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A Vision for Barcelona's Future: City Science Illuminating Urban and Economic Development

Urban And Economic Development Vision and Comparative Analysis Between Amsterdam, Barcelona, Boston, Munich, And Stockholm

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University of Navarra

PPP for CITIES
Specialist Centre on PPP in Smart and Sustainable Cities

ARETIAN
Urban Analytics and Design

PPP FOR CITIES

The Specialist Centre on PPPs in Smart and Sustainable Cities (PPP for Cities) is a research, innovation and advisory center that aims to provide public authorities throughout the world with support in the organization, management and execution of projects involving collaboration between the public and private sector in the field of smart cities.

It is also a platform for partnership between companies and such authorities at the global level, where they can explore the dynamics of public-private partnerships in depth, create best practice guides and standards, and design solutions to the problems faced by cities.

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Contents

Executive Summary

City planners and urban development leaders face innumerable challenges when seeking to shape the social and physical dynamics of urban life in order to raise the standards of living of citizens. Taking a systematic, evidence-based city science approach can help on multiple levels, most importantly by illuminating the best practices and principles that can be applied in different cities and contexts as well as moments in time.

Using novel tools and technologies, Harvard Innovation Lab-based Aretian Urban Analytics and Design worked with IESE Business School to systematically compare and analyze five metropolitan areas: Amsterdam, Barcelona, Boston, Munich, and Stockholm. The aim was to identify top sustainability goals and inform strategies to be implemented by the City of Barcelona within an initiative proposed by the IESE's PPP for Cities Research Center and the City Government of Barcelona: A Vision for Barcelona's Future.

The five urban systems were compared with one another to identify new insights, goals, and strategies for the Barcelona metropolitan region for the coming years; the following domains were explored: 1) urban design patterns, 2) economic development strategies, 3) innovation ecosystems building, 4) housing and standards of living, and 5) mobility and logistics.

By breaking down these systems into 2,512 benchmarkable units, we ranked each and every city, district, neighborhood, and small urban unit, distilling the areas that were systematically outperforming others. We were also able to identify the inherent, common features, and characteristics shared by the most outstanding environments. The results of the analysis and recommendations can be summarized as follows:

1. **Envisioning Sustainable Urban Design Strategy.** By evaluating the relationship between urban design and urban performance KPIs, we determined the main urban typologies of neighborhoods in the five cities. We were able to measure the impact of urban form on citizens' quality of life and identify best practices to inform city design for the Barcelona metropolitan region for the future. Key areas of focus were city development patterns, activity programming, zoning, and urban design best practices. Strategic urban development recommendations include the following:

    - Conceive of a fractal metropolis urban design vision for the Barcelona metropolitan region composed of self-similar morphological patterns and nested hierarchies of network edges (streets, roads, boulevards) and nodes (architectural spaces), aiming to reach average city form fractality of 75% and raising urbanization efficiency by up to >80%.
    - Envision a geospatial growth pattern tailored for each of the 160 municipalities of the metropolitan area, aiming to accommodate 676,000 citizens and 475,000 dwellings, here following sustainable growth patterns.
    - Establish a self-similar zoning and programming strategy following a scale-free geospatial distribution, hence raising the access to amenities across the metropolitan region.
    - Embed intermediate urban entropy values in new developments to increase social interaction and reduce resource consumption.
    - Chisel a network of innovation districts that contribute to increasing knowledge-intensive employment from 125,000 up to 200,000 and generating distributed prosperity in the coming years.

2. **Nurturing Urban Economics and Prosperity:** We evaluated the economic complexity of the service industries and export-oriented products of five global cities to gain a view of the current status of each city in terms of its industry sophistication and diversification. We also identified optimal smart specialization strategies to be pursued based on current capabilities and collective know-how. Strategic economic development recommendations include the following:

   - Raise service industry diversity and sophistication in Barcelona from 321 industries (92 innovative) up to 670 (170 innovative) and manufacturing industries from 89 (39 innovative) up to 119 (45 innovative) to increase overall economic resiliency.
   - Promote industry strengthening to increase the total annual city revenue from €125.823M up to approximately €190.000M by 2040 by pursuing a geographic concentration of closely related sectors in clusters, particularly spread around the five industrial areas in the Besòs riverbed.
   - Increase the number of vertically integrated industries from 255 out of 477 up to approximately 350, hence establishing longer value chains and economies of scope.
   - Raise tech transfer across highly sophisticated sectors to increase the number and knowledge-intensive sectors, thus generating quality employment.
   - Place emphasis on carefully selected Quadrant 1 industries (those that are destined to lead the economy of a city), raising the number of industries with a high degree of global competitiveness from 255 up to approximately 360 industries (out of 775) by 2040.

3. **Propelling Research and Innovation Ecosystems:** The geospatial analysis of knowledge-intensive activities in terms of innovation phases across the five cities, paired with an analysis of the seven phases of innovation in the Barcelona area, revealed the best practices necessary for a highly functioning innovation ecosystem. These ecosystems can generate quality employment opportunities, liberate latent talent of citizens, generate prosperity, and raise standards of living. Strategic innovation ecosystem recommendations include the following:

   - Raise the number of knowledge-intensive jobs from 125,000 up to 200,000, increasing innovation intensity from 15% up to 20% between 2024 and 2040 and concentrating knowledge advancement hubs in strategic locations.
   - Strengthen the three phases of innovation (research, tech transfer, and advanced production) to increase innovation intensity, performance, and impact KPIs; raise revenue/employee from €149,179 up to approximately €200,000 and revenue per resident from €77,818 up to €110,000 by 2040 by providing support across the seven steps of innovation.
   - Conceive a network of innovation districts (most notably, Barcelona-Besòs, Esplugues, Badalona i les Tres Xemeneies) that present innovation intensity upward of 60%; hosting dedicated to applied research areas, innovation centers, startups incubators, coworking, and industry liaison.
   - Define a vision to align the roughly 1,500 applied research fields across all universities and research centers with the 98 innovative sectors (four in research, 17 in tech transfer, 77 in production), to densify knowledge exchange and advancement and realize the multiplying effects of innovation, Increasing the number of R&D-driven startups from 279 out of 1902 up to more than 750 by 2040, which can be done by aligning traditional sectors with cutting-edge R&D.

4. **Providing Quality Housing and Standard of Living:** We carried out a geospatial analysis of the relationship between residential dwellings and urban services and amenities to shed light on the quality of life of citizens, as defined by the 15-minute city quality standards. An evaluation of the urban infrastructure network pointed to growth strategies that can satisfy the unmet housing demand across the Barcelona metropolitan region, including new housing, mixed-use development, and activity programming. Strategic residential recommendations include the following:

    - Accommodate approximately 77,000 new dwellings by 2040 and up to 126,000 by 2050 across the city, for a total of 190,000 new citizens between 2024 and 2050, along with 475,000 new residential dwellings across the 160 municipalities of the metropolitan region while limiting growth in saturated areas.

    - Procure a geospatial distribution of nested hierarchies of education and healthcare amenities to increase accessibility in underserved areas.

    - An increase from a total of 68.32 up to 80 amenities per km^2 within the city.

    - Reduce traditional densification of Barcelona and increase amenities in the metro area from 9,067 up to approximately 15,000 by 2040.

    - Increase amenities from 12,233 up to approximately 20,000 by 2040 within the metro region.

5. **Shaping a Sustainable Mobility and Logistics Strategy:** Network theory-led urban mobility analysis was deployed to assess how the different public transit and urban form and walkability systems contribute to attain sustainable mobility goals. Concepts such as reach, gravity, catchment area, mobility betweenness, and service area were used to assess coverage. The evaluation of the urban infrastructure networks helped discern the critical needs, ingredients, and dynamics required to shape a successful, efficient, sustainable, and affordable intermodal mobility and logistics network. Strategic urban mobility and logistics recommendations include the following:

    - Raise the sustainable mobility ratio (public transit, pedestrians, and individual mobility devices) from 74% up to 80% by 2040, here by means of infrastructure deployment, data science modeling of services, and asset management.

    - Integrate metropolitan area and region systems by deploying data science and software services.

    - Raise the average mobility nodes per km^2 across the 36 municipalities of the metropolitan area from 26.64 up to at least 30, with a particular emphasis on tramway and underground expansion.

    - Raise the average mobility nodes per km^2 across the 160 municipalities of the metropolitan area from 7.01 up to at least 15, with a particular emphasis on commuter rail services (FGC, Rodalies Renfe) and bus transport.

    - Deploy cargo infrastructure, logistics, and operations strategies to migrate 47% of automobile-driven freight to continental Europe to rail systems, raising the sustainability standards for exports representing approximately €77.74B and Tm19.27M per year.

Glossary of Terms

City Form Metrics: The city form characteristics are a set of morphometric KPIs to quantitatively describe a given city's urban features. The KPIs are universal and allow any geographic region, district, or neighborhood to be assessed and benchmarked against analogous areas of interest.

- **Urban Morphology (3D):** The study of physical characteristics and form of cities, their components, buildings, streets, and general layout. The morphology of a city also determines the efficiency of space use and building arrangement that has a spatial and experiential effect on the user. It will also affect accessibility to amenities as well as housing and jobs because it measures the types of buildings and their arrangement throughout the land.
  - **Avg. Area of Building Footprints:** Average area of building footprints within a given building group as a proxy for space utilization within a specific urban unit.
  - **Avg. Area of Tessellations:** Average area of the tessellations or polygons composing a given building group as a proxy for subunit space utilization.
  - **Avg. building orientation:** Building orientation efficiency optimization.
  - **Avg. tessellation orientation:** Average building parcel orientation as a proxy for urban parcel morphological efficiency.
  - **Avg. Street Alignment:** Efficiency of street layout pattern alignment.
  - **Avg. Building Compactness:** Building compactness as an indirect measure of architectural efficiency.

- **Urban Topology (2D):**
  - **Betweenness centrality:** A measure of centrality in a street network based on shortest paths: the higher the betweenness, the higher the predicted human interaction flow.
  - **Avg. Straightness centrality:** Average Euclidean distance between two points as a proxy for network node accessibility efficiency.
  - **Avg. Length of Street Segments:** Average length (normalized) of street segments within the urban unit as a proxy for network connectivity.
  - **Density of Intersections:** Density of intersections per urban unit.
  - **Density of Street Segments:** Density of street segments per standardized building group (submunicipal urban units of approximately 1,000 residents).
  - **Avg. Circuity of Street Network:** Average ratio between network distance to Euclidean distance, a reciprocal concept to network directness, as a proxy for detour ratio.
  - **Avg. Intersection Connectivity:** Average number of street network connections colluding in the same urban network node/intersection within a given building group as a proxy for intersection connections with nearby edges.

- **Urban Entropy:**
  - **Street Orientation Order (Shannon Entropy):** Measure of the average level of regularity or uncertainty inherent in street orientation patterns, ranging from 0 (highly chaotic/irregular) up to 1 (highly orderly structure).
  - **Street Orientation Entropy (Boeing):** Geoff Boeing conceived of a visualization technique to measure and describe in a visually succinct manner the street orientation patterns of a city, hence summarizing, among other aspects, the dominant axes, growth patterns, and degree of regularity observed in a given urban area.

- **Urban Fractality:**
  - **Urban Fractality Index:** Degree of urban form harmony or self-similarity, which is composed of hierarchical nodes structured in a nested fashion whereby there are large central features surrounded by second-tier and then interspersed with third-tier and subsequent tier features. Features can include residential spaces, economic activity, hospital and

educational systems, parks, transportation hubs, and so forth. The higher the number, the greater the fractality and the higher the economic performance, urbanization efficiency, and access to services and amenities. Fractality or self-similarity is equivalent to harmonic polycentrism and is the best predictor for urban design efficiency and high levels of achievement of 15-minute city standards. High urban fractality levels present a combination of a decentralized, distributed urban network with local hubs or leading nodes enabling the multiplying effects of concentration.
  - **Area Compactness:** A measure from 0 to 1, which is the ratio between the total area of the shape and length of the perimeter boundary. A polygon has a low compactness score if the perimeter length is high and the shape area is low.

- **Urban Scale:**
  - Optimal Scale: Desirable population and density ranges based on city science principles and empirical benchmarking and validation.

Urban Performance Indicators:

- **Superlinear:** Nonlinear positive growth pattern observed when evaluating pairwise comparisons in a scatter plot, which is higher growth compared with a straight/proportional regression trend; therefore, as a given metric of a city grows, the independent variable grows at a rate greater than the straight line. When considering cities, some variables present superlinearity benefits, such as the patents per publication, while others present negative trends, such as crime, pollution, or income inequality.

- **Sublinear:** Nonlinear negative growth pattern, which is lower growth compared with a straight line; therefore, as a given metric of a city grows, the independent variable evolves at a rate less than the straight line. When considering cities, some variables benefit from sublinear patterns, such as the total amount of infrastructure required to service the population.

- **Network of Urban Infrastructure:**
  - **Urbanization Efficiency:** Urban development material efficiency per analogous units, enabling fruitful social interaction as well as access to services and amenities.
  - **Building Efficiency:** Morphological efficiency, space programming, placemaking, and social interaction.
  - **Urban Street Flow Centrality:** Avg. betweenness centrality per urban unit.
  - **Urban Node Centrality:** Avg. closeness centrality (local and global) per urban unit.
  - **Reach and Gravity:** Accessibility to services and amenities.
  - **Total Street Length Efficiency:** Area_km2 / total_street_length.
  - **Urban Mobility Efficiency:** Avg. City Form Circuity per urban unit.
  - **Street Network Orientation:** Graphic description of street orientation patterns and layout of a given geographic area.

- **Network of Industries:** Data, models, and design that describe and address businesses, collective know-how, and institutions within a given geographic area. Metrics include but are not limited to industry, employment, innovation metrics, and industry sophistication measurements.
  - **Economic Development:** Measurements that describe how wealth is created through innovation, entrepreneurship, and the development of new buildings, facilities, infrastructure, and organizational programs to support such efforts. Innovation measurements, the innovation pipeline, and the network of urban areas contribute to realizing economic development.
  - **Economic Complexity:** A measure of the collective knowledge in a society as expressed in the products it creates. The economic complexity of a country or city is calculated based on the diversity of exports it produces and their ubiquity or the number of the countries able to produce them (and those countries' complexity). Countries that can sustain a diverse range of productive know-how, including sophisticated, unique know-how, produce a wide diversity of goods, including complex products, that few other countries can make.

