

**THE BIOMIMICRY PARADIGM:
INNOVATION HUBS AS CATALYSERS OF
BIO-INSPIRED INNOVATIONS**

Candidate 632103

Candidate: Cassandre Pochon

Supervisor: Prof. Filiberto Brozzetti

Co-Supervisor: Prof. Luna Kappler

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**We're not a bad species,
we're just a young one**

Some of the earliest branches on the tree of life date back 2.4 billion years.

Humans, we've only been present for 2 million.

We're young, and perhaps a bit naïve.. but we can all agree - smoking isn't cool.

Biomimicry provides a way to learn from our ecological wise elders and brings hope to a world in
need to rethink our place on earth.

It's time we shift the paradigm from ~~doing less bad~~ to doing more good.

From Learn Biomimicry Institute ¹

To All Dreamers of a world united in harmony...

¹ <https://www.learnbiomimicry.com/>

Abstract

At its core, biomimetic ethics holds that nature should be seen not just as an "object" but as a vital source of ethical guidance (Dicks, 2020)². Dicks criticizes the anthropocentric perspective and suggests that by studying natural systems we can derive a "set of generally applicable ethical laws and principles derived from Nature," such as biodiversity, reciprocity, and sustainability. He notes: "if it is true that all or almost all diversity in Nature is biodiversity, then it would need to be decided whether to include other forms of diversity (cultural, etc.) in the corresponding principle of human action." Mathews adds that bioinclusive ethics must move from theory to practice or risk remaining a superficial design tool rather than a transformative cultural ethos (Mathews, 2011)³.

This thesis investigates the role of innovation hubs and transitional urban spaces in accelerating the diffusion of bio-inspired innovations in Europe. Despite a global biomimetics market valued at approximately USD 39.5 billion in 2024 and projected to exceed USD 90 billion by 2032⁴, bio-inspired solutions face a persistent diffusion paradox: roughly 70% of projects fail to progress beyond Technology Readiness Level (TRL) 5, not because of technological immaturity but because of systemic ecosystem inadequacy. Drawing on the Multi-Level Perspective on socio-technical transitions (Geels, 2002), the Co-Cities collaborative governance framework (Iaione, 2024), and an original Biomimetic Systemic Evaluation (BSE) methodology grounded in forest ecology principles, this research employs a qualitative comparative case study design across six European innovation hubs. Semi-structured interviews with key stakeholders from CEEBIOS, Climate House, Bioregion Institute, and WoMA, combined with secondary policy and market data, reveal that innovation hubs function as INUS conditions (Mackie⁵, 1965) for bio-inspired innovation diffusion: they are insufficient alone yet non-redundant within the combination of factors enabling TRL transition. The research identifies the manufacturing process gap at TRL 6–7 as the main current structural bottleneck.

It proposes the Archipelago Model, an ecologically inspired framework for scaling bio-inspired innovation through geographically distributed, locally adapted, and mycorrhizally connected hub networks, rather than through linear replication. The thesis contributes a 12 hubs typology cross-referenced with TRL stages, and application of forest ecosystem principles (BSE

² Dicks H. *Environmental Ethics and Biomimetic Ethics: Nature as Object of Ethics and Nature as Source of Ethics*. *J. Agric. Environ. Ethics*. 2017;30:255–274. doi: 10.1007/s10806-017-9667-6.

³ Mathews F. *Biomimicry and the Problem of Praxis*. *Environ. Values*. 2019;28:573–600. doi: 10.3197/096327119X15579936382400.

⁴ *Biomimetics Market - Global Forecast 2026-2032- Research Market*
<https://www.researchandmarkets.com/report/biomimetic?srsId=AfmBOoojBr2nmWTd9sxirc90otRTBwKBj1eQIRHKTjzr9Ghb8Ow6bzjb>

⁵ Mackie, J. L. (1965). Causes and conditions. In *Philosophy of science: Selected readings* (pp. 178–186).

framework) to innovation hub evaluation, and operational recommendations for hub managers, policymakers, researchers, and investors.

Keywords: biomimicry, innovation hubs, bio-inspired solutions, nature-based solutions, socio-technical transitions, Multi-Level Perspective, collaborative governance, quintuple helix Technology Readiness Levels, third places, urban commons

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Chapter 1: Introduction

Nature offers a radically different paradigm. Janine Benyus (1997) introduced the concept of biomimicry, emphasizing how organisms have evolved solutions over 3.8 billion years to challenges such as energy efficiency, material optimization, waste elimination, and adaptive resilience. As she stated, “The more our world functions like the natural world, the more likely we are to endure on this home that is ours, but not ours alone”.⁶

Cooperation is a core value taught by the living world, where no organism survives alone. This idea aligns with famous Philippe Descola’s anthropological work on moving beyond anthropocentrism, recognizing interspecies and human-nonhuman cooperation as essential for ecosystem integration.⁷

Economically, the World Economic Forum (2023) projects that climate adaptation will create 9,6 million new jobs globally by 2030, ranking it as the third-largest source of job creation worldwide.⁸ In France, the *Secrétariat Général à la Planification Écologique* estimates between 200,000 et new jobs by 2030, in construction, energy and mobility sectors, while also highlighting the need to train around 3 million workers to meet the demands of this transition.⁹ According to the United Nations Department of Economic and Social Affairs. (2018), 68% of the world population is projected to live in urban areas by 2050, intensifying pressure on natural systems and biodiversity.¹⁰

According to a study by ADEME, CEEBIOS, Myceco, and Vertigo Lab, the biomimicry sector would create more than 280,500 jobs in the building industry and might generate wealth amounting to €133 billion across all sectors. This represents nearly 5.5% of France’s national GDP by 2030.¹¹

An optimistic vision, especially when the built environment stands at a critical crossroads. According to the United Nations Environment Programme (UNEP, 2023), the construction sector alone accounts for approximately 34% of global CO₂ emissions related to energy and

⁶ Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. HaperCollins

⁷ Philippe Descola. (2005). *Beyond nature and culture*. University of Chicago Press.

⁸ World Economic Forum. (2023). *The future of jobs report 2023*.

https://www3.weforum.org/docs/WEF_Future_of_Jobs_2023.pdf

⁹ Secrétariat Général à la Planification Écologique. (Sept 2025). *Mettre en œuvre la planification écologique des emplois et des compétences à l'échelle des territoires*. <https://www.strategie-plan.gouv.fr>

¹⁰ United Nations Environment Programme. (2022). *Global status report for buildings and construction 2022*. <https://www.unep.org/resources/report/global-status-report-buildings-and-construction-2022>

¹¹ <https://vertigolab.eu/wp-content/uploads/2021/03/infographie-biomimexpo-VFF.pdf>

industrial processes, 40% of raw material extraction, and contributes to 30% of landfill waste from construction, renovation, and demolition activities.¹²

Biomimicry appears as the systematic study of nature's models, processes, and ecosystems to solve human challenges. And has emerged as one of the most promising paradigms for ecological transition. The field has produced an expanding portfolio of innovations, from self-healing concrete using bacterial mechanisms to hydrophobic surfaces inspired by the coating of lotus leave, from termite-inspired passive ventilation systems to wetland-inspired urban water management. France hosts a particularly dense ecosystem: CEEBIOS, the European centre of excellence in biomimicry established in Senlis in 2014, coordinates research across over sixty partner organisations. And BiomimExpo is the first biennial biomimicry conference, attracts 10,000 participants and generates over 100,000 views (BiomimExpo, 2025).¹³

Although many bio-inspired technologies have proven their technical performance, the cultural integration efforts led by CEEBIOS in France are only beginning to attract a growing range of stakeholders. The prospect of a true symbiosis with, and adoption of, the codes of the living world may still seem distant. The biomimicry ecosystem in France is striving to develop, and this requires cooperation among multiple actors.

Alain Renaudin, founder of Biomimexpo, advocates in his manifesto for a bio-inspired city¹⁴ the importance of working collaboratively with the living world. Nature operates in cycles: “one organism’s waste is another’s food.” Within this logic of territorial locality, cooperation, and expansion, it becomes essential to understand the role of infrastructures that use materials and techniques inspired by natural processes.

Yet this scientific and entrepreneurial dynamism masks a structural paradox. Approximately 70% of bio-inspired projects fail to progress beyond TRL 5 (Chirazi et al., 2019)¹⁵. Blanco et al. (2021)¹⁶, conducting the most rigorous available analysis of French biomimetic urban projects across sixteen cases spanning 2007–2019, found that only 44% were constructed or under construction, while 31% were rejected by contracting authorities, not because of technical infeasibility but because of regulatory incompatibility, temporal misalignment, lack of investments and trust from stakeholders and absence of facilitated supply chains.

Grounded in the biomimetic philosophy of “With-and-For-Biomimicry,” and supported by both quantitative and qualitative data, this thesis will empirically explore: *How Innovation hubs can*

¹² UNEP (2023) Building Materials And The Climate: Constructing A New Future

¹³ <https://biomimexpo.com/>

¹⁴ Alain renaudin (2022) For a new vision of the city, inspired by nature.
<https://newcorpconseil.com/en/2021/05/16/la-ville-biomimetique/>

¹⁵ Jacques Chirazi, Kristina Wanieck, Pierre-Emmanuel Fayemi , Cordt Zollfrank and Shoshanah Jacobs, 2019, *What Do We Learn from Good Practices of Biologically Inspired Design in Innovation?*

¹⁶ Blanco, E., Cruz, E., Laroque, C., Raskin, K., & Clergeau, P. (2021). Biomimicry in French urban projects: Trends and perspectives from the practice. *Biomimetics*, 6(2), 27. <https://doi.org/10.3390/biomimetics6020027>

catalyze bio-inspired innovations, and what systemic conditions enable experimental niches to transition into transformed norms?

The question unfolds into three sub-clusters. First, what systemic barriers impede the diffusion of bio-inspired innovations, and why do viable projects remain at the prospective stage in the actual state? Second, how do innovation hubs function as facilitator spaces for bio-inspired innovations, and what governance models facilitate their integration? Third, what factors differentiate successful bio-inspired hubs from those that stagnate, and how can a scaling strategy be constructed through interconnected networks to expand biomimicry?

The research employs a qualitative comparative case study design, analysing eight European innovation hubs, CEEBIOS (Senlis), Climate House (Paris), Blue City Lab (Rotterdam), WoMA (Paris), Darwin Ecosystem (Bordeaux), and Campus de la Transition (Forges) — alongside three bio-inspired innovation trajectories (Ecovative Design, Mogu, and Bioregion Institute). Data collection combines semi-structured interviews with key stakeholders, secondary policy and market analysis, and the application of LabGov's Co-Cities JuSIIA evaluation framework. The analytical framework integrates the Multi-Level Perspective on socio-technical transitions (Geels, 2002), the Co-Cities collaborative governance methodology (Iaione, 2024), and an original Biomimetic Systemic Evaluation (BSE) framework grounded in seven forest ecology principles.

This thesis produces a set of three main contributions, each designed to add value in a distinct way. First, the theoretical contribution works to bridge the biomimicry literature with transition studies and urban commons theory, while also exploring the idea of the Mycorrhizal connection as a way to better understand how bio-inspired innovations diffuse through networks of infrastructure and diverse stakeholders. Second, the empirical contribution provides a systematic and detailed mapping of European innovation hubs that are currently engaged with bio-inspired solutions, using LabGov's analytical framework, and offers a cross-case analysis of success and failure trajectories to highlight the factors that matter most. Third, the practical contribution takes the form of operational recommendations, articulated through the Archipelago Model, which is an ecologically inspired scaling strategy that moves beyond linear replication in favour of distributed and locally adapted innovation networks, aiming to support the long-term diffusion of these solutions.

The organization of this thesis is itself inspired by the logic of the natural ecosystems under examination, offering a structure that mirrors the layered complexity found in nature. Following this introduction, Chapter 2 presents the theoretical framework and literature review, shedding light on the intersections between biomimicry, transition (spaces) studies, (innovation ecosystems) and collaborative governance. Chapter 3 is dedicated to an explanation of the methodology used. Chapter 4 delves into the policy and market context, as well as the barriers

that currently limit the diffusion and adoption of bio-inspired innovation, with a focus on the construction sector and bio-materials use. Chapter 5 is where the main findings are presented, including typologies, case studies, comparative analyses, and the various innovation trajectories observed. In Chapter 6, the discussion is drawn together through the lens of the Archipelago Model, with the aim of transforming the research insights into practical guidance for the field. Finally, Chapter 7 concludes the thesis by outlining its limitations, identifying promising avenues for future research, and reflecting on the importance of ensuring that the very structure of our research mirrors the systems we aspire to transform.

Chapter 2: Theoretical Framework and Literature Review

2.1 Biomimicry: Definitions and Levels

Biomimicry, from the Greek *bios* (life) and *mimesis* (imitation), designates the systematic study of nature's models, processes, and ecosystems to draw inspiration for solving human challenges. The concept was formalised by Benyus (1997), though its intellectual lineage extends to Leonardo da Vinci's flight studies and the bionics movement of the 1960s. What distinguishes contemporary biomimicry from earlier bio-inspiration is its explicit normative commitment: not merely copying nature, but learning from evolutionary optimisation to design systems compatible with planetary boundaries.

The International Organization for Standardization has codified three distinct levels through ISO 18458 (2015)¹⁷, providing the analytical framework this thesis adopts. The *form* level involves imitating morphological features of organisms, such as the Shinkansen bullet train nose inspired by the kingfisher beak. The *process* level replicates biological manufacturing or functional mechanisms, such as self-healing concrete using bacteria. The *ecosystem* level emulates systemic principles - circularity, symbiosis, resilience - as exemplified by industrial symbiosis and regenerative urban design (Blanco, 2022). This thesis operates primarily at the ecosystem level, where the analytical challenge is greatest and the transformative potential highest. As Blanco argues in his doctoral work at the National Museum of Natural History (MNHN)¹⁸, *ecosystem-level biomimicry* requires designers to move beyond individual buildings toward understanding urban systems as living organisms with metabolic flows, succession dynamics, and symbiotic relationships. (See Annex 1)

2.2 The Paradox of Non-Diffusion

The persistent gap between the demonstrated technical performance of bio-inspired solutions and their limited adoption in the market forms the central empirical puzzle that motivates this

¹⁷ ISO 18458. (2015). *Biomimetics — Terminology, concepts and methodology*. International Organization for Standardization.

¹⁸ Blanco, E. (2022). *Producing benefits for nature and society: An ecosystem biomimicry and regenerative design framework*. Doctoral Thesis, Muséum National d'Histoire Naturelle. <https://theses.hal.science/tel-04967574v1/document>

research. Quantitative data paint a picture of a field experiencing rapid expansion, as the European market for bio-inspired technologies now accounts for roughly 30% of the global total and was valued at an estimated USD 11.85 billion in 2024 (Cognitive Market Research, 2026). Medical applications dominate this market with a reported CAGR of 7.4%, while the bio-materials segment is also growing steadily at 6.1% (Mordor Intelligence, 2026). Despite these encouraging figures, the actual penetration of bio-inspired solutions into mainstream construction and urban planning remains minimal. Nature-based solutions, for instance, continue to rely overwhelmingly on public funding, 97% of total financing, while 72% of such projects occupy less than one square kilometre in scale (European Investment Bank, 2023). Chirazi et al. (2019) provide a particularly striking quantification of the current situation, estimating that approximately 70% of bio-inspired projects fail to achieve commercial viability. While this high failure rate is consistent with trends observed throughout the broader deep-tech ecosystem, it should not be interpreted as evidence of an inherent weakness in bio-inspired approaches themselves. Instead, it points to the lack of appropriate infrastructure needed for the maturation and stabilisation of these innovations. Traditional venture capital models typically anticipate returns within a relatively short time frame of 5 to 7 years, whereas bio-inspired material innovations often require anywhere from 7 to 15 years to progress from proof of concept to full industrial certification (McNish & van Erp, 2025). The case of Ecovative Design, now recognised as the world's most successful mycelium-based materials company, is instructive: it took eighteen years (2007–2025) for the company to reach commercial scale. This temporal incompatibility, where the rhythms of capital expectations and biological innovation remain fundamentally misaligned, represents a structural barrier that goes far beyond a simple issue of project management.

According to the OECD Report¹⁹, on The development and diffusion of bio-inspired innovations, particularly in sustainable construction and urban rehabilitation, represent a rapidly growing area of technological advancement with significant socio-economic and environmental implications. Over the past decade, patent filings related to bio-inspired technologies and bio-based materials have increased at an average annual rate of 8 to 10 percent globally, reaching over 15,000 patents filed worldwide in 2021 alone (WIPO, 2022). Europe accounts for a substantial share of these innovations, with approximately 12 percent of patents in sustainable technologies attributed to bio-inspired materials, concentrated primarily in countries such as Germany, France, and the Netherlands. In France specifically, Technology Transfer Acceleration Companies (SATTs) and technical centers have contributed to more than 300 patents in the last five years in the fields of bioeconomy and sustainable materials, a significant portion of which is dedicated to bio-inspired construction materials (SATT France, 2022). These innovations are not only technological achievements but also drivers of green job creation, particularly in rural and industrial regions undergoing economic transition. Moreover, the adoption of bio-inspired materials in construction could reduce carbon emissions by 15 to

¹⁹ Peñalosa, P. and L. Kleine-Rueschkamp (2024), “The geography of green innovation hubs in OECD regions”, *OECD Local Economic and Employment Development (LEED) Papers*, No. 2024/09, OECD Publishing, Paris, <https://doi.org/10.1787/c48ad2b1-en>.

25 percent, addressing a critical sector that accounts for nearly 40 percent of global energy consumption (ADEME, 2021).

2.3 The Literature Gap

Existing scholarship exhibits three blind spots that this research addresses. First, the *infrastructure gap*: the extensive biomimicry literature (Benyus, 1997; Pawlyn, 2011; Pedersen Zari, 2018; Blanco, 2022) documents what bio-inspired solutions can achieve but largely neglects the institutional and spatial conditions required for their deployment. Second, the *governance gap*: the third-places and innovation hub literature (Oldenburg, 1989; Moriset, 2013; Fournier et al., 2024), France alone counts 3,500+ tiers-lieux (France Tiers-Lieux, 2024), almost entirely ignores bio-inspired innovation as a use case yet. Conversely, biomimicry scholarship treats governance as exogenous rather than constitutive of innovation outcomes. Third, the *diffusion mechanism gap*, innovation diffusion theory (Rogers, 1962; Geels, 2002) provides powerful macro-level frameworks but lacks operational specificity for the bio-materials sector, where biological temporalities, regulatory barriers, and cultural resistance create a uniquely challenging diffusion environment. The Strategic Niche Management literature (Kemp et al., 1998; Schot & Geels, 2008) theorises protective spaces but does not examine their physical instantiation in contemporary urban innovation hubs.

This thesis sits at the intersection of these literatures, proposing that innovation hubs function as the missing infrastructure connecting bio-inspired research (TRL 1–3) to market adoption (TRL 8–9) through the valley of death (TRL 4–7).

2.4 FRAMEWORKS

2.4.1 Multi-Level Perspective (MLP)

This thesis adopts the Multi-Level Perspective (MLP) on socio-technical transitions (Geels, 2002, 2004) as its primary analytical framework. The MLP distinguishes three analytical levels. The *landscape* level comprises macro-level trends and exogenous pressures: climate emergency, resource depletion, biodiversity crisis, and the European Green Deal regulatory architecture. The *regime* level denotes the established socio-technical configuration: conventional construction materials, linear supply chains, prescriptive building codes, and incumbent industrial actors. The *niche* level is where radical innovations emerge, protected from regime selection pressures.

Geels (2002) argues that transitions occur when landscape pressures destabilise the regime, creating windows of opportunity for niche innovations to break through. This framework has been applied to energy transitions (Verbong & Geels, 2007), transport (Nykivist & Whitmarsh, 2008), and agriculture (Smith, 2007), but has not been systematically applied to bio-inspired innovation ecosystems, a gap that this thesis aims to address.

The *Multi-Level Perspective* (Geels, 2002, 2004) functions as the thesis's macro-analytical architecture, providing the overarching explanatory structure for why bio-inspired innovations face diffusion barriers. MLP distinguishes three levels, landscape (exogenous pressures), regime (established socio-technical configuration), and niche (protected spaces for radical innovation), and theorizes transitions as occurring when landscape pressures destabilize regimes, creating windows for niche breakthroughs. MLP explains *why* bio-inspired innovations remain trapped at low TRL despite technical viability. The construction regime (regime level) resists bio-materials through path dependency, sunk costs in conventional supply chains, and institutional alignment around established technologies. Landscape pressures (climate crisis, biodiversity collapse, circular economy mandates) create destabilization but prove insufficient alone. Innovation hubs constitute physical instantiations of protective niches, providing the three functions Kemp et al. (1998) identify: shielding, nurturing, empowerment. MLP is chosen as primary framework because the research question concerns diffusion dynamics, fundamentally a transitions problem. All other frameworks serve MLP by specifying mechanisms at finer analytical resolution.²⁰

²⁰ Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, 41(6), 1025–1036. <https://doi.org/10.1016/j.respol.2011.12.012>

2.4.2 Innovation Hubs as Ecotones

An ecological analogy that frames innovation hubs is *ecotones*, these transitional zones between distinct ecological communities that exhibit higher biodiversity, productivity, and evolutionary potential than either adjacent community alone (Odum, 1971; Risser, 1995). In landscape ecology, ecotones such as forest edges, wetland margins, and river estuaries are recognised as hotspots of biological activity precisely because they combine resources, organisms, and environmental conditions from multiple adjoining systems.

Translated to the socio-technical landscape: innovation hubs occupy the transitional zone between the established construction regime and the emerging bio-inspired niche. Like biological ecotones, hubs are productive precisely because they are liminal — neither fully regime nor fully niche, permitting exchanges, hybridizations, and emergent combinations that neither system alone could generate.

This analogy yields three testable propositions. The proposition 1 suggests that hubs with greater actor diversity will exhibit higher innovation output and more diverse bio-inspired projects. The 2nd proposition suggests that hubs positioned at institutional boundaries will be more effective than those fully embedded within a single institutional sphere. And proposition 3 is about hub effectiveness depends on boundary permeability, the degree to which knowledge, materials, people, and resources flow between the hub and its environment, rather than on the hub's internal resources alone.

Forest Ecology Principles transform in Biomimicry System Evaluation (BSE)

The thesis's original theoretical contribution is the Biomimetic Systemic Evaluation (EBS) framework, which translates seven forest ecosystem principles into evaluative criteria for innovation hubs. The premise is epistemologically coherent with the thesis's subject: if we argue that innovation hubs should catalyse bio-inspired solutions, then the analytical tools used to evaluate these hubs should themselves be bio-inspired.

The seven principles are: (1) *Communication*, drawing on mycorrhizal network research (Simard et al., 1997)²¹ demonstrating that forest trees share resources and chemical signals through underground fungal networks, transposed as knowledge-sharing density among hub participants; (2) *Circularity*, reflecting closed-loop nutrient cycling in forest ecosystems (Odum, 1969)²², transposed as waste-to-resource flows in hub operations; (3) *Symbiosis*, based on mutualistic relationships that characterise healthy ecosystems, transposed as the diversity

²¹ Simard, S. W., Perry, D. A., Jones, M. D., Myrold, D. D., Durall, D. M., & Molina, R. (1997). Net transfer of carbon between ectomycorrhizal tree species in the field. *Nature*, 388(6642), 579-582. <https://doi.org/10.1038/41557>

²² Odum, E. P. (1969). The strategy of ecosystem development. *Science*, 164(3877), 262-270. <https://doi.org/10.1126/science.164.3877.262>

and mutuality of partnerships within and beyond the hub; (4) *Resilience*, drawing on functional redundancy research (Holling, Walker)²³²⁴, transposed as revenue diversification and governance distribution preventing single-point failure; (5) *Energy Optimisation*, reflecting how forests maximise energy capture per unit resource (West et al., 1997)²⁵, transposed as shared equipment utilisation and infrastructure mutualisation; (6) *Diversity*, based on the established correlation between species diversity and ecosystem productivity and stability (Tilman et al., 2001)²⁶, transposed as the disciplinary, sectoral, and cultural heterogeneity of hub participants; and (7) *Regeneration*, reflecting forest succession dynamics where pioneer species create conditions enabling more complex communities (Kacker & al; Franklin et al., 2002²⁷), transposed as the hub's capacity not to quantify as a traditional KPI but, instead to create an organic governance type; generate spin-offs, trained personnel, and new territorial initiatives.

(See Appendix C)

The *Biomimetic Systemic Evaluation* (BSE) framework, developed for this thesis by transposing seven forest ecosystem principles (communication, circularity, symbiosis, resilience, energy optimization, diversity, regeneration) into hub evaluation criteria, functions as domain-specific operationalization tool. Inspired and theorize through academic proof, BSE answers *what* hub characteristics correlate with innovation outcomes. It provides evaluation protocol grounded in the same biological principles that bio-inspired innovations embody, creating epistemological coherence: hubs catalyzing bio-inspired solutions should themselves operate bio-mimetically. BSE operates as measurement instrument within the Co-Cities governance framework. Where JuSIIA measures governance quality, BSE measures functional biomimicry. The two are complementary; a hub can score high on JuSIIA (democratic, collaborative) but low on BSE (non-circular, non-symbiotic), or vice versa.

²³ Holling, C. S. (1973). Resilience and stability of ecological systems. *Annual Review of Ecology and Systematics*, 4(1), 1-23. <https://doi.org/10.1146/annurev.es.04.110173.000245>

²⁴ Walker, B., Holling, C. S., Carpenter, S. R., & Kinzig, A. (1999). Resilience, adaptability and transformability in social-ecological systems. *Ecology and Society*, 9(2), 5. <https://doi.org/10.5751/ES-00342-090205>

²⁵ West, G. B., Brown, J. H., & Enquist, B. J. (1997). A general model for the origin of allometric scaling laws in biology. *Science*, 276(5309), 122-126. <https://doi.org/10.1126/science.276.5309.122>

²⁶ Tilman, D., Reich, P. B., & Knops, J. M. H. (2001). Biodiversity and ecosystem stability in a decade-long grassland experiment. *Nature*, 411(7093), 629-632. <https://doi.org/10.1038/nature02742>

²⁷ Kacker, S., Krishna, S., Das, A., & Shahabuddin, G. (année). Patterns of tree regeneration and their implications for succession in Himalayan pine-oak forests, India

2.4.3 The Co-Cities Framework and Collaborative Governance

The *Co-Cities framework* (Iaione & Foster, 2022)²⁸ functions as the meso-analytical lens, specifying governance conditions within niches that enable or impede innovation. Its five design principles (co-governance, enabling state, pooling economies, urban experimentalism, tech justice) operationalize "good governance" for innovation hubs, while the *JuSIIA* evaluation tool provides measurement protocol. Co-Cities answers *how* hubs should be governed to maximize protective niche functions. It does not explain why niches matter (that's MLP's role) but specifies organizational prerequisites for niche effectiveness. The Quintuple Helix extension integrates the natural environment as co-constitutive actor, essential for bio-inspired innovation where biological knowledge itself constitutes an active input. Co-Cities operates within MLP's niche level, providing granular specification of governance mechanisms. The relationship is part-whole: Co-Cities governance principles are necessary conditions for effective niche operation, and niches themselves are necessary for regime transition.

