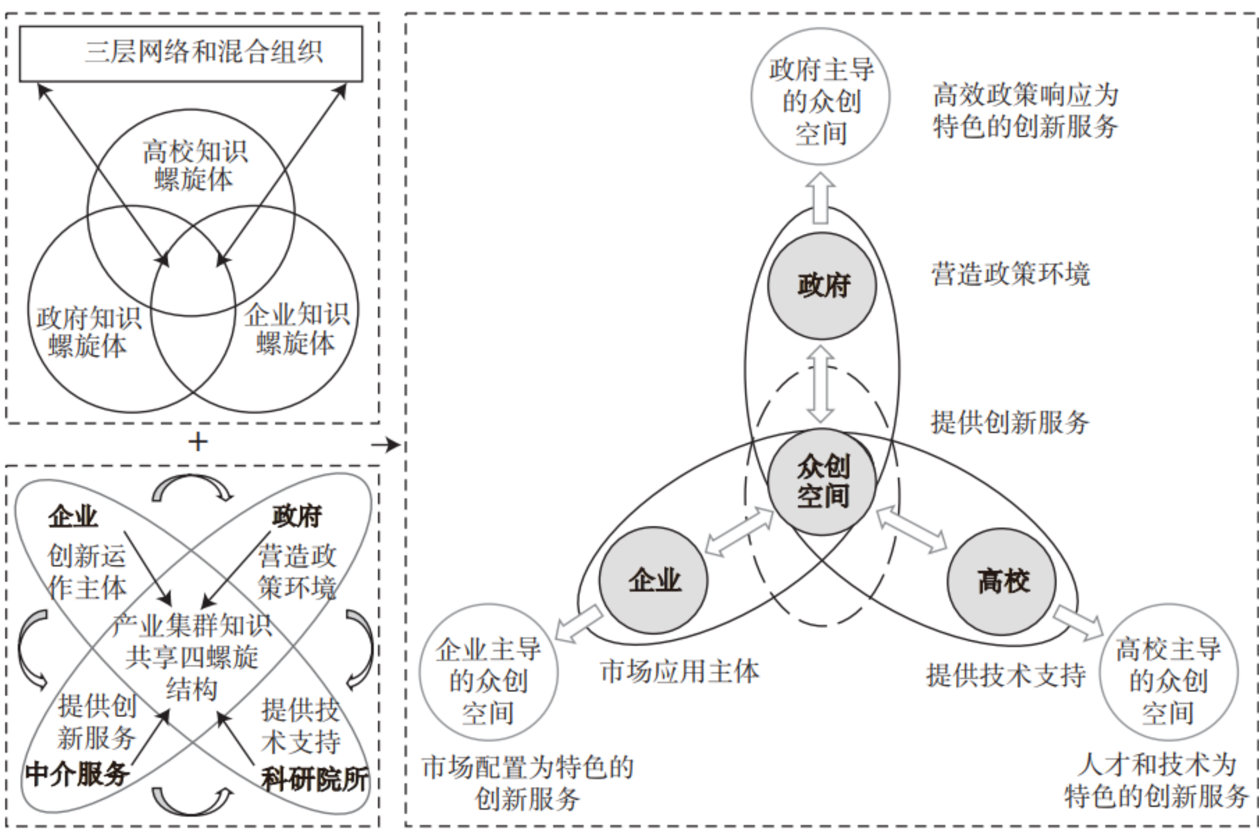

Figure 1. From the Triple Helix and the intermediary-oriented Quadruple Helix to the innovation helix framework proposed in this study

Sources: upper-left panel adapted from [20]; lower-left panel from [15]; right-hand panel developed by the authors.

2 Research Design and Sample

Following the innovation helix model, this study classifies makerspaces into three categories according to their leading actor: government, universities, and private enterprises. It first quantitatively identifies the spatiotemporal characteristics of the three types and then uses interviews to analyze their principal objectives and comparative advantages, thereby revealing the endogenous logic underlying their distribution.

The sample is based on the 2015 and 2022 performance evaluation lists of innovation and entrepreneurship carriers published by the Chengdu Science and Technology Bureau. Detailed information—including addresses, registered operators, and industrial categories—was collected from the Chengdu Science and Technology Innovation Platform, Tianyancha, and related sources. After classification by the three actor types①, databases of 99 makerspaces in 2015 and 229 in 2022 were established. Private-enterprise-led makerspaces formed the largest and fastest-growing group, increasing from 53 to 146 and rising from 54% to 64% of the sample. Government-led makerspaces increased from 24 to 39 but declined in share from 24% to 17%. University-led makerspaces increased from 22 to 44, while their share fell from 22% to 19%.