- **Product Space:** A visualization that depicts the connectedness between export products based on the similarities of the know-how required to produce them. The product space visualizes the paths that countries can take to diversify. Products are linked by their proximity to each other, here based on the probability of co-export of both of the two products. The product space details the connectedness of nearly 775 products and 848 service industries in color-coded sectors, here based on real-world data on the experience of countries' diversification over the past 50 years. We can map a country's location in the product space from its export basket to understand what they are able to make, what products are nearby (at a short distance) that depend on similar know-how to that which currently exists, and to define paths to industrial diversification. The shape of the product space teaches us how diversification works in practice: Countries move from things they know how to do to things that are nearby or related, that is, the adjacent possible knowledge domain or node within a product space network. Products at the periphery require know-how that is less readily redeployed into many new industries.
- **Economic Proximity:** Measures the probability that a country exports product A given that it exports product B or vice versa. Given that a city or country produces one product, proximity captures the ease of obtaining the know-how needed to move into another product. Proximity formalizes the intuitive idea that the ability of a country to produce a product can be revealed by looking at which other products it can produce.
- **Economic Relatedness:** Products are considered related if they are within similar industry codes and have a high degree of proximity.
- **Smart Specialization:** A strategy to combine industrial, educational, and innovation policies to identify and select a limited number of priority areas for knowledge-based investments, focusing on their strengths and comparative advantages.
- **Four Quadrant Analysis:** A statistical analysis of how different industries compare to one another based on their location within the product space and their economic complexity.
- **Revealed Comparative Advantage (RCA):** A group of industries active within the area of analysis that present a high degree of global competitiveness. These industries are generally the greatest contributors to the economy.

• **Access to Urban Amenities:** Measurements to evaluate how easy or difficult it is to access various urban amenities from offices (weighted by employees) or from residents (weighted by population). Distance is measured by willingness to walk standards, which vary based on the type of amenity and local urban conditions. Amenities are gathered from GIS datasets or websites that describe the amenities of a given region.
  - **Education Amenities per km^2:** Universities, colleges, high schools, kindergartens, preschool, tutoring, and research centers.
  - **Mobility and Public Transit per km^2:** Bus stops, above ground metro, underground metro, train, tramway, commuter rail, scooter stations, bike sharing, taxi stands, and so forth.
  - **Healthcare Amenities per km^2:** Hospitals, clinics, urgent care, clinics and medical offices, nursing homes, mental health, and addiction treatment centers.
  - **Sustenance Amenities per km^2:** Restaurants, cafeterias, bars, grocery stores, and convenience stores.
  - **Entertainment Amenities per km^2:** Movie theaters, concert halls, general theaters, amusement parks, and libraries.

• **Network of Talent:** Data, models, and design that describe and address individuals and groups of people working and living within a given geographic area. Metrics include but are not limited to demographics, employment, job tasks and activities, and innovation KPIs.
  - **Innovation Metrics:** A set of metrics that describe measurable innovation activities in a given geographic area.
  - **Innovation Intensity:** The ratio of innovative jobs to regular or service jobs. Based on Aretian's proprietary tagging of industry codes.

- **Innovation Performance:** Total output from innovation activities, including the number of patents, papers, and publications as well as total sales and revenue from such activities.
- **Innovation Impact:** An imputed metric to predict the projected impact that innovation activities will have in a given geographic area. For every innovative job, there are approximately five regular service jobs created.
- **Knowledge Economy:** A system of consumption and production that is based on intellectual capital. Specifically, it refers to the ability to capitalize on scientific discoveries and applied research. The knowledge economy represents a large share of the activity in most highly developed economies.

- **Scale-Free Networks**: A scale-free network is a network whose node degree distribution follows a power law (Pareto) distribution. In a city science context, a scale-free network is frequently associated with highly self-similar or fractal morphological layouts. Scale-free networks present a number of inherent properties that make them particularly interesting and attractive, provided that they combine a highly connected distributed or egalitarian network with nested hierarchies of nodes that often outcompete other network archetypes in terms of overall performance and efficiency.

- **Lognormal (Poisson) Networks**: The most prevalent network structures in urban design and organizational life are Poisson-based lognormal networks, which, in a city science context, are often associated with organic growth patterns. Lognormal networks are often associated with mediocre degrees of urban efficiency and overall performance.

Background: A Global Urban Development Challenge

Urban and economic development leaders face common challenges that require an interdisciplinary approach and the integration of a wide range of criteria. These encompass areas such as urban design criteria, activity programming and zoning, infrastructure investment prioritization, housing development plans, economic development strategies, talent development support and innovation ecosystem nurturing, and educational and healthcare amenity supply.

However, there is often a lack of the right tools and organized information needed to reduce the inherent risks of urban and regional planning decision-making. Evidence-based, data-driven territorial analyses are vital because they can reveal complex problems and causal relationships while informing best practice solutions.

This report presents a comparative analysis of Amsterdam, Barcelona, Boston, Munich, and Stockholm across five dimensions of urban and economic development strategies, here through the lens of city science. The report focuses on identifying urban and economic development strategies through a city science-led analysis of urban models based on both quantitative and qualitative indicators.

The goal was twofold: first, to perform urban diagnostics on evidence-based city digital twin models of Amsterdam, Barcelona, Boston, Munich, and Stockholm and, second, to identify best practices to inform policymaking strategies for conceiving an urban design and economic development vision for the Barcelona metropolitan region. The following five areas were analyzed: 1) urban design patterns, 2) economic development strategies, 3) innovation ecosystems building, 4) housing and standards of living, and 5) mobility and logistics.

IESE Business School leads academic research studies around public–private partnerships to solve complex urban problems. The leadership team at IESE identified a series of core urban challenges and assumptions based on the extensive academic and professional expertise of the team, aiming to support decision-making processes.

Recent advances in the area of city science modeling led by the Aretian team at Harvard University have shed light on the complex systems relationship between urban development patterns (scale and density, topology, morphology, entropy, fractality, urban design patterns, and typologies) and the impact on urban performance, including metropolitan-scale urban and economic development challenges such as city design, sustainable development, activity programming, knowledge economy ecosystems, smart specialization, urban mobility and logistics, and the quality of life of citizens.

These advances enable researchers to (1) quantitatively and qualitatively describe urban development patterns, (2) measure success of urban development projects by means of globally benchmarkable KPIs, (3) understand causal mechanisms and relationships, (4) provide global benchmarks to compare and contrast different cities and urban areas, and (5) apply the predictive power to dramatically reduce uncertainty and identify best practices and data-driven insights and recommendations informing high quality and successful urban and economic development projects.

The selection of the five metropolitan areas analyzed in this report was made in the early stages of the project and was based upon mutual agreement between IESE and Aretian. The aim was to analyze metropolitan areas that present both analogous traits and diverse experiences in shaping metropolitan systems.

Project Purpose and Goals

Using the Aretian method, the team developed a comprehensive city science model for the selected global cities, including the Barcelona area. The software deployed to generate the digital models of the respective cities as well as the data science analyses and visualizations is the Aretian City Analytics Engine is a proprietary solution created by the Aretian Urban Analytics and Design team based out of the Harvard Innovation Lab.

The project comprised two dimensions, as follows:

- An Overview Analysis (metropolitan area diagnostics) of the selected metro regions in three areas:
  - **Network of Talent**: Analyzed the demographic base, labor force, education, knowledge economy, and the Seven Phases of the Innovation Pipeline and networks linking applied research, technology transfer, and innovative companies and startups.
  - **Network of Industries**: Analyzed the collective know-how and industry-specific strengths and weaknesses of the selected metropolitan areas.
  - **Network of Urban Design**: Assessed urban form, building location, and space programming needs and opportunities, including the access to urban amenities and services. Developed a placemaking strategy for increasing the quality of life of citizens, which included an analysis of public and private space placemaking to increase social interactivity and creating new connections with the broader metropolitan area.

- Metropolitan Area Diagnostics and Generalizable Recommendations in the five specific areas targeted for analysis:
  - **Envisioning a Sustainable Urban Design Strategy**: Diagnostics and strategic city design, sustainable development, and zoning recommendations.
  - **Nurturing Urban Economics and Prosperity**: Smart specialization strategies and policymaking recommendations. The smart specialization strategies involve deep analyses of industrial sectors, their product and service sophistication and diversification, and the identification of the most promising economic sectors to target in the coming years, here based on current collective know-how.
  - **Propelling Research and Innovation Ecosystems**: Knowledge economy strategy to propel a prosperous society, which involves the harmonic integration of civil infrastructure and architectural space activity programming and zoning, to shape a balanced equilibrium between applied research, innovation centers, startup incubators, innovative firm centers, and industry verticals. The mutual reinforcement of the three main phases of innovation and the internal subdivision of the seven steps of innovation are key factors that were taken into account.
  - **Providing Quality Housing and Standard of Living**: Recommendations to address urban services and amenities in relation to residential allocation.
  - **Shaping a Sustainable Mobility and Logistics Strategy**: Generalizable urban mobility and logistics diagnostics and recommendations to raise the quality of multimodal sustainable mobility. Logistics studies take into account intermodal logistics needs and strategies to form a successful intermodal freight transportation and urban metropolis ecosystem.

Complex Systems Approach and Public–Private Partnership (PPP) Strategies

The core metropolitan area challenges and corresponding questions addressed were as follows:

Metropolitan Area Challenge	City Science Analysis
Envisioning Sustainable Urban Development	How can we diagnose the quality of the built environment of a given metropolitan area? How can we measure urban design strengths and weaknesses, risks, and opportunities? What types of city development interventions and urban design patterns would benefit the broader metropolitan area? What are the desirable density ranges, urban topology patterns, urban morphology visions, fractality, and entropy? How can PPP urban development projects facilitate the success of ambitious city development projects?
Nurturing Urban Economics and Prosperity	How can evidence-based analyses identify high value-added industries, presenting a local comparative advantage to shape metropolitan area-specific smart specialization strategies? High value-added industries may include sectors such as biotechnology, life sciences, tech/data science and software, scale-up central offices, headquarters for high-tech manufacturing sectors, professional services, and boutique consulting, among others. Can we envision economic development strategies for the short, mid, and long term?
Propelling Metropolitan Innovation Ecosystems	How can we measure, track, and evaluate the knowledge economy ecosystem? How can city science–driven analyses inform accurate and precise innovation ecosystem development strategies? How can PPP urban development projects contribute to igniting the knowledge economy?
Providing Quality Housing and Standard of Living	How can we measure, track, and predict the future residential space demand for each city within the metropolitan area? How can city science–driven analyses inform accurate and precise resource allocation for such types of housing and amenity developments? How can activity programming increase the quality of life of residential and mixed used development areas by using the 15-minute city concept?
Shaping a Sustainable Mobility and Logistics Strategy	What do city science-infused urban mobility and logistics analysis reveal? How can we identify deficiencies in the urban mobility network? How can we increase the sustainable mobility modal split share across the board for a given metropolitan area? How can PPP solutions raise the quality of urban mobility and logistics services?

Challenge 1: Envisioning Sustainable Urban Development Summary

Challenge and Analytical Rationale

The city science-led evaluation of the relationship between urban design (topology, morphology, entropy, density, fractality metrics) and urban performance KPIs provided a critical view of the main urban typologies for neighborhoods in Amsterdam, Barcelona, Boston, Munich, and Stockholm. By measuring the impact of urban form on citizens' quality of life, it was possible to identify urban development best practices for potential implementation in the Barcelona metropolitan region in the future. These practices relate to city development patterns, activity programming, zoning, and urban design best practices.

Results and Insights

The evidence-based evaluation of city form metrics and urban performance provided the following insights:

- City form fractality is the most salient and analytically informative urban design feature when it comes to predicting urbanization efficiency, high-quality social interaction, knowledge economy multiplying effects, and access to services. When doubling city form fractality, a 32% super linear increase in urbanization efficiency and social interaction super linearity occurs.
- The overall ranking in urbanization efficiency was found to be (in order):
    1. Stockholm
    2. Barcelona
    3. Boston
    4. Amsterdam
    5. Munich
- Urban density presents a positive, nonlinear relationship with urban performance (19% increase when doubling density) but is constrained by physical limits. Optimal or desirable density and population growth patterns can be informed based on population and available area.
- A self-similar growth pattern allows for substantially raising a geospatial distribution of services and amenities while using fewer material resources (76% by doubling urban design fractality).
- City planning patterns embedding intermediate (approximately around 50%) urban form entropy values achieve the maximum/optimal degrees of urbanization efficiency.
- An urban design strategy creating nested hierarchies of innovation ecosystems promotes best practices in propelling the knowledge economy by harmoniously integrating highly sophisticated economic activities with space design and programming.

Goals and Recommendations

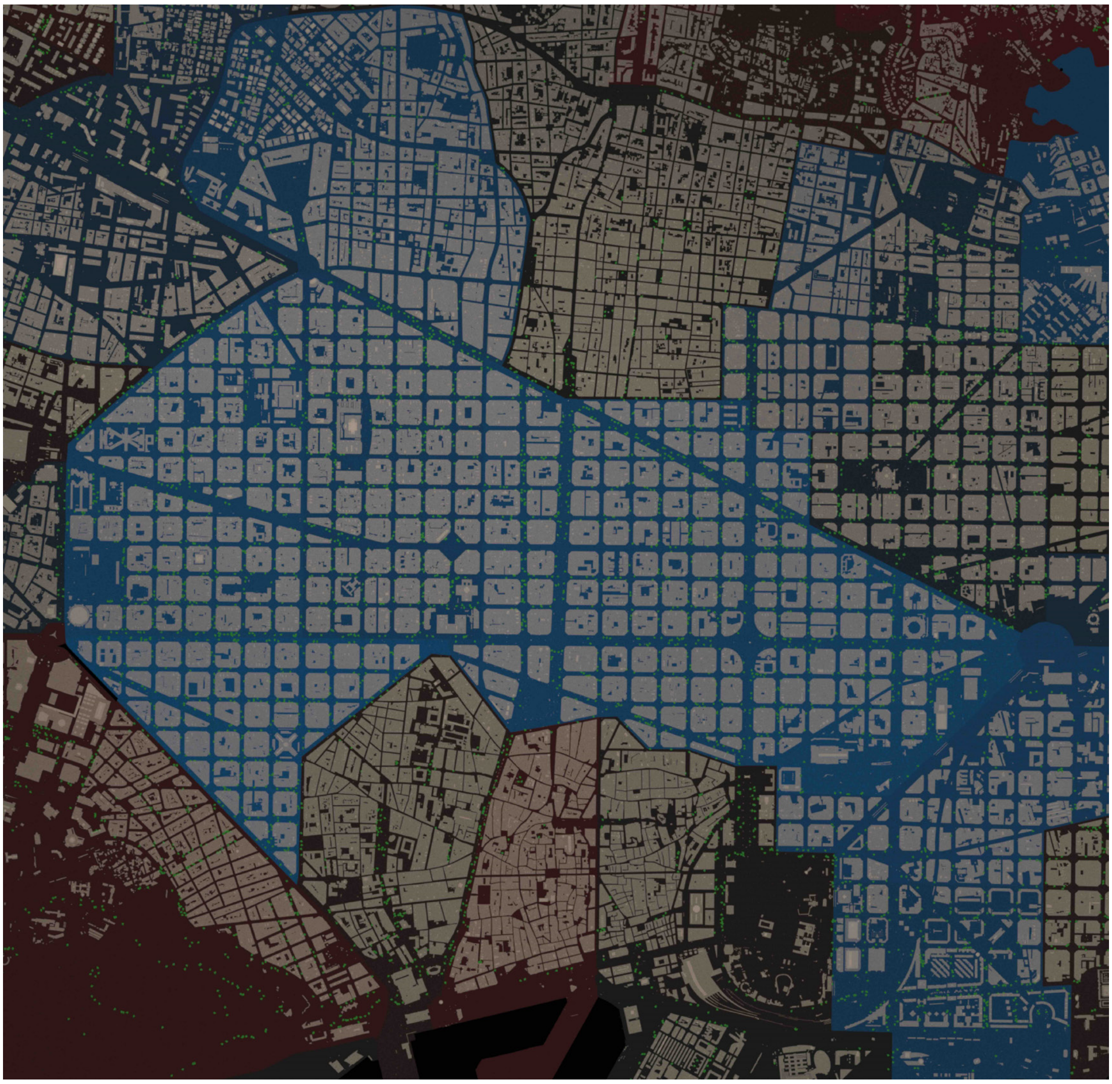
- Conceive an Urban Design Vision: Apply a fractal metropolis urban design vision for the Barcelona metropolitan region composed of self-similar morphological patterns and nested hierarchies of network edges (streets, roads, boulevards) and nodes (architectural spaces), aiming to reach an average city form fractality of 75% and raising urbanization efficiency up to >80%.