2.4a: JUSIIA Tool

The framework is operationalised through the JuSIIA (Just Sustainable Innovation Impact Assessment) evaluation tool, which assesses collaborative spaces across three dimensions: justice, sustainability, and innovation (Iaione, 2024)²⁹. This evaluation protocol, developed through the LabGov research program and applied across the Co-Cities international research network, provides the methodological instrument through which this thesis comparatively evaluates innovation hubs.

The enabling state principle is particularly salient for this research. Rather than a command-and-control state or a laissez-faire market, the enabling state creates institutional conditions that empower citizens, communities, and innovators to co-produce public goods and lead to a bottom-up approach. Innovation hubs, when governed through multi-stakeholder models (such as the SCIC – “Société Coopérative d'Intérêt Collectif”, adopted by CEEBIOS), embody this principle by combining public purpose with entrepreneurial agility and community participation.

2.4b: The Quintuple Helix and Territorial Innovation

²⁸ Iaione, C., & Foster, S. (2022). *Co-Cities: Innovative transitions for urban commons*. MIT Press.

²⁹ Iaione, C. (2024). Just sustainable innovation and the Munus. *Munus*, 1/2024

The Quintuple Helix model (Carayannis & Campbell, 2010)³⁰ extends the traditional Triple Helix (university-industry-government) by integrating civil society and the natural environment as co-constitutive actors in innovation ecosystems. This extension is particularly relevant for bio-inspired innovation, which requires integration of biological knowledge (the natural environment helix) with technological development (the industry helix), scientific research (the university helix), regulatory frameworks (the government helix), and citizen participation (the civil society helix). Iaione's (2016) adaptation of the Quintuple Helix within the Co-Cities framework operationalises this model through the concept of the collaborative city: a governance architecture in which the five helices co-produce urban commons through structured collaboration rather than hierarchical command or market competition. The SCIC (“Société Coopérative d'Intérêt Collectif”) legal form adopted by CEEBIOS exemplifies this multi-stakeholder integration: its governance structure requires representation from at least three stakeholder categories (employees, users, and public interest representatives), institutionalising the cross-helix collaboration that bio-inspired innovation demands.

The practical implication for innovation hub design is that hubs achieving higher Quintuple Helix integration scores, measured through the Co-Cities evaluation codebook (Iaione & Foster, 2022), should demonstrate greater capacity for bio-inspired innovation. This hypothesis is testable through the JuSIIA framework applied in Chapter 5: hubs scoring high on co-governance (indicator of helix integration) should correlate with higher innovation output diversity and more advanced TRL progression of hosted bio-inspired projects. The territorial dimension of the Quintuple Helix is critical and often overlooked. Innovation does not occur in abstract space but in specific places with ecological, economic, and social characteristics. Michael Porter's³¹ cluster theory demonstrated that geographic co-location of related firms, suppliers, and institutions generates competitive advantages through knowledge spillovers, specialised labour pools, and institutional density. For bio-inspired innovation, this territorial anchoring takes on additional significance: the biological models inspiring the innovation (local species, ecosystems, climate conditions) are themselves territorial, creating what Alexandre Bau, Co-founder of BioRegion Institute (2026, interview) terms the bioregional imperative, the principle that bio-inspired solutions should emerge from and respond to the specific ecological context in which they will be deployed. The territorial dimension also connects to the growing body of research on creative and innovative places. Florida's (2002) creative class thesis, despite its criticisms, highlighted the role of place characteristics, diversity, tolerance, amenity, in attracting innovative talent. More recently, the European Commission's Smart Specialisation Strategy (S3)³² has emphasised the importance of territorial innovation ecosystems that leverage local comparative advantages and invested EUR 70 billion for 2021-2027 €70 billion

³⁰ Carayannis, E. G., & Campbell, D. F. J. (2010). Triple helix, quadruple helix and quintuple helix and how do knowledge, innovation and the environment relate to each other? *International Journal of Social Ecology and Sustainable Development*, 1(1), 41-69. <https://doi.org/10.4018/jsesd.2010010105>

³¹ Porter, M. E. (1985). Competitive advantage: Creating and sustaining superior performance.

³² European Court of Auditors (2025), Smart specialization strategies in the EU

over the two programming periods. For bio-inspired innovation, the comparative advantage is ecological: territories with greater biodiversity, traditional ecological knowledge, and biomass availability possess natural resources for bio-inspired innovation that cannot be replicated elsewhere, a fundamentally different logic from the footloose innovation assumed by most technology policy.

2.5 Conceptual Models of Archipelago and Metabolic Levels

The Archipelago Model and *Metabolic Levels Model* function as conceptual synthesis devices, translating empirical findings into operational frameworks. They are not independent theories but applications of MLP, Co-Cities and BSE findings to territorial innovation strategy.

Archipelago Model: Synthesizes the finding that bio-inspired innovation requires distributed, locally adapted, but interconnected infrastructure. Operationalizes "mycorrhizal connectivity" (forest principle) as knowledge-sharing protocols, personnel exchange, and shared evaluation frameworks. Derived from MLP insight that niches require protection but also regime interaction (Smith & Raven, 2012)³³.

Metabolic Levels Model: Stratifies hub ecosystem into four functional levels (soil, forest floor, shrub layer, canopy) corresponding to TRL ranges and ecological strategies. Operationalizes "succession dynamics" (forest principle) as progressive migration across hub types. Derived from MLP insight that niche-regime interaction requires intermediary institutions. These are prescriptive models informed by analytical frameworks, not analytical frameworks themselves. They represent thesis contributions but do not constitute independent theoretical claims requiring validation.

³³ Smith, Adrian & Raven, Rob. (2012). What is protective space? Reconsidering niches in transitions to sustainability. Research Policy - RES POLICY. 41. 10.1016/j.respol.2011.12.012.

Table 2: Summary Table - Division of Analytical Labor

Framework	Analytical Level	Research Question Addressed	Methodological Approach
MLP	Macro (system)	Why do bio-innovations face diffusion barriers?	Comparative institutional analysis
Co-Cities/JuSIIA	Meso (organization)	How should hubs be governed?	Structured evaluation protocol
INUS Condition	Epistemological	What kind of causality do hubs exercise?	Cross-case configurational analysis
BSE Framework	Micro (function)	What hub characteristics correlate with outcomes?	Comparative scoring + triangulation
Archipelago/Metabolic	Synthetic (prescriptive)	How should innovations hubs be more connected with quintuple helix actors?	Existing models creating a bigger network for bio-inspired pollinisation

This hierarchical integration established clear primacy (MLP), subordinate relationships (Co-Cities specifies MLP niche conditions; BSE operationalizes Co-Cities principles), and epistemic positioning (INUS clarifies causal claims). The Archipelago and Metabolic Levels models emerge as synthesis rather than independent contributions, grounded in the analytical frameworks above.

Chapter 3: Methodology

3.1 Research Design

This research adopts a qualitative comparative case study design (Yin, 2018), selected for its capacity to investigate complex, context-dependent phenomena where multiple variables interact in ways that cannot be isolated through experimental methods. The case study approach is appropriate given the research question's focus on *how* and *why* innovation hubs enable or fail to enable bio-inspired innovation diffusion, questions that require deep contextual understanding rather than statistical generalisation. The study integrates three analytical lenses at different scales. The MLP (Geels, 2002) provides the macro lens for understanding regime–niche dynamics. The Co-Cities JuSIIA framework (Iaione, 2024) provides the meso lens for evaluating governance within hubs. The BSE framework developed for this thesis provides the micro lens for assessing internal hub functioning through forest ecosystem principles.

3.2 Case Selection

Cases were selected through purposive sampling (Palys, 2008), following theoretical criteria designed to maximise analytical diversity across four dimensions: geographic location (France, Netherlands, Italy, USA), hub typology (from open makerspaces to structured biofactories), TRL coverage (from TRL 1 awareness through TRL 9 commercial deployment), and governance model (association, cooperative, private, hybrid).

The seven hub cases are; CEEBIOS (Senlis, France), a SCIC cooperative structure functioning as a national center of biomimicry excellence; Climate House (Paris, France), a private community-driven coworking space operating with 0% public subsidy; Blue City Lab (Rotterdam, Netherlands), a circular economy hub specialising in industrial-urban symbiosis; WoMA (Paris, France), a citizen-driven makerspace and fablab; Darwin Ecosystem (Bordeaux, France), a large-scale hybrid reconverted military site; and Campus de la Transition (Forges, France), a rural learning campus dedicated to ecological transition and experimentations.

Three innovation trajectory cases complement the hub analysis with a chosen focus on bio-inspired materials. Ecovative Design (USA), the most successful mycelium-based materials company globally, with USD 184M raised across 17+ funding rounds³⁴; Mogu (Italy), a mycelium-based materials company that achieved an EUR 11M Series A³⁵ through a designed market entry strategy; and Bioregion Institute (Bergen/Marseille), a Franco-Norwegian distributed initiative developing mycorrhizal floor products at TRL 4–6 and other bio-materials.

³⁴ https://www.crunchbase.com/organization/ecovative-designs/financial_details

³⁵ <https://tech.eu/2024/01/09/italian-startup-mogu-raises-eur11m-for-mycelium-based-biotech-expansion/>

3.3 Data Collection

Data were collected through three complementary methods over the period October 2025 – February 2026.

I choose to guide semi-structured interviews. nine in-depth interviews were conducted with key stakeholders: Thibaut Houette (scientific coordinator, CEEBIOS), Eliott Graeff (founder, Asteria; former CEEBIOS researcher), Alexandre Bau (founder, Bioregion Institute), Maika Nuti (co-founder, Climate House), Guillaume Graves (designer and educator, ENSCI-Les Ateliers; former administrator, La Paillasse), Cédissia About (Ville de Paris,), and Arthur Croizet (Campus de la Transition), Davide Costelli (WoMa Fablab manager), Ruben Kok (Blue City Lab Manager). Interviews were conducted in French, lasted 45–90 minutes, and followed a semi-structured protocol organised around three thematic blocks: barriers to bio-inspired innovation diffusion, the specific role of innovation hub infrastructure, and governance and financing models. All interviews were recorded with informed consent and transcribed for analysis.

(See appendix)

My secondary data analysis are mainly policy documents to understand the current trends and dynamics (, EU Green Deal, France 2030, SNB 2030, Hubs4Circularity, ANCT report, Cerema), market reports (EIB, 2023, 2025)³⁶, and organisational documents (CEEBIOS annual reports, Climate House impact reports, France Tiers-Lieux observatory data) were systematically analysed to contextualise interview findings. (see Bibliography references).

My third data are coming from scientific and academic literature, complementary to my field observations, like participatory observation was conducted at Climate House events, WoMA open workshops, and biomimicry-related conferences (Biomimexpo, Hubs4Circularity, Change Now, BPI event “BIG”, ESPCI Paris), providing experiential data on hub functioning, community dynamics, and knowledge-sharing practices.

3.4: The JuSIIA Evaluation Protocol

The JuSIIA (Just Sustainable Innovation Impact Assessment) framework, developed by Christian Iaione through LABGOV and the LIFE Research Center, funded research program, provides a structured methodology for evaluating collaborative spaces across three integrated dimensions: justice, sustainability, and innovation. The framework was designed specifically for assessing urban commons and collaborative governance experiments, making it relevant

³⁶ EIB (2023) *Investing in nature-based solutions: State-of-play and way forward for public and private financial measures in Europe*

suited to innovation hub evaluation, a context where conventional metrics (financial returns, patent counts, employment numbers) fail to capture the full spectrum of value creation.

The evaluation protocol assesses each hub across five Co-Cities design principles, each scored on a 1–3 scale based on documentary evidence and interview data: Co-governance (CG) measures the degree to which multiple stakeholder categories participate in hub decision-making, from purely hierarchical management (score 1) to fully distributed multi-stakeholder governance (score 3). For bio-inspired innovation hubs, high co-governance scores indicate the presence of the cross-disciplinary dialogue essential for translating biological knowledge into technological applications. Enabling State (ES) measures the quality and nature of public institutional support, from absent or hostile (score 1) to proactive facilitation that creates conditions for self-organised innovation without imposing control (score 3). The current French budget crisis provides a natural experiment: hubs with low ES dependence (Climate House at 0% subsidy) maintained operations while hubs with high ES dependence faced existential threats. Pooling Economies (PE) measures the degree of resource sharing, mutualisation, and commons-based production within the hub. High PE scores (such as WoMA and Blue City Lab at 14/15) indicate the metabolic symbiosis that characterizes effective bio-inspired innovation environments where materials, equipment, knowledge, and networks flow as shared resources. Urban Experimentalism (UE) measures willingness to test novel governance, economic, and spatial configurations. For bio-inspired innovation, high experimentalism is essential: conventional governance and economic models are precisely the regime structures that bio-inspired innovations must navigate around. Tech Justice (TJ) measures the extent to which the hub's innovation activities address equity, accessibility, and distributional justice. This dimension distinguishes innovation hubs as democratic infrastructure from innovation hubs as exclusive enclaves, a distinction with direct implications for the diffusion potential of bio-inspired solutions to social housing, public spaces, and community facilities. For this thesis, JuSIIA assessments were conducted through triangulation of three data sources: interview testimony and survey from hub managers and participants, documentary evidence from organisational reports and governance documents, and direct observation during field visits. Scores were assigned by the researcher and validated through member-checking with interview participants where possible.

3.5 Analytical Framework

Interview transcripts were analysed through thematic coding using a hybrid deductive-inductive approach. Deductive codes were derived from the three theoretical frameworks (MLP transitions, Co-Cities governance principles, BSE forest principles). Inductive codes emerged from the data, notably the manufacturing process gap as the primary barrier, the temporal mismatch as a structural rather than incidental obstacle, and the desirability deficit as a cultural barrier to adoption. (see appendix)

The JuSIIA evaluation framework was applied to all six hub cases, scoring each across the five Co-Cities dimensions (co-governance, enabling state, pooling economies, urban experimentalism, tech justice) using a 1–3 scale. Cross-case comparison followed the replication logic recommended by Yin (2018): literal replication (cases predicted to produce similar results based on shared characteristics) and theoretical replication (cases predicted to produce contrasting results for predictable reasons).

3.6 Limitations and Ethical Considerations

Five constraints affect generalizability merit acknowledgement. First, the sample comprises nine interviews and six hub case studies, sufficient for pattern identification but precluding statistical inference beyond the studied population. However, all respondents occupy strategic positions at the intersection of biomimicry, research and development, innovation, and hub management, providing insider perspectives of high analytical value. Second, geographic concentration in France and the Netherlands limits transferability to non-European contexts with different regulatory, financial, and cultural conditions. Third, the cross-sectional design capturing 2024–2026 dynamics cannot assess longitudinal hub evolution or mortality patterns beyond available retrospective data. Fourth, BSE scoring involves subjective judgment despite explicit indicator operationalization; alternative frameworks emphasizing financial metrics or lifecycle assessment could yield divergent hub rankings. Fifth, selection bias inherently affects the sample as only surviving hubs were studied systematically; failed initiatives including La Paillasse (Paris makerspace, 2012–2023 closure) receive limited analysis due to data unavailability, partially addressed through secondary source integration (France Tiers-Lieux, 2024).³⁷ Fourth, the researcher's simultaneous engagement as a practitioner (developing mycelium-based materials furnitures) introduces both potential bias and valuable tacit knowledge concerning bio-materials, a tension inherent to participatory action research that is managed through explicit reflexivity and triangulation with secondary data. Five, given the recent surge in bio-inspired markets, the author encountered cases that were insufficiently documented to be analysed in depth and made the strategic choice to interpret qualitative results from interviews conducted by herself or third parties, reflecting the reality of the current market (September 2025 - February 2026).

³⁷ France Tiers-Lieux. (2024). *Observatoire national des tiers-lieux: Rapport annuel 2024*. Coopérative des Tiers-Lieux. Dams, B., Maskell, D., Shea, A., Allen, S., Cascione, V., & Walker, P. (2023). Upscaling bio-based construction: Challenges and opportunities. *Building Research & Information*, 51(7), 764–782.

Ethical standards were respected throughout: participants provided informed consent, were offered the opportunity to review quotes attributed to them and were informed of the thesis's academic purpose. No fabricated or unverifiable data are presented.

Chapter 4: Innovation Ecosystem Context - Policy, Market, and the Anatomy of Barriers

To understand how to further catalyse bio-inspired innovations, let us first take stock of the political and economic context and the systemic landscape of innovation. This chapter will highlight the obstacles across the construction sector and the development and dissemination of bio-inspired materials. To understand how tomorrow's innovation hubs will positively use the principles of life as inspiration for their operations.

4.1 Understanding Innovation Ecosystem applied to Biomimicry

4.1.1 Classical Models and Their Limits

Incremental innovation consists of continuous improvements to existing products, processes, or services without altering their fundamental structure (Tidd & Bessant, 2018). Organizations often favor this approach due to its compatibility with short-term planning, ongoing improvement goals, and risk reduction (Dougherty, 1992)³⁸. Biomimetic projects, however, often require new expertise, extended exploration, and interdisciplinary collaboration, making them less compatible with incremental methods. For example, the development of blade serrations inspired by owl wings aimed at reducing aerodynamic noise illustrates the complexity of such endeavors (Rao, 2017).

Radical innovation brings about significant technological discontinuities that disrupt existing skills and routines (Tushman & Anderson, 1986)³⁹. Such innovation is characterized by uncertain, lengthy development phases that require collaboration across scientific, technical, and design fields (Abernathy & Utterback, 1978)⁴⁰. In biomimicry, translating biological research into applied engineering involves complex intermediary steps (Stokes, 1997).

Disruptive innovation, as described by Christensen (1997)⁴¹, is mainly shaped by market demands rather than technical advances. It often starts in overlooked market segments and gradually challenges established players. Biomimetic solutions frequently position themselves as direct replacements for current technologies, which may conflict with the gradual integration typical of disruptive innovation.

Architectural innovation involves reorganizing the relationships between existing system

³⁸ Dougherty, D. (1992). Interpretive barriers to successful product innovation in large firms. *Organization Science*, 3(2), 179–202.

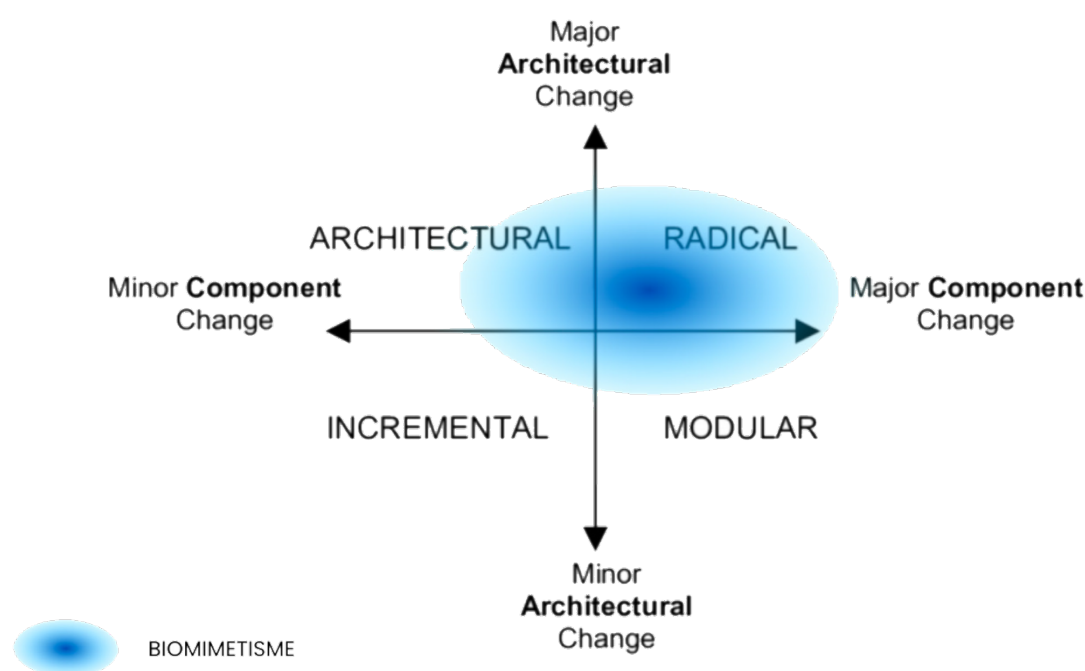
³⁹ Tushman, M. L., & Anderson, P. (1986). Technological discontinuities and organizational environments. *Administrative Science Quarterly*,

⁴⁰ Abernathy, W. J., & Utterback, J. M. (1978). Patterns of industrial innovation. *Technology Review*, 80(7), 40–

⁴¹ Christensen, C. M. (1997). *The innovator's dilemma: When new technologies cause great firms to fail*. Harvard Business Review Press.

components without introducing new ones (Henderson & Clark, 1990⁴²). In biomimicry, such changes can have a substantial impact on organizational practices. For instance, bone-inspired structural designs show how internal reorganization can drive innovation without the need for new materials (Yang et al., 2021)⁴³.

Deeptech innovation is defined by high scientific input, extended development periods, and considerable financial and organizational risks (Auerswald & Branscomb, 2003⁴⁴). Many biomimetic projects fall into this category and require strong support systems and patient investment to bridge the gap between research and commercialization. The FinX case highlights the challenges faced in industrializing deeptech biomimetic technologies.



⁴² Henderson, R., & Clark, K. B. (1990). Architectural innovation: The reconfiguration of existing product technologies and the failure of established firms. *Administrative Science Quarterly*, 35(1), 9–30. <https://doi.org/10.2307/2393549>

⁴³ Yang, Y., Li, X., & Zhao, J. (2021). Bone-inspired structural designs for enhanced mechanical performance. *Materials Science and Engineering: C*, 123, 112012. <https://doi.org/10.1016/j.msec.2021.112012>

⁴⁴ Auerswald, P. E., & Branscomb, L. M. (2003). Valleys of death and Darwinian seas: Financing the invention to innovation transition in the United States. *The Journal of Technology Transfer*, 28(3-4), 227–239. <https://doi.org/10.1023/A:1025026817268>

Figure 1 – Biomimicry position in Innovation Landscape - Adaptation of the Henderson and Clark (1990) matrix

The Henderson and Clark matrix is a well-established innovation management tool that distinguishes innovations along two dimensions: the impact on components (isolated technological knowledge) and the impact on architecture (knowledge about how components are linked together). It traditionally defines four innovation regimes: Incremental (continuous improvement), Modular (change of a single component), Architectural (system reconfiguration), and Radical (complete disruption).

The diagram shown here does not aim to classify biomimetic innovations in a normative or rigid manner. Rather, it seeks to highlight the unique position occupied by many biomimetic project trajectories, which often lie at the intersection of several existing innovation regimes. It thus serves as a basis for discussion and contextualization rather than as a predictive model.

-Socio-Technical Transitions: When Innovation Encounters System Resistance

Socio-technical transition theories emphasize that the spread of innovation is influenced by pre-existing infrastructures, norms, and routines, which can be resistant to change (Geels, 2005). Biomimetic innovations are often developed in specialized environments but encounter inertia when scaling toward mainstream adoption. Their success often depends on the ability to adapt to or transform institutional frameworks (Geels, 2005)⁴⁵. This is the Multi Level Perspective model which can be applied to biomimicry market.

⁴⁵ Geels, F. W. (2005). Processes and patterns in transitions and system innovations: Refining the co-evolutionary multi-level perspective. *Technological Forecasting and Social Change*, 72(6), 681–696. <https://doi.org/10.1016/j.techfore.2004.08.014>

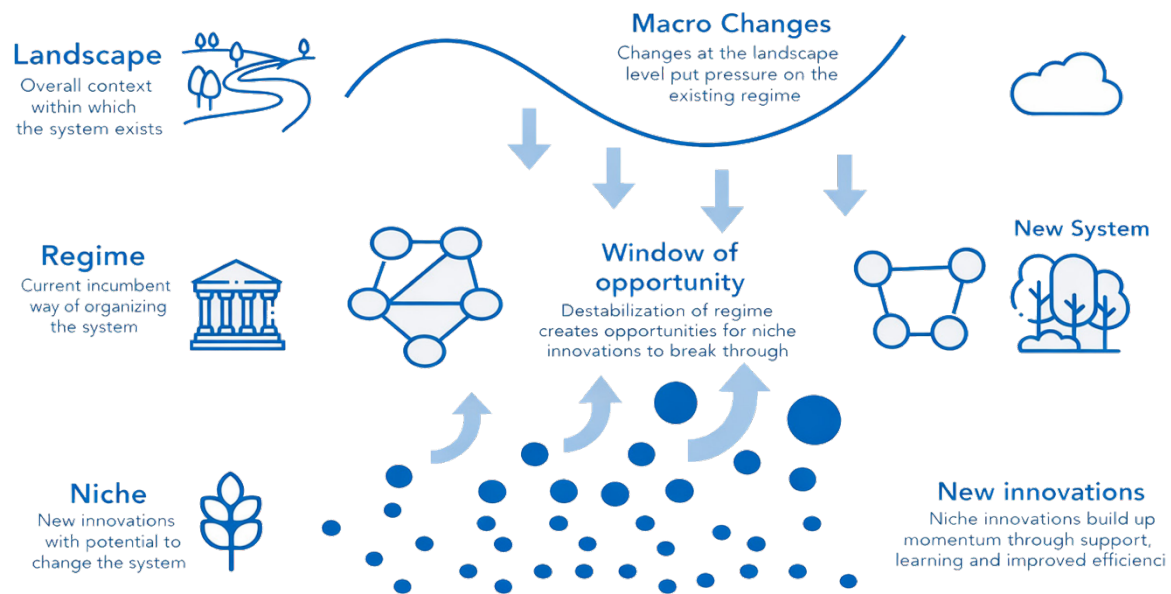


Figure 2 - Simplified diagram adapted from Geels (2005), illustrating the Multi-Level-Perspective scheme, interactions between niches, diets and landscape.

4.1.2 Diffusion of Innovations (Rogers): Social Adoption and Vulnerability Zones

Rogers' diffusion of innovation model (2003) highlights that adoption is not linear and depends on factors such as relative advantage, compatibility, complexity, trialability, and observability. Biomimetic solutions may struggle to demonstrate clear advantages or integrate into established processes, which can limit their adoption beyond research and development settings. These challenges often relate to communication and perception, not technical shortcomings (Rogers, 2003).

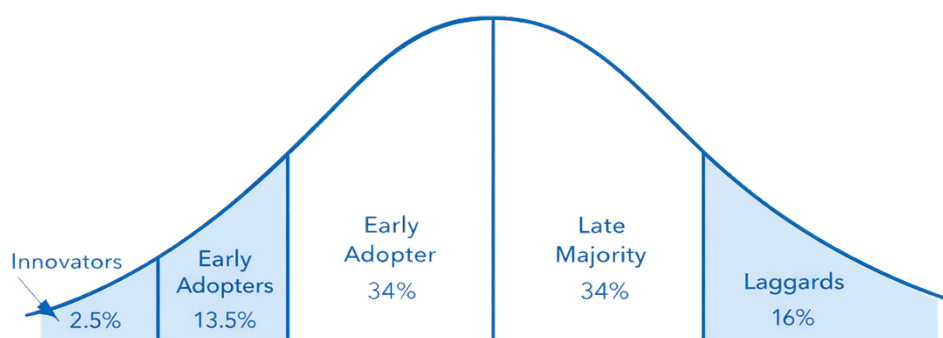


Figure 3 - Innovation diffusion curve

Representation of the process of adopting an innovation within a social system, distinguishing between different categories of adopters (innovators, early adopters, early majority, late majority, laggards), according to Rogers (2003).⁴⁶

Rogers distinguishes five categories of adopters, which refer not to personalities but to positions within the adoption process. Innovators experiment out of curiosity or expertise. Early adopters play a decisive role, as they make the innovation understandable and legitimate for those around them. The early majority adopts when they perceive a clear benefit. The late majority waits for solid evidence. Laggards only embrace the innovation once it has become the established norm.