The study combines quantitative and qualitative methods. Spatial patterns are examined using Moran's I, kernel density estimation, and standard deviational ellipse analysis. Global Moran's I is first used to determine whether each type exhibits overall spatial clustering, after which local Moran's I is applied to identify the location and form of clusters. Following Zhu Yunhan and Zhang Yifan [24], subdistricts and towns are used as the basic spatial units. Kernel density estimation identifies varying degrees of concentration across the city and is interpreted together with local Moran's I (LISA) maps. Standard deviational ellipses are additionally used to reveal the directional tendency of spatial distribution.

To investigate the logic underlying these patterns, interview-based qualitative analysis was conducted. Taking account of operator type, locational representativeness, and interview feasibility, the research team carried out on-site interviews with the managers, founders, or contact persons of 19 makerspaces between April and August 2016 and 39 makerspaces between August and December 2023. Interview topics included the operating actor, business model, location choice, and policy influence.

3 Spatiotemporal Evolution of the Three Types of Makerspaces in Chengdu

3.1 Evolution of the Overall Distribution

Between 2015 and 2022, makerspaces expanded from a concentration in the city center toward the outer urban rings [Figures 2(a) and 2(b)]. Private-enterprise-led makerspaces showed particularly strong growth in the outer rings. Government- and university-led makerspaces also expanded, but over a comparatively more limited area.

To identify changes in both the overall distribution and the three actor-specific types, global Moran's I was calculated for all makerspaces and for each category in 2015 and 2022. With the exception of university-led makerspaces in 2015, all categories exhibited statistically significant spatial clustering, permitting further analysis using local Moran's I and LISA maps (Figure 2). A high–high cluster indicates that both a given area and its neighboring areas contain many makerspaces, together forming a makerspace cluster. The LISA maps for the full sample reveal a dual-core pattern in both 2015 and 2022 [Figures 2(c) and 2(d)]. In 2015, clusters in the first urban ring② were concentrated in Jinjiang District and Chengdu Hi-tech South Zone, while second-ring clusters appeared in Chengdu Hi-tech West Zone, Shuangliu District, and Tianfu New Area. By 2022, the second-ring clusters had expanded markedly, especially in the north.

3.2 Government-Led Makerspaces: Outward Expansion from a Single Core

In 2015, government-led makerspaces formed a single core concentrated mainly in Chengdu Hi-tech South Zone and Wuhou District [Figure 2(e)]. By 2022, the cluster had expanded outward toward second-ring areas, including Shuangliu District, Tianfu New Area, and Longquanyi District [Figure 2(f)].

3.3 University-Led Makerspaces: From Multiple Dispersed Sites to Three Cores

University-led makerspaces did not exhibit significant clustering in 2015. Kernel density analysis [Figures 2(i) and 2(j)] shows a shift from dispersed points in the central ring toward axial expansion into the second ring. The 2022 LISA map [Figure 2(k)] identifies a distinct three-core pattern in Chengdu Hi-tech West Zone, Tianfu New Area, and Longquanyi District. Because the distribution remained relatively dispersed, standard deviational ellipse analysis was used to reveal its directional tendency. As shown in Figure 2(l), the principal orientation shifted from Wenjiang and Longquanyi toward Pidu District and Tianfu New Area.

3.4 Private-Enterprise-Led Makerspaces: From One Core to Two

In 2015, private-enterprise-led makerspaces formed a single cluster in Chengdu Hi-tech South Zone [Figure 2(g)]. By 2022, two major changes had occurred. First, the distribution evolved from a single core to a dual-core structure: a new northwestern core emerged in Chengdu Hi-tech West Zone, Pidu District, and Wenjiang District in addition to the original southern core. Second, the pattern shifted from dispersion to clustering. Low–high clusters in the second ring declined markedly and were replaced by high–high clusters, indicating the gradual formation of second-ring concentrations. High–low clusters in the third ring also decreased substantially, revealing a transition from scattered third-ring locations toward concentration within the second ring.