- Density: Envision a geospatial growth pattern tailored for each of the 160 municipalities of the metropolitan area, aiming to accommodate 676,000 citizens and 475,000 dwellings by following sustainable growth patterns and informing smart allocation of new residential areas. Currently, 51 municipalities exceed their optimal density, and 109 present substandard values.

- Activity Programming and Zoning: Establish a zoning and programming strategy following a scale-free geospatial distribution, with amenities of order 1 located in tier 1 areas so forth: the more sophisticated and complex the activity, the more concentrated.

- Entropy: Embed intermediate urban entropy values, between 45% and 55%, in all new urban developments and resource allocation strategies.

- Urbanism Propelling Prosperity and the Knowledge Economy: Chiseling a network of innovation districts, strategically located, near the top research centers, hosting the physical spaces providing support to raise knowledge employment from 125,000 up to 200,000 in the coming years.



Challenge 2: Economic Development Summary

Challenge and Analytical Rationale

The level of industry sophistication and diversification of each of the five cities was determined through an economic complexity-led evaluation of service industry codes (North American Industry Classification System or NAICS codes) and export-oriented product codes (Harmonized System or HS codes). Also identified were the optimal smart specialization strategies pursued by each metropolitan area based on current capabilities and collective know-how.

Results and Insights

- A combination of a highly diversified economy (PDI, resilience, adaptability) and sophisticated/complex (PCI) products and services creates the optimal combination to achieve global competitiveness (RCA) and increase exports, well-remunerated employment, and prosperity.

- The results of the economic complexity analysis allow for classifying any industry within a city across density, complexity, revenue, and RCA, hence tailoring recommendations for each sector and city.

- The overall economic complexity ranking was found to be (in order):
  1. Munich
  2. Boston
  3. Stockholm
  4. Amsterdam
  5. Barcelona

  Challenges such as geospatial dispersion of industries across multiple industrial clusters, short value chains (low PDI), feeble critical mass (low revenue), and excessive reliance on low value-added services (such as tourism, accommodation, low PCI) and manufacturing sectors weaken the overall competitiveness of Barcelona's economic base.

- The four quadrant analysis of industry sectors classified sectors into high performing (Q1), traditional and stagnant (Q2), emerging industries (Q3), and at-risk sectors (Q4), informing priorities tailored for each knowledge domain and activity.

- Barcelona can extract lessons from long-term investment in high value-added manufacturing industries from Munich as well as high-tech sectors in the Boston area.

Goals and Recommendations

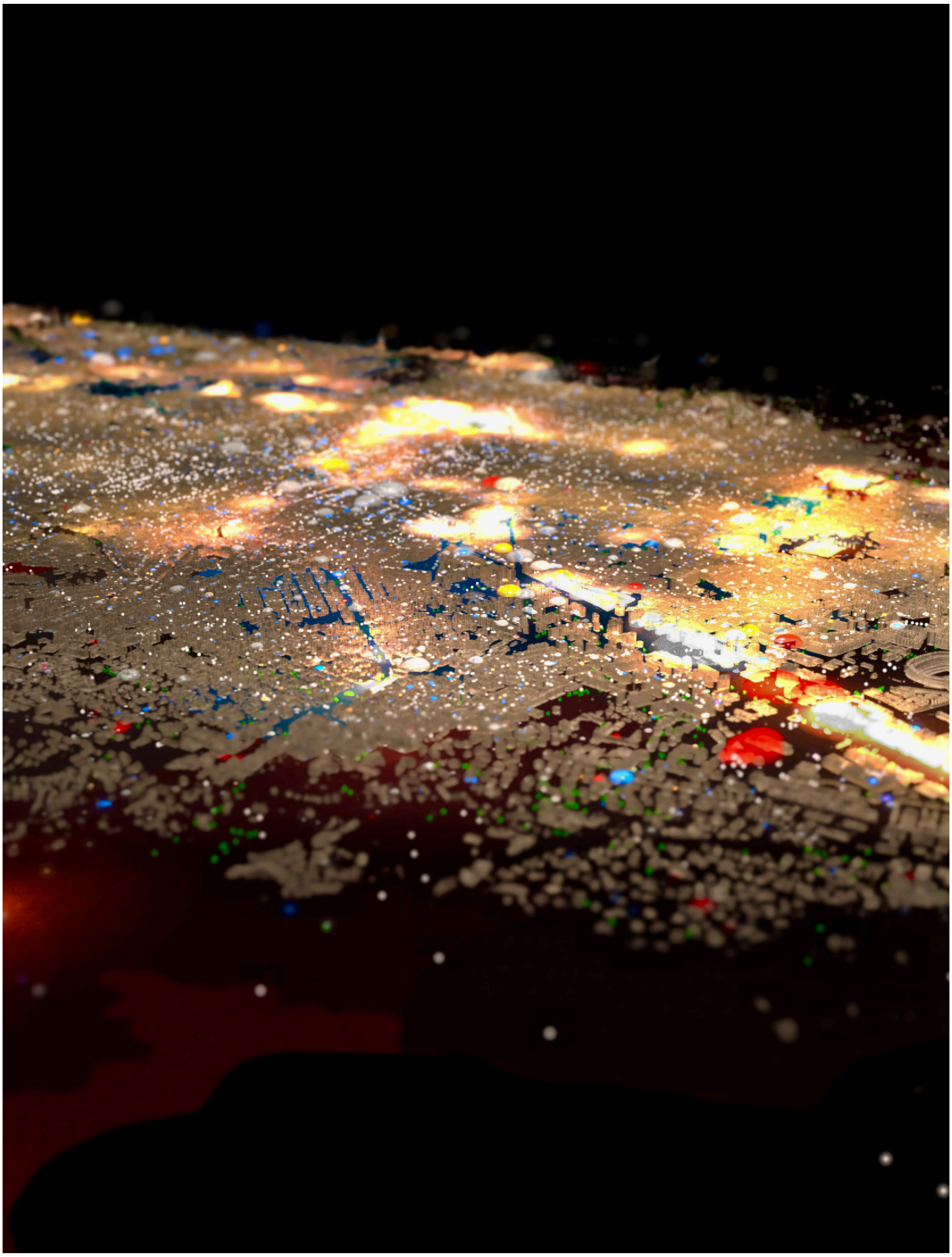
- Economic Development Strategy: Raise the NAICS industry diversity and sophistication in Barcelona from 321 industries (92 innovative) up to 670 (170 innovative), and manufacturing industries from 89 (39 innovative) up to 119 (45 innovative). Strategy: geospatial concentration by sector (pharmaceuticals, automobile, high-tech, precision instruments, machinery) by 2040.

- Economies of Scale: Increase the total annual city Revenue from €125.823M up to ≅€190.000M by 2040 and the innovation-related revenue from €29.882M up to ≅€60.000M. Strategy: Pursue geographic concentration of closely related sectors in clusters, particularly spread around the five industrial areas in the Besòs riverbed (Bon Pastor, Torrent de l'Estadella, Montsolís, La Verneda, Verneda Industrial) next to the upcoming Sagrera intermodal station.

- Economies of Scope: Increase the number of high-density industries from 255 out of 477 up to ≅350, by means of vertical integration processes, and facilitating the establishment of longer value chains (multiple companies contributing to a final product within physical proximity, retaining IP core).

- Industrial Innovation Strategy: To increase the number and knowledge-intensive sectors and focus on raising tech transfer across the Q1, Q2, and Q3 sectors, hence boosting PCI values.

- Smart Specialization Strategy: Place emphasis on newly potential Quadrant 1 industries, raising the number of industries with a global revealed comparative advantage (RCA) from 255 up to ≅360 industries (out of 775) by 2040 by reinforcing the product sophistication of sectors presenting preexisting knowledge.



Challenge 3: Innovation and Talent Summary

Challenge and Analytical Rationale

The geospatial analysis of knowledge-intensive activities based on innovation phase (research, tech transfer, advanced production) across the five cities, paired with an analysis of the seven phases of innovation in the Barcelona area, reveals best practices for creating a dynamic innovation ecosystem. This ecosystem can generate quality employment opportunities, liberate the latent talent of citizens, generate prosperity, and raise the standards of living.

Results and Insights

- Innovation KPIs: The geospatial concentration of knowledge economy employment—paired with a knowledge exchange among academia, startups, and innovative firms—can generate multiplying effects of scale-free innovation network concentration.

- The overall innovation ecosystem ranking is (in order) as follows:
    1. Boston
    2. Stockholm
    3. Amsterdam
    4. Munich
    5. Barcelona

- The Boston area presents examples of the best practices of fostering a knowledge economy by integrating highly sophisticated innovation ecosystems with urban design strategies.

- Successful Innovation Ecosystems: The Boston area presents a series of high-quality examples of successful innovation districts, including Kendall Square, Longwood, Seaport, and Harvard.

- Innovative Sectors: Physical atomization and lack of proper tech transfer platforms across innovation phases prevent from establishing a creative tension between university and industry.

- Research Networks: The analysis of the three innovation phases across cities and districts and seven steps of innovation in Barcelona, revealing that there are numerous applied research domains presenting attractive opportunities for knowledge transfer.

- Multiplying Effects: Only 279 out of 1,902 Barcelona startups are knowledge intensive.

Goals and Recommendations

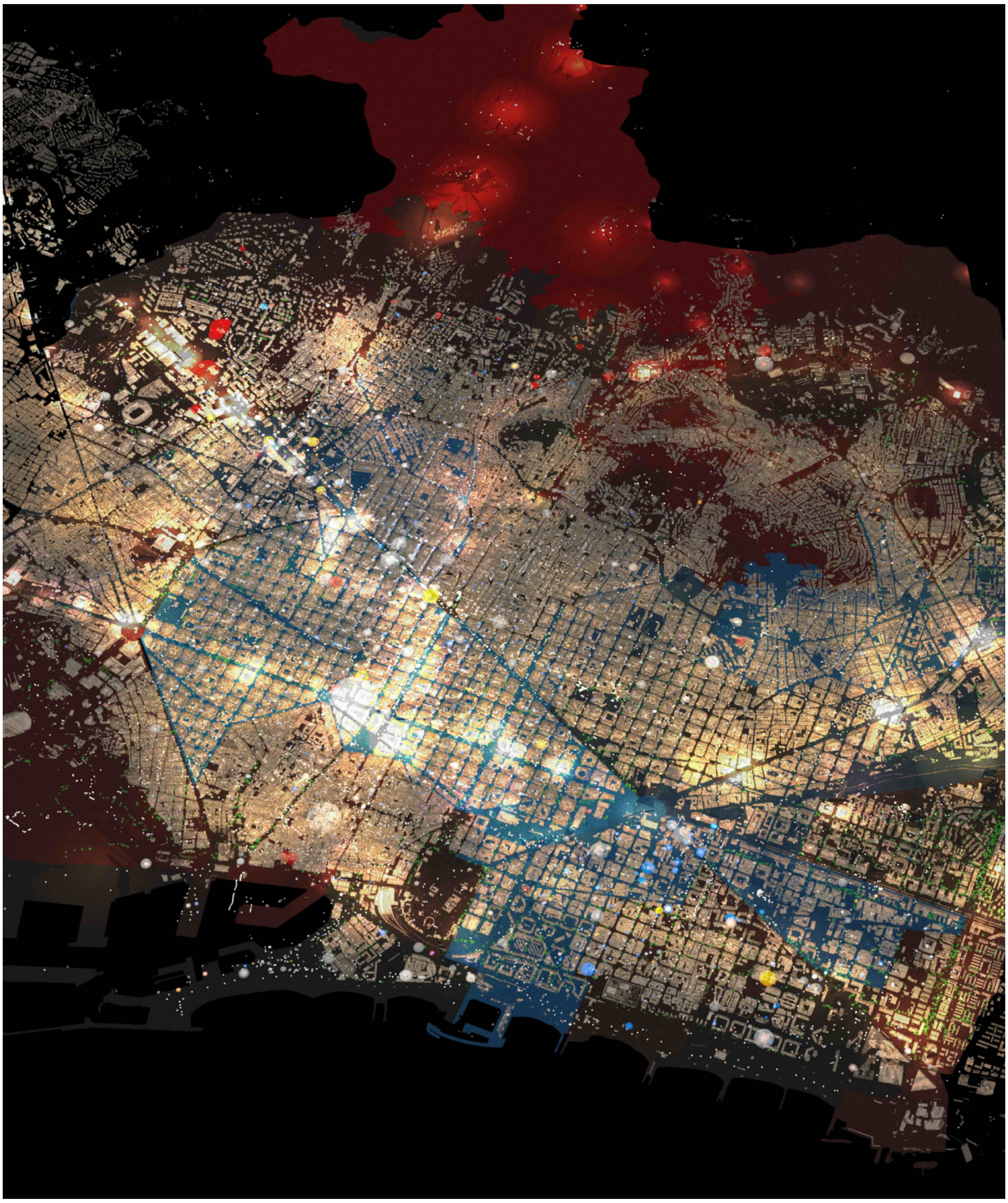
- World-Class Innovation Ecosystem: Raising the number of knowledge-intensive jobs from 125,000 up to 200,000 (hence, increasing innovation intensity from 15% up to 20%) between 2024 and 2040 by concentrating knowledge advancement hubs in strategic locations.