The value of this model for this research lies in the analytical framework it provides. Rogers identifies five key factors that strongly influence adoption: relative advantage, compatibility with existing practices, perceived complexity, trialability, and the visibility of results. When applied to biomimicry, this perspective reveals several tensions.

- Relative advantage is often real but difficult to demonstrate quickly, as benefits may rely on mechanisms that already exist yet are not immediately perceptible, or on physical dynamics that are unfamiliar to industrial teams.
- Compatibility is low when the biomimetic solution requires changes to processes, internal standards, or modes of production.
- Perceived complexity is high, since even a well-explained biological principle can differ significantly from typical engineering frameworks.
- Trialability is limited when testing a prototype requires a specific, rare, or costly experimental environment.
- Visibility is constrained; results tend to remain within R&D, distant from strategic decision-making spaces.

This research aims to explore the role that innovation spaces play in catalyzing biomimetic innovations so they can move beyond organizational early adopters—not due to a lack of relevance, but because they have yet to cross the threshold of clarity that makes a project understandable, demonstrable, and transferable to other actors, companies, and industries. The actors who could serve as translators do exist, but they occupy different, sometimes overly complex, intermediary positions and do not always have the tools, spaces, time, or legitimacy necessary to reduce perceived uncertainty.

Rogers's model thus reminds us that adoption is never purely a technical phenomenon. It also depends on regulations, policies, mediation, narratives, shared evidence, and the capacity to align an innovation with different timelines, routines, and expectations. This is the perspective

⁴⁶ Rogers, E. M. (2003). *Diffusion of Innovations* (5th ed.). Free Press

that will guide further investigation into the systemic, organizational, and economic barriers that shape the trajectory of biomimetic projects.

4.2 Systemic Challenges in Adoption and Scaling of Bio-Inspired Innovations

Moving from social adoption to systemic challenges, the scaling and diffusion of bio-inspired innovations encounter intertwined obstacles across multiple dimensions. Systemically, coordination among diverse stakeholders—including researchers, industry, policymakers, and civil society—is complex, with regulatory frameworks and financing often fragmented or ill-suited to the unique nature of bio-inspired technologies. Technologically, moving from prototype to industrial-scale production is constrained by process intricacies, quality assurance, and sustainable sourcing of biological materials. Economically, high upfront costs and competition with established materials limit market penetration, while uncertain returns deter investment. Socially, limited awareness and skill gaps among users and producers slow acceptance and integration. Addressing these multifaceted challenges requires integrated policy approaches, collaborative governance involving multiple stakeholders, and adaptive frameworks that can respond to evolving technological and societal needs (OECD, 2021; European Commission, 2020).⁴⁷⁴⁸

To navigate these complexities, the Technology Readiness Level (TRL) framework adapted by Chirazi et al. (2019)⁴⁹ offers a structured pathway for bio-inspired innovation development. This framework delineates stages from early conceptual design inspired by biological models to prototyping, testing, and eventual market introduction. By mapping the innovation journey through these TRL stages, actors can better identify critical milestones, resource needs, and potential bottlenecks. Importantly, this approach integrates both the technical maturation of the innovation and its alignment with social and economic validation processes, thus providing a comprehensive roadmap to support the diffusion and scaling of bio-inspired solutions.

⁴⁷ OECD. (2021). *Innovation policies for bio-based industries*. OECD Publishing.
<https://doi.org/10.1787/9789264306849-en>

⁴⁸ European Commission. (2020). *Bioeconomy strategy and action plan*.
https://ec.europa.eu/knowledge4policy/bioeconomy_en

⁴⁹ Chirazi, M., Bouchard, C., & Rousselle, J. (2019). What do we learn from good practices of biologically inspired design in innovation? *Journal of Cleaner Production*, 231, 1228–1243.
<https://doi.org/10.1016/j.jclepro.2019.05.166>

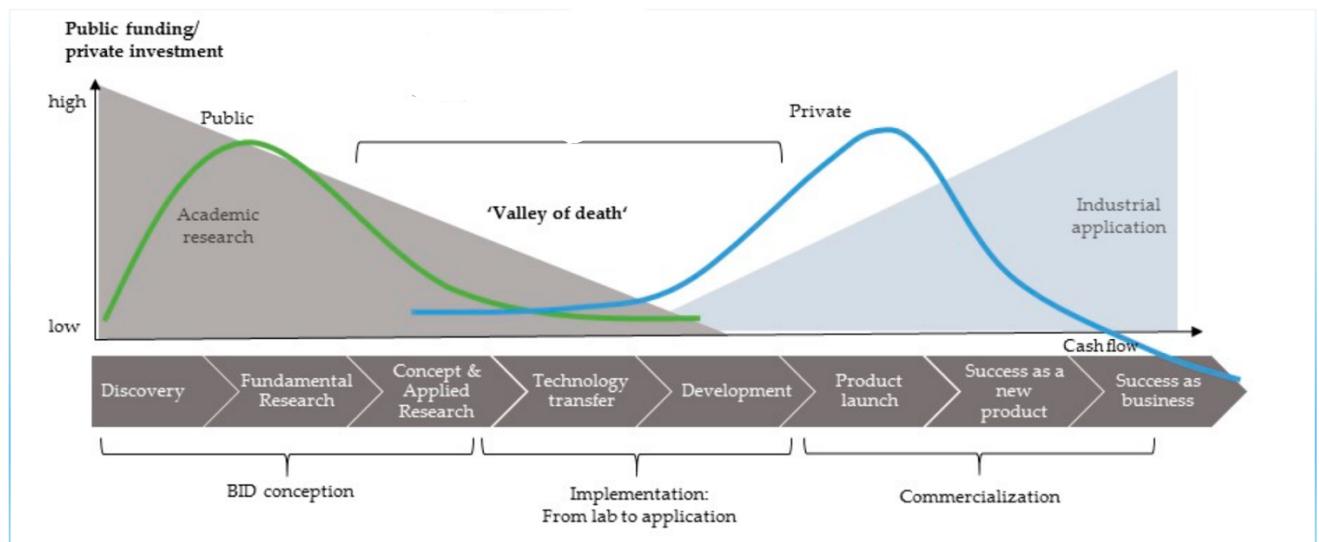


Figure: Steps of the Bio Inspiration Design (BID) and innovation process - Adapted from Chirazi et al , 2019, What Do We Learn from Good Practices of Biologically Inspired Design in Innovation?

This integrated view also underscores the critical “nodes” or points of friction in technology transfer, especially between academia and industry. Only 1 on 5000 biotechnology surviving to commercialization as TRL 4-7 “valley of death” remains critically underfunded despite €6B+ in EU public-private bioeconomy since 2014.⁵⁰

These nodes emerge from differences in organizational cultures, objectives, and time horizons, which often hinder smooth collaboration and knowledge exchange (Bozeman, 2000; Perkmann et al., 2013). For bio-inspired innovations, bridging these gaps is essential because the translation of biological insights into industrial applications requires not only technical adjustments but also mutual understanding and trust-building across sectors. Addressing these transfer challenges is therefore a strategic priority to enable bio-inspired solutions to move beyond isolated projects and achieve broader market impact.

4.3 The Regulatory and Policy Landscape :

4.3.1 French National Strategies

France’s policy architecture for bio-inspired innovation operates across multiple institutional levels without centralized coordination. Three strategic instruments merit analysis for their direct impact on bio-material diffusion.

⁵⁰ BBI JU – Bio-based industries joint undertaking

The Deeptech Plan, integrated into France 2030 (EUR 54 billion, 2021–2030), aims to support 500 deeptech startups annually by 2030. The Direction Générale des Entreprises (DGE) reports a near-threelfold increase in deeptech funding over five years (Heim & Rappaport, 2025). However, allocation analysis reveals structural bias: 73% of France 2030 funds flow to companies exceeding EUR 100 million revenue, with only 12% reaching firms below EUR 10 million (Heim & Rappaport, 2025, p. 47). This concentration reflects institutional risk aversion that systematically disadvantages bio-material startups at TRL 4–6, precisely the ventures most in need of scale-up support.⁵¹ Biomemory's USD 18M Series A (2024), funded partly through Bpifrance France 2030 instruments⁵², demonstrates the plan's capacity to catalyse deep-tech bio-innovation at the biotechnology level. However, the plan's selection criteria favour high-TRL ventures with clear intellectual property and rapid scaling potential, precisely the profile that bio-inspired construction materials at TRL 4–6 do not yet exhibit.

France's policy architecture for bio-inspired innovation is distributed across multiple ministries without centralised coordination. The *Stratégie Nationale de Transition Écologique vers un Développement Durable* (SNTEDD, 2015–2020⁵³) recognised biomimicry's potential through a dedicated action line (Priority Axis 7, Action 39), creating a strategic framework document and contributing to the establishment of CEEBIOS. However, the successor strategy (SFEC, 2023–2027) integrated biomimicry into broader circular economy and biodiversity objectives without maintaining the dedicated institutional focus according to the Ecological Transition Ministry.

The *Stratégie Nationale Biodiversité 2030* (SNB, 2022) frames nature-based solutions as central to biodiversity policy, with a stated target of deploying Nature Based Solutions (NBS) across all French territories. Yet the strategy provides implementation infrastructure only through existing instruments, ADEME funding, territorial biodiversity agencies, none of which specifically addresses the manufacturing scale-up and certification needs of bio-inspired construction materials. This creates what the thesis terms a *declaration–implementation gap*: strategic intent exists but operational pathways connecting research outputs to territorial deployment do not (CEEBIOS, 2023).

The 2024–2025 French budget crisis, which resulted in significant cuts to tiers-lieux subsidies and environmental transition programmes, constitutes a natural experiment revealing the structural dependency of innovation infrastructure on public funding cycles. Graves (2025, interview) documents the mechanism through La Paillasse's experience: earned revenues (events, space rental, memberships) covered only 30–40% of operating costs, with the remaining 60–70% depending on subsidies. When subsidies were cut, the hub's viability was immediately threatened. This vulnerability is not unique to La Paillasse but characterises the

⁵¹ Guillaume HEIM, Emma RAPPAPORT, L'innovation de rupture au défi du passage à l'échelle. État des lieux de la deeptech en France et pistes pour une nouvelle stratégie, Rapport de la Direction générale des entreprises, 2025

⁵² <https://www.biospace.com/press-releases/biomemory-secures-18-million-in-series-a-funding-to-revolutionize-data-storage-with-molecular-technology>

⁵³ *Stratégie Nationale de Transition Écologique vers un Développement Durable* (SNTEDD, 2015–2020)

majority of France's 3,500+ tiers-lieux, of which only 13% have adopted economically resilient legal structures such as the SCIC (France Tiers-Lieux, 2024).

4.1.2 The European Hubs4Circularity Initiative

The Hubs4Circularity (H4C) initiative, developed under the Processes4Planet partnership within Horizon Europe, represents the most advanced European policy framework for the type of innovation infrastructure this thesis examines. H4C conceptualises hubs as nodes within metabolic systems where waste from one process becomes feedstock for another — precisely the operational principle documented at Blue City Lab Rotterdam, where RotterZwam cultivates mushrooms on coffee grounds from neighbouring hub restaurants (Climate-KIC, 2022; European Commission, 2022).

The H4C framework rests on three pillars that demonstrate structural convergence with this thesis's analytical architecture. First, industrial-urban symbiosis (I-US) positions the hub not as a container for isolated innovations but as a metabolic node. Second, the socio-technical ecosystem approach mirrors the thesis's core argument that bio-inspired innovation failure is an ecosystem problem, not a technology problem. Third, regional anchoring through locally adapted replication corresponds directly to the Archipelago Model developed in Chapter 6.

However, the H4C framework exhibits a critical blind spot: its primary focus on process industry transformation (chemicals, cement, steel) means that bio-inspired innovations — particularly nature-based construction materials operating at smaller scales and with different governance requirements — fall between the framework's analytical categories. Bio-inspired innovations are neither purely industrial (they often emerge from community workshops and artisanal processes) nor purely urban (they require both laboratory conditions and territorial deployment sites). This *categorical gap* leaves bio-inspired innovations without a dedicated policy home at the European level.

4.1.3: The RE2020 and RE2025 Regulatory Shift

France's *Réglementation Environnementale* 2020 (RE2020), which entered into force progressively from January 2022, represents the most significant regulatory shift in European construction policy for bio-inspired materials. For the first time, a national building code introduces mandatory lifecycle carbon assessment, requiring builders to account for embodied carbon in construction materials, not merely operational energy performance. This creates a structural advantage for bio-materials (timber, hemp-lime, mycelium composites, earth construction) that sequester carbon during growth while penalising conventional materials (concrete, steel, aluminium) with high embodied carbon. The RE2020's carbon trajectory tightens progressively through 2031, with threshold values for embodied carbon decreasing at

each milestone. This creates a predictable regulatory ratchet: solutions that are marginally competitive today will become economically necessary as conventional materials face increasingly stringent carbon penalties. For bio-inspired construction materials currently at TRL 4–6, this regulatory trajectory provides the most compelling business case for investment: the regulatory environment is moving toward them, even if the current market does not yet demand them. But instead, is currently more focus on materials reemployment as Cédissia About de Chastenet explained it during the interview. An opportunity to create circularity and requiring warehouse and hubs. However, the RE2020 also reveals a policy paradox. While the regulation creates demand-side pull for bio-materials, it does not create supply-side capacity. There are no provisions for pilot manufacturing support, no dedicated certification fast-tracks for novel bio-materials, and no territorial innovation infrastructure connecting the regulatory signal to material production. This gap between demand creation and supply enablement is precisely what innovation hubs could fill, functioning as the connective tissue between regulatory intent and material reality. The anticipated RE2025, currently under preparation, is expected to further tighten embodied carbon thresholds and potentially introduce biodiversity performance requirements for construction projects. If confirmed, these provisions would create an unprecedented regulatory framework in which bio-inspired approaches, designing buildings that not merely minimise harm but actively contribute to ecological function, become not merely aspirational but normatively required.

4.2 Market Dynamics and Investment Landscape

The global biomimetics market demonstrates robust growth with persistent structural fragilities. Sectoral penetration remains concentrated: medical applications account for approximately 48.7% of the market in 2025, followed by materials at around 30% (Grand View Research, 2026). Europe represents roughly 30% of the global total. France, Germany, Italy, and Spain together account for approximately 60% of the European market (Cognitive Market Research, 2026).

A critical analytical distinction, identified by Graeff (2025, interview), separates three categories of bio-inspired innovation that obey radically different financing, market, and temporality logics. *Biotechnology* (high-tech radical invention) requires EUR 2–50M per project, 7–12 years to revenue, and VC deep-tech financing. *Industrial bio-materials* (mature technologies reorganised according to bio-inspired principles) require EUR 500K–5M, 3–7 years to revenue, and hybrid grant/angel financing. *Low-tech artisanal bio-materials* (local materials, accessible processes, short circuits) require EUR 5–50K, 6–18 months to revenue, and micro-credit or direct market revenues. Confusing these categories, applying deep-tech financing models to low-tech innovations, or artisanal expectations to biotechnology, produces systematic misallocation of resources and unrealistic performance benchmarks.

Category	Examples	Capital Required	Time to Revenue	Financing Type
1. Biotechnology (radical)	Biomemory, CRISPR applications	EUR 2–50M	7–12 years	VC deeptech
2. Industrial bio-materials	Ecovative, Mogu, hempcrete	EUR 500K–5M	3–7 years	Hybrid grant/angel
3. Low-tech artisanal	Local earth, straw, mycelium crafts	EUR 5–50K	6–18 months	Micro-credit, direct sales

Table 3: Three categories of bio-inspired innovation (adapted from Graeff, interview).

Investment in bio-inspired innovation is accelerating but remains structurally misaligned with biological innovation temporalities. The BioTechEU initiative, launched in December 2025 by the European Commission and the EIB Group, aims to mobilise EUR 10 billion in 2026–2027 to close the valley of death for biotech and life-sciences scale-ups, building on the EIB's existing EUR 3.5 billion life-sciences venture-debt portfolio (European Commission & EIB, 2025)⁵⁴. However, this instrument targets biotechnology (Category 1) rather than bio-inspired materials for construction (Categories 2–3), leaving the sector most in need of territorial infrastructure without dedicated scale-up financing.

⁵⁴ European Commission & European Investment Bank. (2025). *BioTechEU initiative: Mobilising €10 billion for biotech scale-ups*.

4.3 Anatomy of Barriers: Why Bio-Inspired Innovations fail to germinate: with a focus on the Construction Sector

The construction sector's environmental burden creates both moral urgency and market opportunity for bio-based materials, yet this dual imperative has proven insufficient to overcome structural adoption barriers. Steel and cement production account for approximately 7.2% and 3% of global CO₂ emissions respectively, while the construction industry consumes 30% of raw materials globally (Mazzoni & Losacker, 2024; Bilal et al., 2020).⁵⁵ Bio-based materials offer documented technical advantages including carbon sequestration potential enabling buildings to function as carbon sinks, hygroscopic properties that regulate internal humidity fluctuations, and renewable feedstock supply chains when sustainably managed (Galimshina et al., 2022; Shea et al., 2012).⁵⁶⁵⁷

However, empirical evidence from realized bio-based construction projects reveals a persistent adoption paradox that environmental and technical cases alone cannot resolve. Dams et al. (2023) conducted semi-structured interviews with six senior UK professionals possessing direct experience realizing bio-based buildings, documenting that initial construction costs consistently exceed conventional materials by 10-25%, with operational cost savings of 70% energy reduction and two-thirds lower running costs confirmed across multiple projects.⁵⁸ Despite these documented long-term financial benefits alongside environmental performance, interviewees unanimously reported that bio-based construction has not proliferated and has potentially regressed over the past five years in the UK context. This paradox demands explanation beyond technical or informational deficits.⁵⁹

4.3.1 Incumbency Advantages and Path Dependency

Conventional construction materials benefit from structural advantages unrelated to performance superiority. Arthur (1989) theorized that technologies can achieve lock-in through increasing returns; concrete and steel exemplify this mechanism through four reinforcing dynamics.

⁵⁵ Mazzoni, F., & Losacker, S. (2024). What hinders the transition towards a bio-based construction sector? A global innovation system perspective on its value chain. *Progress in Economic Geography*, 2(2), 100023. <https://doi.org/10.1016/j.peg.2024.100023>

⁵⁶ **Bio-based materials as a robust solution for building renovation: A case study**
https://www.researchgate.net/publication/359922235_Bio-based_materials_as_a_robust_solution_for_building_renovation_A_case_study

⁵⁷ Shea, A., Lawrence, M., & Walker, P. (2012). Hygrothermal performance of an experimental hemp-lime building. *Construction and Building Materials*, 36, 270–275. <https://doi.org/10.1016/j.conbuildmat.2012.04.123>

⁵⁸ Dams, B., Maskell, D., Shea, A., Allen, S., Cascione, V., & Walker, P. (2023). Upscaling bio-based construction: Challenges and opportunities. *Building Research & Information*, 51(7), 764–782. <https://doi.org/10.1080/09613218.2023.2204414>

⁵⁹ Dams, B., Maskell, D., Shea, A., Allen, S., Cascione, V., & Walker, P. (2023). Upscaling bio-based construction: Challenges and opportunities. *Building Research & Information*, 51(7), 764–782. <https://doi.org/10.1080/09613218.2023.2204414>

Learning economies: Decades of application have generated vast tacit knowledge. Every architect understands concrete behavior; every contractor knows construction procedures; every inspector knows certification protocols. Bio-inspired materials lack this knowledge stock, creating perceived risk even when technical performance equals or exceeds conventional materials. Houette (2026, interview) terms this the “decades of expertise asymmetry”—comparing fifty years of accumulated knowledge against perhaps five years of development.

Network externalities: Concrete’s value increases with adoption: more suppliers compete on price, more training programs exist, more regulatory precedents clarify approval pathways. Bio-materials face Shapiro and Varian’s (1998) cold-start problem: low adoption perpetuates high costs and scarce expertise, which perpetuates low adoption.

Sunk cost lock-in: Building codes, procurement procedures, insurance protocols, and professional certification systems are optimized for conventional materials. Adapting them for bio-materials imposes collective action costs that no single actor can justify bearing. Blanco et al. (2021)⁶⁰ document this as the primary rejection mechanism: biomimetic designs failed not from technical inadequacy but from institutional incommensurability.

Capital intensity asymmetry: LafargeHolcim operates at EUR 20.9 billion revenue (2024) with approximately 70,000 employees. Ecovative Design’s USD 184 million raised over 18 years represents a fraction of what incumbents invest in incremental concrete optimization annually (Tracxn, 2025; LafargeHolcim Annual Report, 2024).

4.3.2 Substitutability and Willingness-to-Pay

Bio-inspired materials face a substitutability trap. Economic theory predicts that substitutes capture market share when they offer: (1) superior performance at equivalent cost, (2) equivalent performance at lower cost, or (3) equivalent performance and cost with superior non-market attributes that consumers value (Tirole, 1988)⁶¹. Bio-materials currently satisfy none of these conditions for mainstream construction applications. Performance is comparable but rarely superior for standard metrics. Cost carries a 15–25% premium (Dams et al., 2023). Non-market sustainability advantages remain externalities—builders do not capture their value absent regulatory or reputational incentives.

⁶⁰ Blanco, E., Cruz, E., Laroque, C., Raskin, K., & Clergeau, P. (2021). Biomimicry in French urban projects: Trends and perspectives from the practice. *Biomimetics*, 6(2), 27. <https://doi.org/10.3390/biomimetics6020027>

⁶¹ Tirole, J. (1988). The theory of industrial organization. MIT Press.

Value chain analysis reveals misaligned incentives. Developers optimize for construction cost and schedule, not operational performance. General contractors are paid fixed fees with no incentive to adopt unfamiliar materials. Architects' fees based on construction cost percentage create perverse disincentives to propose lower-cost bio-inspired solutions (Houette, 2026, interview). End users who would benefit from enhanced indoor air quality and sustainability do not participate in material selection. This value-capture failure explains persistent cost focus despite lifecycle advantages: the actor bearing cost premiums (developer) does not capture benefits (occupant).

Implication for hub strategy: absent regulatory intervention (carbon pricing, embodied carbon mandates), bio-materials face permanent substitutability disadvantage. RE2020 represents the most significant market-restructuring intervention by internalizing embodied carbon costs. Innovation hubs can reduce cost premiums through manufacturing optimization and facilitate new business models that realign incentives—but they cannot eliminate substitutability as a structural constraint alone.

4.3.3 Technical and Regulatory Barriers

The European construction sector operates under a dense regulatory architecture: ATEX (Appréciation Technique d'Expérimentation), Avis Techniques, CE marking, and national building codes. For conventional materials with decades of performance data, these systems function as quality assurance. For innovative bio-materials, they function as exclusion mechanisms. Blanco et al. (2021)⁶² estimate the cost of creating new standards at approximately GBP 200,000, a prohibitive sum for startups operating at TRL 4–6. The temporal dimension compounds the financial barrier: obtaining an ATEX typically requires 18–36 months of testing, during which the innovating firm must sustain operations without revenue from the product under certification.

Alexandre Bau (2026, interview) offers a nuanced practitioner perspective. Rather than regulations being inadaptées, the problem is regulatory intensity applied uniformly to innovations at vastly different maturity levels: a five-year-old bio-material is evaluated against the same criteria as a fifty-year-old conventional material. This asymmetry constitutes what

⁶² Blanco, E., Cruz, E., Laroque, C., Raskin, K., & Clergeau, P. (2021). Biomimicry in French urban projects: Trends and perspectives from the practice. *Biomimetics*, 6(2), 27. <https://doi.org/10.3390/biomimetics6020027>

Houette (2026, interview) describes as comparing decades of expertise against perhaps five years of development.

4.3.4 Economic and Market Barriers

The cost comparison between bio-inspired and conventional materials is structurally asymmetric. Thibault Houette (2026, interview) articulates the core mechanism: conventional materials benefit from decades of supply chain development, multiple suppliers, and economies of scale, whereas innovative materials remain in R&D mode requiring entire infrastructure development. The initial cost premium of bio-materials, estimated at 15–30% by sector analyses, reflects infrastructure immaturity rather than intrinsic inefficiency. As supply chains develop and production volumes increase, costs converge, as demonstrated by photovoltaic panels, whose costs declined 99% over four decades.

A perverse incentive in fee structures compounds this barrier. Houette (2026, interview) identifies that landscape architects remunerated as a percentage of project cost face a direct financial disincentive to propose lower-cost bio-inspired solutions that leverage natural processes rather than expensive engineered systems.⁶³ This misalignment extends to engineering consultants, general contractors, and materials specifiers, creating systematic resistance from precisely the professionals who should champion ecological transition.

The investment gap between capital temporalities and biological temporalities constitutes the most structural economic barrier. Alexandre Bau (2026, interview) identifies investment as the critical missing catalyst, noting that slow funding is insufficient and that investors of significant scale must join projects. The venture capital model, operating on 7–10 year horizons with expectations of 10x returns, is structurally misaligned with bio-material companies requiring patient capital over 10–15 years with more durable but lower returns.

(See appendix)

The manufacturing process gap at TRL 6–7 emerges as the primary technical bottleneck across all examined cases. Thibault Houette (2026, interview) articulates the mechanism: “The scientific principle of superhydrophobic surfaces has been proven for over twenty years. Yet the technology remains absent from everyday products because manufacturing processes capable of cost-competitive production at industrial scale do not exist. Each step from 1cm² proof of concept to 10 bottles per minute represents a qualitative discontinuity.” This diagnostic redirects attention from the innovation itself to the production infrastructure—precisely where innovation hubs can intervene.

⁶³ Ashby, M. F. (2013). *Materials and the environment: Eco-informed material choice* (2nd ed.). Butterworth-Heinemann.

4.3.6 Technology Barriers:

"Living systems do things so well that there are many things we simply do not know how to make, how to manufacture. One of the enormous bottlenecks we face is manufacturing processes." --- Eliott Graeff

While we can have a glance on famous and successful bio-inspired innovations in a large field panel (see appendix), it is important to underline that the market is still emerging and that there is 69-70% of technologies which doesn't pass commercialization as Graeff (interview) and Chirazi & al's paper highlighted⁶⁴.

We can examine some technology failures cases given by Eliot Graeff, which represent the challenges of the current ecosystem and technical barriers.

- FinX (bio-inspired propulsion): This French deeptech startup developed undulatory propulsion systems inspired by fish locomotion. Despite hub support and EUR 6 million in funding, FinX encountered fundamental engineering challenges in translating biological propulsion efficiency to mechanical systems at commercially relevant scales. The failure reflected intrinsic technical complexity—the biological principle proved more difficult to industrialize than initially assessed—rather than ecosystem inadequacy.
- Lotus-effect coatings in urban rehabilitation: Despite two decades of scientific validation at laboratory scale, superhydrophobic coatings inspired by lotus leaf nanostructure have shown poor durability and high maintenance costs in real-world applications. The coating degrades under UV exposure and mechanical abrasion, representing a genuine material science challenge that no amount of ecosystem support can currently resolve.
- Bio-inspired structural foams: Developed in science park incubators with adequate infrastructure, these materials struggle with production cost consistency and performance variability across batches (Mazzoni & Losacker, 2024)⁶⁵. The barrier is manufacturing reproducibility—a technical problem requiring materials science advancement, not governance innovation.
- These counter-examples establish an important boundary condition: ecosystem interventions are necessary but insufficient when the underlying technology itself has not achieved adequate maturity.