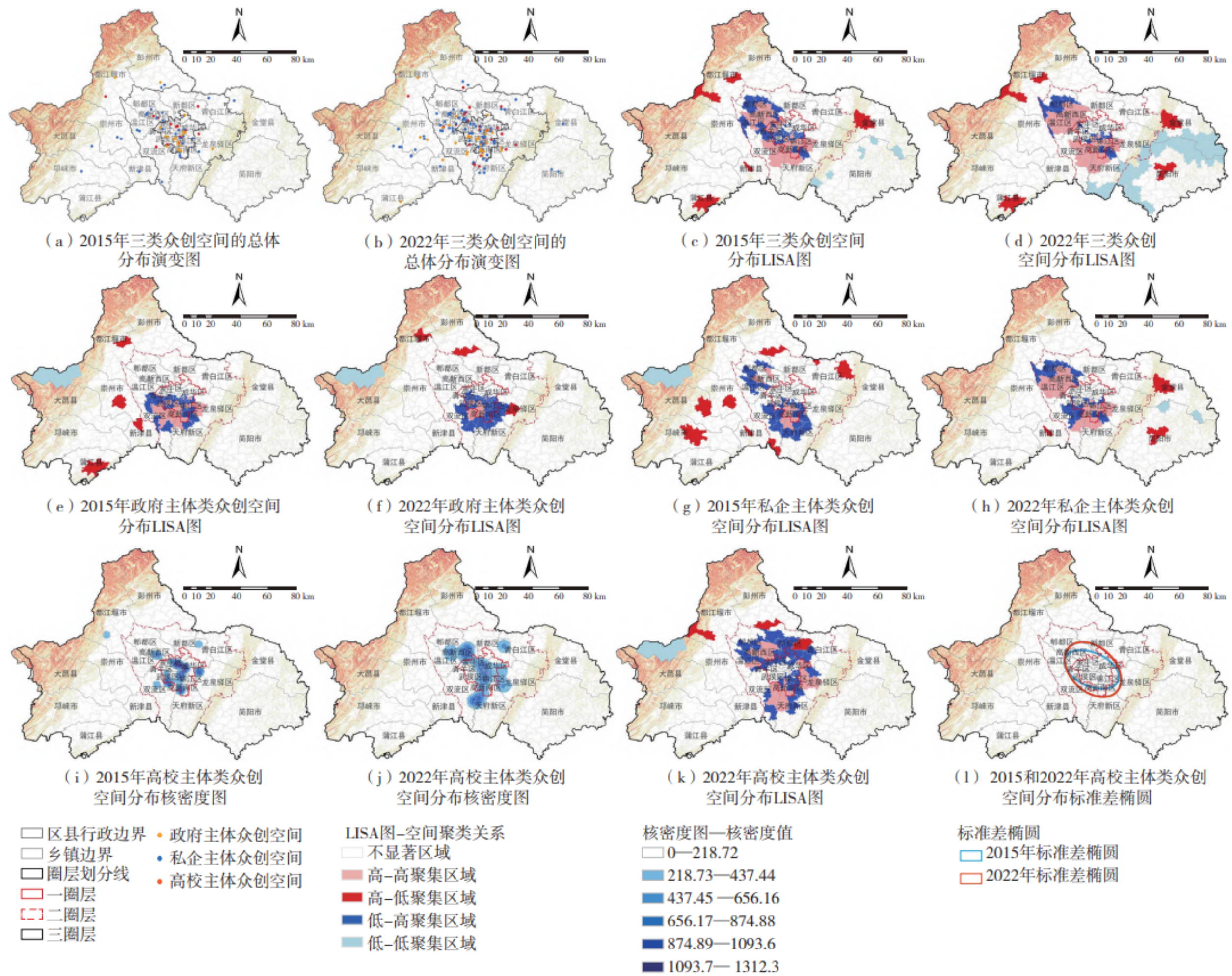

Figure 2. Distribution, LISA, kernel density, and standard deviational ellipse maps of the three types of makerspaces in Chengdu

4 Endogenous Logic behind the Divergent Spatiotemporal Evolution of the Three Types

The three types display clearly differentiated cluster structures: government-led makerspaces form a concentrated single core, university-led makerspaces form three dispersed cores, and private-enterprise-led makerspaces form a comparatively balanced dual-core structure. The innovation helix model provides a basis for explaining the endogenous logic of these differences.

4.1 Government-Led Makerspaces: Demonstrating Innovation Policy

Government plays a service-oriented and guiding role in innovation [25] and performs public-service functions. Government-led makerspaces are commonly established to advance public objectives, including the cultivation of a regional innovation environment [26] and the provision of specialized services to designated groups, such as cross-strait entrepreneurs or military veterans. They therefore have two major advantages: relatively low sensitivity to land and rental costs, and the capacity to respond rapidly to policy.

Under this mechanism, government-led makerspaces initially clustered in Chengdu Hi-tech South Zone within the first urban ring. Policy orientation encouraged them to locate first in innovation-driven areas such as the high-tech zone in order to create demonstrative effects. At the same time, public support reduced rental pressure and allowed them to absorb the high costs of central-city locations. The state-owned TF Software Park Entrepreneurship Hub reported frequent and efficient policy communication with government and, with public support, halved rents for resident firms during the COVID-19 pandemic. Such policy advantages did not extend equally to privately operated makerspaces. The private FH Electrical Incubator observed: “During the pandemic, the government offered rent exemptions to resident firms, but private operators like us received no subsidy.” Preferential support thus strengthened the risk resilience and central-city rental capacity of government-led makerspaces, reinforcing their concentration in the urban core.

As the sector matured, marketization and changes in outer-ring policy gradually pushed government-led makerspaces outward. On the one hand, the growing vitality of the private economy encouraged more market-oriented operating models, increasing sensitivity to land costs and promoting expansion beyond the core. DJJY Creative Industry Park, a government-led makerspace in the central city, reported that “operation was entrusted to a private company beginning in 2021” and that “as land prices rise, occupying large premises for a makerspace generates limited returns and the space may gradually withdraw.” Such privatization reforms indicate a shift toward locations outside the urban core and a growing emphasis on self-sustaining revenue generation.