- Innovation Pipeline and KPIs: Strengthen the three phases of innovation (research, tech transfer, advanced production) to increase innovation intensity, performance, and impact KPIs to raise revenue/employee from €149,179 up to ≅€200,000 and revenue/resident from €77,818 up to ≅€110,000 by 2040 by means of providing support across the seven steps of innovation.

- A Thriving Network of Innovation Districts: Strategically located in the Esplugues- Alta diagonal (109 Ha, potentially 23,000 new employees), Barcelona-Besòs (140 Ha, potentially 24,000 new employees), Badalona i les Tres Xemeneies (190 Ha, potentially 27,500 new employees), and innovation intensity ranging from 40% up to upwards of 60%, hosting dedicated applied research areas, innovation centers, startups incubators, coworking, and industry liaison.

- Applied Research Knowledge Transfer Focus: Define a vision to align the roughly ≅1,500 applied research fields across all universities and research centers with the 98 innovative sectors (four in research, 17 in tech transfer, 77 in production) to densify mutual knowledge exchange and technology advancement and realize the multiplying effects of innovation (potentially 4x more innovations per capita, 15x more knowledge employment, and x25 more revenue per resident).

- Focus on Technology Industries with a Global Comparative Advantage: Emphasize aligning traditional sectors with cutting-edge research and development. With respect to the startup scene, aim to increase the number of R&D-driven startups from 279 out of 1,902 up to more than 750 by 2040.



Challenge 4: Providing Quality Housing and Standard of Living Summary

Challenge and Analytical Rationale

The quality of citizens' life—as defined by 15-minute city accessibility to amenity standards—was determined through a geospatial analysis of the relationship between residential dwellings and urban services and amenities. By evaluating the current urban infrastructure network, in terms of residential capacity and access to services by type, growth strategies can be designed that satisfy the unmet housing demand. These strategies should be informed by best practices in terms of the strategic location of new housing across the Barcelona metropolitan region, mixed-use development, and activity programming in alignment with 15-minute city criteria.

Results and Insights

- Housing: Based on the optimal population density and morphological best practices, the ideal or target distribution of 475,000 new residential dwellings was conceived of. This vision takes into account the current territorial model as well as the impracticality of attaining the ideal distribution pattern of new residential units across the metropolitan region, here given inherited deficiencies (51 municipalities already present much higher density than the optimal).

- 15-Minute City Standards: High-quality 15-minute city standards can be derived from evaluating multiple cities across the board. The amenity ranking is (in order) the following, although none of the cities meets the standards:
    1. Barcelona
    2. Stockholm
    3. Amsterdam
    4. Boston
    5. Munich

- Amenity Distribution: Barcelona remarkably outperforms any other city in terms of sustenance amenities per km^2 (53,61, exceeding desirable 50) as well as in healthcare centers per km^2 but falls short on entertainment (1.14<1.5) and education (1.68<3).

- Metropolitan Area Distribution of Amenities: There is a relatively balanced distribution of healthcare centers, yet the education and cultural amenities fall short of satisfying 15-minute city standards in the overwhelming majority of areas.

- Regional Distribution of Amenities: There is a relatively balanced distribution of healthcare centers, yet the education and cultural amenities fall short of satisfying the 15-minute city standards in the overwhelming majority of areas.

Goals and Recommendations

- Residential Dwellings: Proposed distribution of 475,000 new residential dwellings across the 160 municipalities of the metropolitan region based on an integrated model combining inherited rigidness and design optimization.
  - Barcelona: Accommodate ≅77,000 new dwellings by 2040 and up to 126,000 by 2050 for a total of 190,000 new citizens between 2024 and 2050.
  - Limit growth in overcrowded cities: L'Hospitalet, Santa Coloma, Badia del Vallès, and so forth.
  - Increase housing and services: Terrassa and Sant Cugat del Vallès, among others.

- 15-Minute City Standards: Nested hierarchies of education and healthcare amenities.

- Amenity Distribution: Raise the geospatial presence of education and entertainment amenities, particularly in nontourist areas within the city, increasing from a total of 68.32 up to 80 per km^2.

- Metropolitan Area Distribution of Amenities: Opportunity to raise citizens' living standards by balancing out the traditional macrocephaly of Barcelona and increase amenities from 9,067 up to ≅15,000 by 2040.

- Regional Distribution of Amenities: Opportunity to raise the standards of living of citizens by balancing out the traditional macrocephaly of Barcelona and increase amenities from 12,233 up to ≅20,000 by 2040.

Challenge 5: Shaping a Sustainable Mobility and Logistics Strategy Summary

Challenge and Analytical Rationale

To assess how public transit and urban form/walkability systems contribute to attain sustainable mobility goals, network theory–led urban mobility analysis was deployed. Concepts such as reach, gravity, catchment area, mobility betweenness, and service area were applied to assess coverage across the five cities. The evaluation of the urban infrastructure networks helped discern the critical needs, ingredients, and dynamics required to shape a successful, efficient, sustainable, and affordable intermodal mobility and logistics network.

Results and Insights

- Sustainable Mobility Assessment: The sustainable transport index ranking for internal flows is as follows:
    1. Amsterdam and Barcelona (74%)
    2. Stockholm (68%)
    3. Munich (63.5%)
    4. Boston (51%)

- Urban Mobility Infrastructure: The Barcelona area presents overall better coverage because of medium–high-density levels, relatively high city form fractality, and an overall rational distribution of stations. The geospatial analysis of reach and gravity for intermodal mobility systems with willingness to walk considerations (300 m for bus, 450 m for taxi, 600 m for tramway, 800 m for rail, and 1000 m for metro) reveals public transit coverage gradients and accessibility.

- Metropolitan Systems Integration: The Barcelona metropolitan area is underserved in terms of the integration of mobility systems, and network science insights illuminate the most critical deficiencies.

- Metropolitan Region Integration: The metropolitan region is severely underserved in terms of the integration of public transit, and evidence-based insights can help inform investment and management.

- Intermodal Logistics: Using geospatial data imputation mechanisms, it is possible to accurately estimate the supply chain management needs of a given city. Currently, there is an over reliance on automobile-driven physical exports. Given that 67% of cargo is mid-range, for continental Europe destinations, we can estimate that approximately 47% of Barcelona province's exports by truck could be migrated to freight rail systems, hence contributing to sustainable logistics goals.

Goals and Recommendations

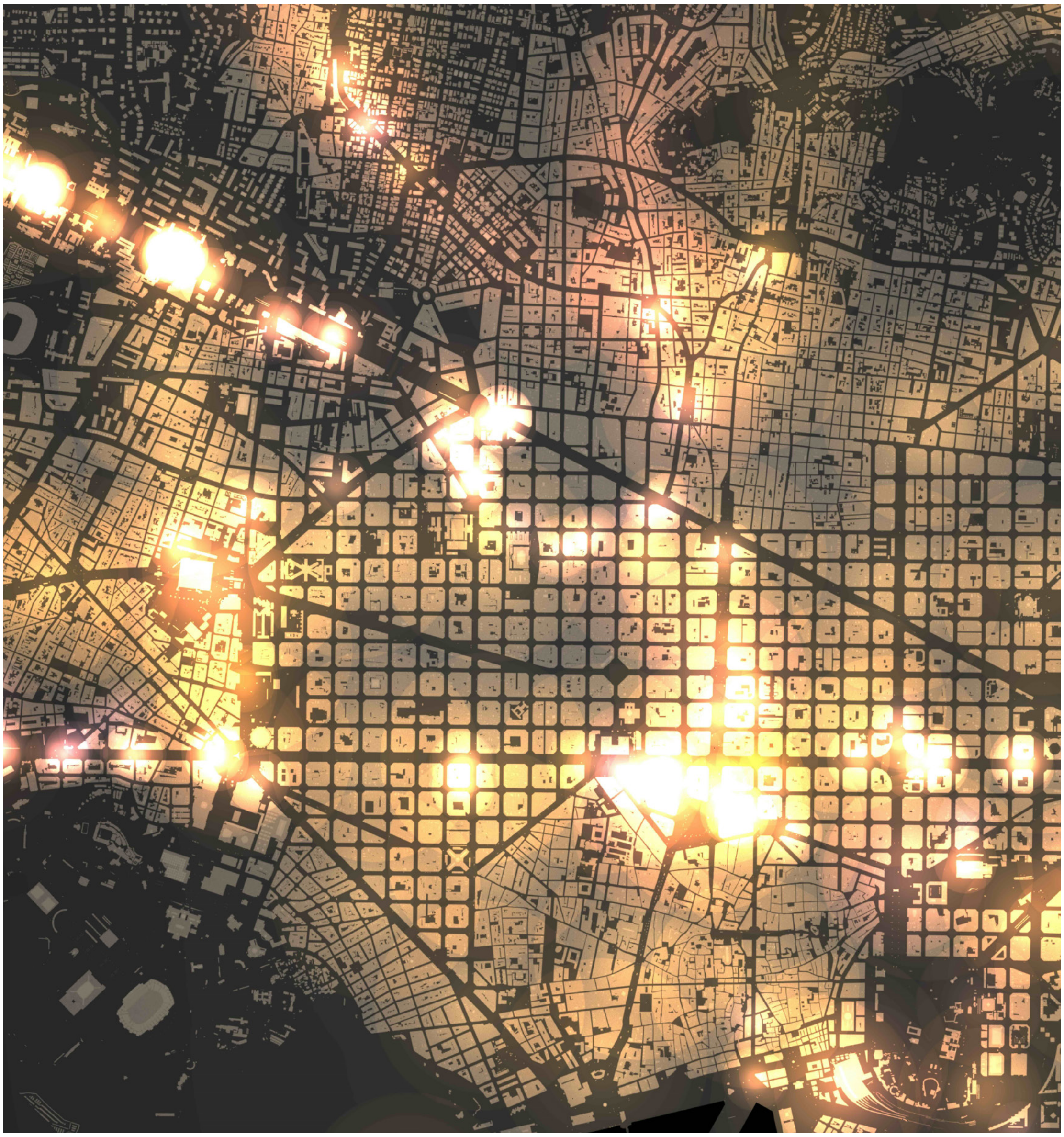
- Sustainable Mobility Ratio: Increase the sustainable mobility ratio (public transit, pedestrians, and individual mobility devices) from 74% up to 80% by 2040 by means of infrastructure deployment, data science modeling of services and asset management, and investment prioritization.

- Urban Mobility Infrastructure: The overall mobility infrastructure network of Barcelona meets relatively high standards, even though there is a lack of a proper metropolitan area and region systems integration.

- Metropolitan Area Systems Integration: Increasing the average mobility nodes per km^2 across the 36 municipalities of the metropolitan area from 26,64 up to at least 30, with a particular emphasis on tramway and underground/metro expansion as well as metropolitan bus routes.

- Metropolitan Region Systems Integration: Expansion of routes within the metro region.

- Intermodal Logistics: Deployment of cargo infrastructure, logistics, and operations strategies to migrate 47% of automobile-driven freight to continental Europe to rail systems (Corredor del Mediterrani), accounting for approximately €77.74B and Tm19.27M per annum.



Challenge 1:

Envisioning a Sustainable Urban Design Strategy

Challenge 1: Envisioning a Sustainable Urban Design Strategy

Evaluating City Form and Activity Programming Features and Patterns

"Earth has not any thing to show more fair:
Dull would he be of soul who could pass by
A sight so touching in its majesty:
This City now doth, like a garment, wear
The beauty of the morning; silent, bare,
Ships, towers, domes, theatres, and temples lie
Open unto the fields, and to the sky;
All bright and glittering in the smokeless air.
Never did sun more beautifully steep
In his first splendour, valley, rock, or hill;
Ne'er saw I, never felt, a calm so deep!
The river glideth at his own sweet will:
Dear God! the very houses seem asleep;
And all that mighty heart is lying still!"

William Wordsworth

Composed upon Westminster Bridge

In an evocative poem of great beauty, the celebrated English poet William Wordsworth condensed the deep impression caused when contemplating the city of London. "Composed upon Westminster Bridge" eloquently summarizes the state of awe experienced by the sight of a vibrant urbs, subtly implying the beauty, genius, and sophistication embedded in the collective and gargantuan effort required to envision, design, build, and contribute to set in motion a thriving urban environment. In fact, what the illustrious lyrist proposes is that cities may very well be the most sophisticated and revolutionary of all human creations.

The urban planners of the twenty-first century face a daunting task: updating the science of cities to offer viable solutions to the challenges posed by the increasing population concentration in metropolitan areas, an issue observed as a byproduct of an unprecedented worldwide demographic explosion paired with rapid technological progress. In 2015 and 2016, the United Nations General Assembly published a series of reports emphasizing that 55% of the world's population and 70% of global Gross domestic product (GDP) was concentrated in cities, and by 2050, these figures were expected to reach 70% and 85%, respectively. Cities also accounted for more than 60% of global energy consumption, 70% of greenhouse gas emissions, and nearly 70% of the waste generated on a global scale.

At the same time, cities around the world have greater income inequality and per capita crime rates than rural areas with low population density. The New Urban Agenda (2016) aimed to inform a series of Sustainable Development Goals (SDGs) for 2030, such as promoting sustainable growth patterns, generating prosperity and employment opportunities, guaranteeing universal access to quality urban services, and addressing the climate and environmental issues that confront us. Cities are the greatest battlefield in the struggle to reach the SDGs, but they also represent our greatest hope of achieving them.

Urban development leaders constantly face a myriad of decision-making processes and questions whose answers are critical for shaping urban life. How does urban design impact the social dynamics of citizens and the quality of life in a given city? What type of urban growth pattern should be pursued by urban designers in each context? What are the desirable population density ranges in each context? What should be the space programming, zoning, and resource allocation guidelines to create a balanced community that is able to satisfy the essential needs of its citizens? How can evidence-based and network science analyses help achieve sustainable urban development goals while contributing to an efficient intermodal mobility system? What are the implications of different economic development strategies? How can we combine city planning and economic development strategies to propel the knowledge economy and create sustained cycles of prosperity?