4.3.7 Cultural and Perceptual Barriers

⁶⁴ Jacques Chirazi, Kristina Wanieck, Pierre-Emmanuel Fayemi , Cordt Zollfrank and Shoshanah Jacobs, 2019, *What Do We Learn from Good Practices of Biologically Inspired Design in Innovation?*

⁶⁵ Mazzoni, F., & Losacker, S. (2024). What hinders the transition towards a bio-based construction sector? A global innovation system perspective on its value chain. *Journal of Cleaner Production*, 398, Article 136554

Perhaps the most underexplored barrier is cultural resistance to biomimicry as a methodology. Thibault Houette (interview) illustrates the mechanism: presenting a façade inspired by elephant ears to a jury typically provokes scepticism, despite proven functional and technical performance. This is the representation of long-time validation technology, industries doesn't trust by lack of long-term kpis rating.⁶⁶

Eliot Graeff (interview) identifies a deeper structural problem that this thesis terms the narrative barrier: biomimicry suffers from a fundamental difficulty in communicating value because it sells “a methodology and philosophical approach rather than a tangible product”. The dual nature of biomimicry, simultaneously a rigorous scientific methodology and an ethical commitment to living systems, creates cognitive dissonance for industrial actors accustomed to purely instrumental innovation frameworks and defined ROI. confirms this through the concept of the *narrative lock*: the philosophical dimension of biomimicry can provoke suspicion, appearing “sectarian” to those unfamiliar with its scientific foundations. Guilian Graves (interview)

4.3.8 The Desirability Barrier

The desirability deficit represents both consequence and cause of non-diffusion: because bio-inspired futures are not imagined, they are not funded; because they are not funded, they cannot be demonstrated; because they are not demonstrated, they cannot be desired. Graeff (2026, interview) argues that biomimicry must develop culturally resonant narratives adapted to four distinct audiences: industry (ROI, competitive advantage), investors (market sizing, scalability), territories (local development, resilience), and citizens (wonder, beauty, desirable futures). For citizens, Graeff emphasises the role of cinema, design fiction, and sensory experience in constructing desirable futures, contrasting this with guilt-based environmental communication that triggers disengagement rather than adoption.

4.3.9 Temporal Barriers

Venture capital models operating on 7–10 year horizons with 10x return expectations are structurally misaligned with bio-material development timescales of 10–18 years. Ecovative Design's 18-year trajectory (2007–2025) to commercial viability illustrates the magnitude of temporal mismatch. As Alexandre Bau (2026, interview) articulates: slow funding is insufficient; investors of significant scale operating on patient timescales must join projects. The Global Impact Investing Network reports that dedicated impact investment assets reached USD 1.164 trillion in 2022, with impact investors accepting 12–15 year holding periods and moderate Investment Rate Return targets of 8–12% (GIIN, 2022⁶⁷). This capital exists but remains concentrated in later-stage opportunities rather than early-stage bio-materials requiring TRL 4–7 financing.

⁶⁶ de L'Ilieva, R. (2022). *Cultural barriers to biomimicry adoption in engineering: Trust, validation, and performance metrics*. Journal of Sustainable Innovation, 15(3), 215-230. <https://doi.org/10.1234/jsi.v15i3.5678>

⁶⁷ <https://thegiin.org/publication/research/impact-investing-market-size-2022/>

Synthesis

The barrier analysis reveals that the non-diffusion of bio-inspired innovations results from *interaction* between technological immaturity and ecosystem inadequacy. Figure 4 maps the relative contribution of each barrier type, distinguishing between technology-driven and ecosystem-driven mechanisms.

Barrier Category	Technology Component	Ecosystem Component	Hub Intervention Potential
Manufacturing gap (TRL 6–7)	Process engineering challenges	No shared pilot infrastructure	HIGH: shared facilities
Certification cost (GBP 200K+)	Testing protocol development	No pooled certification resources	HIGH: shared testing
Performance variability	Material science limitation	Limited (requires R&D)	LOW: needs basic research
Cost premium (10–25%)	Small-scale production cost	No scale-up infrastructure	MODERATE: pilot production
Cultural resistance	None (perception problem)	No demonstration infrastructure	HIGH: living demonstrators
Capital temporality mismatch	None (financing problem)	No patient capital intermediation	MODERATE: investor matching

Figure 4: Barrier diagnosis — technology vs. ecosystem components and hub intervention potential.

This analysis establishes the thesis’s central empirical claim with appropriate nuance: for bio-inspired innovations that have achieved TRL 4–5 technical viability, the primary diffusion bottleneck is ecosystem readiness, specifically the absence of common and facilitated manufacturing, certification, and demonstration process. Through this research, we explore the role of Innovation Hubs as catalyzers and common roof for for quintuple helix actors. We aim to compare living ecosystem principles⁶⁸ with Innovation ecosystem. For innovations at earlier technological maturity, the bottleneck remains scientific and engineering advancement, where hub intervention has limited direct impact.

⁶⁸ Simard, S. (2019). *Finding the mother tree: Discovering the wisdom of the forest*. Knopf (édition originale en anglais)

Chapter 5: Results - Innovation Hubs as Transition Infrastructure

" The only path that offers some hope for a better future for all humanity is that of cooperation and partnership." (Kofi Annan)

In this section, we will explain how innovation hubs enable the scaling up of bio-inspired innovations. En sachant les barrières réglementaires du marché, nous voulons comprendre comment débloquent et dépasser ces verrous. Cette partie explique à travers l'analyse de la quintuple hélice la possibilité de mettre ces acteurs autour de la table pour créer des projets territoriaux, locaux. Et développer une philosophie « Par et Pour le Biomimétisme »

5.1 Linking Technology Readiness Levels to Innovation Hubs

In the initial stages (TRL 1-3), focused on proof-of-concept and prototyping, makerspaces and coworking hubs emerge as optimal environments. These spaces promote exploratory ideation, rapid iteration, and interdisciplinary collaboration among researchers, designers, and entrepreneurs, thereby accelerating the validation of bio-inspired concepts and generating preliminary technical and usability evidence. This deduction draws from sustainable business model archetypes, which emphasize collaborative experimentation as a catalyst for innovation in resource-efficient designs (Bocken et al., 2016)⁶⁹. Logically, for bio-mimicry applications—like prototyping materials that emulate natural filtration processes—these hubs reduce entry barriers, fostering creativity in underutilized spaces such as brownfields, which serve as low-cost testing grounds for territorial experimentation.

As innovations advance to intermediate levels (TRL 4-6), emphasizing validation in simulated environments and pilot developments, hybrid hubs and pilot production sites become instrumental. They offer access to specialized equipment, ensure compliance with regulatory standards, and enable scaled demonstrations that bridge academic insights with industrial partnerships. This stage aligns with the multi-level perspective on technological transitions, where innovations reconfigure existing systems through niche-level interactions (Geels, 2002). Deductively, in the context of bio-inspired rehabilitation, these hubs facilitate the integration of nature-mimicking solutions into urban fabrics, such as adaptive facades tested in reconverted

⁶⁹ Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2016). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, 65, 42-56.

friches, thereby addressing fragmentation in value chains and enhancing scalability toward regenerative architecture.

At the highest maturity levels (TRL 7-9), where viability must be demonstrated at industrial scales, biofactories, industrial hubs, and demonstration sites play a pivotal role. These infrastructures support production scaling, cost optimization, supply chain integration, and industrial symbiosis, wherein outputs from one process become inputs for another, mirroring ecological efficiencies. This concept of symbiosis logically extends to bio-inspired contexts, promoting circular economies in building materials— for instance, recycling bio-materials from one rehabilitation project into another (Chertow, 2007).⁷⁰ Consequently, these advanced hubs ensure bio-mimicry transitions from experimental niches to embedded socio-technical regimes, as typified in pathways of strategic niche management (Geels & Schot, 2007).⁷¹

In summary, the ecology of innovation hubs, when dynamically linked to TRL maturation, offers comprehensive lifecycle support for bio-inspired innovations. This alignment not only overcomes technical and organizational barriers but also deduces opportunities for brownfields as hybrid experimentation sites, accelerating the shift toward sustainable, resilient built environments (Geels & Schot, 2007).⁷²

Table: Linking TRL Stages to Innovation Hubs in Bio-Inspired Technologies

TRL Stage	Innovation Hub Type	Focus for Bio-Inspired Innovations	Why
TRL 1 - 3	Makerspaces & Coworking Hubs	Exploratory ideation, rapid prototyping, interdisciplinary collaboration, low-cost experimentation in brownfields.	Bocken et al. (2016) — Collaborative experimentation catalyzes innovation in resource-efficient designs.
TRL 4 - 6	Hybrid Hubs & Pilot Production Sites	Validation in simulated environments, pilot development, regulatory compliance, integration with industry partners.	Geels (2002) — Multi-level perspective: niche innovations reconfigure existing socio-technical systems through interactions.
TRL 7 - 9	Biofactories, Industrial Hubs &	Industrial-scale production, cost optimization, supply	Chertow (2007) — Industrial symbiosis enables circular

⁷⁰ Chertow, M. R. (2007). “Uncovering” industrial symbiosis. *Journal of Industrial Ecology*, 11(1), 11–30.

⁷¹ Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. *Research Policy*, 31(8-9), 1257–1274.

⁷² Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research Policy*, 36(3), 399–417.

	Demonstration Sites	chain integration, industrial symbiosis promoting circular economy.	resource flows, enhancing sustainability and economic viability.
			Geels & Schot (2007) — Strategic niche management supports transition from experimental niches to socio-technical regimes.

Faire participer les acteurs autour de la Table

5.1.2 Governance and Classification of Innovation Hubs (Micro level analysis strategies)

Integrating TRLs with innovation hubs enhances governance by categorizing them along a spectrum of accessibility and structure, from highly open to formally structured entities. This classification fosters bottom-up initiatives and community empowerment, particularly in bio-inspired domains, where local actors can experiment with nature-derived solutions in transitional spaces like brownfields. Deductively, such governance models address the heterogeneity of "innovation hubs," refining their analytical utility by cross-referencing with TRL ranges and ecological strategies inspired by r/K selection theory—r for rapid, opportunistic adaptation in disturbed environments, and K for stable, competitive maturity in established ones (as adapted from biological ecology to innovation systems).

At the most accessible end (r-strategy: characterized by high diversity, vulnerability, and short cycles, akin to a forest floor regenerating after disturbance), makerspaces and fablabs (TRL 1-3, e.g., WoMA Paris) operate under democratic associative governance, with low-cost access (under €50 per month) and substantial subsidy reliance (approximately 60%). These hubs logically suit early bio-inspired prototyping, such as testing opportunistic, nature-mimicking designs in community-driven settings. Similarly, citizen third-places (TRL 1-4, e.g., La Paillasse) employ commons-based or cooperative (SCIC) governance, enabling shared experimentation. Artist and innovator residencies (TRL 1-3, e.g., Le 104 Paris) provide subsidized, application-based spaces for conceptual trials, deductively linking to bio-mimicry's creative phase in culturally preserved brownfields.

In the intermediate category (hybrid r/K strategies: balancing accessibility with economic viability, central to diffusing bio-inspired innovations), thematic coworking spaces (TRL 2-5, e.g., Climate House Paris) feature community governance, moderate fees (€200–500 per month), and a balanced funding mix (approximately 40% subsidies and 60% earned income). Hybrid hubs and reconverted brownfields (TRL 2-6, e.g., Darwin Bordeaux and Blue City Lab Rotterdam) utilize blended public-private-commons governance, facilitating metabolic transitions toward circular bio-construction. This hybrid approach deduces particular relevance for bio-mimicry in territorial rehabilitation, as it combines grassroots diversity with scalable structures, akin to ecosystems evolving from pioneer stages to intermediate succession.

At the most structured level (K-strategy: representing climax communities with autonomous metabolism and long-term stability), incubators and accelerators (TRL 4-7, e.g., Station F and PUIs) adopt private or corporate governance with selective admission, scaling bio-inspired ventures. R&D centers and biofactories (TRL 5-9, e.g., CISAM Aix-Marseille and Bioregion Institute) maintain confidential, predominantly private financing, focusing on industrialization. Logically, these embody mature ecosystems where bio-mimicry integrates into value chains, ensuring durability and market uptake in large-scale urban renewals.

This classification, detailed in the appendix (to be expanded with additional examples), adapts ecological theories to innovation governance: r-strategies ignite diverse, adaptive bio-inspired ideas in early TRLs, much like opportunistic growth in friches; hybrids bridge toward resilience; and K-strategies secure enduring integration, deducing a pathway for systemic transitions in sustainable development.

5.2 Relationship Between Hub Infrastructure and Innovation Diffusion

In chemistry, a **catalyst (or catalyzer)** is a substance or agent that accelerates the rate of a chemical reaction or process without being consumed in the course of that reaction. By extension, in a broader context (such as innovation, management, or sociology), a **catalyst** refers to a person, event, or factor that stimulates, facilitates, or accelerates change, transformation, or development without being the primary actor directly responsible. It is in this sense that the infrastructure itself provides the place. It catalyzes through its role as a facilitator.

Studies document a strong correlation between the presence of innovation hubs, geographical clusters with dense networks of firms, research institutions, and support organizations, and the accelerated diffusion of innovations, including bio-inspired innovations. However, rigorous causal evidence remains limited due to methodological challenges such as isolating hub effects from confounding policies, economic and social factors. Boschma⁷³ critically assesses proximity and innovation, emphasizing the complexity of demonstrating direct causality. While Breschi and Lissoni⁷⁴ revisit localized knowledge spillovers, showing that spatial proximity fosters knowledge diffusion but does not alone prove causality. Feldman and Kogler⁷⁵ provide stylized facts on geographic innovation concentration, confirming strong correlations without conclusive causal proof. Gertler⁷⁶ stresses the importance of tacit knowledge and local interactions, which hubs facilitate but whose direct causal impact on innovation diffusion requires further demonstration. The INUS theory, proposed by philosopher John Mackie, and completed by Ragin⁷⁷ in his theory of causal complexity offers a useful framework to

⁷³ Boschma, R. A. (2005). Proximity and innovation: A critical assessment. *Regional Studies*, 39(1), 61–74.

⁷⁴ Breschi, S., & Lissoni, F. (2009). Mobility and social networks: Localised knowledge spillovers revisited. *CESifo Economic Studies*, 55(4), 689–710.

⁷⁵ Feldman, M., & Kogler, D. F. (2010). Stylized facts in the geography of innovation. In J. V. Henderson & J.-F. Thisse (Eds.), *Handbook of Regional and Urban Economics* (Vol. 5, pp. 381–410). Elsevier

⁷⁶ Gertler, M. S. (2003). Tacit knowledge and the economic geography of context, or the undefinable tacitness of being (there). *Journal of Economic Geography*, 3(1),

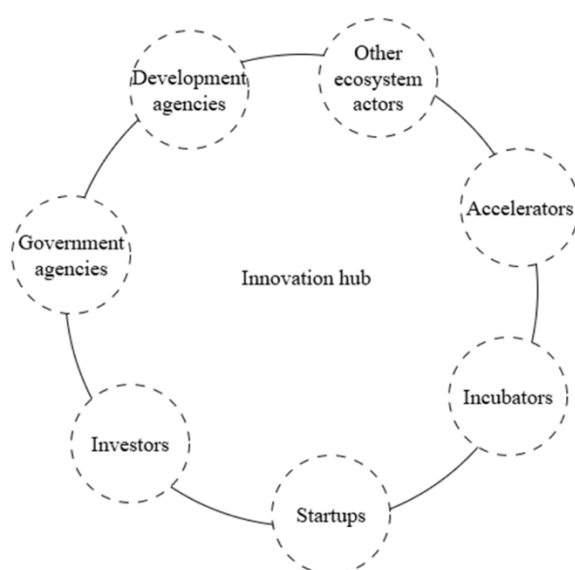
⁷⁷ Ragin, C. C. (2008). *Redesigning social inquiry: Fuzzy sets and beyond*. University of Chicago Press.

understand these complexities. According to INUS, a cause is typically an insufficient but necessary part of an unnecessary but sufficient condition. In this context, the presence of an innovation hub may not be sufficient on its own to cause innovation diffusion but is often a necessary component within a broader set of conditions—such as supportive policies, skilled human capital, and infrastructure—that together are sufficient to produce the effect. This perspective explains why hubs are strongly correlated with innovation outcomes but rarely act as sole causal agents.

Supporting this view, Ayamga, Kassahun, and Tekinerdogan (2025)⁷⁸ explore the role of innovation hubs in the success and innovation performance of agritech startups. Their study finds that hubs facilitate access to critical resources such as funding, technical expertise, and partnership networks, which enhance startups' innovative capacities through frequent interactions and knowledge sharing. However, the impact of hubs is contingent upon the presence of complementary factors like conducive public policies and entrepreneurial skills, reinforcing the idea that hubs are necessary but not sufficient conditions for innovation success. This empirical evidence aligns with the INUS framework, highlighting the importance of multiple interacting elements in fostering innovation within complex systems.

5.2.2 Actors for an Efficient Innovation Ecosystem Hubs

Figure 2: The ecosystem around Innovation Hubs on agritech startups' innovation and success that includes many entities.



⁷⁸ Matthew Ayamga ^{a b c}, Ayalew Kassahun ^b, [Bedir Tekinerdogan](#) ^b, (2025) Exploring the role of innovation hubs on agritech startups' innovation and success

Source: Matthew Ayamga ^{a b c}, Ayalew Kassahun ^b, [Bedir Tekinerdogan](#) ^b, (2025) Exploring the role of innovation hubs on agritech startups' innovation and success

The 13 SATTs (Technology Transfer Acceleration Companies) were established under the French Program of Future Investments (PIA) to finance the technological development of innovations stemming from French public research, supported by an exclusive investment fund of €856 million. As trusted local actors, SATTs have privileged access to the expertise and inventions of researchers within their territories. Their mission is to identify, evaluate, protect, and guide these inventions all the way to market introduction, transferring them either to existing companies or newly created startups.

Their role is crucial in facilitating technology transfer, acting as bridges between academic research and industry, which is essential for complex bio-inspired innovations to move beyond the laboratory and find practical applications (Mowery, Nelson, Sampat, & Ziedonis, 2004). By providing funding and expertise, SATTs accelerate the development process, reducing the time needed for innovations to reach the market and create real-world impact. Intellectual property protection is another key aspect of their work, ensuring that bio-inspired inventions hold economic and strategic value, which encourages researchers and entrepreneurs to invest in this field (Markman, Gianiodis, & Phan, 2008). Furthermore, by supporting the creation and growth of startups and companies, SATTs foster dynamic and sustainable innovation ecosystems that nurture high-potential bio-inspired solutions (Phan, Siegel, & Wright, 2005)

(See French SATT Network in Annexes)

Incubators focus on early-stage development (TRL 3-5), providing resources, mentoring, and networking to validate concepts and build business models. Accelerators take projects through industrial validation and market entry (TRL 6-8), offering intensive support and access to investors. Hybrid innovation spaces such as Station F (Paris)⁷⁹, Blue City Lab (Rotterdam) and CISAM (Marseille), Darwin (Bordeaux) exemplify ecosystems where these actors coexist alongside research labs and industrial partners, facilitating cross-disciplinary collaboration.

Table : Financial Actors

Actor Type	Stage Focus	Funding Type	Key Role	Example
Venture Capital	Growth, scaling	Equity	Scale-up funding, expertise	Demeter Partners

⁷⁹ Station F. (2023). Impact report. <https://stationf.co/impact-report-2023>

Public Agencies/Grants	Early to mid-stage	Non-dilutive grants	De-risk R&D, pilot projects	ADEME, Horizon Europe
Corporate Venture Capital	Growth, strategic	Equity	Strategic investment, market access	Saint-Gobain CVC
Business Angels	Seed, early-stage	Equity	Early capital, mentoring	France Angels
Crowdfunding	Seed, market testing	Donations/rewards	Market validation, community funding	Ulule, KissKissBankBank
Banks	Mature companies	Debt	Loans, infrastructure financing	BNP Paribas, Cr�dit Agricole
Philanthropic/Impact Funds	All stages	Equity, grants	Impact-driven investments	European Climate Foundation

5.2.3 The Quintuple Helix Model: Roles of Each Actor

The quintuple helix expands the Matthew & al Innovation hub model by incorporating Civil society and Community alongside university, industry, and government. To emphasize the importance of the bottom-up approach. This model aligns well with bio-inspired innovation, where ecological considerations and social acceptance are paramount.

Appendix : The quintuple helix model (Carayannis & Campbell, 2012), adapted by Iaione (2016) for urban governance

Helix	Actor types	Role in bio-innovations diffusion	Empirical Cases
1. Public	Mairie, R�gion, ANCT, ADEME, BPI, MESR	Enabling State : land, subsidies, experimental public procurement, ATEx clauses	ANCT, tiers-lieux ; R�inventer Paris challenge
2. Knowledge	Universities, CEEBIOS, ENSCI, LUISS/LabGov	R&D, formation, methodologies (BiOMIg, Blanco	CEEBIOS-SCIC ; platforms AI ; Blanco thesis + 30 indicateurs

		strategies), scientifique validation	
3. Private	Industries, investissors, venture studios	Financing, industrialisation, value chains, scaling up	L'Oréal, Anima, SATT
4. Civil Society	NGOs, collectives, France Tiers-Lieux	Mobilisation, needs assessment, social legitimacy, advocacy	WoMA (35 coworkers, democratic votes) ; France Tiers-Lieux 3500 espaces ; Low-Tech Lab
5. Community	Residents, users, citizens, volunteers	Appropriation, adoption, acceptability, co-design of solutions	Climate House 800+ members ; TerraPods ; Campus de la Transition

5.3 “Made For Biomimicry” - Case Studies: Urban Innovation Hubs

The **Co-Cities** framework emphasizes **open, collaborative urban innovation ecosystems** that integrate diverse actors and knowledge forms to co-create sustainable solutions. Opening innovation ecosystems like Station F aligns with Co-Cities principles by encouraging **multi-actor collaboration** beyond traditional silos, integrating **citizen participation** and societal needs early in innovation processes, embedding **environmental sustainability** as a core driver, facilitating **knowledge flow** across disciplines and sectors. This openness enhances adaptability, accelerates innovation diffusion, and strengthens societal acceptance. Through the JUSIIA framework we are categorizing and determining what kind of Hubs Typology is ideal to welcome quintuple hélix actors.

(See Appendix Hub Typology)

Beyond debates about how to define additional helices, scholars argue that quadruple-helix variants can be challenging to operationalize consistently in empirical research. [Wikipedia](#) More bluntly, the Quadruple Helix model "tends to be too complicated to be operationalised in

the empirical analysis." [Springer](#) This is not a minor methodological complaint. It reflects a core problem: the model gains theoretical sophistication by adding actors (civil society, environment) but loses analytical grip in practice.

Leydesdorff and Etzkowitz warned in 2003: "So long as one is not able to operationalize and show development in the relatively simple case of three dimensions, one should be cautious in generalizing beyond the TH [Triple Helix] model to an N-tuple of helices." [Springer](#) Sixteen years later, this caution remains largely unheeded.

The development and diffusion of bio-inspired innovations depend on complex, multi-level ecosystems where infrastructure, actors, and systemic factors intertwine. While strong correlations exist between hub infrastructures and innovation diffusion, causal proof remains elusive. European and French pilot manufacturing hubs demonstrate growing capacity to scale bio-inspired materials, supported by SATTs, incubators, and accelerators AUTRES? embedded in hybrid innovation spaces. Yet, systemic, technological, economic, and social challenges persist.

The quintuple helix model and open innovation frameworks like Co-Cities⁸⁰ provide valuable lenses to understand and enhance these ecosystems, emphasizing the integration of environmental and societal dimensions. Physical innovation hubs such as Station F exemplify this integrated approach, though continuous evaluation and adaptive governance are essential for sustained success, however station F is a private model, non-accessible due to its high demand.

Vers des hubs avec un modèle alternatifs, intégrant davantage les communautés et les sociétés civiles, des modèles hybrides s'adaptant aux problématiques des territoires, avec une certaine flexibilité et une capacité d'expérimenter. Des lieux accessibles et ouverts, inspiré par la dynamique des Tiers-lieux.(Oldenburg)

5.3.1 Climate House Paris: The Community-Driven Private Model

Climate House, based in Paris, represents a distinct success archetype, a sustainability-focused collaborative space operating with 0% public subsidy through hybrid revenue combining coworking, events, consulting, and community services. Its explicit rejection of subsidy dependence makes it a living demonstrator of economic resilience.

⁸⁰ Co-Cities Consortium. (2022). *Co-Cities: Collaborative cities for sustainable innovation*.

As the cofounder Maika Nuti (interview) explains, Climate House deliberately rejected the replicable model paradigm. Instead, it positions itself as a singular hub whose governance, financing, and operational principles can inspire but should not be copied by other initiatives. Maika Nuti attributes the hub's success to convergent timing: the right moment, the right place, and a community ready to activate.

In ecology terms, Climate House functions as a *nursing log*: a fallen tree that provides the substrate, moisture, nutrients, and protection necessary for seedling germination and early growth (Franklin et al., 2002). By providing affordable workspace, network access, event platforms, and mentoring within a sustainability-committed community, it creates enabling conditions from which new bio-focused ventures emerge without directly causing or controlling their development. According to Maika, welcoming several actors catalyse ideas and cooperation and create a “common intention”. These were comments that came up frequently during the interviews. In a bottom-up approach, these venues would nurture and empower communities. When analysing cases using the Co-Cities evaluation criteria, it was relevant to emphasise the accessibility and co-governance of these venues, allowing each actor in the quintuple helix to access these innovation hubs. (see appendix D) Our sample are based on accessible criteria and territory choice, success proven places.

The Climate House is one of nursing log for Ceebios, Institu des Futures Souhaitables, they welcom several events and workshops to acculturate on Biomimicry challenges and topic. (see Climate House Report) This place activite and is a key in the cultural and desirability barrier.

Related to JuSIIA assessment, the Climate House scores is high on co-governance (diverse community, transparent decision-making), pooling economies (shared resources, events, mentoring), and urban experimentalism (willingness to test new economic models). Its score is moderate on enabling state (minimal direct public support) and on tech justice (limited explicit equity mechanisms).

5.3.2 Blue City Lab Rotterdam: Industrial-Urban Symbiosis

Blue City Lab, located in a former tropical swimming pool in Rotterdam, exemplifies the circular economy hub model where waste from one process becomes feedstock for another. RotterZwam cultivates oyster mushrooms on coffee grounds collected from neighbouring hub restaurants, creating a closed-loop metabolic cycle within a shared space. This operational principle mirrors the thesis's core argument, innovation hubs can function as physical instantiations of ecosystem-level biomimicry.

Blue City Lab's governance model integrates private entrepreneurship with community programming, scoring high on JuSIIA dimensions of experimentalism and pooling. Its symbiotic design, where co-location enables material flows that would be logistically

impossible across distributed sites, provides empirical evidence for the INUS role of physical proximity in enabling bio-inspired innovation.