On the other hand, governments in peripheral districts increasingly recognize the role of innovation-driven industries and use makerspaces to cultivate local innovation environments. Changes in high–high clusters [Figures 2(e) and 2(f)] show that Tianfu New Area and Longquanyi District—both in the second ring—became new government-led clusters. A comparison of Tianfu New Area’s 13th and 14th Five-Year Plans shows that “scientific and technological research and development” was newly added to its leading industries, signaling a transition toward innovation-driven development. In response, the local government actively established government-led makerspaces to create an innovation climate in advance, thereby promoting outward expansion.

4.2 University-Led Makerspaces: Expanding the Application of Technology

Universities are responsible for talent cultivation and scientific research [25]. University-led makerspaces therefore aim not only to train innovative talent but also to integrate industry, universities, and research and to expand the application of technology. They have two principal advantages. First, abundant faculty, student, and research resources provide frontier talent and technological support for innovation and entrepreneurship [27]. Second, as incubators of interdisciplinary knowledge, universities can facilitate the rise of emerging industries [19], creating incentives for local governments to cooperate with them in pursuing new industrial development. University-led makerspaces therefore tend to remain closely connected to campus locations, while government land support also encourages them to locate in government–university cooperation zones.

In 2015, the distribution of university-led makerspaces was strongly associated with university locations: 72.73% were located within a 0.5-km buffer of a campus, demonstrating a clear preference for proximity to talent. By 2022, university-led makerspaces had gradually expanded beyond campuses, and the share within this buffer had fallen to 56.82%.

This change resulted from the combined effects of market demand and policy guidance. In the knowledge economy, universities also bear responsibility for commercializing scientific and technological achievements and therefore seek platforms that connect research outputs with market demand.

University-led makerspaces consequently moved toward industrial development zones. XNJT National Science Park explained: “At first, faculty members mainly formed their own teams and contacted investment institutions. Later, the university established the XNJT Research Institute (Incubator) in Tianfu New Area specifically to commercialize scientific and technological achievements.” The movement from campus-adjacent sites toward industrial zones also explains the shift in the standard deviational ellipse toward Pidu District and Tianfu New Area.

At the same time, local governments strengthened cooperation with universities to enhance regional innovation capacity and clustering [28]. DZKJ’s “Three Medical Fields + AI” Makerspace noted that “the government provided more than 60 hectares of land,” illustrating the direct effect of policy on university-led locations. Some local governments also guided universities and local firms to establish market-oriented makerspaces [29], although interviews with GG Café in Pidu District revealed persistent communication barriers in university–enterprise cooperation. Under these dual forces, university-led makerspaces gradually expanded from dispersed campus-adjacent sites toward the outer rings and formed three major clusters.

4.3 Private-Enterprise-Led Makerspaces: Increasing Industrial Specialization

Enterprises are the most important market actors and the direct creators of economic value in innovation activities [19]. They are typically profit-oriented, emphasize industrial-chain integration [30], and seek to enlarge scale in order to strengthen competitiveness. Private-enterprise-led makerspaces are therefore closely connected to the market, provide innovation services characterized by market allocation, respond rapidly to market change, and possess stronger potential for self-sustaining operation. These advantages encourage locations near markets, production bases, and established industrial clusters.

Driven by profitability and market sensitivity, private enterprises rapidly responded to the early policy dividends of innovation and established makerspaces to reduce costs. Private-enterprise-led makerspaces consequently clustered strongly in Chengdu Hi-tech South Zone in 2015, reflecting a clear early preference for innovation hotspots. GG Café stated that it selected the area because “innovation policies in the Hi-tech South Zone were relatively favorable,” demonstrating the strong locational pull of early policy incentives. The same operator in Pidu District, however, observed that incubators in the Hi-tech South Zone shifted from intense competition for tenants in 2016 to partial withdrawal by 2023, indicating subsequent decline.

As the sector matured, private-enterprise-led makerspaces placed greater emphasis on industrial scale and sustainable development. Under market pressure and profitability requirements, they optimized industrial chains to reduce costs [31] and moved closer to production origins, markets, and clusters in the same industrial category. HXJ Horticulture Industry Technology Incubator stated that it was “established on the basis of local flower and nursery-stock production.” Such industry-chain-based location choices reveal a trend toward industrial specialization. A classification of the industrial orientation of private-enterprise-led clusters③ (Table 1) shows that in 2015 the numbers of makerspaces with and without a specific industrial orientation were similar. By 2022, however, makerspaces dominated by a specific industrial category outnumbered general-purpose spaces by roughly three to one. Private-enterprise-led makerspaces had therefore become increasingly specialized and increasingly aligned with clusters in the corresponding industry.