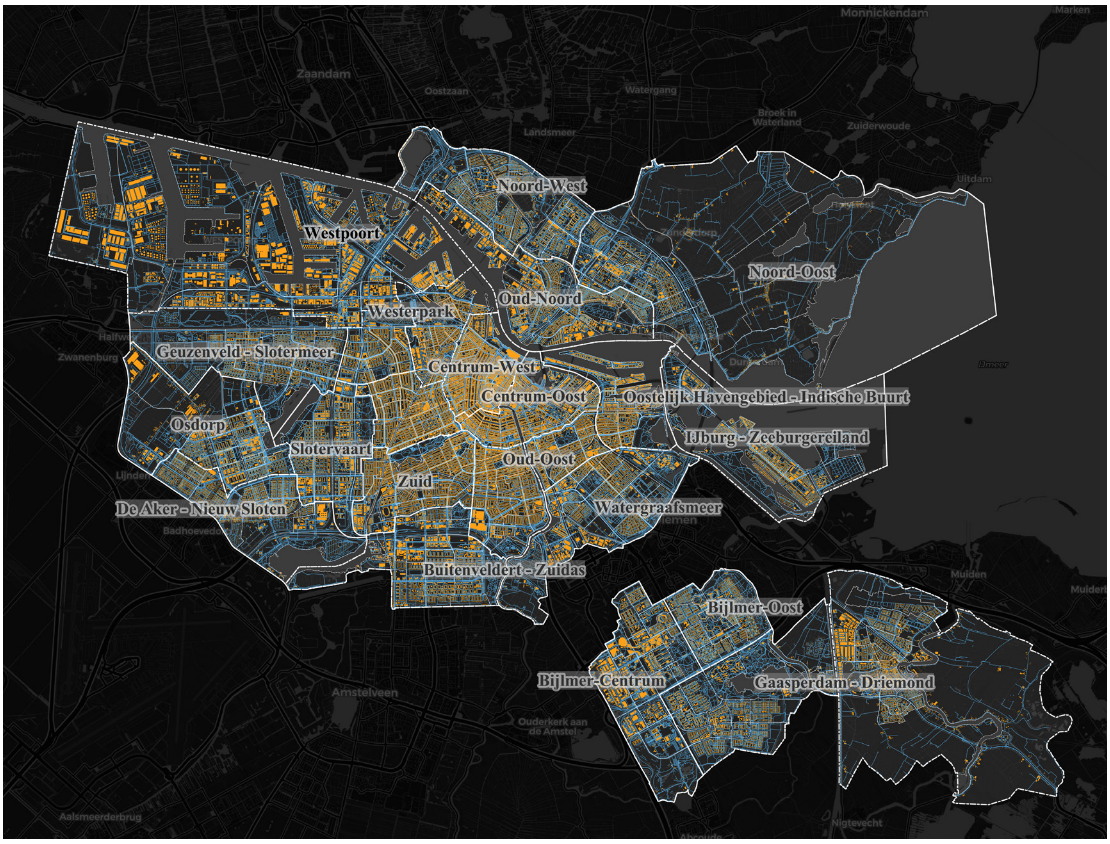
A systematic, evidence-based city science approach to urban challenges can help us model cities in a three-dimensional, multilayered manner. Urban Science methods can also define key performance indicators (KPIs) to estimate the degree of success of a particular policy; ascertain the dynamics that define the unique properties of a municipality or neighborhood; compare and contrast the implications of a variety of urban and economic development strategies across a wide array of cities and urban environments; and highlight complex systems patterns that can be traced back to their root causes. Finally, city science approaches can deduce the universal causal mechanisms between human decisions and their social impact while extracting generalizable best practices that can be combined with design and policymaking principles to be applied to a particular city, context, and moment.

Aretian Urban Analytics and Design worked with IESE Business School to lead a collaborative project that aimed to raise the methodological standards and level of understanding of five cities and their metropolitan areas—Amsterdam, Barcelona, Boston, Munich, and Stockholm—as a way to help inform their urban and economic development decision-making policies. Novel urban analysis techniques, tools, and visualizations of data sets and KPIs developed in recent years at the Harvard Innovation Lab were deployed to extract valuable insights, identify the utmost germane SDGs for the upcoming years, and inform the decision-making strategies to be addressed by Barcelona and its area in the near future, in the context of the urban innovation initiative proposed by the IESE PPP for Cities Center: “A Vision for Barcelona’s Future.”

Urban Development Challenges Facing the Selected Global Cities

Amsterdam

Figure 1. Districts and Neighborhoods (Amsterdam)

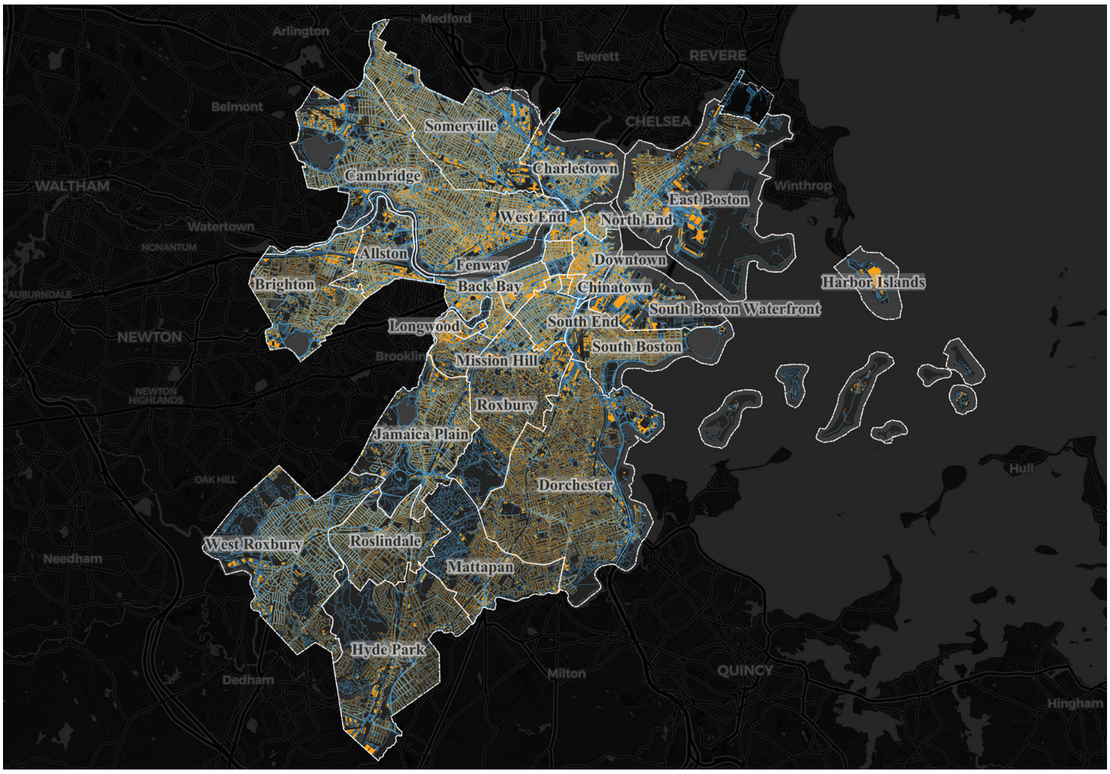


With a population of 921,400 citizens and a metropolitan area composed of 36 municipalities and encompassing 2.52M citizens, Amsterdam is the capital of the Netherlands. The city government identified a series of pressing challenges in a report issued in 2021. These included 1) the need to accommodate 250,000 new residents in mixed-use neighborhoods; 2) counterbalancing the inherited macrocephaly of Amsterdam's city core with a more distributed urban design layout across the city and the broader metropolitan area; 3) more equally distributing employment opportunities across the metropolitan region; 4) facilitating equal access to public transit and mobility services across districts and cities; and 5) promoting a healthy lifestyle in an increasingly sedentary society. The council adopted the *Comprehensive Vision Amsterdam 2050: A Humane Metropolis* on July 8, 2021, replacing *Structuurvisie Amsterdam 2040.* The 2050 Comprehensive Vision is structured around the following principles:

- polycentric urban growth patterns within city limits
- densification of urban core areas
- the construction of 150,000 new dwellings with over 50% of social and affordable housing
- the creation of 200,000 new strategically distributed jobs
- the expansion of high-quality public transport and the metro network
- the development of station districts
- implementing a public transit–led mobility system as opposed to an automobile-centric model
- the reduction of unnecessary daily commutes and rush hour congestion by geospatially distributing the different services and amenities in a more distributed manner

Boston

Figure 2. Districts and Neighborhoods (Boston, Cambridge, Somerville)

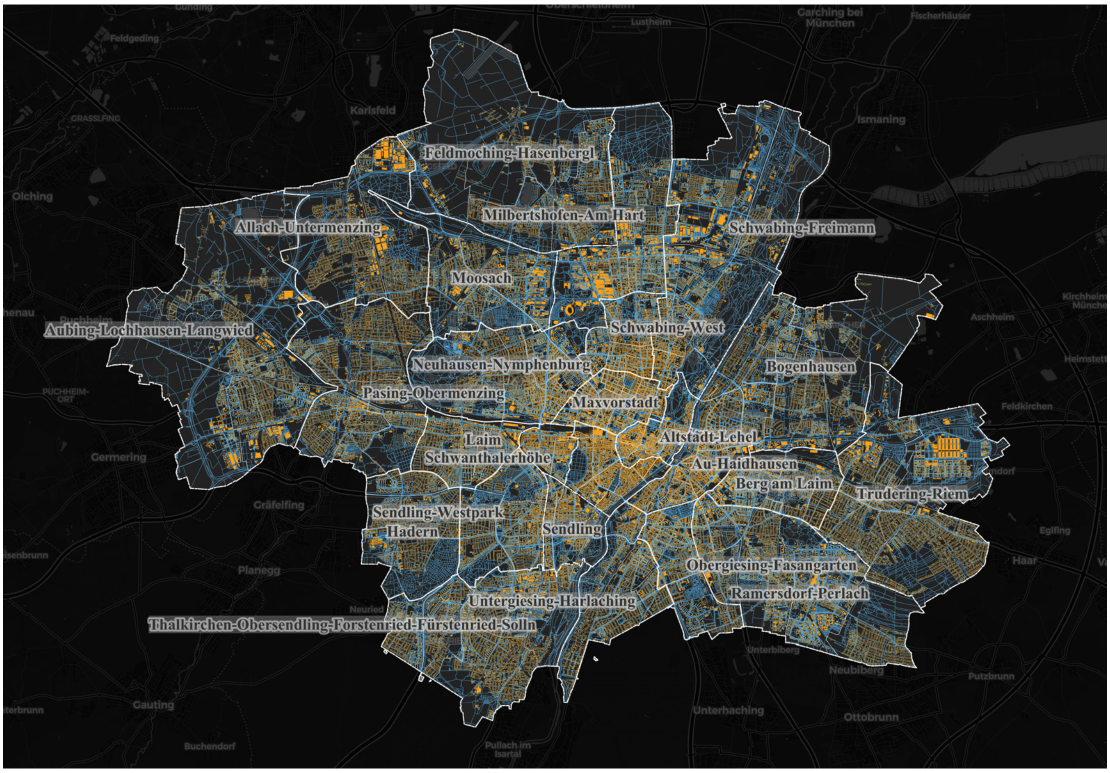


With a population of 654,000 citizens (852,000 if we include the contiguous cities of Cambridge and Somerville) and a metropolitan area encompassing 3.4M citizens, Boston is the capital of the Commonwealth of Massachusetts. Boston has experienced a remarkable transformation since the early 1980s, resulting in one of the most vibrant networks of innovation districts around the world (including Kendall Square/MIT, Harvard Square and Allston, the Longwood Medical Area, Boston Seaport Innovation District, and Union Square in Somerville). Since 2010, the city has grown twice as quickly as the nation, creating an opportunity to imagine—and enact—major policies that will fuel thriving urbanization for future generations. The city government identified a series of pressing challenges in a report issued in 2017, *Imagine Boston 2030: A Plan for the Future of Boston* (City of Boston 2017). This was the first citywide plan put forth in 50 years, and since the general plan of 1965, which sought to reverse the relative decline seen from 1950 to 1980. Created through the input of more than 15,000 residents, Imagine Boston 2030 identified the following:

- the need to accommodate 70,000 new residents by 2030 and 150,000 by 2050
- increase employment from 829,000 up to over 900,000 by 2050
- raise the median household income to mitigate disposable income challenges faced by citizens in one of the priciest metropolitan areas in the country
- promote mixed-use neighborhoods and encourage affordability
- reduce demographic displacement
- expand six neighborhoods (Sullivan Square, Newmarket and Widett Circle, Fort Point Channel, Suffolk Downs, Readville, and Beacon Yards) while providing significant new mixed-use housing
- encourage job growth in transit-accessible areas at the edges of existing neighborhoods

Munich

Figure 3. Districts and Neighborhoods (Munich)

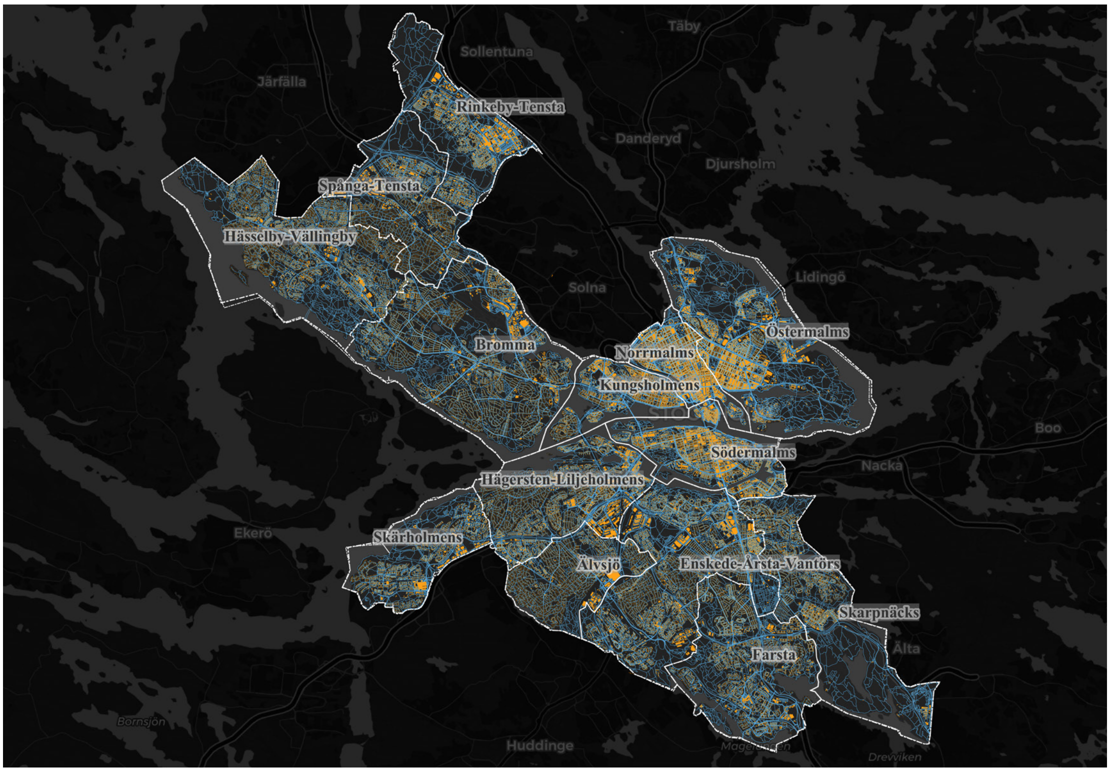


With a population of 1.472M citizens (1.592M with the surrounding cities) and a metropolitan region encompassing 5.98M citizens, Munich is the capital of the state of Bayern in Germany. Demographic projections by the City of Munich Department of Urban Planning—cited in the reports *Urban Form and Public Space in Munich* and *Shaping the Future of Munich*—estimate that Munich's dynamism will lead to a population increase of 1.8 million inhabitants by 2030. As a result, there is increasing demand for housing, which the city is currently struggling to meet. Munich is disadvantaged in terms of housing growth prospects, given the scarcity of available land. A lack of proper regional planning—in terms of labor, housing, local amenities, or transit services—has led to longer trips and greater distances for both commuting and completing activities. This lack of planning has also led to car dependency, aggravating the problem of an overloaded transport system that has resulted from fast growth regarding the total number of trips within the region. On the positive side, the city's resilient economic model has led to an unemployment rate of 3.9%, the lowest rate of all German cities with more than 500,000 inhabitants.