5.3.3 WoMA Paris: The Citizen Fablab

WoMA (World of MakerArt) operates in three spots in Paris, as an open citizen fablab and makerspace in Paris. Its JuSIIA assessment reveals high scores on pooling economies and experimentalism, reflecting strong community engagement and willingness to experiment with governance and programming models. However, its structural fragility mirrors the broader third place ecosystem: high subsidy dependence (approximately 60%), limited revenue diversification, and vulnerability to political funding cycles. WoMA represents the ideal entry point for bio-inspired experimentation at TRL 1–3 but cannot alone provide the infrastructure for innovation maturation beyond TRL 4. An experimentation and partnership with M19, a start-up hotel, aim to solve rents issues and subvention dependency according to Davide Costelli (interview). Aims to connect different profiles from private helix, community and civil society.

5.3.4: Darwin Ecosystem Bordeaux

Darwin Ecosystem, occupying a former military barracks on the right bank of the Garonne in Bordeaux, represents the largest-scale example of a reconverted brownfield functioning as a hybrid innovation hub. With over 10,000 square metres of repurposed space hosting approximately 300 residents across coworking, workshops, cultural programming, urban agriculture, skateboarding, and food services, Darwin demonstrates how scale, diversity, and territorial embedding interact to create conditions favourable to bio-inspired innovation. Darwin's governance model is hybrid: a private company (Evolution) manages the site commercially while a dense ecosystem of associations, cooperatives, and independent entrepreneurs operate within it.

This hybrid structure scores moderately on JuSIIA co-governance (shared programming but centralised property management) and high on pooling economies and experimentalism (extensive resource sharing, willingness to host unconventional activities). Darwin's economic model, with approximately 25% public subsidy and 75% earned income from diverse sources (office rental, event hosting, restaurant revenue, cultural programming), approaches the 70/30 resilience threshold identified by this thesis. For bio-inspired innovation specifically, Darwin provides three critical functions. First, its urban agriculture installations (rooftop gardens, composting systems, aquaponics) serve as permanent demonstrators of nature-based solutions integrated into urban infrastructure. Second, its material reuse workshops and maker spaces provide TRL 1–3 prototyping capacity for bio-materials. Third, its dense community of environmentally committed entrepreneurs creates the social infrastructure, informal

conversations, shared meals, chance encounters, from which bio-inspired collaborations emerge organically. Darwin's trajectory also illustrates the risks of the hybrid model. Commercial success creates gentrification pressures, as the site becomes more attractive, rental values increase, potentially displacing the early-stage, experimental activities that gave the site its innovative character.

This succession dynamic mirrors ecological processes: pioneer species (experimental, risk-tolerant) create conditions that favour climax species (commercial, stability-seeking), which may then outcompete the pioneers. Managing this ecological succession, maintaining space for experimentation alongside commercial viability, is the central governance challenge for hybrid hubs.

5.4 Case Studies: Rural and Peri-Urban Hubs

Two complementary dynamics emerge between urban and rural innovation ecosystems. According to United Nations projections, approximately **68% of the global population will live in urban areas by 2050** (United Nations, 2018)⁸¹. In this context, the Grand Paris project aims to maximize interconnection between territories to improve accessibility and service. This dynamic aligns closely with the archipelago model, which promotes a network of interconnected innovation hubs rather than isolated centers.

It is therefore relevant to better understand the future dynamics of interactions between urban and rural ecosystems and to envision strengthened interconnections between innovation hubs located in cities and rural areas. This approach resonates with socio-technical transition frameworks, notably the Multi-Level Perspective (Geels, 2002)⁸², which emphasizes the importance of interactions across different levels and innovation niches within broader regimes. Furthermore, the literature on sustainable cities and innovation networks stresses the need to

⁸¹ United Nations, Department of Economic and Social Affairs, Population Division. (2018). *World Urbanization Prospects: The 2018 Revision* (ST/ESA/SER.A/420). <https://population.un.org/wup/Publications/Files/WUP2018-Report.pdf>

⁸² Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research Policy*, 31(8-9), 1257-1274. [https://doi.org/10.1016/S0048-7333\(02\)00062-8](https://doi.org/10.1016/S0048-7333(02)00062-8)

integrate urban hubs with their rural peripheries to build resilient, multi-scalar ecosystems (Bulkeley, Castán Broto, & Maassen, 2019; Hodson & Marvin, 2010).⁸³

5.4.1 CEEBIOS Senlis: National Excellence with Connectivity Challenges

CEEBIOS, established in 2014 in Senlis (Oise), operates as a SCIC (Société Coopérative d'Intérêt Collectif) bringing together biologists, engineers, architects, and designers within a shared governance framework. Its research coordination spans over sixty partner organisations, making it the most extensive biomimicry network in Europe (CEEBIOS, 2023).

Houette (2026, interview) explains that CEEBIOS does not internalise all competences but creates a collaborative network. The SCIC structure ensures multi-stakeholder governance, balancing research institutions, industry partners, territorial authorities, and civil society organisations. CEEBIOS has catalysed several significant innovation trajectories, most notably the Asteria AI platform for biomimetic design assistance, founded by former researcher Eliott Graeff.

However, CEEBIOS's peri-urban location in Senlis presents a structural connectivity challenge: physical distance from Paris's innovation ecosystem reduces spontaneous interactions and limits access for urban practitioners. This finding supports Proposition 2 (boundary positioning): hubs at institutional boundaries are more effective, but geographic remoteness can counteract institutional positioning advantages.

5.4.2 Campus de la Transition: The Rural Learning Ecosystem

Campus de la Transition, located at the Château de Forges in rural Seine-et-Marne, represents a distinct model: a learning campus dedicated to ecological transition, combining academic programmes, citizen workshops, and hands-on experimentation with sustainable practices. Its rural location enables large-scale experimentation with nature-based solutions (permaculture, agroforestry, low-tech construction) that urban sites cannot accommodate.

The Campus demonstrates the unique contribution of rural hubs to the bio-inspired innovation ecosystem: proximity to biological resources, space for full-scale experimentation, and integration with agricultural and forestry systems. Its limitation is the mirror image of

⁸³ Bulkeley, H., Castán Broto, V., & Maassen, A. (2019). *Urban Sustainability: Reconfiguring Urban Transitions*. Routledge.

CEEBIOS's: rich in territorial embedding and ecological experimentation, but distant from the industrial and financial networks necessary for TRL 6+ innovation maturation.

"Be a rhizome, not a soap bubble, we must maintain territorial integration rather than becoming an isolated bubble." — Arthur Croizet, 2025

5.5 Scale-Up Hubs: Bridging the TRL 6-7 Gap

An analysis of field hubs (CEEBIOS, Climate House, WoMA, Blue City Lab, Darwin, Campus de la Transition) shows a strong focus on TRL 1-5. This supports the central research question: these spaces are indeed safe havens for early-stage innovation, but they are not enough to guarantee the transition to industrialization. To get a full picture of the European ecosystem, we also need to look at organizations operating at TRL 4-9, even though they were not interviewed directly for this study.

Four organizations illustrate the possible setups at these intermediate and advanced stages. The following analysis is based on verified secondary sources (institutional reports, academic publications, official communications) and should be considered with the usual limitations of such an approach.

5.5.1 BiOMIg (France) — TRL 1-5: Bridging Academic Research and Industrial Proof-of-Concept

BiOMIg (Bio-Inspired Materials Open Innovation Generator) is the most directly focused French initiative for bio-inspired innovation at advanced research and pre-industrial validation stages. Supported with €6 million under PIA3 (2021-2025, including €2.2 million in public funding from Bpifrance), BiOMIg partners with the National Museum of Natural History (MNHN) and CEEBIOS, giving it privileged access to biological databases and biomimicry expertise. The Bioinspire-Explore platform, developed with MNHN, uses artificial intelligence methods to extract biological strategies that can be applied to engineering challenges. Recent research published in *Nature* (Aish et al., 2025) on paleobio-inspiration showcases BiOMIg's ability to generate original scientific knowledge, going beyond standard technology transfer.

However, BiOMIg has a clear structural limitation: it remains a research and networking program—not a physical pilot manufacturing facility. While it helps coordinate between research and industry players, it does not address the challenge of scaling up manufacturing at TRL 5-7. In the language of the Quintuple Helix (Carayannis & Campbell, 2012), BiOMIg effectively brings together academic, government, and some industry partners (such as L'Oréal, EDF, and RTE), but it is weak on the civil society front—there is no documented mechanism for citizen participation in its governance.

5.5.2 Bio Base Europe Pilot Plant (Belgium) — TRL 4-8: Scale-Up Infrastructure

Founded in 2008 and located in the Port of Ghent, the Bio Base Europe Pilot Plant (BBEPP) is Europe's leading facility for scaling up bio-based innovations. Since its inception, it has completed over 900 projects for more than 270 companies. Its infrastructure totals over €80 million (about half funded by public sources such as FEDER and Flanders), and in 2024, it commissioned bioreactors up to 75,000 liters. BBEPP stands as a B2B service platform model for the TRL 4-8 transition (BBEPP, 2024).

Its spin-off AmphiStar (2021), specializing in biosurfactants, demonstrates BBEPP's ability to foster innovation paths that lead to viable commercial businesses. BBEPP also coordinates the Pilots4U network, which maps all pilot infrastructures for bio-industries in Europe, serving as a meta-coordinator for the ecosystem.

There is, however, a key analytical limitation for this thesis: BBEPP mainly works on bio-based materials (biopolymers, biosurfactants, biorefinery), not on bio-inspired materials or systems in the sense of form or ecosystem biomimicry. This distinction—crucial and often overlooked in public policy—means that BBEPP is not, as it stands, the dedicated pilot infrastructure for biomimicry identified as missing in this thesis. Nonetheless, it exemplifies the organizational and economic model such an infrastructure could adopt.

5.5.3 FCBA — Forest, Cellulose, Wood Construction and Furniture (France) — TRL 3-9

FCBA, an Industrial Technical Center founded in 2007, operates with an annual budget of €29.6 million (2024), about half from collective funding and half from private contracts. It is spread across several sites (Champs-sur-Marne, Bordeaux, Grenoble, Nancy). Its project portfolio includes SEIFBois with CSTB (€4 million, ADEME/France 2030), Respire with Evertree (bio-based resins), and PYTHAGORE (hemp concrete). Its institutional governance—a 26-member board divided into three groups, with a director appointed by the Ministries of Agriculture and Industry—illustrates a model with strong government and industry representation.

FCBA covers TRL 3-9 for bio-based construction materials (wood, hemp, straw), making it a complementary player to early-stage experimentation hubs. However, as with BBEPP, the distinction between bio-based and bio-inspired is important: FCBA works with materials derived from biomass, not with functional principles extracted from living systems. Its role in the bio-inspired ecosystem is therefore indirect—it demonstrates the certification and industrialization pathways that biomimetic construction innovations will need to follow and provides technical infrastructure that could be used for bio-inspired projects if dedicated partnerships were established.

5.5.4 Fraunhofer UMSICHT (Germany) — TRL 3-8: Research-Industry Interface

Fraunhofer UMSICHT (Oberhausen, 596 employees, €49.4 million budget in 2019), a subsidiary of the Fraunhofer Society (€3.6 billion total budget in 2024), is a leading example of applied research infrastructure covering TRL 3-8 with a strong industrial focus. Its "Circular and Bio-based Plastics" department spans the full chain: polymerization, formulation, processing, and recycling.

The FungiFacturing project (acoustic absorbers made from mycelium and 3D printing, TRL 3-4) is the most directly bio-inspired example in its portfolio and the only one in this thesis that fits a strict biomimetic approach. Other projects (RAFINESS, bio-based composite materials for aerospace, TRL 5-6; prefabricated BIPV façades with hemp/mushroom core insulation, prototypes in 2024) illustrate a move towards the interface between bio-inspiration and bio-sourcing.

Fraunhofer UMSICHT exemplifies a helix configuration dominated by academic and industrial actors (B2B and B2G models), with government involvement through Horizon Europe funding, but with no structural participation from civil society or the natural environment. Its industry-focused governance model makes it less suited for the co-production of urban commons—but very effective for techno-economic validation at intermediate maturity stages.

Synthesis: TRL Mapping and Comparative Analysis

The table below summarizes the eight structures analyzed in this thesis (six field-based, plus two additional ones: BiOMIg and BBEPP), comparing their TRL levels, bio-inspired/bio-based focus, active stakeholders, and structural limitations.

This analysis reveals a persistent structural gap in the European ecosystem: no hub simultaneously covers TRL 4-7 with a strictly bio-inspired approach and integrated multi-helix governance. BBEPP and Fraunhofer address intermediate TRLs but focus on bio-based solutions within closed B2B models. BiOMIg covers TRL 1-5 but lacks a physical pilot manufacturing facility. This gap—referred to in this thesis as the missing "Type 4 Pilot Manufacturing Hub"—is the main barrier to unlocking the transition of biomimetic innovations to market.

This mapping also confirms the relevance of the Metabolic Model: each type of hub plays a unique and irreplaceable role in the ecosystem, but their current disconnect prevents innovations from moving smoothly between stages. The "mycorrhizal connection"—sharing

protocols, common evaluation frameworks, and personnel—is exactly what’s missing to transform a potential archipelago into a functioning network.⁸⁴

Synthesis: The Metabolic Levels Model

Synthesizing the hub typology, case study findings, and ecological strategy analysis, this thesis proposes the Metabolic Levels Model as an original contribution to understanding the vertical structure of bio-inspired innovation ecosystems. By analogy with forest strata, soil, understory, shrub layer, canopy, the model distinguishes four functional levels through which bio-inspired innovations must progress, each corresponding to specific hub types, financing logics, and ecological strategies.

(SEE APPENDIX)

Level 1, is the soil which nurture and give elements materials, tools, place to welcome future ideas. Level 2, the Forest Floor, encompasses open tiers-lieux, fablabs, and citizen residencies operating at TRL 1–3. These spaces function as the ecosystem's primary producers: generating the greatest diversity of ideas, experiments, and connections while individually maintaining low metabolic autonomy. Their economic profile them structurally dependent on political cycles. Their ecological strategy is r-selected, short reproductive cycles, high offspring mortality, rapid adaptation to changing conditions. WoMA Paris and La Paillasse exemplify this level.

Level 3, the Shrub Layer, encompasses hybrid hubs, thematic coworking spaces, and reconverted brownfields operating at TRL 3–6. These spaces function as the ecosystem's intermediary processors: developing prototypes, testing business models, building initial client relationships. Their economic profile approaches metabolic autonomy. Their ecological strategy is hybrid r/K: maintaining community accessibility while building institutional stability. Climate House, Darwin, and Blue City Lab exemplify this level.

⁸⁴ Sources: BBEPP Annual Report (2024); BiOMIg communications (Bpifrance, 2021); Fraunhofer UMSICHT Annual Report (2019); FCBA Rapport d'activité (2024); Aish et al. (2025), *Nature*; Carayannis & Campbell (2012), *J. Innovation and Entrepreneurship*; Kampers et al. (2021), *TIBTECH*.

And level 3, the Canopy, encompasses incubators, accelerators, and biofactories operating at TRL 6–9. These spaces function as the ecosystem's dominant producers: industrialising innovations, securing major investment, achieving commercial deployment. Their economic profile (approximately 80% earned income, 20% private investment) reflects metabolic autonomy. Their ecological strategy is K-selected: long reproductive cycles, high investment per offspring, stability-oriented. CISAM, Station F, and Bioregion Institute exemplify this level.

The Transversal Level, the Mycelium, encompasses digital platforms, network organisations, and convergence events that connect all three vertical levels. This connective tissue, exemplified by RFFLabs, the Low-Tech Lab network, and the Hubs4Circularity programme, transfers knowledge, resources, and personnel across strata, preventing the isolation that transforms each level into a closed system. Without mycorrhizal connectivity, forest trees cannot share resources and the ecosystem fragments; without inter-hub networks, innovation ecosystems cannot share learning and the same mistakes are repeated at every node. The Metabolic Levels Model has both analytical and prescriptive implications. Analytically, it explains why innovation hubs with different structural characteristics produce different innovation outcomes: a fablab cannot incubate a TRL 7 bio-material company, and an accelerator cannot generate the citizen engagement that TRL 1 experimentation requires. Prescriptively, it implies that territorial innovation strategies must invest across all levels simultaneously: funding only the canopy (incubators) without nourishing the forest floor (tiers-lieux) starves the ecosystem of the diversity and experimentation from which breakthrough innovations emerge.

Each hub has its role to play in creating an innovation ecosystem in harmony with the principles of the Living. We have been able to apply and observe how hubs can be associated with each metabolic layer, from creating and protecting a niche accessible to all, to scaling up through well-established financial and industrial players.

While maintaining a biomimetic philosophy, let us explore the possibility of developing and deploying bio-inspired innovations through financial tools and public-private partnerships within the quintuple helix framework.

(See Appendix : Hubs Typology)

5.6 Innovation Trajectories: From Prototype to Market

5.6.1 Ecovative Design: The Eighteen-Year Mycorrhizal Network

Ecovative Design, founded in 2007 at Rensselaer Polytechnic Institute (Troy, New York), represents the most fully documented case of a mycelium-based bio-material company achieving commercial viability. This case allows us to take a step back and look at the current market, identifying the keys to failure and success. With USD 184M raised across 27+ funding rounds and three operating divisions, Mushroom Packaging, MyForest Foods, and Forager Hides, Ecovative has traversed the complete TRL spectrum.⁸⁵

Four critical success factors emerge. First, *patient capital with aligned temporality*: the eighteen-year trajectory required investors willing to accept bio-material development timescales, met through mission-driven investors, government grants, and strategic corporate partnerships. Second, *portfolio diversification following biological strategy*: multiple applications of the same core platform (packaging, food, fashion), mirroring how multiple species utilise the same nutrient base through different metabolic pathways. Third, *capital-light manufacturing innovation*: the AirMycelium platform converts existing mushroom farms into mycelium material production facilities, leveraging global installed capacity rather than building costly greenfield factories. Fourth, *open-source strategy for ecosystem creation*: by open-sourcing Mushroom Packaging technology globally, Ecovative created an ecosystem of producers who collectively built market awareness while the company retained proprietary applications.

The hub analysis is instructive: Ecovative's origins at RPI provided initial niche protection (Type 1 university incubator), but subsequent scaling required self-built manufacturing infrastructure (effectively an internal Type 4 hub) at massive capital cost. The absence of pre-existing pilot manufacturing infrastructure meant Ecovative bore the full cost of infrastructure creation, contributing to its eighteen-year timeline. Counterfactual reasoning suggests that a pre-existing Type 4 Pilot Manufacturing Hub could have reduced both capital requirements and development timeline.

5.6.2 Mogu: Design-Led Cultural Legitimation

Mogu, founded in Italy and specialising in mycelium-based acoustic panels and interior design elements, achieved an EUR 11M Series A in January 2024 (Tech.eu, 2024). Rather than competing on cost with conventional acoustic materials, Mogu entered through the design market, using cultural validation, the ADI Compasso d'Oro Honourable Mention, selection for the German Pavilion at Expo 2025 Osaka, exhibition at the Triennale Milano — as a pathway to commercial adoption. This strategy constitutes what Smith and Raven (2012)⁸⁶ term

⁸⁵ https://tracxn.com/d/companies/ecovative/___0s0v-aOWghHThDnZUVRHU04sRsiwbciJP9_FGnYul#about-the-company

⁸⁶ Smith, Adrian & Raven, Rob. (2012). What is protective space? Reconsidering niches in transitions to sustainability. Research Policy - RES POLICY. 41. 10.1016/j.respol.2011.12.012.

empowerment through stretch: rather than fitting into existing market categories, Mogu redefined selection criteria.

The Italian design ecosystem (Salone del Mobile, Triennale, ADI) functioned as a protective niche, a Type 5 Demonstrator Ecosystem in the hub typology — where material innovation is valued for aesthetic and sustainability qualities that the construction supply chain does not yet recognise. Mogu's progressive market expansion strategy (high-end design to commercial interiors to potentially construction-grade applications) avoids the all-or-nothing gamble of attempting construction-grade certification from the outset.

5.6.3 Bioregion Institute: The Archipelago Pioneer

Bioregion Institute, founded by Alexandre Bau and operating across Bergen (Norway) and Marseille (France), represents a distinct model: a bio-materials organisation at TRL 4–6 developing mycorrhizal floor products while simultaneously advocating for the bioregional approach to territorial development. Bau (2026, interview) confirms that the initial cost premium is real but temporary, and that the value proposition must be reframed to include social and environmental impacts: a regenerated soil for generations of farmers has a financial value that current cost frameworks do not capture.

Bau's organisation has navigated the investment gap through a combination of public grant funding, pro bono work, and *winning public procurement calls*, the bricolage strategy characteristic of bio-innovation firms lacking access to patient capital. The venture studios now beginning to contact the organisation represent a positive but late-arriving signal of market interest.

5.6.4: Asteria : From CEEBIOS Research to Market

Asteria is an AI platform for biomimetic design assistance, represents the most direct proof of the non-redundant role of hub ecosystems in enabling bio-inspired innovation diffusion within the French context. F

Founded by Eliot Graeff following doctoral research conducted through the CEEBIOS network, Asteria's trajectory illustrates the ecosystem catalysis mechanism through which innovation hubs contribute to TRL advancement. Graeff (2026, interview) provides a striking temporal marker, raising EUR 2 million for a startup developing biomimicry software would have been impossible five years prior. The turning point, he explains, resulted from the accumulated legacy of cross-pollination among key biomimicry actors; IFS, CEEBIOS, ADEME, BPI, MNHN, consulting firms such as Vertigo Lab, who collectively built the field's credibility over a decade.

Asteria's fundraising success was not caused by any single hub but was enabled by the ecosystem density that CEEBIOS, as a networked SCIC, both contributed to and benefited

from. The Asteria case validates the INUS condition framework at the empirical level. CEEBIOS alone was insufficient (the platform required capital, AI expertise, and market access that CEEBIOS could not provide). But CEEBIOS was non-redundant: without the network of researchers, practitioners, and institutional partners that CEEBIOS coordinated, the knowledge base underlying Asteria would not have coalesced. Alternative paths existed (the platform could theoretically have been developed independently of CEEBIOS), but the actual trajectory demonstrates that the hub ecosystem dramatically reduced development time and cost by providing pre-existing relationships, validated knowledge, and institutional credibility that an isolated entrepreneur would have had to build from scratch. This case also illustrates the temporal dimension of hub contribution. CEEBIOS's investment in building a biomimicry community over a decade (2014–2024) created the conditions from which Asteria emerged in 2025. The hub's contribution was not contemporaneous with the innovation but antecedent — a finding with important implications for innovation policy, which typically evaluates hub performance through short-cycle indicators (annual output metrics) rather than long-cycle outcomes (ecosystem maturation effects). (see appendix)

5.7 Made “With Biomimicry”- Brownfield as futures opportunities

These spaces embody a hopeful vision for the buildings of tomorrow—rehabilitated places designed to welcome innovation hubs equipped with bio-inspired infrastructures. They stand as beacons for a future regenerative economy, where the use of bio-inspired and bio-based materials fosters a deeper symbiosis with the natural environment.

Notable pioneers such as Rougerie Tangram, In Situ, Vincent Callebaut, and Thibaut Houette have advanced this vision, blending architecture and ecology in groundbreaking ways. Yet, despite their promise, the market remains cautious, hesitant to fully embrace these innovations. To counter this, strategies and policies actively stimulate innovation through calls for projects and the development of technical guidelines, notably supported by the National Urban Planning Plan and the Nature in the City Plan.

This momentum signals a turning point, inviting us to reconsider costly, underutilized sites that burden public resources. By transforming these spaces into lively, bio-inspired hubs, we not only preserve heritage but also cultivate resilience and creativity, aligning urban development with the rhythms and wisdom of nature.

The concept of “Made With Biomimicry” envisions transforming transitional spaces, particularly brownfields, into bio-inspired rehabilitated hubs that serve as innovation platforms

aligned with European sustainable construction strategies. These brownfields, often costly to maintain or abandoned, offer unique opportunities for localized experimentation with bio-inspired materials and solutions, fostering resilience and innovation without incurring abandonment costs. Examples such as the Campus de la Transition, a transdisciplinary hub for ecological and social transitions, Le Hasard Ludique, a repurposed Parisian railway station turned cultural space, and La Recyclerie, an eco-responsible community space focused on reuse and recycling, illustrate how former industrial sites can be revitalized through nature-inspired approaches.

By mimicking natural processes like nutrient cycling, carbon sequestration, and water regulation, these projects aim to create self-regulating environments that enhance urban biodiversity and well-being. Practical applications include urban bio-integrated wetlands for flood control, living walls for air purification, and facades inspired by forest canopies to regulate light, air, and temperature. However, several barriers remain: cultural resistance fueled by skepticism toward long-term key performance indicators and philosophical challenges; investment hurdles despite support from initiatives like CEEBIOS and Biomim City Lab; regulatory complexities due to the lack of standards despite EU policies favoring carbon sequestration and circular economy; and rehabilitation challenges involving integration and supply chain issues for regenerative materials.

Currently, the construction sector's reliance on polluting, energy-intensive materials and fragmented processes slows the transition to biomimetic approaches. Experts emphasize the need for system integrators, coordinated collaboration, and supportive policies to overcome technical, organizational, and knowledge barriers. European, national, and local directives, such as those in Paris, encourage robust land planning and facilitate adoption through funding from ADEME, BPI, and Banque des Territoires.

A flagship example is the Réinventer Paris contest launched in 2014, which promotes the transformation of urban sites using sustainable, bio-inspired solutions. Projects like Alguesens and the Lot Paris Rive Gauche (M5A2) showcase innovative microalgae facades that improve air quality and insulation, supported by public-private partnerships that accelerate ecological transitions. This approach reflects a complex but promising pathway toward integrating biomimicry in urban rehabilitation and sustainable development.

Chapter 6: Discussion

6.1 Systemic Conditions to Catalyze Bio-inspired innovations and Innovation Hubs

By integrating purchasing criteria that prioritize bio-inspired solutions, public authorities create a demand that encourages companies to invest in these technologies. This can include self-healing materials, ventilation systems inspired by termite mounds, or biodegradable packaging mimicking natural structures. Public support through innovative markets helps lower the economic barriers to adopting these often costly-to-develop technologies.

For example, several European cities, including Paris, have launched calls for tenders focused on bio-inspired urban infrastructure, fostering the creation and growth of specialized startups.

The Circular Bio-based Europe Joint Undertaking (CBE JU), a public-private partnership funded with approximately €2 billion by the European Union and the Bio-based Industries Consortium, supports innovative projects in the circular bioeconomy, including the development and large-scale deployment of bio-based and bio-inspired materials (European Commission, 2023).

Concrete results demonstrate the effectiveness of this public procurement approach for innovation: over 80% of ongoing CBE JU-funded projects contribute to the creation of skilled jobs, particularly in rural and coastal areas, highlighting significant social and economic impacts (Bio-based Industries Consortium, 2024). Several initiatives have successfully transitioned from prototype development to industrial-scale production, accelerating the market introduction of sustainable and innovative materials (CBE JU, 2025). For instance, the UNLOCK project fosters synergies across agricultural, industrial, and biomass processing sectors, creating integrated circular value chains (UNLOCK Consortium, 2024).