Table 1. Changes in the industrial composition of private-enterprise-led makerspace clusters

Private-	No specific industry orientation	Dominated by a specific industry

enterprise-led makerspace cluster		category		
	Number	Share (%)	Number	Share (%)
New clusters in 2022	11	25.58	32	74.42
Existing clusters in 2022	14	22.22	49	77.78
Clusters in 2015	10	40.00	15	60.00

Industrial policy reinforced this trend. By promoting the formation of specific industry clusters, it attracted makerspaces in the corresponding category. YCBK Biomedical Innovation Nursery in Pidu District reported that "local policy support and surrounding industrial agglomeration influenced the location choice." Newly established industrial development zones in Wenjiang and Pidu, focused on pharmaceuticals and modern agriculture, facilitated the formation of specialized local clusters and attracted makerspaces in those fields. The interaction of market conditions and industrial policy thus generated new private-enterprise-led clusters.

5 Synthesis of Spatiotemporal Evolution Patterns and Their Logic

Because the three leading actors differ in operating objectives and comparative advantages, the three makerspace types follow distinct locational logics (Figure 3). Government-led makerspaces seek to cultivate an innovation climate and serve designated groups; supported by low rental pressure and rapid policy feedback, they favor the urban core and priority innovation-driven districts. University-led makerspaces respond to talent needs and the commercialization of research; supported by talent, technology, and government land provision, they favor research institutions and government–industry cooperation zones. Private-enterprise-led makerspaces pursue profitability and scale expansion; because of their market sensitivity, they favor policy-incentive zones, markets, production origins, and clusters in the same industrial category.

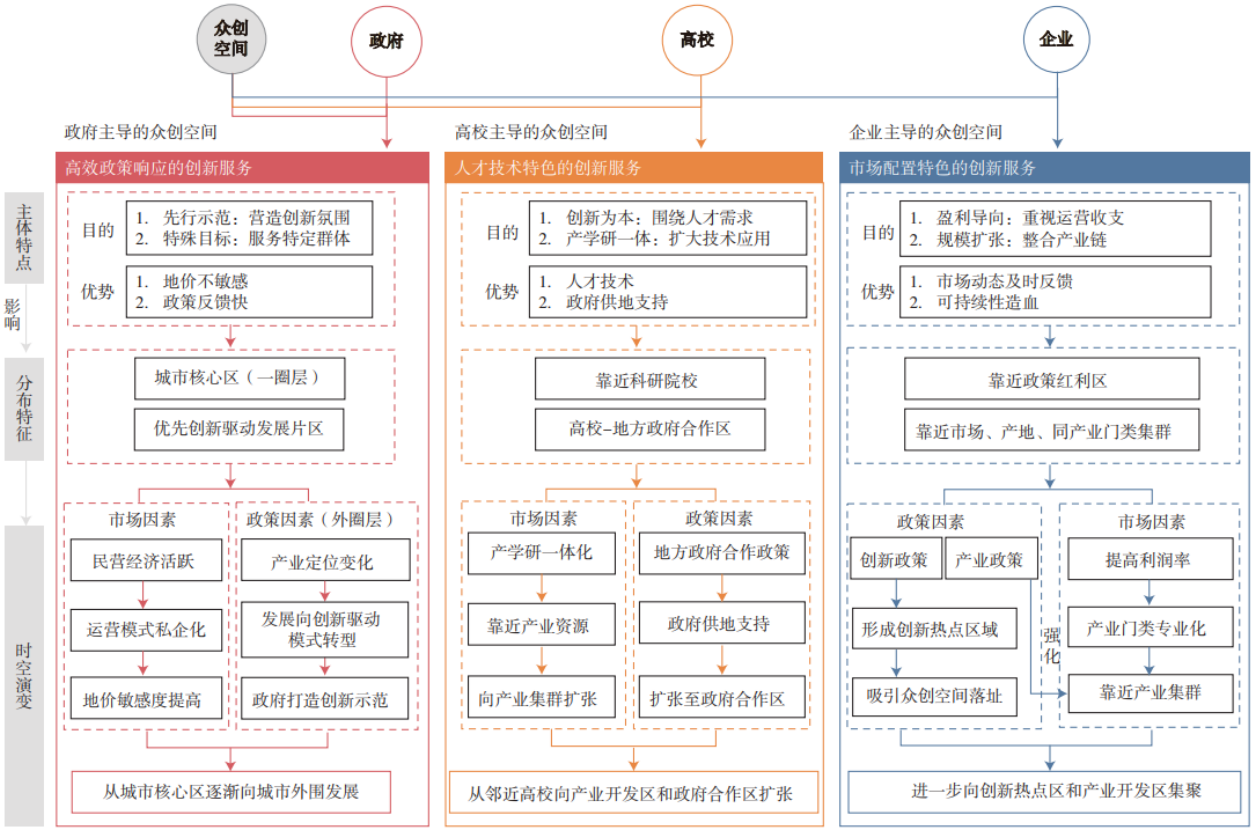

Figure 3. Synthesis of the spatiotemporal evolution logic of makerspaces led by different actors

Under this mechanism, the three types exhibited different distributions during their initial and mature stages. In the initial stage [Figure 4(a)], government-led makerspaces clustered in the urban core and innovation-driven districts because they faced relatively little land-price pressure and were intended to create an innovation climate. University-led makerspaces located around campuses in response to faculty and student entrepreneurship needs. Private-enterprise-led makerspaces clustered in innovation-driven districts because of policy incentives. Their early geography therefore reflected the functional characteristics of a single helix: government-led spaces emphasized policy response, university-led spaces centered on talent and technology, and enterprise-led spaces emphasized market allocation. The three types were functionally complementary but interacted only weakly.