The annual volume of housing construction (less than 10,000 housing units per annum in recent years) fails to meet the rise in demand, which is estimated at approximately 8,500 new residential units per year, 2,000 of which should be units with moderate or subsidized prices. The structural shortage of several tens of thousands of residential units is illustrated by a vacancy rate that is virtually negligible. Initiatives such as *Simply Munich, Perspective Munich, Munich: Future Perspective and Vision Mobility 2050 Munich* aim to coordinate efforts to align the incentives of critical stakeholders to fulfill the urban and economic development goals set by the government.

Stockholm

Figure 4. Districts and Neighborhoods (Stockholm)

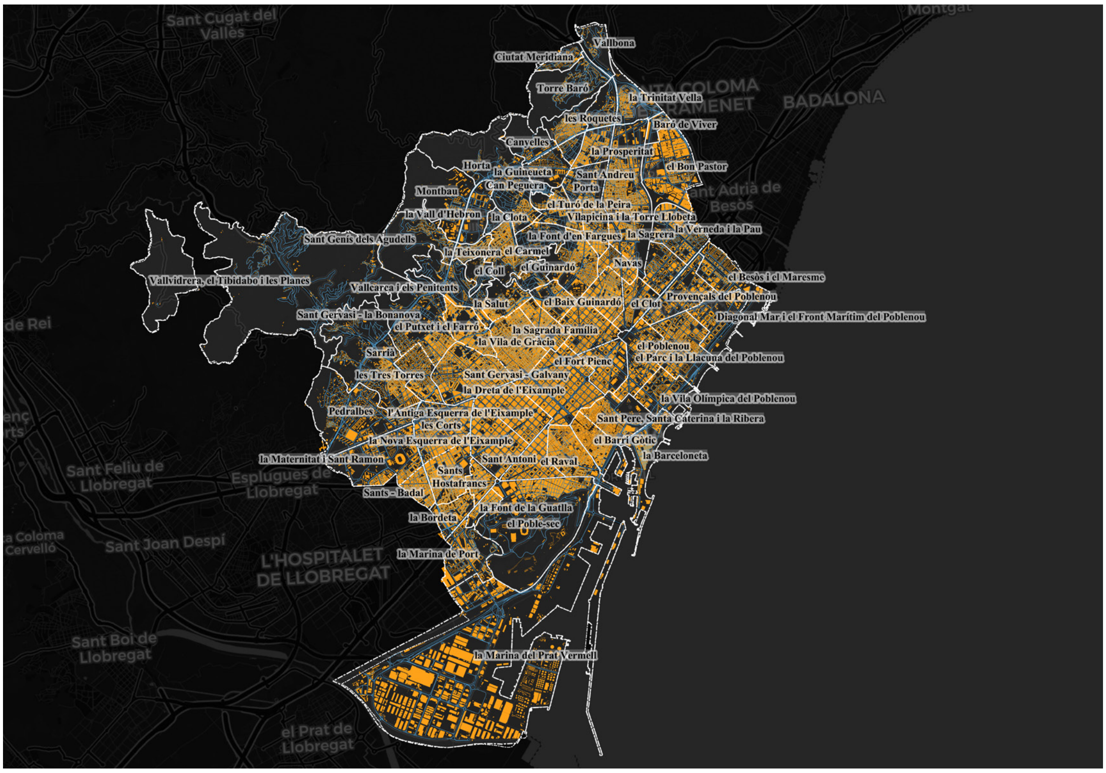


Known as "the Beauty on Water," Stockholm is the capital of Sweden. It has a population of 984,000 citizens with a metropolitan region encompassing 1.72M citizens. The city is currently undergoing a period of unprecedented population growth dynamics and is expected to reach between 1.2M and 1.4M residents by 2040. To satisfy this spike in demand for new dwellings, 140,000 new residences are expected to be constructed by 2030. Stockholm can legitimately claim to be a true champion and pioneering city in terms of climate mitigation strategies and sustainable development initiatives. The metropolis has endured a series of climate crises since the 1980s, including rising air and water pollution as well as critical infrastructure issues. In 1996, Stockholm adopted its first Climate Plan, which set ambitious targets for reducing greenhouse gas emissions. Further revisions were set in 2009, with updated targets for 2020 and 2050.

The city also regularly monitors its emissions and progress toward its targets. Stockholm has reduced its carbon footprint in terms of greenhouse gas emissions by 50% since 1990. Currently, approximately 70% of the city's energy consumption is derived from renewable sources. At the same time, it has heavily invested in its public transportation system, with a focus on reducing emissions and increasing efficiency. The city has an extensive metro system, and buses and trains run on renewable energy. As a result, public transportation accounts for 80% of all trips taken in the city, significantly reducing traffic congestion and emissions. The city had set a target to become zero waste by 2040, and as of 2021, over 99% of the city's waste is recycled or used for energy production. This growth has spurred extensive urban redevelopment efforts, with cultural institutions and infrastructure serving as the focal points for numerous mixed-use projects.

Barcelona

Figure 5. Districts and Neighborhoods (Barcelona - Barris)



With a population of 1.66M citizens, a metropolitan area composed of 3.2M citizens, and a metropolitan region encompassing 5.2M citizens, Barcelona is the capital of the region of Catalonia, Spain. The work-in-progress Pla Director Urbanístic Metropolità (PDUM) contemplates an estimated net population growth of around 676,000 citizens and 475,000 new residential dwellings across the metropolitan region between 2021 and 2050 (PDUM- Memòria, Àrea Metropolitana de Barcelona, 2023). Such remarkable growth prospects require the articulation of a proper city and metropolitan-scale vision and methodology to accommodate expected growth as well as forming an urban design and economic development strategy that surpasses the outdated plans of 1953, 1968, and the Pla General Metropolità (PGM) approved in 1976. Barcelona and its metropolitan area have been struggling to overcome the negative effects of the 2008 financial crisis, which led to a long decade characterized by economic stagnation and a relative impoverishment and worsening of the living conditions of broad segments of society. Barcelona has traditionally been the economic powerhouse of Catalonia and, more broadly, Spain and Southern Europe, and is home to a highly diversified industry base and numerous research institutions. However, there is civic concern about an excessive focus placed on low-skill sectors such as tourism and the weakening of the manufacturing industry in recent decades. Barcelona has been a pioneering municipal government across Europe in terms of creating a city-specific economic development agency (Barcelona Activa), promoting public transit-oriented mobility systems, and pursuing ongoing efforts to support SDGs that can benefit from city science–infused analyses, design, and management insights.

City Science Foundations

The modern discipline of city science has experienced an impetuous renaissance with the theoretical-practical advances achieved by academics and professionals in recent decades. The profession of modern urbanism is based on solid foundations established by nineteenth-century geniuses. Chief among these are Ildefons Cerdà and Louis Durand, the authors of masterpieces such as the *General Theory of Urbanization* (1867) and the pioneering studies *Recueil et parallèle des édifices en tout genre, anciens et moderne*s (1801) and *Précis des leçons d'architecture données à l'école polytechnique* (1805).

However, their legacy did not always enjoy deserved social recognition. The influence of authors and artists such as Mondrian, Malevich, and some influential city planning theorists who spuriously questioned the relationship between form and function in urban design, dominated for much of the twentieth century. Nonetheless, the academic contributions of the Santa Fe Institute complex systems research team led by Geoffrey West and Luis Bettencourt have shed new light on the understanding of urbanization.

The research team at the Santa Fe Institute published a series of scientific articles that put forward the idea of urbanization as a complex system capable of being modeled by using advanced mathematics and representation techniques such as network theory and system dynamics. In particular, the investigations led by Bettencourt et al. (2006) describe patterns of emergence of complex systems eventually modeling the superlinear relationship between the quantitative growth of the population of human settlements and factors such as wealth creation (2006), income, the performance of intensive activities in innovation (2007), the speed of social interaction in urban environments (2008), and the diversity of services and industries (2013). They also describe the sublinear relationship and the advantages associated with the economies of scale derived from population growth, such as infrastructural efficiency (2010), and per capita resource consumption.

Articles such as "A Physicist Solves the City" (*New York Times*, December 17, 2010), "The Hidden Maths of Organisms, Cities and Companies" (*The Economist*, May 11, 2017), and "How Laws of Physics Govern Growth in Business and in Cities" (*New York Times*, May 26, 2017) eloquently celebrated the accomplishments of the Santa Fe Institute team and anticipated the progress achieved by multiple teams around the globe.

Other outstanding contributions to the city science discipline in recent years include insights provided by Kent Larson's city science team at the MIT Media Lab, Sandy Pentland's Human Dynamics group, Andres Sevtsuk's City Form Lab at the Harvard GSD, Carlo Ratti's Senseable City Lab, Ricardo Hausmann's Growth Lab at the Harvard Kennedy School, César Hidalgo's Economic Complexity Team, and Michael Batty's Center for Advanced Spatial Analysis at the University College London (CASA- UCL), as well as the global group of professionals assembled under the Paris-based Urban AI umbrella, such as Laura Narváez Zertuche, Stephan van Dijk, Iacopo Testi, Stefaan Verhulst, Adrienne Schmoeker, Ana Brandusescu, Steve Grimes, and Suzanne Fritelli, among others.

Yet one field of academic research relevant to the practice of urban design and strong socio-economic implications has remained relatively unexplored: the identification and analysis of archetypal morphological urban patterns, their underlying core typologies, and inherent complex systems properties impacting the social dynamism and quality of life of citizens worldwide.

The Aretian Methodology

Recent advances achieved in the sphere of city science research and economic complexity modeling developed by the Aretian team at the Harvard Innovation Lab illuminate how urban development typologies and economic development strategies impact growth patterns and citizens' quality of life. By recreating urban environments and modeling their features and their urban performance levels, it is possible to evaluate the relationship between urban policies and city performance. Subtle, nontrivial relationships between decision-making and societal impact can also be examined. We can then proceed to identify the underlying ingredients and dynamics behind the success of a given city or community.

The methodology deployed in the present study is based on the research and practice contributions holistically presented by the Aretian team in *City Science: Performance Follows Form* (Actar Publishers 2023) as well as on a series of research and academic publications that delve into various aspects of the methodology presented in the 2018 dissertation titled, *Urban Innovation Hub Design: Building Bridges to Prosperity. A Network Theory-based Approach to Promote Sustained Cycles of Prosperity by Designing Innovation Districts and High-Performance Architectural Spaces in Synergy with Logistics Hubs*.

City Science: Performance Follows Form (2023) presents a novel methodology to model cities and urban environments as three-dimensional complex systems that are susceptible to being evaluated, analyzed, and represented by means of network science principles. The book introduces five core hypotheses and their evidence-based validation, illustrating the fundamental concepts by analyzing 100 global cities through the lens of the new method.

The *Atlas of Innovation Districts* (2019) introduces a series of modeling concepts and key performance metrics to define the inherent properties and estimate the success of thriving urban ecosystems, as illustrated by analyzing 50 notable innovation districts across the U.S. *Multiplying Effects of Urban Innovation Districts. Geospatial Analysis Framework for Evaluating Innovation Performance Within Urban Environments* (2022) measures the nonlinear surplus associated with mature knowledge economy ecosystems across the entire U.S. territory. *Geospatial Analysis Framework for Evaluating Urban Design Typologies in Relation With the 15-Minute City Standards* (2022) presents 10 city form typologies, their analogy with complex networks, and their intrinsic properties before then identifying the fundamental relationships between urban design typologies and social interaction patterns.

The approaches presented in the sources cited above have been applied to modeling the cities of Amsterdam, Barcelona, Boston, Munich, and Stockholm. They have also been used to evaluate their city form properties, economic development features, innovation ecosystems, mobility systems, and the distribution of urban services and amenities. Finally, some in-depth insights were extracted from the detailed urban science models built during the conception of three innovation districts master plans: *Masterplan i Estratègia de desenvolupament urbanístic i econòmic de l'àmbit d'oportunitat Porta de Barcelona, Esplugues de Llobregat* (2023); *Masterplan Urbanístic i Econòmic de la Ciutat de Badalona. Servei de redacció del treball de definició de la transformació econòmica i urbanística de Badalona* (2023); and *Masterplan - Estudi d'Estratègies de Desenvolupament Urbanístic i Econòmic dels Teixits Productius i Teixit Industrial del Besòs del Municipi de Barcelona* (2022).

City Form Metrics

By analyzing the morphological patterns in urbanism, we can see how architectural and engineering design, combined with ongoing space programming decision-making, structurally impacts the individual and collective psyche. We can also observe what types of social interaction patterns and human dynamics are stimulated. The purpose of city form–urban performance geospatial analysis is to identify urban design patterns within each city, district, neighborhood, and architectural space and measure their impact on urban life. At the same time, this form of analysis seeks to evaluate the structural relationships between those features to identify best practice recommendations to guide future decision-making.

Through a comparison of each urban development pattern type with a series of evidence-based performance KPIs, we can identify areas that are over- and underperforming. We can also pinpoint the design and policymaking decisions that favor each type of urban lifestyle. The combination of deductive, inductive, and abductive reasoning techniques permits the extraction of the causal patterns behind the success or failure of a particular area and can guide future decision-making in multiple domains; these include choosing new areas for intervention and future development to improve KPI metrics and boost socio-economic performance, environmental impact mitigation, and the overall quality of life of each city.

The urban infrastructure model and database were gathered from sources that included urban infrastructure and open street maps, business data sets, the geospatial distribution of urban services, and Aretian's proprietary databases. Geographic administrative boundaries, which are sized to contain roughly the same number of residents (typically around ~2,000 citizens), let us compare polygon boundaries. The city form models contain information about buildings, roads and streets, open and public places, and amenities. Economic datasets included geospatial business activity, innovation and knowledge economy metrics, and activity classification codes. The deployment of network theory–based algorithms allows calculating various success metrics and KPIs and using them to produce visualizations, which are then analyzed and distilled into topic- and context-specific recommendations.