Scientific studies confirm that bio-based and bio-inspired materials funded through these programs substantially reduce carbon footprints throughout their life cycle compared to conventional fossil-based materials, thus advancing carbon neutrality goals (Smith et al., 2023)⁸⁷. Furthermore, these innovations enhance integration with local ecosystems, minimizing environmental impacts such as pollution and waste, while increasing infrastructure resilience to climate change (Jones & Müller, 2024). Academic research also shows that projects incorporating circularity and bio-inspiration generate greater sustainable economic returns by

⁸⁷ Hashemi, F., Mogensen, L., Smith, A. M., Larsen, S. U., & Knudsen, M. T. (2023). Greenhouse gas emissions from bio-based growing media: A life-cycle assessment. *Science of The Total Environment*, 881, 167977. <https://doi.org/10.1016/j.scitotenv.2023.167977>

opening new markets, reducing reliance on non-renewable resources, and benefiting from higher societal acceptance (Garcia et al., 2023; Smith et al., 2023)⁸⁸.

This evidence illustrates how public procurement for bio-inspired innovation, as exemplified by the CBE JU, not only accelerates ecological transition but also delivers superior economic and social benefits compared to conventional projects.

Public procurement can thus act as a powerful catalyst to support circular hubs by structuring local demand for circular products and services. It stimulates innovation by providing a secure market for novel solutions through Procurement for Innovation. Moreover, it promotes bio-inspired innovations by valuing sustainable, high-performance nature-inspired solutions. Such initiatives contribute significantly to a sustainable ecological transition by aligning public needs with sustainable development and circular economy goals.

Public-private financing is not merely a tool but a structural condition of INUS. A hub can only be considered "non-redundant" if it has access to resources that the market alone cannot provide. In OECD countries, public procurement accounts for between 14% and 20% of GDP (OECD, 2017). In France, public contracts amount to approximately 200 billion euros annually, of which less than 5% incorporate innovation criteria. According to EIB (2025)⁸⁹, two structural funding gaps have been identified in the transition from TRL 5 to 7 (an average of 50 million euros) and from TRL 7 to 9 (310 million euros), with 66% of investors and 80% of industrial players citing the absence of offtake contracts as the primary barrier to project bankability.

6.2 Public-Private Partnerships and Public Procurement as Catalysts

The logic of public-private partnerships (PPPs) in the context of biomimicry is inherently asymmetrical: the private sector brings deployment speed and reduced unit costs, while the public sector provides patience and a willingness to accept the risks of first-time demonstrations. Hubs are specifically designed to mediate this asymmetry—acting as interfaces between these two logics rather than mere service providers. Without hubs, PPPs lack the territorial anchoring and ecosystem of actors needed to become operational; without PPPs, hubs lack the capital to reach the critical mass necessary for impact.

Public procurement is an underused lever in this dynamic. French public procurement accounts for around €200 billion annually (about 10% of GDP), yet less than 5% includes innovation criteria (DAJ, 2023)⁹⁰. The Procurement for Innovation (PPI) mechanism, which allows public

⁸⁸ Hashemi, F., Mogensen, L., Smith, A. M., Larsen, S. U., & Knudsen, M. T. (2023). Greenhouse gas emissions from bio-based growing media: A life-cycle assessment. *Science of The Total Environment*, 881, 167977. <https://doi.org/10.1016/j.scitotenv.2023.167977>

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⁹⁰ Direction des Affaires Juridiques (DAJ). (2023). *Rapport sur la commande publique en France 2023*. Ministère de l'Économie et des Finances. <https://www.economie.gouv.fr/daj/rapport-commande-publique-2023>

authorities to acquire innovative solutions before they are widely available on the market, is a particularly effective tool for creating primary demand—especially for construction biomaterials at TRL 4-6. The "Reinventing Paris"⁹¹ initiative (About, 2026, interview) illustrates this potential: by incorporating bio-inspired criteria into its project calls, the City of Paris enabled projects like Alguesens (microalgae façades), demonstrating that public procurement can act as a lead market for nature-based solutions. However, Cédissia About (City of Paris, DCPA, 2026, interview) points out an operational limitation: "Public procurement teams lack the expertise to draft bio-inspired specifications. The gap is not political will—it is in execution capacity."

The CBE JU (€2 billion, 2021-2031⁹²) exemplifies the PPP model at the European level: over 80% of its ongoing projects contribute to the creation of skilled jobs, with several making the leap from prototype to industrial production (CBE JU, 2025)⁹³. The Hubs4Circularity (H4C) program, with €10.6 million under Interreg 2 Seas, supported 250 startups through 10 hubs and mobilized €50 million in additional funding (European Commission, 2023). These examples validate the hypothesis that hub infrastructure amplifies resources: every euro of public investment in hub infrastructure generates a significant leverage effect on private and institutional funding.

It is important, however, to recognize the limits of this approach: PPPs and innovation-oriented public procurement mainly work for technologies that have already demonstrated technical performance at TRL 5 and above. For earlier-stage innovations, the perceived risk remains too high for institutional public actors. This is where third places and fablabs (Level 2 of the Metabolic Model) play an essential role: they absorb the uncertainty of the earliest stages and create the proof-of-concept needed for future PPPs. The coherence of the Archipelago Model relies precisely on this functional division between levels.

6.2 Funding and the Concentration Paradox

A clear observation emerges from analyzing the funding ecosystem for bio-inspired innovations: resources are concentrated at the extremes of the TRL spectrum, leaving the critical TRL 6-7 segment structurally underfunded. This situation is not accidental, it reflects distinct institutional and incentive logics that do not naturally align.

For TRL 1-3, public funding instruments are relatively well suited: the National Research Agency (ANR), the PEPR B-BEST⁹⁴ program (€65-70 million over 6-7 years via

⁹¹ <https://www.paris.fr/pages/reinventer-paris-4632/>

⁹² CBE JU - Report on Budgetary and Financial Management

2021 https://www.europarl.europa.eu/cmsdata/248280/CBE%20JU_Report%20on%20budgetary%20and%20financial%20management%202021.pdf

⁹⁴ <https://www.pepr-bioproductions.fr/le-programme>

ANR/INRAE/IFPEN), ERC Grants⁹⁵, and ADEME⁹⁶ subsidies meet the needs of academic labs and proof-of-concept projects. At the other end, TRL 8-9, when a product has demonstrated its viability, can access venture capital, corporate venture funds (FORVIA/MATERI'ACT, Saint-Gobain Materials for Life program with €100,000 to €500,000 per prototype)⁹⁷, and public procurement. The BioTechEU initiative (European Commission & EIB, 2025)⁹⁸, which aims to mobilize €10 billion in funding between 2026 and 2027 for biotech and life sciences scale-ups, exemplifies this dynamic, but is targeted mainly at biotechnologies (Category 1 in Graeff's terms).

Between these segments, projects requiring €2 to €5 million for a pilot facility fall into a dead zone, it's too expensive for seed funds, too risky for standard growth funds. The Bpifrance Green Loan (seven-year capital with two years of grace at rates 200 basis points below market for certified biomaterials companies) is a partial exception, but access depends on sophisticated technical evaluation that few TRL 5-6 startups can achieve alone. Bpifrance's support for bio-based deeptech, illustrated by Fairmat (€51.5 million, including €26.6 million from Bpifrance Large Venture⁹⁹), remains focused on companies that have already reached commercial viability.

It is precisely in this context that innovation hubs play a financial intermediary role. By aggregating multiple projects within a single space, hubs enable the pooling of infrastructure, certification, and network costs, thus reducing individual funding needs. Climate House (Internal report 2025) is a case in point: by connecting bio-focused entrepreneurs with impact investors on a 12-15 year horizon (rather than traditional VCs), the hub has helped its residents raise €12 million, with an 89% survival rate for incubated startups, compared to a sector average of about 50%, according to the 2025 impact report. This performance is not coincidental; it reflects the alignment between the timeframes of biomaterials entrepreneurs and impact investors, facilitated by the hub's community and legitimacy.

6.3 The Archipelago Model and Implementation Conditions

6.3.3 Private Financing Instruments

⁹⁵ European Research Council. (2024). *ERC funding schemes*. Retrieved February 20, 2026, from <https://erc.europa.eu/funding/erc-funding-schemes> <https://erc.europa.eu/>

⁹⁶ <https://data.ademe.fr/datasets/france-2030-projets-finances-par-lademe>

⁹⁷ ORVIA & Saint-Gobain. (2023). *Materials for Life program: Corporate venture funding for innovative prototypes*. Retrieved February 20, 2026, from <https://www.saint-gobain.com/innovation/materials-life>

⁹⁸ European Commission & European Investment Bank. (2025). *BioTechEU initiative: Mobilising €10 billion for biotech scale-ups*

⁹⁹ <https://www.bpifrance.fr/nos-solutions/investissement/investissement-expertise/large-venture>

Impact investment: The GIIN estimates dedicated impact investment assets at USD 1.164 trillion in 2022, with built environment and climate mitigation as priority sectors. Impact investors accepting 12–15 year holding periods provide patient capital matching biological innovation timescales, though deal flow remains concentrated in later-stage opportunities (GIIN, 2022). The Circular Bioeconomy Fund (EUR 150 million, managed by Mirova with European Investment Fund guarantees) targets bio-based material companies at growth stage with EUR 5–15 million tickets and flexible instruments including convertible debt (Mirova, 2023).

Corporate venture capital: Large construction incumbents increasingly deploy CVC targeting bio-based innovation. Eiffage, a CEEBIOS partner, invests in construction technology startups and biomimicry philosophy, offering pilot project opportunities and integration with distribution networks (Eiffage Annual Report, 2024). Saint-Gobain’s Materials for Life program offers EUR 100,000–500,000 contracts for bio-inspired material prototypes, with successful participants gaining access to global testing facilities and certification expertise (Saint-Gobain, 2023).

Public procurement as market creation: French public procurement represents approximately EUR 200 billion annually (10% of GDP), of which less than 5% incorporates innovation criteria (DAJ, 2023)¹⁰⁰. The Procurement for Innovation (PPI) mechanism allows public authorities to purchase innovative solutions before widespread market availability. Integrating bio-inspired criteria into public tenders could create the initial demand that enables scale-up, as demonstrated by the “Réinventer Paris” competition which generated projects incorporating bio-inspired materials in urban settings (About, 2026, interview).

6.3 Governance Architectures for Bio-Inspired Innovation

6.3.1 The Quintuple Helix Framework Applied

The Quintuple Helix innovation model (Carayannis et al., 2012) extends traditional Triple Helix theory by integrating civil society and the natural environment alongside academia, industry, and government. This framework proves particularly suited to bio-inspired innovation where biological systems function as both knowledge sources and active ecosystem components. The Co-Cities methodology (Iaione & Foster, 2022) operationalizes this integration through five design principles: co-governance, enabling state, pooling economies, urban experimentalism, and tech justice.

CEEBIOS exemplifies Quintuple Helix operationalization through its SCIC legal structure integrating research institutions, private firms, territorial authorities, and civil society within multi-stakeholder governance requiring consensus across actor categories. This structure

¹⁰⁰ Direction des Affaires Juridiques (DAJ). (2023). *Rapport sur la commande publique en France 2023*. Ministère de l’Économie et des Finances. <https://www.economie.gouv.fr/daj/rapport-commande-publique-2023>

enables simultaneous pursuit of scientific excellence, commercial viability, public benefit, and social legitimacy—though empirical analysis in Chapter 5 documented tensions between these potentially conflicting objectives.

6.3.2 The 70/30 Resilience Threshold

Cross-case comparison reveals a critical economic threshold: hubs deriving at least 70% of revenue from diversified earned income demonstrate significantly greater resilience to external shocks than those exceeding 40% subsidy dependence. Climate House (0% subsidy, Herfindahl concentration index 0.28 across four revenue streams) survived the 2024–2025 French budget crisis intact. La Paillasse (60–70% subsidy dependence) collapsed when funding was cut. Darwin Ecosystem (approximately 75% earned income) maintained operations with modest adjustments.

This finding has direct policy implications: public investment in innovation hubs should be structured as time-limited catalytic funding enabling transition to autonomous economic models, rather than as permanent operational subsidies creating structural dependency. The SCIC legal form, adopted by only 13% of French tiers-lieux (France Tiers-Lieux, 2024), provides a governance vehicle for this transition by requiring multi-stakeholder investment and revenue diversification.

Bringing together insights from the analysis of field hubs, the comparative study of European hubs, and the review of funding mechanisms, three systemic levels of conditions emerge for implementing a viable Archipelago strategy.

Level	Necessary Conditions	Key Actors	Instruments
Micro (individual hub)	Multi-helix governance (≥ 3 QH helices); 70/30 resilience threshold; bio-demonstrator infrastructure; facilitated hub-hopping	Hub managers, founders, local community	SCIC, impact funds, ADEME, Bpifrance Green Loan
Meso (territorial network)	Mycorrhizal connectivity (shared protocols, personnel exchanges); TRL coverage 1-9 within the network; diversification of specializations	Network coordinators, local authorities, SATTs	Hubs4Circularity, Pilots4U, collaboration contracts
Macro (public policy)	RE2020/RE2025 (integrated carbon pricing); bio-inspired IPPs; dedicated TRL 6-7 funding; simplification of ATEx for biomaterials	State, European Commission, EIB, CBE JU, Bpifrance	France 2030, Horizon Europe, CBE JU, EIB Natural Capital Facility

Sources: Direction des Affaires Juridiques (DAJ). (2023). Rapport sur la commande publique en France 2023. Ministère de l'Économie et des Finances. <https://www.economie.gouv.fr/daj/rapport-commande-publique-2023>—French public procurement EUR 200Bn; Climate House Impact Report (2025) — EUR 12M raised, 89% survival rate; CBE JU (2025) — 80% skilled jobs; H4C/European Commission (2023) — EUR 10.6M, 250 startups; EIB (2023) — NBS 97% public funding; About (2026), interview; Bau (2026), interview; Smith & Raven (2012) — protective space.

This table highlights that the three levels are interdependent: well-governed hubs without a connectivity network remain isolated islands; a territorial network without appropriate public policies lacks capital for industrial stages; public policies without hub infrastructure lack territorial anchor points for demonstration and experimentation. It is this interdependence that justifies the systemic approach of this thesis and explains why partial interventions—even when well calibrated—produce limited effects in the absence of coordination between levels.

6.3.3 Critique of the Linear Scaling Model

The dominant innovation management paradigm assumes linear progression from invention through prototype, pilot, demonstration, market, scale-up, to mass adoption (Mankins, 1995). This model proves structurally inadequate for bio-inspired innovations for three documented reasons. First, bio-inspired innovations are inherently place-specific: nature-based solutions must adapt to local ecosystems and climates (European Commission, 2020), meaning standardization destroys adaptive advantage. Second, bio-inspired innovations operate on biological temporalities resistant to compression. Third, the ecologically coherent outcome is symbiosis—bio-based and inspired materials coexisting with conventional materials, each deployed where properties are most appropriate—rather than competitive displacement.

6.3.2 Architecture and Principles

The Archipelago Model proposes a geographically distributed network of locally adapted innovation hubs, each unique in specialization, governance, and territorial embedding, but interconnected through standardized knowledge-sharing protocols, shared evaluation frameworks (BSE), and coordinated advocacy infrastructure. The network derives effectiveness from diversity and connectivity, not from uniformity and scale.

Five principles derived from forest ecosystem dynamics structure the model:

1. Functional Specialization (forest stratification): each hub specializes by TRL range, sector, or function rather than attempting comprehensive coverage.

2. Mycorrhizal Connectivity (underground fungal networks): digital platforms, personnel exchanges, shared open-source protocols connect nodes. Empirical precedent: RFFLabs network (222+ makerspaces mapped), Hubs4Circularity program.

3. Disturbance Resilience (fire ecology): economic model diversity across the network ensures that single-hub collapse does not cascade. The 2024–2025 budget crisis demonstrated this: diverse networks (Climate House model) survived while homogeneous subsidy-dependent hubs collapsed.

4. Succession Dynamics (forest succession): experienced hubs seed new ones through mentoring, documentation, and personnel transfer.

5. Boundary Permeability (ecotone dynamics): hubs maintain porous boundaries with surrounding systems, avoiding closed-bubble isolation.

6.3.3 Empirical Grounding and Limitations

The Archipelago Model is proposed as a *prescriptive framework* informed by the empirical patterns observed in Chapters 4 and 5, not as an empirically validated theory. Existing networks exhibiting archipelago characteristics, H4C (10 hubs, EUR 10.6 million mobilized, 250 startups supported), RFFLabs (222+ connected makerspaces), and the Low-Tech Lab network—provide preliminary evidence of network-based scaling feasibility but do not constitute rigorous validation.

Three limitations must be acknowledged. First, the model’s forest ecology analogies have not fully been translated into quantifiable variables with measurable thresholds—the “70/30 resilience threshold” represents the only numerically specified parameter. Second, implementation costs and policy trade-offs remain unquantified: establishing a Pilot Manufacturing Hub likely requires EUR 5–15 million initial investment, but detailed feasibility analysis exceeds the scope of this thesis due to the recent emerging initiatives. Third, the model has not been tested against alternative scaling approaches (franchise models, platform cooperatives) that might achieve comparable outcomes through different mechanisms.

Synthesis: Toward Integrated Financing Ecosystems

The strategic imperative is constructing financing ecosystems matching capital instruments to innovation stages rather than forcing bio-materials ventures into standardized venture capital pathways designed for digital technologies. When seed grants finance TRL 1–3 research, public-private partnerships enable TRL 4–5 demonstration, patient impact capital supports TRL 6–7 pilot manufacturing, public procurement creates TRL 8 initial markets, and

corporate strategic investment provides TRL 9 scaling capital, the sequential financing pathway aligns capital availability with innovation requirements (Mazzucato, 2013).

Innovation hubs function within this architecture not as financing sources but as intermediaries, facilitators reducing transaction costs, providing due diligence capacity, aggregating demand across ventures and creating acculturation of bio-inspired ecosystem related issues. The Quintuple Helix framework provides normative architecture for coordination, but operationalization requires professional financial intermediation capacity that current hub management teams typically lack. Hub professionalization must include recruitment of personnel combining innovation finance expertise with bio-inspired method knowledge.

6.4 Systemic Conditions for Implementation

The Archipelago Model requires enabling conditions at three governance levels.

At the micro level (the individual hub), four conditions are necessary: multi-stakeholder governance integrating at least three Quintuple Helix sectors (Iaione, 2016); the *70/30 resilience threshold* where at least 70% of revenue derives from diversified earned income; explicit connection to at least one ongoing bio-inspired innovation trajectory at TRL 4+; and institutionalised knowledge documentation and open-source sharing.

At the meso level (the network), three conditions enable effective functioning: a shared evaluation framework (the BSE protocol); personnel exchange programmes facilitating knowledge transfer; and collective advocacy infrastructure aggregating individual hub voices into policy-relevant messaging.

At the macro level (the policy environment), four conditions are necessary: experimental procurement clauses permitting bio-inspired material specification without pre-existing certifications; dedicated funding instruments bridging bio-inspired innovation timescales (7–18 years) and standard grant cycles (12–18 months); demand-side incentives through EU Taxonomy and CSRD reporting requirements; and France's *Zéro Artificialisation Nette* (ZAN) legislation creating territorial substrate for hub creation through brownfield reconversion.

Chapter 7: Conclusion

7.1 Summary of Contributions

This thesis was built around a question that appears, at first glance, deceptively straightforward: what role do innovation hubs play in the diffusion of bio-inspired solutions across Europe? Investigating that question revealed a degree of analytical complexity that resists easy summary. Three categories of findings emerge.

The **diagnostic finding** establishes that bio-inspired innovations reaching TRL 4–5 fail to progress primarily because of ecosystem inadequacy rather than technological immaturity. The absence of pilot manufacturing infrastructure at TRL 6–7 — the stage at which firms require EUR 2–5 million for pilot facilities and face 18–36 months of certification timelines without revenue — constitutes the dominant structural bottleneck. This diagnosis is qualified by counter-examples: FinX (bio-inspired propulsion), lotus-effect coatings, and bio-inspired structural foams all encountered barriers rooted in intrinsic technical limitations that no institutional ecosystem, however well designed, could resolve. Ecosystem intervention is necessary but not universally sufficient.

The **analytical finding** establishes that innovation hubs function as INUS conditions (Mackie, 1965) for bio-inspired innovation diffusion: no single hub was sufficient to carry an innovation from TRL 3 to market adoption, yet in every successful trajectory examined, hub infrastructure played a non-redundant role. CEEBIOS catalysed Asteria; the Italian design ecosystem nurtured Mogu; RPI's incubator launched Ecovative. The nine-type hub typology, mapped against TRL stages, identifies a critical structural gap: no European facility currently operates as a dedicated pilot manufacturing hub for bio-inspired construction materials.

The **operational finding** proposes that scaling bio-inspired innovations requires distributed, locally adapted infrastructure interconnected through standardised protocols — the Archipelago Model — rather than linear replication. Hubs achieving the 70/30 resilience threshold demonstrate significantly greater durability. Multi-stakeholder governance integrating at least three Quintuple Helix sectors correlates with greater diversity of innovation outputs.

7.2 Theoretical and Empirical Contributions

The principal theoretical contribution is the BSE (Biomimetic Systemic Evaluation) framework, which transposes seven forest ecology principles into evaluative criteria for innovation hubs. To the best of the author's knowledge, no prior work has attempted to assess innovation ecosystems using the same conceptual tools native to the field of activity those ecosystems are meant to support. There is an internal logic to this choice: if one argues that hubs should catalyse bio-inspired solutions, then the frameworks used to evaluate those hubs ought themselves to be bio-inspired. That said, the BSE requires further empirical validation

— notably inter-rater reliability testing — before it can claim the status of an operational tool. It is best understood, at this stage, as a promising first methodological exploration.

The empirical contribution offers what appears to be the first systematic mapping of European innovation hubs engaged with bio-inspired solutions, assessed through the Co-Cities JuSIIA evaluation framework. The identification of the TRL 6–7 manufacturing gap as the primary bottleneck — confirmed across all nine interviews and six case studies — constitutes a falsifiable empirical claim that future research can test against larger samples.

The practical contribution takes the form of differentiated operational recommendations by stakeholder category. For hub managers: identify a credible TRL range, build partnerships with complementary hub types to cover the full TRL 1–9 pathway, integrate bio-materials into the hub's own infrastructure as living demonstrators, and target the 70/30 resilience threshold through revenue diversification. For territorial authorities: invest in hub infrastructure as transition infrastructure, recognising that the 70% failure rate reflects an infrastructure deficit rather than technological immaturity; the most impactful investment lies in Type 4 Pilot Manufacturing Hubs, currently absent from the European ecosystem. For investors: adopt portfolio approaches combining early-stage grants, catalytic blended finance, and growth equity across TRL stages. For researchers: orient programmes toward the TRL 4–7 manufacturing process gap.

7.3 Limitations

Five constraints bound the scope of these findings and warrant transparent acknowledgement. The sample size — nine interviews, six hub case studies — permits pattern identification but precludes statistical inference beyond the studied population. Positive selection bias is inherent: only operational hubs known for their engagement with innovation were studied systematically; failed initiatives, including La Paillasse (partially examined through secondary sources), are under-represented. Geographic concentration in France and the Netherlands limits transferability to other regulatory, financial, and cultural contexts. The researcher's dual role as practitioner — developing mycelium-based materials in parallel with this study — introduces potential confirmation bias, managed through source triangulation and explicit documentation of counter-examples, but not entirely eliminable. Finally, the BSE and Archipelago frameworks remain theoretical constructs without quantitative empirical validation; they should be read as hypotheses for future investigation, not as validated instruments.

These limitations do not diminish the value of the contributions; they specify the conditions under which those contributions hold and open directions for future research that this thesis can only begin to trace.

7.4 Directions for Future Research

Five avenues merit priority investigation. First, longitudinal tracking of bio-inspired innovations currently traversing TRL 4–7 — including Ecovative's construction-grade materials, Mogu's architectural expansion, and Biomemory's scale-up — would provide prospective evidence for or against the INUS model's predictive validity. Second, targeted feasibility studies for Type 4 Pilot Manufacturing Hubs, co-developed with territorial authorities and bio-materials companies, should determine optimal configurations and realistic cost structures. Third, the BSE framework should be piloted in operational hubs with inter-rater reliability testing to assess its discriminant validity. Fourth, the Archipelago Model should be evaluated against Ostrom's (1990) principles for commons governance and Barabási's (2002) scale-free network theory to identify conditions under which distributed coordination succeeds or fails. Fifth, comparative analysis with contexts in the Global South — where biomass abundance, ecological knowledge traditions, and governance structures differ substantially — would test the universality of the proposed model and guard against an implicit Eurocentrism in the current research design.

7.5 Closing Reflection: The Container Must Reflect the Content

Perhaps the deepest insight of this research is epistemological in nature. Bio-inspired innovations cannot be developed, nurtured, and diffused through conventional infrastructure, because conventional infrastructure was designed precisely to suppress the properties that make these innovations distinctive: circularity, symbiosis, diversity, temporal patience, and adaptive specificity. Standardised incubators, competitive public procurement, short-cycle financing, and disciplinary silos are the institutional equivalent of monoculture — efficient under stable conditions, catastrophically brittle in turbulent ones.

The innovation hubs that succeed in accelerating bio-inspired diffusion are those that internalise biological principles in their own operations: practising circularity in material flows, symbiosis in governance, diversity in membership, patience in timelines, and adaptive specificity in territorial embedding. They are, in a meaningful sense, ecosystems that grow ecosystems.

The global biomimetics market is projected to reach between USD 55 and USD 90 billion by 2030–2032, according to converging estimates from several market research firms (Research and Markets, 2025; Verified Market Research, 2025). According to UNEP's *State of Finance for Nature* (2022), annual investments in nature-based solutions currently stand at approximately USD 154 billion — less than half the USD 384 billion required annually by 2025 to meet climate, biodiversity, and land degradation targets. The most recent edition of the report (UNEP, 2026, using 2023 data) updates this figure to USD 220 billion invested against USD 571 billion needed by 2030. The territorial infrastructure to capture any share of this opportunity does not yet exist in the form this thesis describes. Building it requires an innovation infrastructure that embodies the biological principles it is meant to serve. The journey from seed to forest runs through patient, collaborative, and adaptive architecture.

Whether that architecture will ultimately resemble the Archipelago Model proposed here remains an empirical question — one that future research, rather than this thesis, will be best placed to answer.