As the sector matured, the locational pattern changed [Figure 4(b)]. Government-led makerspaces expanded toward the second ring because privatization reforms increased their sensitivity to land costs and because governments in second-ring districts increasingly prioritized innovation-driven industries. University-led makerspaces clustered in industrial development zones and government cooperation zones because universities sought broader market connections for technology transfer, while governments attempted to attract university-led spaces to their jurisdictions. Private-enterprise-led makerspaces continued to concentrate in innovation-driven areas under the pull of innovation policy and, with increasing industrial specialization, moved toward industrial development zones. Makerspace locations therefore became progressively shaped by the influence of other helices.

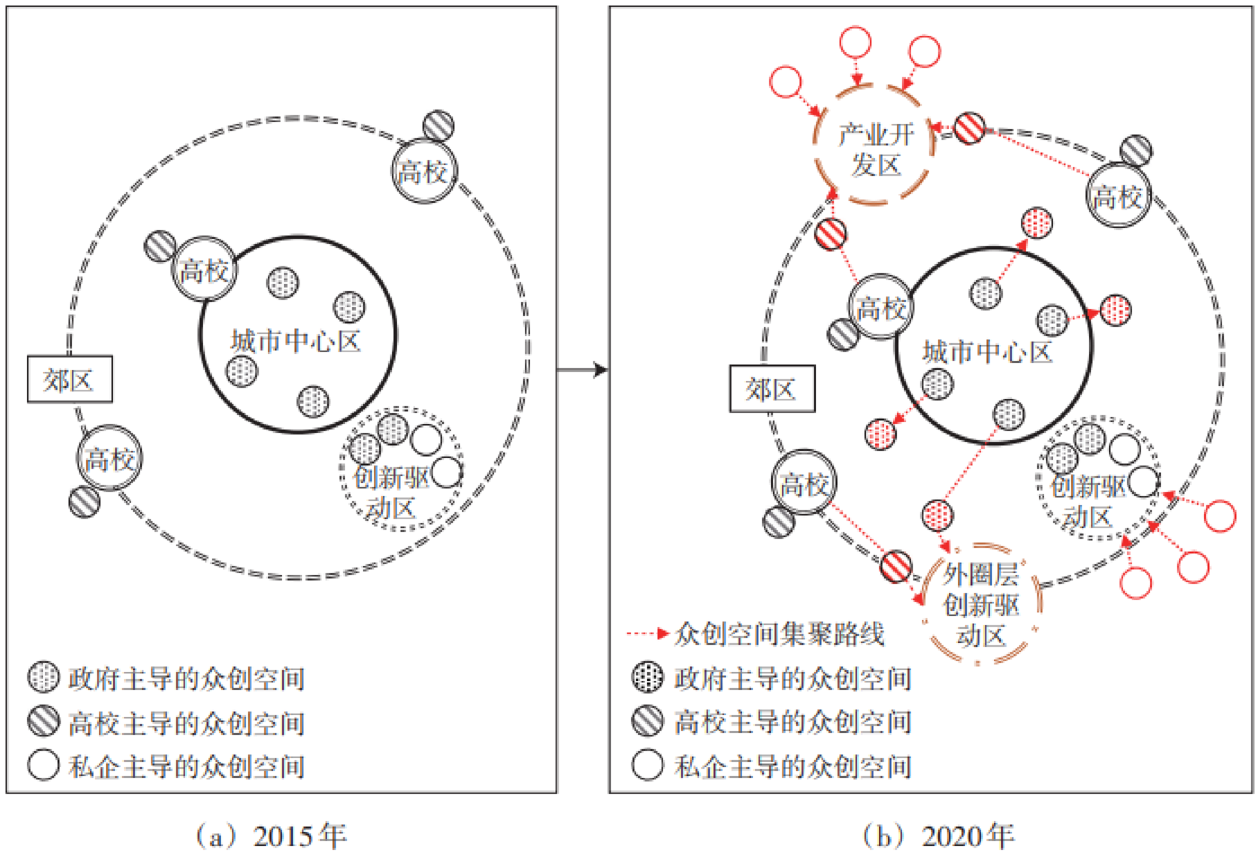

Figure 4. Spatiotemporal evolution patterns of makerspaces led by different actors

Note: Red elements in Figure 4(b) indicate changes.