City Form Characteristics

City form is one of the largest contributors to the overall efficiency and sustainability for cities around the world. Ideally, cities are efficiently planned for their clever and savvy use of materials and resources. Cities can be measured in terms of their super linear and sublinear distribution of services, amenities, employment and wealth creation opportunities, accessibility, and social interaction statistics. There are major benefits when there are healthy socialization patterns and higher access to amenities and resources—as well as quality jobs, critical services, and entertainment—within cities. The city form characteristics are a set of custom KPIs to quantitatively and qualitatively describe the morphological properties and features of a given city. The city form KPIs are universally applicable, allowing any geographic region, district, or neighborhood to be assessed, evaluated, and benchmarked against similar or different areas of interest.

The city form features reveal the underlying design patterns that characterize the urban fabric of every city. The topological network describes the underlying bidimensional transport and communications infrastructure that connects any given location and facilitates the territorial relationships between individuals and communities. The morphological system characterizes the three-dimensional architectural properties, features, and characteristics such as location, building shape and form, building height, space programming, capacity, and connectivity to nearby activities. The scale describes the orders of magnitude of city size and density levels. Finally, entropy is a holistic measure for regularity of the overall urban form composition, while fractality describes the quality or self-similarity of a three-dimensional system and to what extent it is characterized by harmonic polycentrism and virtuous properties.

Urban Topology Metrics

- Avg. streets per node: Average count of streets per node
- Street density: Street length total per sq km
- Avg. length of street segments: Average normalized length of street segments within the building group, as a proxy for network edge connectivity
- Density of intersections: Density of intersections per urban polygon unit
- Density of street segments: Density of street segments per standardized urban polygon unit
- Avg. circuity of street network: Average ratio between network distance to Euclidean distance, which is a reciprocal concept to network directness, as a proxy for the detour ratio
- Avg. intersection connectivity: Average number of street network connections colluding in the same urban network node/intersection within a given census tract, here as a proxy for intersection connections

Urban Morphology Metrics

- Avg. area of building footprints: Average area of building footprints within a building group as a proxy for space utilization within a given urban unit
- Avg. area of tessellations: Average area of tessellations or polygons composing a given building group (BG) as a proxy for subunit space utilization
- Avg. building orientation: A measure of building orientation optimization efficiency
- Avg. tessellation orientation: Average building parcel orientation, here as a proxy for urban parcel orientation efficiency
- Avg. building compactness: Building form compactness as an indirect measure of Architectural efficiency

Urban Fractality Metrics

- City form fractality: This is a measure of a city's level of urban form harmony or self-similarity. This measure refers to the replication of scale-free morphological patterns in a hierarchical nested fashion such that large central features are surrounded by a second tier and then interspersed with subsequent tiers' features. A highly fractal urban design configuration is characterized by harmonic polycentrism, where there is the coexistence of a decentralized or distributed, egalitarian base network, with local hubs or leading nodes enabling the realization of the multiplying effects of concentration.

Urban Entropy Metrics

- Street orientation order (Shannon entropy): The concept of information entropy was introduced by Claude Shannon in his 1948 paper "A Mathematical Theory of Communication" and is also referred to as Shannon entropy. Geoff Boeing, an urban planner and spatial analysis professor, conceived a visualization technique to describe in a visually succinct manner the street orientation patterns of a city, hence summarizing, among other aspects, the dominant axes, growth patterns, and the degree of regularity observed in a given urban area.

The combination of topological, morphological, compactness, entropy, and city form fractality features tends to adhere to archetypal design patterns. Each pattern is characterized by a specific aesthetic, inner structure, preferential attachment dynamics, and functional properties. This, in turn, reveals the *Weltanschauung*, or worldview, composed by the driving values and sense of beauty of a given society. The architectural forms, structural shapes, selected materials, street layouts, and activity programming constitute an ever-evolving dynamic system that can be analyzed through the lens of complex systems and network theory principles. Aretian's 10 City Typologies set an analytically solvent framework to measure how the physical layout of a given town and social organization structures affect urban life performance. The systematic evaluation of urban networks of metropolitan areas around the globe reveals that most urban environments follow variations of 10 archetypal patterns: the small world city; the radial city; the reticular city, the linear city, the organic city, the random city, the atomized city, the monumental city, the garden city, or finally the fractal city. Each archetypal typology is characterized not only by a set of similar morphological features but also by common network science characteristics, emergent properties, and inner dynamics.

How do we define urban design fractality?

Urban fractality measures the degree of urban form harmony or self-similarity composed of hierarchical nodes structured in a nested fashion whereby there are large central features, surrounded by a second tier and then interspersed with a third tier and the subsequent tiers' features. Features can include residential spaces, economic activity, hospital and educational systems, parks, transportation hubs, and so forth. The higher the number of morphological tiers and the greater the fractality, the higher the economic performance, urbanization efficiency, and access to services and amenities.

Fractality or self-similarity is equivalent to harmonic polycentrism and is the best predictor for urban design efficiency and high levels of achievement of the 15-minute city standards. High urban fractality levels present a combination of a decentralized, distributed urban network with local hubs, or leading nodes enabling the multiplying effects of concentration.

Brilliant French-Polish mathematician Benoît Mandelbrot developed the concept of the fractal dimension, and contributed to bridging the gap between art and science, proving that these two worlds are not mutually exclusive. Mandelbrot observed that self-similar structures could be frequently observed in nature as well as in art and that morphological self-similarity properties presented an unusual combination of formal beauty and empirical efficiency. In his own words, "The form of geometry I increasingly favored is the oldest, most concrete, and most inclusive, specifically empowered by the eye and helped by the hand and, today, also by the computer... bringing an element of unity to the worlds of knowing and feeling ... and, unwittingly, as a bonus, for the purpose of creating beauty. [...]. Clouds are not spheres, mountains are not cones, coastlines are not circles, and bark is not smooth, nor does lightning travel in a straight line." City form fractality can be measured by means of the Hausdorff–Besicovitch dimension.

Highly fractal or self-similar design patterns can be perceived both in world-class architectural masterpieces, such as Cattedrale di Santa Maria del Fiore, Sagrada Família in Barcelona, the Real Chiesa di San Lorenzo in Turin, the Boston Back Bay Area, Ely Cathedral, Frauenkirche, Dresden, the City of Blois in France, Frederiksberg Denmark, and the Hofburg Palace in Vienna as well as in global examples of vernacular architecture such as Castle Combe in England.

Extract from City Science: Performance Follows Form (2023)

Urban Performance KPIs: Measuring the Quality of Urban Development

Urbanization Efficiency KPIs

- Urbanization efficiency: A dimensional measure of urban design efficiency, here in terms of the ability to realize social interaction patterns and achieve key performance metrics per unit of infrastructure, all else being equal
- Avg. straightness centrality: Average Euclidean distance between two points, as a proxy for network node connectivity
- Avg. betweenness centrality: A measure of centrality in a street network based on shortest paths as a proxy to discern the areas capturing the largest human mobility flows and social interaction opportunity
- Avg. closeness centrality: Average distance required to reach from that origin to all the specified destinations that fall within the search radius along the shortest paths as a measure of how close an origin point is to destinations within a given distance threshold

Access to Urban Services KPIs

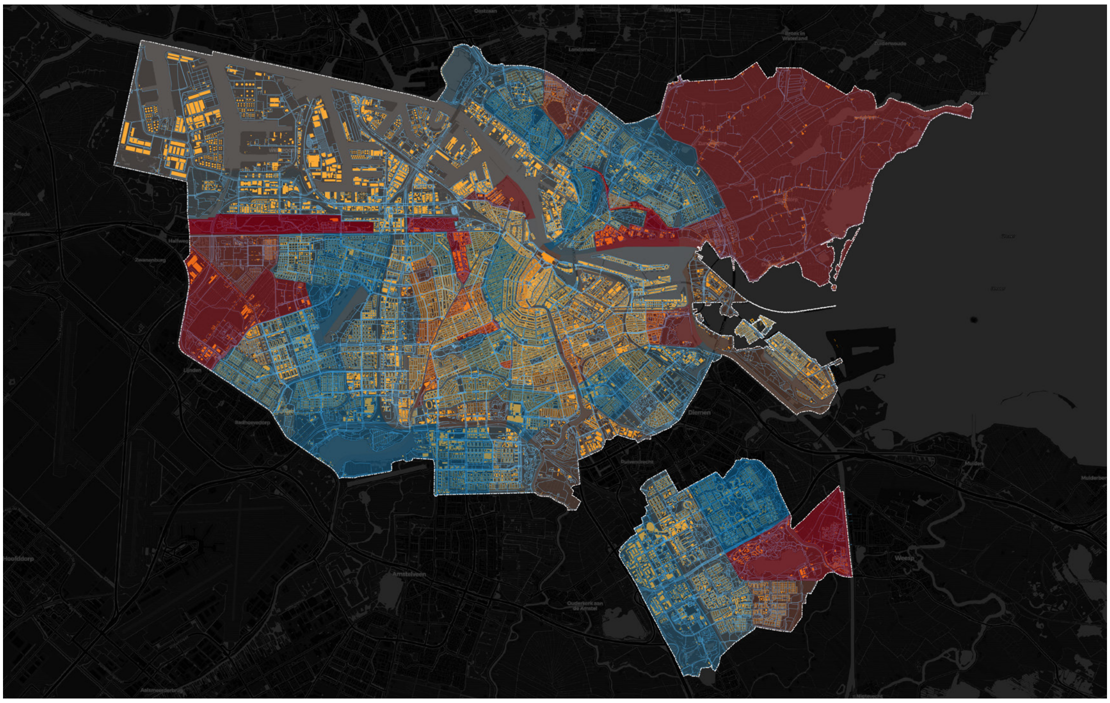
- Reach, Gravity, and Catchment Area Access to Education Centers per km^2
- Reach, Gravity, and Catchment Area Access to Healthcare Centers per km^2
- Reach, Gravity, and Catchment Area Access to Sustenance Amenities per km^2
- Reach, Gravity, and Catchment Area Access to Entertainment Amenities per km^2
- Reach, Gravity, and Catchment Area Access to Green Spaces per km^2
- Reach, Gravity, and Catchment Area Access to Mobility Services per km^2
- Access to Urban Amenities: Minimum Distance to the 1st Amenity
- Access to Urban Amenities: Minimum Distance to the 5th Amenity

Knowledge Economy KPIs

- Innovation Intensity: Can be measured both in terms of the number of knowledge-intensive jobs (absolute value) within an urban unit and the ratio of innovative jobs to regular or service jobs (%), here as estimated upon the number of new products, new services, patents, publications, and R&D initiatives and inventions. Generally speaking, Western countries present an average of approximately 10–12% of innovation intensity, highly innovative cities present over 20% of innovation intensity, and innovation districts present more than 35% of innovation intensity, often exceeding 50%.
- Innovation Performance: Can be measured both in terms of the total output from innovation activities including number of patents, papers, and publications as well as the total sales and revenue derived from those knowledge-intensive contributions.
- Innovation Impact: The number of knowledge-intensive jobs created per unit of resident as a proxy to estimate the opportunities to access merit-based quality jobs for a given city or area.

Amsterdam

Figure 6. City Form Fractality Gradient (Amsterdam)



City Form Typologies:

- Radial/Small World: Centrum-West, Centrum-Oost, Oud-Noord, Oud-Oost, Watergraafsmeer, De Pijp- Rivierenbuurt
- Atomized: Westpoort, Westerpark, Oostelijk Havengebied- Indische Buurt, IJburg-Zeeburgereiland, Osdorp
- Organic: Gaasperdam- Driemond, Zuid, Bijlmer-Oost, Bos en Lommer, Noord-West, Buitenveldert-Zuidas, Bijlmer-Centrum, Slotervaart, De Baarsjes- Oud-West
- Garden: Noord-Oost, Amsterdam Nieuw-West, Geuzenveld- Slotermeer, De Aker- Nieuw Sloten

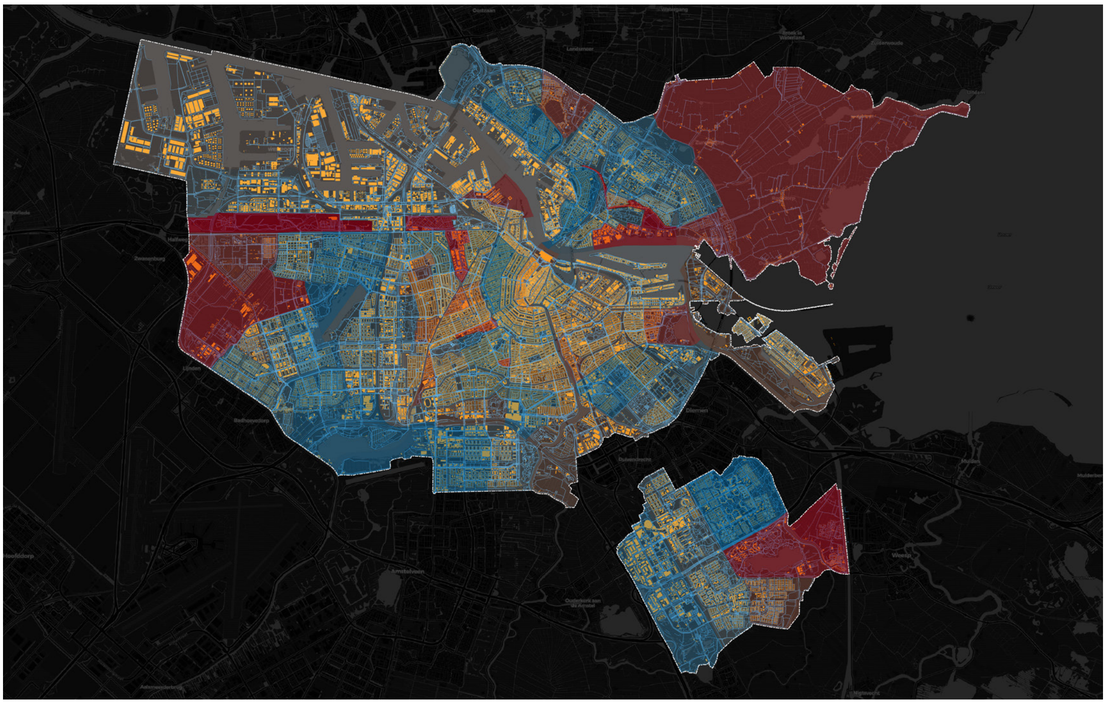
Table 1. City Form Fractality at the District and Neighborhood Scale Comparison (Amsterdam)

Fractality	
Highest	**Lowest**
Slotervaart	Gaasperdam - Driemond
Bijlmer - Oost	Noord - Oost
Buitenveldert - Zuidas	Osdorp
Noord - West	Ijburg - Zeeburgereiland
Oud - Noord	
Watergraafsmeer	