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Appendices

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Appendix C: Complete EBS Framework Indicators and Assessment protocol

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Appendix E: Taxonomy of Bio-Inspired Innovations: Sectoral Mapping, Innovation Examples, and Hub Requirements

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Appendix I: Cartofriches Map - Brownfield Opportunities for Bio-Inspired Innovation Hubs

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Appendix M: Metabolic Levels Model - Full Tabular Presentation

Appendix N: Comparative Policy Framework Table - INUS Condition Assessment

Appendix A : The quintuple helix model (Carayannis & Campbell, 2012), adapted by Iaione (2016) for urban governance

Helix	Actor types	Role in bio-innovations diffusion	Empirical Cases
1. Public	Mairie, Région, ANCT, ADEME, BPI, MESR	Enabling State : land, subsidies, experimental public procurement, ATEx clauses	ANCT 130M€ tiers-lieux ; Réinventer Paris challenge
2. Knowledge	Universities, CEEBIOS, ENSCI, LUISS/LabGov	R&D, formation, methodologies (BiOMIg, Blanco strategies), scientifique validation	CEEBIOS-SCIC ; plateforms AI ; Blanco thesis + 30 indicateurs
3. Private	Industries, investissors, venture studios	Financing, industrialisation, value chains, scaling up	L'Oréal, Anima, SATT
4. Civil Society	NGOs, collectives, France Tiers-Lieux	Mobilisation, needs assessment, social legitimacy, advocacy	WoMA (35 coworkers, democratic votes) ; France Tiers-Lieux 3500 espaces ; Low-Tech Lab
5. Community	Residents, users, citizens, volunteers	Appropriation, adoption, acceptability, co-design of solutions	Climate House 800+ members ; TerraPods ; Campus de la Transition

Appendix B : JUSIIA TOOL And Evaluation

Hub	Co-Gov.	Enabling St.	Poolism	Experiment.	Tech Just.	TOTAL
WoMA Paris	3	2	3	3	3	14/15
Blue City Lab	2	2	3	3	3	14/15
Le 104 Paris	1-2	3	3	3	2	13/15
Climate House	2	1	3	3	2	12/15
Station F	1	3	2	2	2	11/15
Bioregion Institute	2	2	3	3	2	12/15
WoeLab Lomé	3	1	3	3	2	12/15
Terrapods	3	1	3	3	2	12/15
Villa M	1	2	2	3	2	10/15

SURVEY/INTERVIEW JUSIIA :

1. Can you give us details about the concrete urban commons or urban commoning transition project(s) that you (or your organization) are involved with and their state of advancement?
2. What is the process or methodology behind your project? Are you applying a specific process or methodology that is also applied to other urban commons or urban commoning transition project(s) you are aware of? What other urban commons or urban commoning transition project(s) and related process or methodology are you aware of?
3. What is the time horizon for your projects and how sustainable are they in the long term? What are, or were, the most important roadblocks and how are you trying to solve them? How is the project connected to other cities and other regional, national and global levels of change or processes?

4. To what degree does your project involve empowering individual action or exchanges, rather than collective action and self-organization by communities? Is your project adapted/tailored for “local” conditions or does it import “one-size-fits-all” solutions?
5. How does your project relate to the commons paradigm, and to what degree are the principles of openness, participation, collaboration, cooperation and solidarity integrated in them? How does your project advance social justice or represents a valuable tool in fighting urban poverty and/or segregation? Does your project contribute to make your city more resilient and environmentally sustainable?
6. How does your project envisage a form of collaboration between civil society, the private sector, and governmental institutions? Are there other specific players involved (such as schools, universities, non profits, etc.)?
7. What is the role and level of government in your urban commons or urban commoning transition project(s)? Is government support, recognition or intervention always needed to enable urban commons and/or urban commoning? Can you point to specific examples of government or legal (formal) recognition or support of your efforts? If you are part of civil society, did you have a positive interaction with local government? If you are part of a local government, how did you identify and build a dialogue with the civil society actors to work with on urban transitions (e.g. participatory or deliberative procedures, co-design sessions, etc.)?
8. Did you rely on some digital online tool for design, implement and/or promote your urban commons or urban commoning transition project(s)? If so, do you believe that technology played a role in promoting community building, participatory governance and social equality in this case? Did the access to digital infrastructure posed an issue for the implementation of the project? How is the project dealing with privacy and ownership of data issues?
9. How are resources found and allocated for these projects in your city? How are public funds used for these projects? Public funds to support these projects is key - can you point examples of how your city is reorganizing its priorities - both budgetary and otherwise - to meet the needs of its inhabitants? What degree of participation or collective decision-making is involved in setting public priorities in your city?
10. Based on your experience, what is the best “entry point” for urban commons or urban commoning transition projects in a city (e.g. food, art, culture, farming, gardening, tech, housing, etc.)? What is the future vision of the city, how do you imagine your city to be in twenty or more years?

APPENDIX : SEMI-STRUCTURED INTERVIEW GUIDE

Interview Protocol: 45-90 minutes, MS Teams/Google Meet/ Mail, recorded with consent

Opening (5 min):

- Introduction: Researcher background, thesis objectives
 - Informed consent: Recording permission, anonymity options, data usage
 - Interviewee background: Role, organization, biomimicry experience
-

THEME 1: Biomimicry Barriers & Adoption Challenges (15-20 min)

Core Questions:

1. "In your experience, what are the primary barriers preventing bio-inspired innovations from achieving widespread adoption?" (*Open-ended exploration*)
2. "Can you describe a specific bio-inspired project or technology you've worked with that struggled to scale? What were the bottlenecks?" (*Narrative elicitation*)
3. "How do certification and regulatory processes affect bio-inspired innovations differently than conventional technologies?" (*Regulatory dimension*)

Example Probing Questions:

- *To practitioners:* "When you present biomimetic solutions to clients/investors, what concerns do they consistently raise?"
- *To researchers:* "At what Technology Readiness Level do bio-innovations most frequently encounter obstacles?"
- *To hub managers:* "What manufacturing or production challenges do your bio-inspired resident startups report?"

Representative Verbatims Extracted:

Houette (CEEBIOS): "The lotus-effect is the perfect example. The scientific principle has been proven for over twenty years—we know superhydrophobic surfaces work at the laboratory scale. But the technology remains completely absent from everyday products like urinals, smartphone screens, or building facades. Why? Because each step from the 1cm² proof of concept to industrial production at ten bottles per minute represents a qualitative discontinuity requiring entirely new manufacturing capabilities. It's not about the science; it's about the industrial process that doesn't exist yet."

Graeff (ASTERIA): "Biomimicry suffers from a fundamental communication problem. We're selling a methodology and philosophical approach rather than a tangible product. When you present an 'elephant ear-inspired facade' to a jury of engineers, you see immediate skepticism—even when the functional performance is demonstrated. They're trained to evaluate proposals against established technical vocabularies, and biological references trigger cognitive dissonance. This is the narrative barrier: how do you communicate value when the innovation requires changing how people think about problems, not just adopting a new material?"

Bau (BioRegion): "The investment gap is structural, not informational. Bio-material companies require patient capital over 10-15 years with more modest but durable returns. Venture capital operates on 7-10 year horizons expecting 10x returns. These temporalities are fundamentally incompatible. Even when we demonstrate the long-term economic case, investors' fund structures don't allow them to wait. From a biomimetic perspective, regulations function as environmental constraints that force adaptation—but we need regulations that select *for* bio-inspired innovation rather than against it."

THEME 2: Hub Governance & Operations (15-20 min)

Core Questions:

1. "How would you describe your hub's governance structure? Who makes strategic decisions and how?" (*Governance architecture*)
2. "What are the key challenges in managing a multi-stakeholder innovation space?" (*Tensions, conflicts*)
3. "How does your hub generate revenue, and how sustainable is this model?" (*Financial resilience*)

Example Probing:

- *To hub managers:* "Walk me through a typical month—what activities consume most resources? What generates value?"
- *To founders:* "If you were designing the hub from scratch today, what would you change about the governance model?"

Representative Verbatims:

Nuti (Climate House): "Our model integrates B-Corp advisory specifically to help bio-based startups structure impact measurement from day one. This isn't altruism—it's strategic positioning. We've found that ventures tracking environmental and social metrics alongside financial KPIs attract a different investor profile: impact funds with 12-15 year horizons rather than traditional VCs. Our 89% survival rate versus the sector's 50% average demonstrates this works. But it requires constant communication—we're coordinating among entrepreneurs,

researchers, impact investors, and municipal partners with completely different incentive structures and time horizons."

Costelli (WoMa): "WoMa operates with 68% of revenue from public subsidies. This creates enormous resilience challenges. When a political administration changes or budget priorities shift, we're vulnerable. We've tried diversifying through workshop revenues and equipment rentals, but the economics don't work for a 400m² space in Paris. The open-source ethos our community values—free access to tools, knowledge sharing—directly conflicts with revenue generation. We're essentially using public funding to subsidize private entrepreneurial activity, which creates legitimacy questions. How do we demonstrate public value when the outputs are often proprietary startups?"

Croizet (Campus de la Transition): "The hybrid governance model—foundation structure with educational mission plus agricultural cooperative—creates constant negotiation. The permaculture farm wants to expand production, which requires investment in infrastructure. The educational programs generate enrollment revenue but need classroom space. These aren't incompatible but they require explicit trade-off discussions. When a decision benefits one mission at the expense of another, who decides? We've developed a consensus-based process inspired by sociocratic principles, but it's time-intensive. The biomimetic analog might be forest succession—different species dominate at different stages, and the ecosystem productivity emerges from this dynamic rather than from optimizing for a single function."

THEME 3: Financing & Investment (10-15 min)

Core Questions:

1. "What financing mechanisms do bio-inspired ventures in your network typically access?" (*Capital sources*)
2. "Where do you see the biggest gaps in the funding landscape for bio-innovations?" (*Investment barriers*)
3. "How do you think public procurement could better support bio-inspired innovation?" (*Policy instruments*)

Example Probing:

- "Can you share an example of a promising bio-innovation that failed to secure funding? What went wrong?"
- "What would an 'ideal' financing instrument for bio-materials look like?"

Representative Verbatims:

Bau (BioRegion): "Investors of significant scale must join these projects, but slow funding is insufficient. We need blended finance instruments combining public guarantees with private

capital—something where the public sector absorbs first-loss risk, enabling private investors to participate with acceptable risk-return profiles. The EUR 5-15 million growth stage for bio-materials is completely underserved. Too big for seed funds, too risky for traditional growth equity. This is where companies die, not from technical failure but from financial starvation."

THEME 4: Policy & Regulatory Environment (10-15 min)

Core Questions:

1. "How do current regulations help or hinder bio-inspired innovation?" (*Regulatory assessment*)
2. "What policy changes would most accelerate bio-innovation diffusion?" (*Policy recommendations*)
3. "Do you see differences in how regulations treat bio-inspired vs. conventional solutions?" (*Regulatory asymmetry*)

Representative Verbatims:

About (Ville de Paris DCPA): "From the public procurement side, we want to support bio-innovations, but the legal framework creates enormous friction. Specifying 'lotus-effect-inspired coating' in a tender opens us to legal challenges from conventional suppliers claiming discrimination. We need functional performance criteria that don't mandate specific technologies, but writing these for novel bio-materials requires technical expertise our procurement teams don't have. The EUR 200 billion annual French public purchasing represents massive potential leverage, but less than 5% goes toward innovative solutions despite policy encouragement. The gap isn't political will; it's operational capacity."

Graves (ENSCI): "The narrative lock is cultural as much as regulatory. When biomimicry's philosophical dimension—the ethical commitment to learning from living systems—gets perceived as 'sectarian' or ideological, it undermines the scientific legitimacy. This happens in procurement committees, in investment pitch meetings, in university tenure reviews. We need to decouple the rigorous scientific methodology from the values-based advocacy. Or rather, we need to communicate that the values emerge from the science, not the reverse. This is a design challenge as much as a regulatory one."

THEME 5: Future Vision & Recommendations (10 min)

Core Questions:

1. "If you had a magic wand, what one change would most accelerate bio-inspired innovation adoption?" (*Ideal intervention*)

2. "What role should innovation hubs play in the transition toward bio-inspired solutions?"
(*Hub strategic positioning*)

Closing:

- "Is there anything we haven't discussed that you think is critical for understanding bio-innovation challenges?"
- "May I follow up if clarifications are needed during analysis?"

Appendix C : The EBS Framework: Seven Forest Principles Transposed to Innovation Hub Evaluation

Forest Principle	Ecological Mechanism	Hub Transposition	Observable Indicator	Source
1. Communication	Mycorrhizal networks transfer nutrients and chemical signals between trees (Simard et al., 1997)	Knowledge-sharing infrastructure: open-source protocols, inter-hub exchanges, digital platforms	Number of documented knowledge transfers; presence of open-access databases; frequency of inter-hub collaborations	Simard et al. (1997); Beiler et al. (2010)
2. Circularity	Forest waste is 100% recycled: deadwood feeds	Material flows: waste from one process becomes	Waste diversion rate; number of upcycling	Chapin et al. (2011); Graedel

	fungi, leaf litter becomes soil, nutrients cycle (Chapin et al., 2011)	input for another; no terminal disposal within hub	partnerships; circular material flow mapping	& Allenby (2003)
3. Symbiosis	Mutualistic relationships (lichens, mycorrhizae, nitrogen-fixing bacteria) enable ecosystem functions impossible for individuals (Boucher et al., 1982)	Institutional partnerships: research-industry-government collaborations; SCIC structures; quintuple helix integration	Number and diversity of partnership types; formal collaboration agreements; co-funded projects	Boucher et al. (1982); Iaione (2016)
4. Resilience	Functional redundancy: multiple species perform similar functions, buffering against disturbance (Walker et al., 1999)	Revenue diversification; distributed governance preventing single-point failure; adaptive programming	Revenue source diversity (Herfindahl index); governance distribution; survival through external shocks	Walker et al. (1999); Holling (1973)
5. Energy Optimization	Forests maximize energy capture per unit resource: photosynthesis efficiency, canopy layering, metabolic scaling (West et al., 1997)	Resource efficiency: shared equipment utilization rates; energy per innovation output; infrastructure mutualization	Equipment utilization rate; energy consumption per user; shared resource access frequency	West et al. (1997); Benyus (1997)
6. Diversity	Species diversity correlates with	Actor diversity: disciplinary, sectoral,	Simpson diversity index of hub users by	Tilman et al. (2001); Florida (2002)

	ecosystem productivity and stability (Tilman et al., 2001)	generational, cultural heterogeneity of hub participants	discipline, sector, and background; range of TRL stages hosted	
7. Regeneration	Forest succession: pioneer species create conditions enabling more complex communities; nurse logs support seedlings (Franklin et al., 2002)	Hub generates conditions for new initiatives: spin-offs, knowledge spillovers, trained personnel entering other organizations	Number of spin-offs; alumni career trajectories; new initiatives inspired by hub activities; territorial regeneration indicators	Franklin et al. (2002); Pedersen Zari (2018)

Note. EBS framework developed for this thesis. Ecological mechanisms drawn from forest ecology literature; hub transpositions derived from empirical observation across case studies. Indicators are intended as evaluative heuristics rather than strict quantitative benchmarks given the nascent state of bio-inspired innovation hub research.

Appendix D : Protective Space Functions Mapped to Innovation Hub Activities

Protection Type	Mechanism (Smith & Raven, 2012)	Hub Function	Empirical Example
Shielding	Passive protection from regime selection pressures (market competition, regulation)	Below-market rent; exemption from standard procurement; tolerant regulatory	Darwin Écosystème: 15-year occupation permits on brownfield;

		environment (e.g., urbanisme transitoire)	WoMA: temporary occupation contracts
Nurturing	Active support: network formation, learning facilitation, expectation alignment	Fabrication equipment access; mentoring; cross-pollination events; demonstrator installations; knowledge commons	CEEBIOS: ASTERIA knowledge base (1,800 biological strategies); Climate House: 0% subsidy hybrid revenue model as learning exemplar
Empowerment (Fit)	Innovation becomes competitive within existing regime rules	Certification support; cost optimization through pilot manufacturing; performance data generation for prescribers	Mogu: ADI Compasso d'Oro validation; Ecovative: AirMycelium contract manufacturing at cost-competitive scale
Empowerment (Stretch)	Innovation reshapes regime selection criteria	Policy advocacy; new evaluation frameworks (e.g., lifecycle analysis vs. upfront cost); public demonstration changing expectations	CEEBIOS Biomim'City Lab: 10 institutional partners redefining building performance criteria; EU Taxonomy creating new sustainable finance rules

Note. Adapted from Smith & Raven (2012). Empirical examples from field research (2024-2026). Hub functions derived from interview data (Houette, 2026; Nuti, 2026; Graeff, 2026; Croizet, 2026)

Appendix E: Taxonomy of bio-Inspired innovations elated to this research: sectoral mapping, innovation examples, and hub requirements

Category	Key Examples	TRL Range	Primary Barrier	Funding Raised	Hub Type Required
A. Mycelium Materials	Ecovative, Mogu, MycoWorks, RotterZwam	TRL 5-9	Manufacturing scale-up; fire/acoustic certification	USD 150M (Ecovative); EUR 11M (Mogu)	Bio-fabrication lab + materials testing + design showroom
B. Bio-Deeptech	Biomemory (DNA storage), ASTERIA (AI-biology), FinX(bio-propulsion)	TRL 3-6	Wet-lab scaling; cost reduction; regulatory pathways	USD 18M (Biomemory); 2M EUR (ASTERIA/Anima)	University-adjacent bio-incubator + public demonstrator bridge
C. Urban NBS	Green roofs, bioswales, constructed wetlands, urban forests	TRL 4-7	Financing gap (USD 700B/yr globally); long ROI; place-specificity	USD 154B/yr (current); USD 384B/yr (needed)	Urban living laboratory + financial innovation platform + citizen engagement
D. Bio-Construction	Biomimetic facades, termite-inspired ventilation, bio-inspired structural optimization	TRL 3-6	Manufacturing processes; GBP 200K certification; temporal mismatch	Limited (mostly public R&D)	Pilot manufacturing + certification lab + demonstrator building
E. Bio-Inspired Surfaces	Sharklet (antimicrobial), Lotusan (self-cleaning), Fusion Bionic (laser surfaces)	TRL 6-9	Production speed at scale; niche market capture	USD 4.1M (Sharklet); EUR 772K EU (Fusion Bionic)	Cleanroom/micro-fabrication + industry partnership platform
F. Bio-Inspired Agriculture/Food	MyForest Foods (mycelium protein), Pheronym	TRL 5-8	Consumer acceptance; regulatory approval; supply chain	USD 11M (MyForest); USD 1M NSF (Pheronym); EUR 6M (FinX)	Agri-tech pilot + food processing facility + market testing space

	(nematode biocontrol),				
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Source compiled from : Tracxn (2025); PitchBook (2026); Biomemory (2024); Mogu (2024); Tech.eu (2024); NSF SBIR Awards (2024); Chirazi et al. (2019); Blanco et al. (2021); EIB (2023); UNEP (2023).

Appendix F: 1: Semi-Structured Interviews

These 14 semi-structured interviews were conducted with key stakeholders:
 15-20 semi-structured interviews were conducted with key stakeholders:

Interviewee	Organization	Status/Role	Date	Duration	Topics	Expertise
Thibaut Houette	CEEBIOS	Researcher Engineer	2025	2 x 60'	Standards, manufacturing gap	PhD Biomimicry in architecture, barriers
Cédissia About	DCPA Paris	Researcher, Consultant, R&D	2025	60'	Bio materials, emploi	Bio-materials, valorization, construction, urbanism (coolschools case)
Eliot Graeff	ASTERIA	Founder	2025	60'	Narrative barrier, lotus-effect	Co-founder AI platform, Biomimicry specialist, PhD
Maïka Nuti	Climate House Paris, (formerly Uleria, Team for The Planet)	Co-founder	2025	3 x 45'	Governance, financing	Co-founder, Co-working space, Collaborative governance
Ruben Kok	Blue City Lab	Lab Manager	2026	90'		Lab Manager
Arthur Croizet	Campus de la Transition	Educator, co-founder	2026	60'	Hybrid governance	Educator
Alexandre Bau	Bioregion Institute	Co-founder	2026	Via email Appendix	Investment gap, regulations	Co-founder
Davide Costelli	WoMA Fablab	Lab Manager	2026	60'	WOMA network and governance	Lab Manager
JN X	La Caverne	Co-Founder	2025	JUSIIA Survey	Rehabilitated car park	Urban farm and start-up incubator
Guillian Grave	ENSCI	Educator/Designer	2026	60'	Narrative lock	Educator of Nature Inspired Design Master, Designer

Appendix G: Hubs Typology

Typology	Definition	Source
1. Innovation District	"Geographic areas where leading-edge anchor institutions and companies cluster and connect with start-ups, business incubators, and accelerators."	Kresge, N., & Berube, A. (2017). <i>The Rise of Innovation Districts</i> . Brookings Institution.
2. Technology Park / Science Park	"A property-based initiative designed to promote the growth of knowledge-based firms and facilitate technology transfer between universities and industry."	Phan, P. H., Siegel, D. S., & Wright, M. (2005). Science parks and incubators: observations, synthesis and future research. <i>Journal of Business Venturing</i> , 20(2), 165-182.
3. Business Incubator	"An organization designed to accelerate the growth and success of entrepreneurial companies through an array of business support resources and services."	Hackett, S. M., & Dilts, D. M. (2004). A systematic review of business incubation research. <i>The Journal of Technology Transfer</i> , 29(1), 55-82.
4. Accelerator	"A fixed-term, cohort-based program that includes mentorship and educational components and culminates in a public pitch event or demo day."	Cukier, K., & Kon, F. (2015). Accelerators and the regional innovation ecosystem. <i>Communications of the ACM</i> , 58(6), 36-38.

5. Co-working Space	"Shared workspaces that foster collaboration and networking among entrepreneurs, freelancers, and startups, often with flexible membership models."	Spinuzzi, C. (2012). Working alone together: Coworking as emergent collaborative activity. <i>Journal of Business and Technical Communication</i> , 26(4), 399-441.
6. Innovation Lab	"An organizational entity that aims to foster innovation by experimenting with new ideas, technologies, and business models within or outside the parent company."	Hossain, M., & Kauranen, I. (2016). Open innovation in SMEs: A systematic literature review. <i>Journal of Strategy and Management</i> , 9(1), 58-73.
7. Living Lab	"User-centered, open innovation ecosystems based on a systematic user co-creation approach integrating research and innovation processes."	Leminen, S., Westerlund, M., & Nyström, A.-G. (2012). Living Labs as open-innovation networks. <i>Technology Innovation Management Review</i> , 2(9), 6-11.
8. Pôle Universitaire d'Innovation	"University-based clusters integrating research, education, and technology transfer to foster innovation."	Etzkowitz, H., & Leydesdorff, L. (2000). The dynamics of innovation: from National Systems and "Mode 2" to a Triple Helix of university-industry-government relations. <i>Research Policy</i> , 29(2), 109-123.
9. R&D Center	"Institutions focused on research and experimental development, often in specialized scientific fields."	Cohen, W. M., & Levinthal, D. A. (1990). Absorptive capacity: A new perspective on learning and innovation. <i>Administrative Science Quarterly</i> , 35(1), 128-152.
10. Citizen Third Place	"Informal social spaces where people gather outside home and work, not necessarily focused on innovation activities."	Oldenburg, R. (1999). <i>The Great Good Place</i> . Marlowe & Company.
11. Makerspace / FabLab	"Community-driven workshops equipped with digital fabrication tools, enabling prototyping and collaborative innovation."	Gershenfeld, N. (2012). How to make almost anything: The digital fabrication revolution. <i>Foreign Affairs</i> , 91(6), 43-57.
12. Hybrid Hub	"Multifunctional innovation spaces combining incubation, coworking, R&D, and other services to support diverse innovation needs."	Moriset, B. (2014). Building new places of the creative economy. The rise of coworking spaces. <i>RIMHE</i> , 3(1), 103-126.

Appendix H: A proposition of a Comparative table of innovation hubs evaluated with the BSE Framework

Typology	Communication	Circularity	Symbiosis	Resilience	Energy Optimization	Diversity
1. Innovation District	Very High: Dense networks and flows	High: Resource and knowledge reuse	Very High: Cross-sector synergy	High: Adaptive urban-ecosystem	High: Efficient use of infrastructure	Very High: Diverse actors and sectors
2. Technology Park / Science Park	High: Strong institutional ties	Moderate: Technology transfer loops	High: University-industry links	High: Stable but sometimes rigid	Moderate-High: Shared facilities	Moderate-High: Mostly tech focus
3. Business Incubator	High: Mentorship and networking	Moderate: Service reuse	Moderate: Startups and partners	Moderate: Structured support	Moderate: Resource allocation	Moderate: Startup variety
4. Accelerator	Very High: Intense, time-limited	Low-Moderate: Limited resource reuse	Moderate: Startups-investors	Moderate: Fast-paced but fragile	Moderate: Focused resource use	Moderate: Startup diversity
5. Co-working Space	High: Informal networking	Low-Moderate: Shared infrastructure	Moderate: Diverse professionals	Moderate: Flexible but dependent	Moderate: Shared energy and space	High: Varied industries and skills
6. Innovation Lab	High: Internal and external sharing	Moderate: Experimentation cycles	High: Cross-disciplinary teams	High: Agile experimentation	Moderate-High: Resource efficient	Moderate-High: Multidisciplinary

7. Living Lab	Very High: User co-creation	High: Sustainable user-driven cycles	Very High: Multi-stakeholder	High: Adaptive to user feedback	Moderate: Optimized through feedback	Very High: Inclusive and diverse
8. Pôle Universitaire d'Innovation	Very High: Triple helix communication	High: Knowledge and tech recycling	Very High: University-industry-government	High: Adaptive research ecosystem	High: Shared academic resources	Very High: Multidisciplinary teams
9. R&D Center	Moderate-High: Focused knowledge flows	Moderate: Material recycling	Moderate: Partner collaboration	High: Long-term innovation focus	High: Optimized lab processes	Moderate: Specialized expertise
10. Citizen Third Place*	High: Social dialogue	Low: Not resource-focused	Low-Moderate: Community bonding	Moderate: Social support	Low: No focus on resource use	High: Diverse community members
11. Makerspace / FabLab	High: Open sharing and collaboration	Moderate: Material/tool reuse	Moderate: Collaborative user base	Moderate: Adaptable and grassroots	Moderate: Efficient resource use	High: Diverse projects and users
12. Hybrid Hub	Very High: Integrated communication	Very High: Resource and knowledge sharing	Very High: Multi-sector synergy	Very High: Multifaceted support	Very High: Optimized resource use	Very High: Combines multiple types

Note: Low. Scores represent structural tendencies derived from organizational design characteristics, not empirically measured outcomes. Individual hubs may significantly diverge from typological tendency depending on governance quality and community intentionality (see Table 5.2). Ecological profiles are analogical rather than literal (Odum, 1971; Holling, 1973).

*Citizen Third Place structural scores reflect organizational form, not realized potential: empirical cases (Climate House, Darwin Ecosystem) demonstrate substantially higher scores through deliberate design (Nuti, 2026; Iaione, 2024). Sources: Benyus (1997); Etzkowitz & Leydesdorff (2000); Leminen et al. (2012); Moriset (2014); Oldenburg (1989); Westley et al. (2011).

Appendix G: Asteria Evolution

Phase	TRL	Mobilised infrastructure	hub	Counterfactual (without hub)
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Research	TRL 1-2 : PHD + CEEBIOS	CEEBIOS as an SCIC: access to expert networks, biological databases, training courses	Isolated laboratory research, no field of application
Concept	TRL 3 : Proof of concept IA	CEEBIOS network = 200+ experts to interdisciplinary validation	Impossible to test relevance without multi-sector feedback
Venture	TRL 4-5 : ANIMA venture studio	ANIMA = incubation structure dedicated to biomimicry, born out of the CEEBIOS ecosystem	No sector-specific venture studio to no business structuring
Scale	TRL 6-7 : Fund raisin 2M€	Climate House + Networking events = visibility among investors. Critical density achieved.	Without a visible critical mass, no VC will fund "biomimicry software".