This process can be interpreted as a transformation in relations among the actors in the innovation helix. During the early stage, the three helices remained largely in a phase of single-actor cooperation, producing a pattern of “one actor + makerspace.” Their functions were complementary, but interaction remained limited. As the system matured, each helix actively sought to incorporate the advantages of the others in response to its own development needs, and relations gradually shifted from “functional complementarity” to “mutual reinforcement of demand.” According to the neo-evolutionary mechanism of the triple helix, government, universities, and enterprises extend their functions through dynamic interaction during the evolution of innovation [21]. This interaction is driven primarily by each actor’s expectation of profits, although the substantive meaning of “profit” differs among actors [20]. This study interprets such expectations more broadly as “development needs” and uses the helix framework to specify how these needs mutually reinforce one another (Figure 5). Government, universities, and enterprises pursue cross-helix cooperation through the makerspace intermediary. This process enables actor-led makerspaces to absorb the differentiated functions of other actors and generates new spatial responses under their influence.

More specifically: (1) Government seeks university cooperation in order to promote knowledge-driven regional innovation, thereby encouraging university-led makerspaces to cluster in government–university science and technology cooperation zones. Government also uses policy incentives to cultivate a regional innovation climate, strengthening the concentration of private-enterprise-led makerspaces in innovation-driven and other policy-favored areas. (2) Universities, seeking to commercialize scientific and technological achievements, participate in the optimization and upgrading of private industrial chains [25], promoting university–enterprise cooperative makerspaces in industrial development zones. To support student employment and disseminate research outcomes, universities also respond to local government innovation initiatives and establish government–university cooperative makerspaces in designated cooperation zones. (3) Enterprise development advances marketization, prompting government-led makerspaces to adopt private-sector operating models and expand toward the urban periphery. At the same time, enterprises pursuing high-value-added industrial chains cooperate with universities that possess talent and technology, encouraging market-oriented research collaboration in university-led makerspaces and drawing them toward industrial development zones. Overall, as makerspaces move from initial development to maturity, the major helices shift from functional complementarity to mutual reinforcement of demand. Leadership becomes increasingly hybrid rather than dominated by a single helix, and this transformation reshapes location patterns.

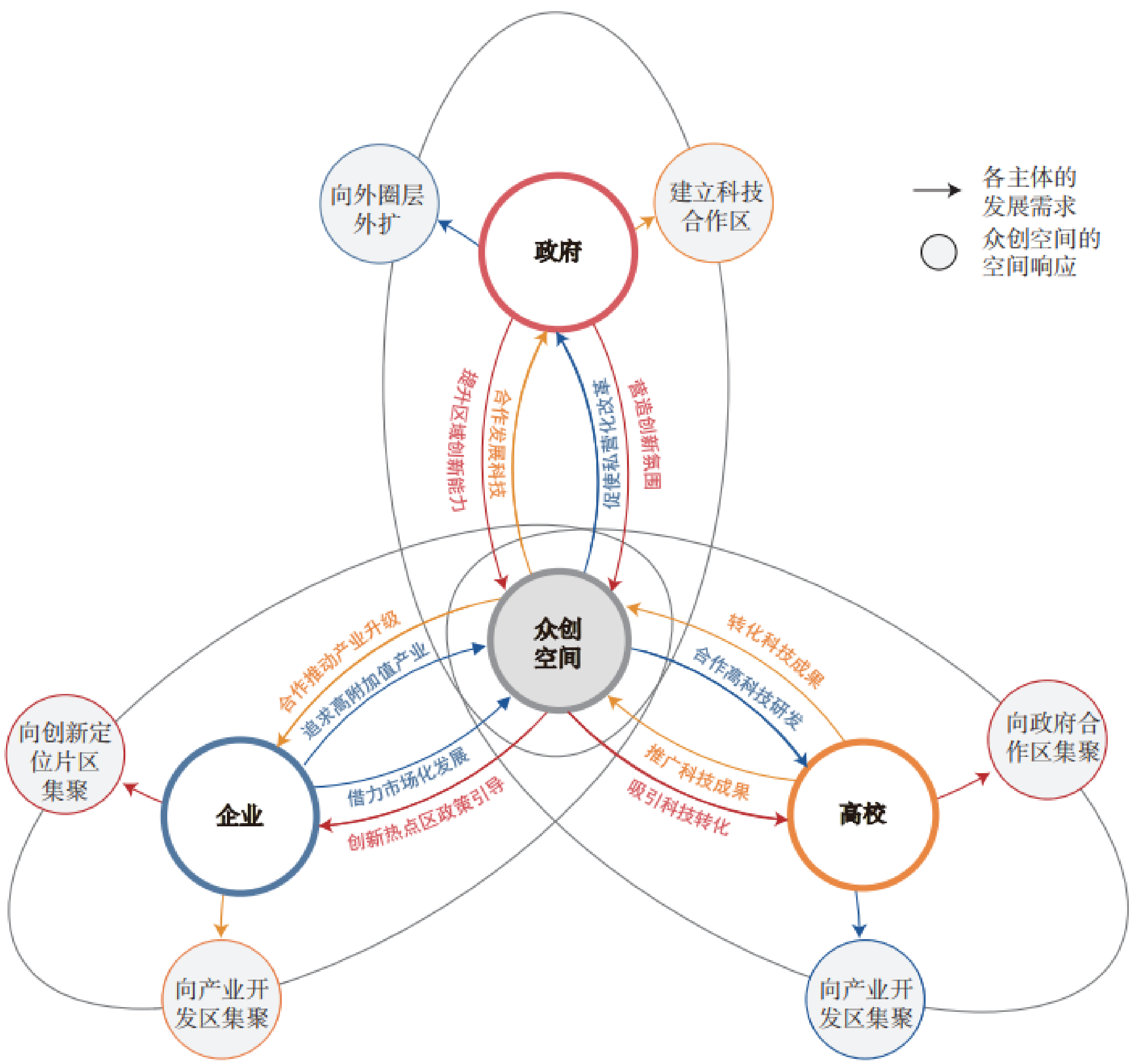

Figure 5. Mechanism of mutual demand reinforcement among the principal actors of makerspaces

6 Conclusions and Recommendations

Using the innovation helix model, this study analyzed the spatiotemporal evolution of government-, university-, and private-enterprise-led makerspaces in Chengdu. Three main conclusions emerge. First, because of their demonstrative role in innovation policy and their relative advantage in absorbing land costs, government-led makerspaces clustered early in the urban core. As operation became more market-oriented and peripheral districts placed greater emphasis on innovation-driven growth, they gradually expanded outward. Second, under the combined influence of technology-transfer needs and government cooperation, university-led makerspaces evolved from dispersed campus-adjacent locations into clusters in industrial development zones and government cooperation areas. Third, private-enterprise-led makerspaces were profit-oriented: they initially concentrated in innovation hotspots because of policy dividends, but subsequently became more specialized by industrial category and moved toward industrial development zones under the joint influence of markets and government.

The three types also face different practical challenges. (1) Government-led makerspaces remain highly policy-dependent, and differences in the transparency and efficiency with which government-led and private-enterprise-led makerspaces access policy support can undermine market fairness. Government-led spaces should strengthen their capacity for sustainable self-financing and balance preferential policy with market-based operation. Their location should not be limited to policy hotspots; they should expand toward peripheral areas, connect with industrial clusters, and deepen market-oriented operation. (2) Communication barriers persist between universities and enterprises. University–enterprise incubator exchange platforms should be established to improve industrial matching and the success rate of collaboration. Industrial development zones should attract university-led makerspaces in corresponding industrial fields, build specialized talent and technology ecosystems, and facilitate bilateral cooperation. (3) Private-enterprise-led makerspaces were strongly policy-following in the early stage but later encountered ambiguous development positioning; some chain-based makerspaces failed to adapt to local markets. Policy should respond to their actual development drivers, relying primarily on indirect, enabling industrial policy and secondarily on direct innovation subsidies. Once they expand in scale, they should be guided toward production bases, markets, and industrial clusters to support sustainable growth.

The sample was drawn from the official list of innovation and entrepreneurship carriers and represents one of the most comprehensive and objective currently available collections of Chengdu makerspaces. Nevertheless, the limited sample size may constrain the generalizability of the conclusions. Future studies can use big data to broaden information channels and expand the sample, thereby testing and extending the findings. As interaction among the helices intensifies, further research should also examine the operating models and location factors of makerspaces jointly led by multiple actors.

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Notes

① After excluding three socially oriented nonprofit makerspaces not covered by the triple helix model, the 2022 sample comprised 16.8% government-led, 19.0% university-led, and 62.9% private-enterprise-led makerspaces. According to the Chengdu Science and Technology Bureau’s Annual Report on Incubators and Makerspaces in Chengdu (2022), government departments (government institutions only), state-owned enterprises (including universities), and private enterprises accounted for 9.16%, 25.64%, and 61.17%, respectively. Given the different classification standards, the results of this study are broadly consistent with the official report.

② The Chengdu 14th Five-Year Water Development Plan defines Jinniu, Chenghua, Qingyang, Jinjiang, Wuhou, and Chengdu Hi-tech Zone as the central urban area (the first urban ring); the central urban area plus Pidu, Wenjiang, Xindu, Qingbaijiang, Longquanyi, Tianfu New Area, Shuangliu, and Xinjin as the main urban area (the second urban ring); and the remaining districts and counties as general areas (the third urban ring).

③ Based on the industrial categories in Chengdu's Outline of the 14th Five-Year Plan for National Economic and Social Development and the Long-Range Objectives through 2035 and the Chengdu Industrial Development White Paper (2019), makerspaces that selectively recruit entrepreneurial teams in research and manufacturing, modern services, or new-economy industries are classified as having a specific industrial orientation. Makerspaces without such selection are classified as general-purpose spaces with no specific industrial orientation.

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