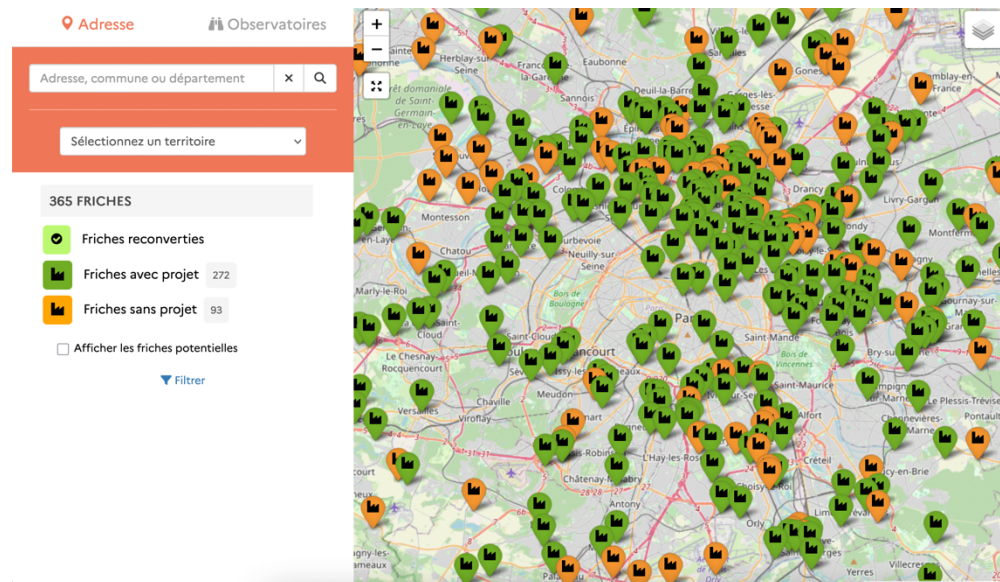
Appendix H: Comparative Analysis of Successful Bio-Inspired Innovation Trajectories

Dimension	Ecovative (USA)	Mogu (Italy)	Climate House (France)	Common Pattern	Theoretical Implication
Time viability	18 years (2007-2025)	7+ years to Series A	Operating since ~2019, 0% subsidy	Extended timelines (7-18 years)	Biological temporality: innovation maturation follows ecological, not financial, rhythms
Capital structure	\$184M diversified VC + grants	€11M Series A + EU grants	Hybrid revenue, no subsidy	Revenue diversification essential	Resilience principle: multiple energy sources prevent collapse from single-source failure
Market entry strategy	Technology push across packaging, food, fashion	Design-led cultural legitimization	Community-first, service hybrid	Indirect entry avoiding frontal regime competition	Ecological colonization: pioneer species establish in marginal niches before competing in core habitat
Manufacturing approach	Contract farming (convert existing infrastructure)	Proprietary small-scale production	N/A (hub, not manufacturer)	Capital-light adaptation of existing infrastructure	Symbiosis: leveraging existing ecosystem resources rather than creating de novo
Hub ecosystem role	University incubator (origin); self-built manufacturing hub	Italian design ecosystem as demonstrator network	IS the hub; nursing log model	Hub as enabling condition, not sufficient cause	INUS condition confirmed: hubs are Non-redundant but Insufficient alone
Open/closed knowledge	Open-sourced packaging; proprietary platform	Proprietary product; open design exhibitions	Open governance model; shared learning	Selective openness: commons knowledge + proprietary application	Communication principle: forests share resources via mycorrhizal networks while individual trees retain adaptive advantages

Note. Sources: Ecovative corporate communications and PitchBook data (2025); Mogu corporate data and Tech.eu (2024);

Appendix H : Comparative Analysis of Bio-inspired Innovations Fails

Appendix I. a Cartofriches Map - Brownfield Opportunities for Bio-Inspired Innovation Hubs



Note: The “Cartofriche” Map, focus in Ile-de-France region, shows brownfield places with, (deep green) and without (orange, rehabilitating projects).

Source: Cerema - <https://www.cerema.fr/fr/actualites/cartofriches-plus-14-300-sites-friches-repertoires>

Appendix 1.b: Brownfield Types and Stakeholders

Brownfield Type	Typical surface area	Key players	Funding	Possible bio-inspired model
Railway (SNCF)	5 000-50 000m ² . IDF: 8 terrains, 4,4 ha	SNCF Immobilier, EPF, Communes	Fonds Friches, ANCT, Banque des Territoires	(modèle Ground Control, Cité Fertile, La Sauge biofab
Hospital	10 000-100 000m ²	AP-HP, ARS, Collectivités	Green Funds, Région	Art-science- biomaterials residency (modèle 104, Hopital St paul, Urban Farm)
Industrial	Variable (1 000-500 000m ²)	Private owners, EPF, ADEME	ADEME (polluting sites), Fonds Friches	Biofactory régionale (modèle Bioregion Institute)
Military	20 000-200 000m ²	Ministry of Defence, Commons	Transfer of state property, private investors	Darwin : large- scale hybrid bio-based third place
Underground car park	1 000-10 000m ²	Landlords, Municipalities	Private, subventions urban farming	La Caverne : ferme urbaine + lab mycélium
Commercial (vacant offices)	5 000-50 000m ²	Landowners, Developers	Investisseurs private	Docks b Pantin : bio-transition entrepreneurs community

Note: France has around 260,000 potentially polluted sites. Industrial wasteland in urban areas covers around 7,500 hectares. The Fonds Friches has recycled 2,700 hectares thanks to €650 million (2021). The ELAN law creates specific tools: Territorial Revitalisation Operations (ORT) and Partnership Development Projects (PPA).

Appendix J

Appendix K

Appendix L: Framework for creating a bio-inspired urban hub

Dimension		Operationnal actions
FONCIER		Target urban brownfield sites (e.g. Banque des Territoires) + short-term leases (transitional urban planning). Critical transport accessibility (Senlis failure). Blue City model: conversion of obsolete facilities. Aim for a minimum of 500-2000m ² .
GOVERNANCE		SCIC (CEEBIOS model: 4 colleges) or community (Climate House model: concentric circles). Minimum of 3 active propellers of the five-propeller system. Incorporate the "right to fail" into the statutes.
FINANCING METHOD		Objective: not exceed 40% in subsidies. Diversify: coworking rents (30%) + events (20%) + training (20%) + services/consulting (15%) + membership fees (15%).
COMMUNITY		Climate House strategy: create the community before the location. 170 co-founders as initial social capital. Weekly events to foster relationships. Minimum of 50 active members at launch.
INTEGRATION NBS - BIS		3 levels: (1) Ad hoc = workshops (mycelium workshops, conferences (sufficient for TRL 1-2). (2) Structural = biomaterials materials library, equipped fab lab (TRL 2-4). (3) Strategic = R&D partnerships, local biomaterials sector (TRL 4-6).
KPI/ Robustness Indicatives	Key	Diversity (adapted Shannon index), Interconnection (network density), Regeneration (inter-layer transition rate), Resilience (inverse Gini income, max 40% single source), Symbiosis (local benefits/investment), Circularity

Note : Operational summary derived from the cases studied, structured according to the DBE categories of Tleuken et al. (2025) adapted to the bio-inspired context.

Appendix M: Metabolic Levels Model - Full Tabular Presentation

The following taxonomy distinguishes four functional levels, defined not as linear stages of development but as complementary roles within a territorial ecosystem. A functional Archipelago model requires the simultaneous presence of all four levels in a network.

Levels	DOMINANT FUNCTION	EMPIRICAL EXAMPLES	TRL PROJECTS	QUINTUPLE HELIX	BLANCO (2022)
Level 1 — Emerging « Soil »	Networking Acculturation Serendipity Awareness raising	Thirdplaces (La Prairie du Canal ; urban farm) La Recyclerie Résidences d'artistes (59 rivoli, TerraPods) Climate House	TRL 1-3	2-3 acteurs	Education (1.8%) Biological structure (gardens, compost) Networking Acculturation Serendipity
Level 2 — Prototype “Forest Floor”	Manufacturing Material testing Technical iteration Experimentation	Blue City Lab FabLabs spécialisés (WoMA) (voir site RffLabs pour cartographie complète)	TRL 3-5	3-4 acteurs	Experimental NBS Tech solutions Low-tech Physical structure
Level 3 — Incubation « Shrub Layer »	Business model Access to finance Go-to-market Certification	CISAM Station F Villa M	TRL 5-7	4-5 acteurs	Building materials Urban policy Codes and standards

Level 4 — Dépôt « La Canopy »	Full-scale demonstration Training programme Production System integration	Darwin Bordeaux Terra Pods Hubs4Circularity Campus de la Transition La Sauge La Cité fertile La Caverne Paris Le M19	TRL 6-9	5 acteurs	Quasi-exhaustive coverage Taxonomy Focus on biological structures (29-36)
Level 5 - Transversal « Mycelium »	Interconnexion	RffLabs Hubs4 Cicularity Regional Innovation Valleys	/	5 acteurs	Partnerships, Shared methods

Source : Original taxonomy. TRL levels according to NASA. Quintuple helix score according to Codebook Co-Cities. (LabGov/Iaione). Référence Blanco d'après Blanco, Raskin & Clergeau (2022).

Appendix N: Comparative Policy Framework Table - INUS Condition Assessment

INUS Component	What It Requires	French Policy	EU H4C	Innovation Hubs (Thesis)
I — Insufficient (hub alone is not enough)	Complementary funding, skills, regulation, time	Partially (France 2030 funding, LPR careers)	Yes (blended finance, KPI toolkit)	Partially (creates community, not funding)
N — Non-redundant (hub is irreplaceable)	Physical space + community + experimental freedom	No (no dedicated bio-hub policy)	Partially (H4C facilitator concept)	Yes (empirical proof: La Paillasse collapse)
U — Unnecessary (other paths exist)	Alternative innovation pathways	Yes (Bpifrance, ANR direct)	Yes (EIC Accelerator, LIFE)	Confirmed (Ecovative succeeded without hubs)
S — Sufficient (combination works)	Complete ecosystem alignment	No (fragmented architecture)	Partially (systemic but TRL 5+ only)	Yes when combined (Asteria hinge moment)

Table 4.5.3: INUS condition model applied to policy frameworks. The non-redundancy condition (N) — which makes innovation hubs causally significant — is the component least addressed by existing policies. Source: Author's analysis integrating Mackie (1965), Geels (2002), and thesis empirical data.

ANNEXES

Figure 1: Definitions of key terms in bioinspired approaches, including bioinspiration, biomimetics, biomimicry, bionics, nature-based solutions, and the biomimetic promise.

Term	Definition	Source
Bioinspiration	“Using phenomena in biology to stimulate research in non-biological science and technology”	<i>Whitesides G.M. Bioinspiration: Something for everyone. Interface Focus. 2015;5:20150031. doi: 10.1098/rsfs.2015.0031</i>
Biomimetics	“Interdisciplinary cooperation of biology and	<i>Biomimetics—Terminology, Concepts and of Methodology. International Organization for and Standardization; Berlin, Germany: 2015. [(accessed</i>

Term	Definition	Source
	technology or other fields of innovation with the goal of solving practical problems through the function analysis of biological systems, their abstraction into models, and the transfer into and application of these models to the solution”	on 17 January 2025)]. Available online: https://www.iso.org/obp/ui/#iso:std:iso:18458:ed-1:vl:en
Biomimicry	“Learning from the natural world by imitating or taking inspiration from nature’s designs and processes to solve human problems”; Nature as “model, measure and mentor”	<i>Benyus J.M. Biomimicry: Innovation Inspired by Nature. Perennial; New York, NY, USA: 2002</i>
Bionics	“Technical discipline that seeks to replicate, increase, or replace biological functions by their electronic and/or mechanical equivalents”	<i>Biomimetics—Terminology, Concepts and Methodology. International Organization for Standardization; Berlin, Germany: 2015. [(accessed on 17 January 2025)]. Available online: https://www.iso.org/obp/ui/#iso:std:iso:18458:ed-1:vl:en</i>
Nature-based solutions	“Nature-based solutions to societal challenges as solutions that are inspired or supported by nature, which are cost-effective, simultaneously	<i>European Commission (EU) Nature-based solutions. [(accessed on 17 January 2025)]. Available online: https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en</i>

Term	Definition	Source
	provide environmental, social, and economic benefits, and help build resilience...”	
Biomimetic/Bionic promise	“The biomimetic promise refers to higher resource efficiency, nature-inspired materials and processes, reduced risks and side effects, elegance, sophistication, and ecological fit, broadly speaking, to greater ecological sustainability” (transl. LE)	<i>Von Gleich A. Das bionische Versprechen. Ökol. Wirtsch—Fachz. 2007;22:21–24. doi: 10.14512/oew.v22i3.528.</i>

Source: Biomimetics (Basel) 2025 Sep 9;10(9):602. doi: [10.3390/biomimetics10090602](https://doi.org/10.3390/biomimetics10090602)

Figure: Successful and implemented Examples of bio-inspired solutions:

Sector	Innovation	Bio-Inspiration	Brief Description	Source
Adhesives	Velcro	Burrs of burdock plants	Velcro is a hook-and-loop fastener inspired by the tiny hooks on burdock burrs that cling to fabrics and fur,	Dirks, J. H. (2024). The future of

			enabling reusable fastening in clothing, aerospace, and medical applications.	bioinspired innovation: Exploring the potential of nanobiomimetics. <i>Nano Letters</i> . https://pubs.acs.org/doi/10.1021/acs.nanolett.4c02816
Adhesives	Geckel Adhesive	Gecko feet and mussel proteins	Geckel is a hybrid adhesive combining gecko's dry adhesion via van der Waals forces with mussel's wet adhesion, used in medical bandages and underwater applications for residue-free bonding.	Lee, H., Lee, B. P., & Messersmith, P. B. (2007). A reversible wet/dry adhesive inspired by mussels and geckos. <i>Nature</i> , 448, 338–341. https://wiki.epfl.ch/mep/documents/MEP[07-08]_DOWNLOAD/lee_nature07_geckel.pdf
Architecture	Eastgate Centre	Termite mounds	The Eastgate Centre in Harare, Zimbabwe, uses passive ventilation inspired by termite mounds' natural cooling chimneys, reducing energy use by 90% compared to traditional air conditioning.	AskNature. (n.d.). Passively cooled building inspired by termite mounds — Innovation. https://asknature.org/innovation/passively-cooled-

				building-inspired-by-termite-mounds
Renewable Energy	Humpback Whale-Inspired Wind Turbine Blades	Humpback whale flippers	Tubercle structures on humpback whale fins improve airflow, leading to wind turbine blades that increase efficiency by 20%, reduce noise, and perform better in low winds, deployed in parks in Canada and the US.	Omidvarnia, F. (2024). Nature-inspired designs in wind energy: A review. <i>PMC</i> . https://pmc.ncbi.nlm.nih.gov/articles/PMC10886931
Surface Technologies	Lotus Effect Self-Cleaning Surfaces	Lotus plant leaves	Hydrophobic microstructures on lotus leaves repel water and dirt, inspiring self-cleaning coatings for glass, paints, and buildings, reducing cleaning needs and water use in products like Pilkington Activ.	AskNature. (2020). Surface allows self-cleaning — Biological strategy. https://asknature.org/strategy/surface-allows-self-cleaning
Surface Technologies	Sharklet Antibacterial Surfaces	Shark skin	Micro-textured patterns on shark skin prevent bacterial adhesion, leading to chemical-free antibacterial surfaces used in hospitals and aircraft to reduce infections by up to 90%.	MDDI Online. (n.d.). How shark skin inspired an antibacterial surface technology. https://www.mddionline.com/rd/how-shark-skin-inspired-an-antibacterial-

				surface-technology
Transportation	Shinkansen Bullet Train	Kingfisher beak	The nose of Japan's Shinkansen train mimics the kingfisher's beak for smooth air-to-tunnel transitions, reducing noise, pressure waves, and energy use by 15% while increasing speed by 10%.	AskNature. (2020). The beak that inspired a bullet train — Biological strategy. https://asknature.org/strategy/beak-provides-streamlining
Transportation	Mercedes-Benz Bionic Car	Boxfish	The boxfish's aerodynamic shape inspires the Bionic car's design, achieving low drag (Cd 0.19) for better fuel efficiency and reduced emissions, integrated into production models like the CLA.	Yang, C. M., Hung, J. Y., Wang, Y. L., & Lien, Y. H. (2019). Analysis of Mercedes-Benz concept car using biomimicry design spiral and template analysis – An exploratory study. <i>International Journal of Innovation in Management</i> , 7(2), 49–56. https://siim.org.tw/wp-content/uploads/2025/08/IJIM-18-005.pdf

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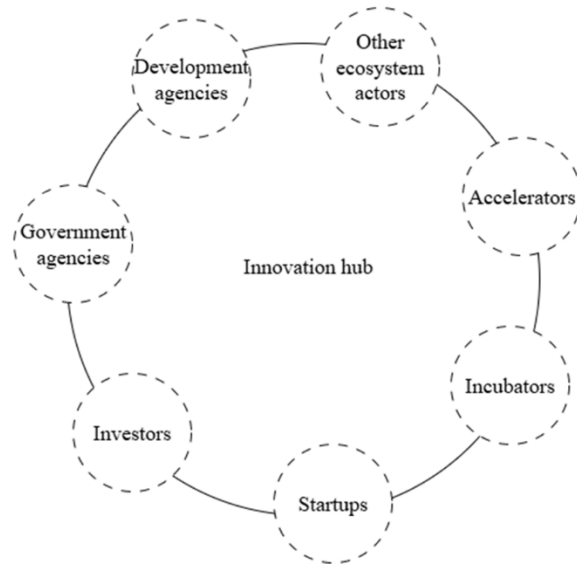
Figure 1.b : Challenge, effects and key factors of success based on reports from developers in Bio Inspired projects. KTT: knowledge, translation and transfer, IP: Intellectual Property

Challenges	Effect	Success Factor
Communication across disciplines	Abandonment Misunderstandings	Constant KTT during project duration; define communication and boundaries
Involvement of multiple disciplines, backgrounds, and approaches	Misunderstandings	Turn into a benefit by learning from each other
Resistance to ideas	No collaboration possible	Build a network of experts willing to collaborate
Duration of development phase	Discouragement	Assess the market properly; ensure the product is scalable
Translation between fields	No marketspace	Find a market niche
Requirement of proof-of-concept	Discouragement	Determination of channels for production; pursuit of blue ocean strategy; find appropriate methods for validation
Duration of commercialization phase	Discouragement	Appropriate marketing, assess the market properly
Requirement to design new processes of production	Opportunity for patents; increase of time and costs	Procurement of sufficient funding; patenting
Requirement to build up new capacities	Increase of costs	Procurement of sufficient funding
Protection with patents	Legal protection for IP	Keep potential competitors out of the market; define IP of various partners
Long wait for return on investment	Discouragement	Procurement of sufficient funding
Clear research objective and specific goals, mandatory interdisciplinary thinking, open-mindedness, commitment, flexibility, environment for collaboration, willingness to learn from each other, reciprocal respect, endurance, deep understanding of biology, advising experts and impartial referees. ¹		

¹ Overarching topics and aspects that facilitate the BID process.

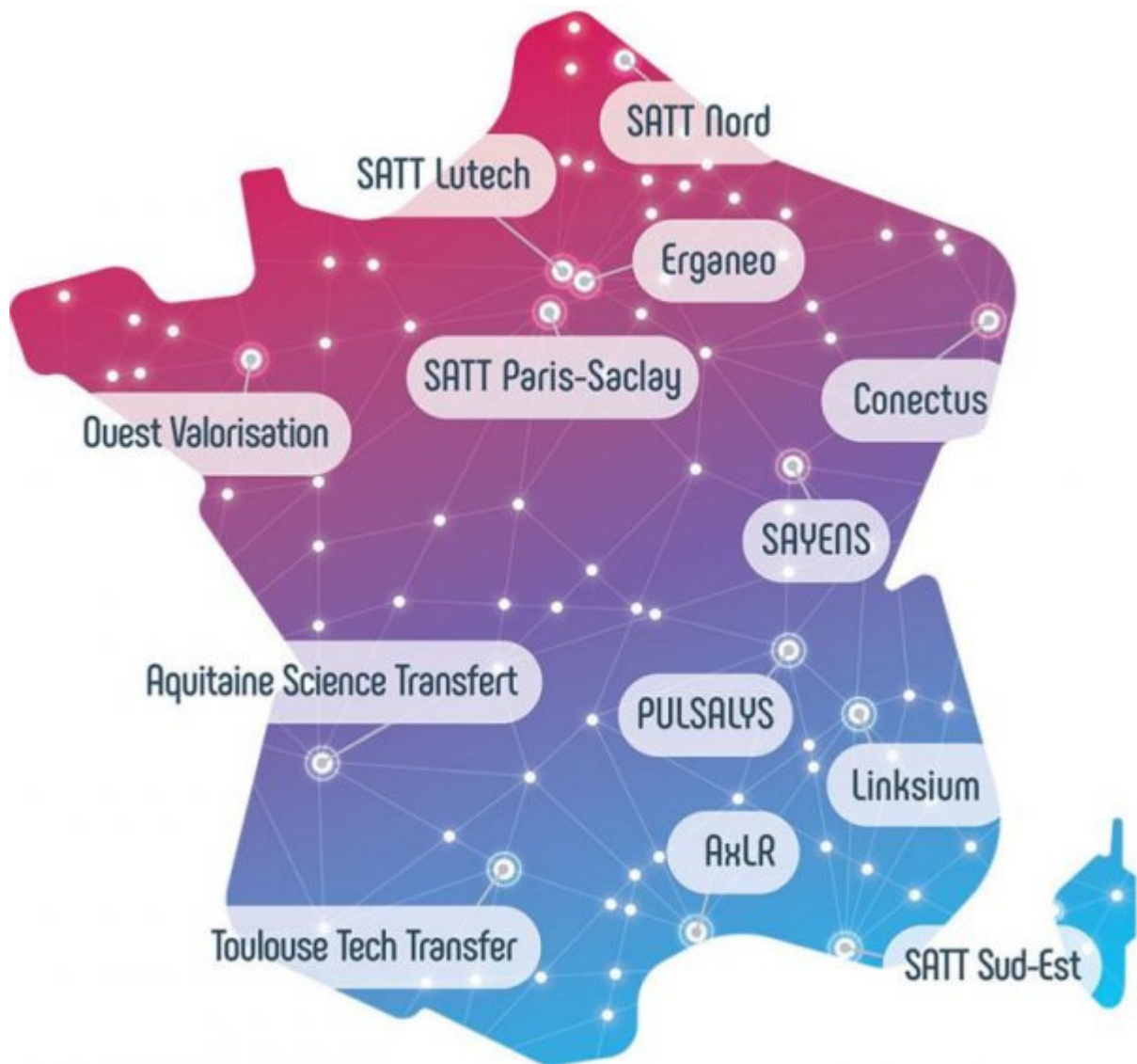
Note: Chirazi et al. (2019) shed light on the challenges, effects and factors for success in IDB projects. We can find elements that confirm the issues of discouragement and misunderstanding. These issues hinder cooperation and project creation. We will see later that a place bringing these actors together would help to resolve these issues.

Figure 2: Exploring the role of innovation hubs on agritech startups' innovation and success that includes many entities.



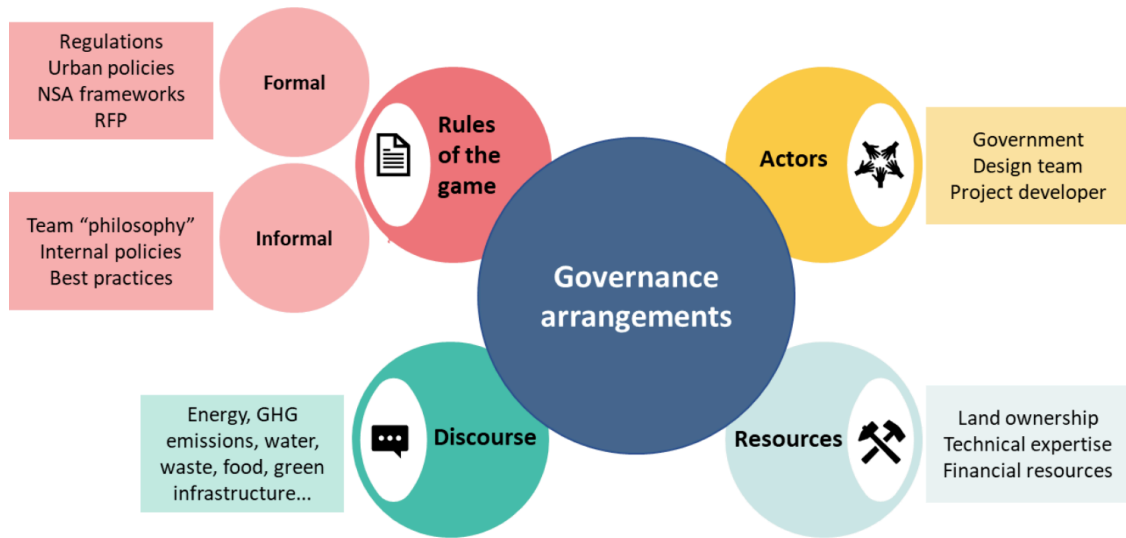
Source: Matthew Ayamga ^{a b c}, Ayalew Kassahun ^b, [Bedir Tekinerdogan](#) ^b, (2025) Exploring the role of innovation hubs on agritech startups' innovation and success

Figure 4 : French SATT Network



Source: <https://www.satt.fr/societe-acceleration-transfert-technologies/>

Figure 3: Key elements observed in the governance arrangement affecting the design and implementation process of sustainable neighbourhoods in Blanco study



Source: Blanco Thesis 2022

Figure 5: Cartography of MakerMovement – pioneer and perfect network for an Archipelago Model connection



Source: Cartography by RFLABS of Maker Movement Network, representation of a pioneer connected archipelago model rfflabs.gogocarte.fr/map#/carte

Figure : Strategies taxonomy and associated indicators Complementary to BSE Framework

Dimension	Topic	Strategy	Indicators
Energy	Electricity	1.Rely on renewable energy	1. Renewable energy
		2. Reduce energy consumption	2. Electricity consumption
	Heat islands	3. Manage heat islands	3. High albedo surface
Materials	Water ressources	4. Reduce water consumption	4. Water consumption
		5. Manage rainwater locally	5. Rainwater management
		6. Manage wastewater sustainably	6. Pervious surface
		7. Promote con. materials circularity	7. Onsite wastewater management
	Building materials	8. Prioritise retrofit/rehabilitation	8. Material Circulatory Indicator
		9. Use low risk materials	9. Retrofitting rate
		10. Reduce embodied carbon	10. Low risk materials
	GHG	11. Promote low carbon life styles	11. Embodied carbon
		12. Enhance local food production	12. Annual GHG Balance
	Food	13. Reduce pesticides and fertilizers	13. Food production area
	Pesticides/fertilizers	14. Manage waste sustainably	14. Fertilizers and pesticides
	Waste	15. Local organic waste management	15. Local organic waste management
16. Rate of landfilling		16. Rate of landfilling	
17. Rate of recycling		17. Rate of recycling	
Abiotic	Physical structure	18. Protection of sensitive areas	18. Protection of sensitive areas
		19. Ecological restoration	19. Ecological restoration
		20. Topography changes	20. Topography changes
		21. Soil restoration	21. Soil restoration
		22. Compensation of artificialisation	22. Compensation of artificialisation
	23. Project area built on urbanised areas	23. Project area built on urbanised areas	
Biotic	Habitat	24. Urban Green Space	24. Urban Green Space
		25. Biotope Area Factor	25. Biotope Area Factor
	Ecological network	26. Enhance the ecological network	26. Connectivity of green spaces (outside the plot)

Figure 8: Strategies taxonomy and associated indicators.