Table 2. City Form Betweenness at the District and Neighborhood Scale Comparison (Amsterdam)

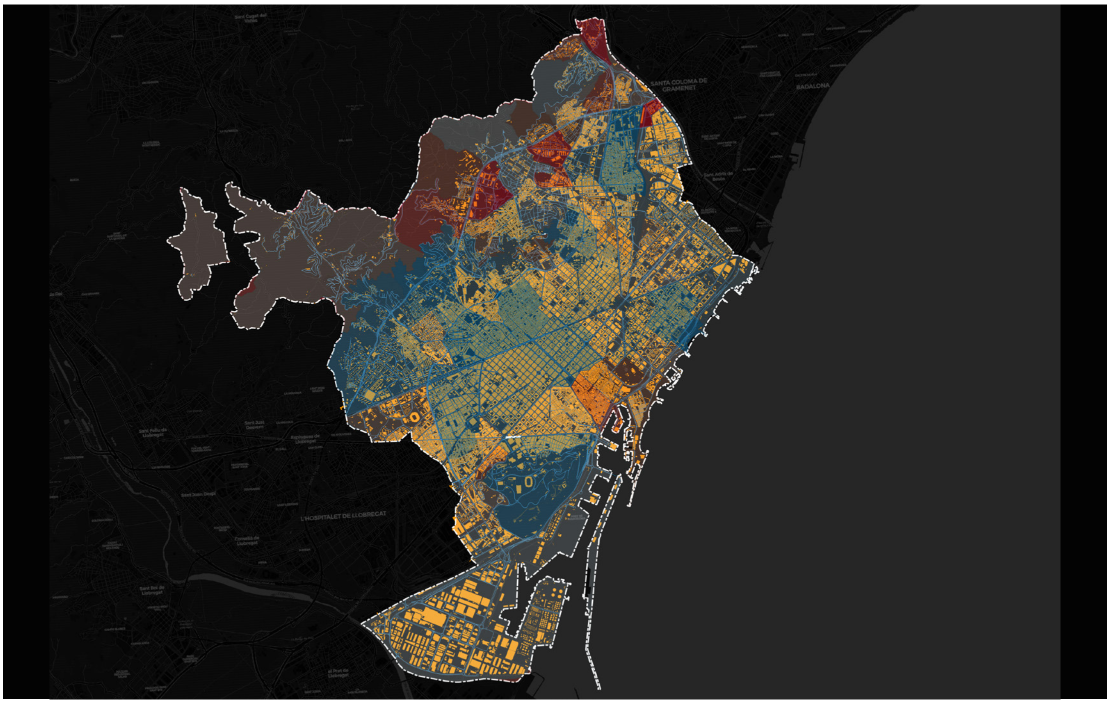
Betweenness	
Highest	**Lowest**
Slotervaart	Osdorp
Buitenveldert - Zuidas	Gaasperdam - Driemond
Bijlmer - Oost	Westerpark
Bijlmer - Centrum	Noord - Oost
Watergraafsmeer	

Figure 7. City Form Betweenness Gradient (Amsterdam)



Barcelona

Figure 8. City Form Fractality Gradient (Barcelona)



City Form Typologies:

- Fractal: Eixample (la Dreta de l'Eixample, l'Antiga Esquerra de l'Eixample, la Nova Esquerra de l'Eixample, Sant Antoni, la Sagrada Família, el Fort Pienc), Sarrià-Sant Gervasi (Sant Gervasi-Galvany, les Tres Torres, Sant Gervasi- la Bonanova), Sant Martí (el Parc i la Llacuna del Poblenou, el Poblenou, la Vila Olímpica del Poblenou, Diagonal Mar i el Front Marítim del Poblenou, Provençals del Poblenou)
- Fractal / Reticular: Gràcia (la Vila de Gràcia, el Camp d'en Grassot i Gràcia Nova), Sant Martí (Sant Martí de Provençals), Sants- Montjuïc (la Marina del Prat Vermell), Sant Martí (el Camp de l'Arpa del Clot, el Clot)
- Organic: Sant Andreu (la Trinitat Vella, Baró de Viver, el Bon Pastor, Sant Andreu, la Sagrera, el Congrés i els Indians, Navas), Sants- Montjuïc (la Marina del Port, la Font de la Guatlla, la Bordeta), Sarrià- Sant Gervasi (el Putxet i el Farró), Horta-Guinardó (Vallcarca i els Penitents, el Coll, la Salut), Horta-Guinardó (el Baix Guinardó; Can Baró; el Guinardó; la Font d'en Fargues; el Carmel; la Teixonera; Sant Genís dels Agudells; Montbau; la Vall d'Hebron; la Clota; Horta)
- Small World: Ciutat Vella (el Raval, el Barri Gòtic, Sant Pere, Santa Caterina i la Ribera), Sarrià- Sant Gervasi (Sarrià)
- Monumental: Les Corts (les Corts, la Maternitat i Sant Ramon, Pedralbes)
- Reticular: Ciutat Vella (la Barceloneta)
- Linear: Sants-Montjuïc (Sants, Sants- Badal, Hostafrancs, el Poble-sec)
- Random: Nou Barris (Vilapicina i la Torre Llobeta, Porta, el Turó de la Peira, Can Peguera, la Guineueta, Canyelles, les Roquetes, Verdun, la Prosperitat, la Trinitat Nova, Torre Baró, Ciutat Meridiana, Vallbona), Sant Martí (el Besòs i el Maresme), Sant Martí (la Verneda i la Pau)
- Garden: Sarrià- Sant Gervasi (Vallvidrera, el Tibidabo i les Planes)

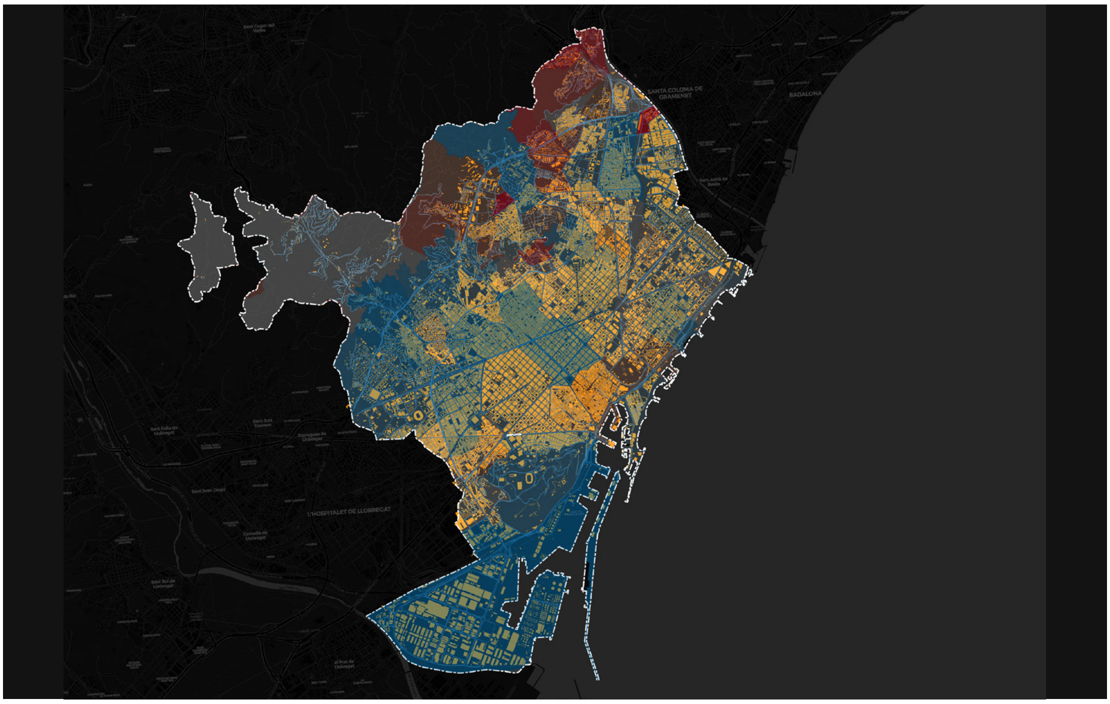
Table 3. City Form Fractality at the District and Neighbourhood Scale Comparison (Barcelona)

Fractality	
Highest	**Lowest**
Eixample	Nou Barris
Sant Gervasi	Barri Gòtic
Sant Martí - El Poblenou	Horta-Guinardó
Les Corts	Sant Andreu - Bon Pastor
Gràcia	

Table 4. City Form Betweenness at the District and Neighborhood Scale Comparison (Barcelona)

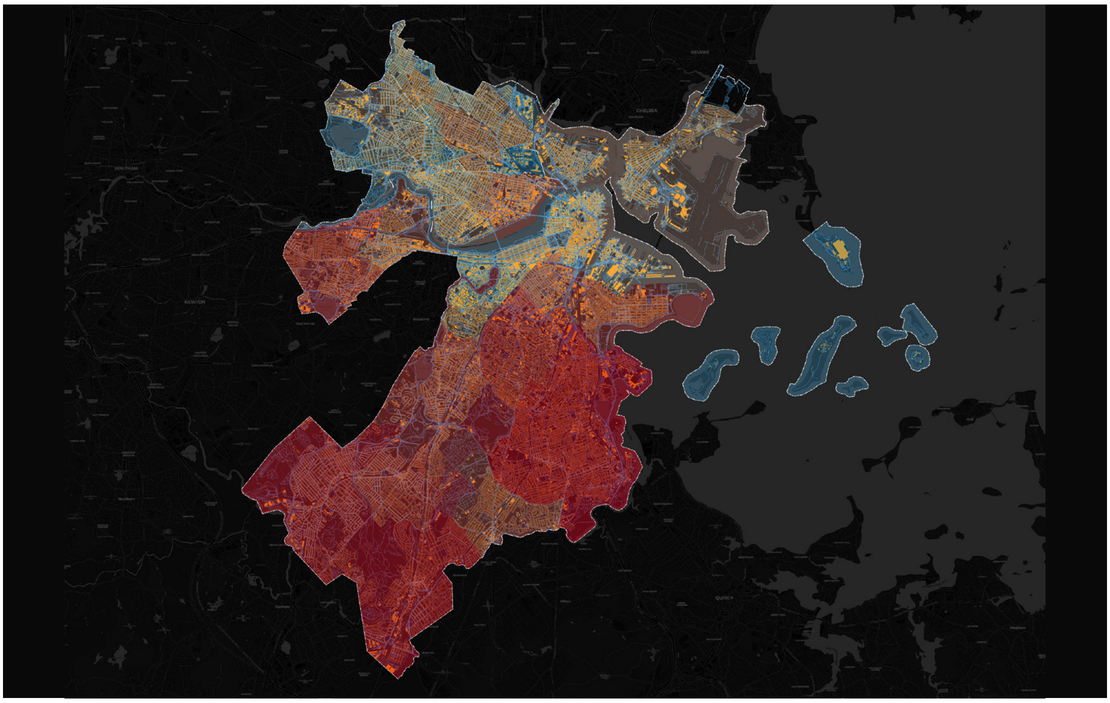
Betweenness	
Highest	**Lowest**
Eixample	Nou Barris
Sant Martí - El Poblenou	Horta-Guinardó
Sant Andreu - Sant Andreu Comtal	
Sant Gervasi	
Gràcia	

Figure 9. City Form Betweenness Gradient (Barcelona)



Boston

Figure 10. City Form Fractality Gradient (Boston)



City Form Typologies:

- Fractal: Back Bay, South End, Beacon Hill
- Linear-Fractal: Cambridge
- Organic: West End, Longwood, South Boston Waterfront, Chinatown, Harbor Islands, Mission Hill
- Small World: Downtown Boston, North End
- Reticular: South Boston, East Boston
- Random: Charlestown
- Linear: Fenway
- Garden: Allston, Roxbury, Dorchester, Jamaica Plain, Roslindale, West Roxbury, Hyde Park, Mattapan, Brighton, Somerville

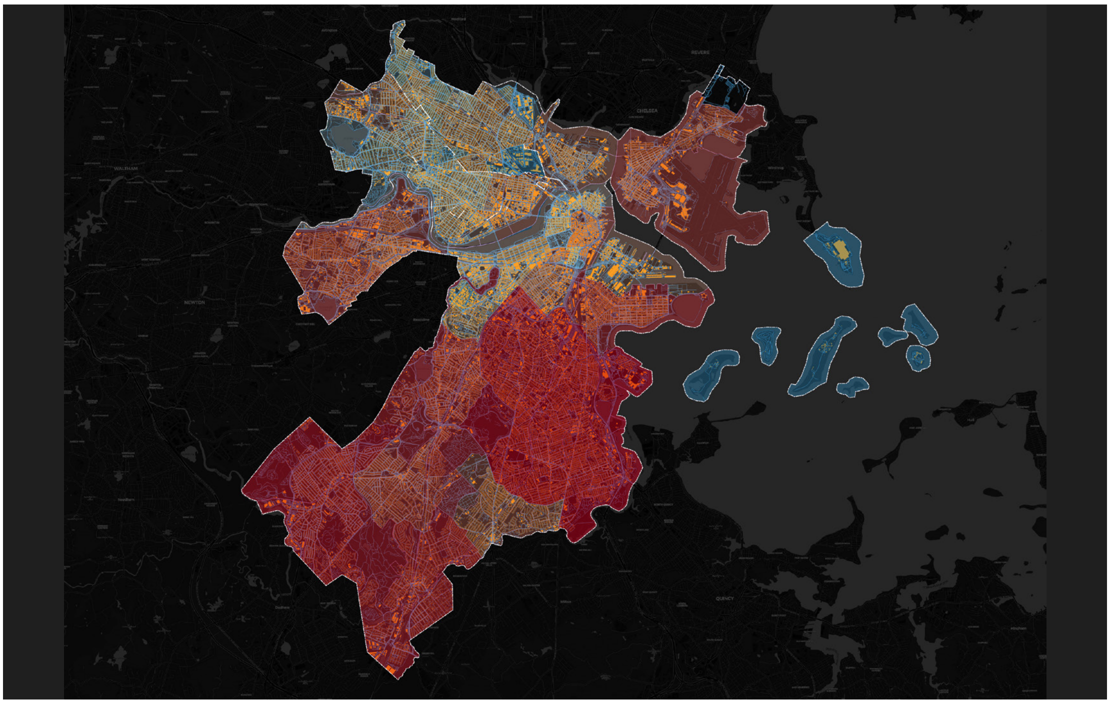
Table 5. City Form Fractality at the District and Neighborhood Scale Comparison (Boston)

City Form Fractality	
Highest	**Lowest**
Back Bay, Beacon Hill	South Boston
Fenway Kenmore	Roxbury, West Roxbury
Downtown	Dorchester
Seaport	Jamaica Plain
East Boston	Roslindale

Table 6. City Form Betweenness at the District and Neighborhood Scale Comparison (Boston)

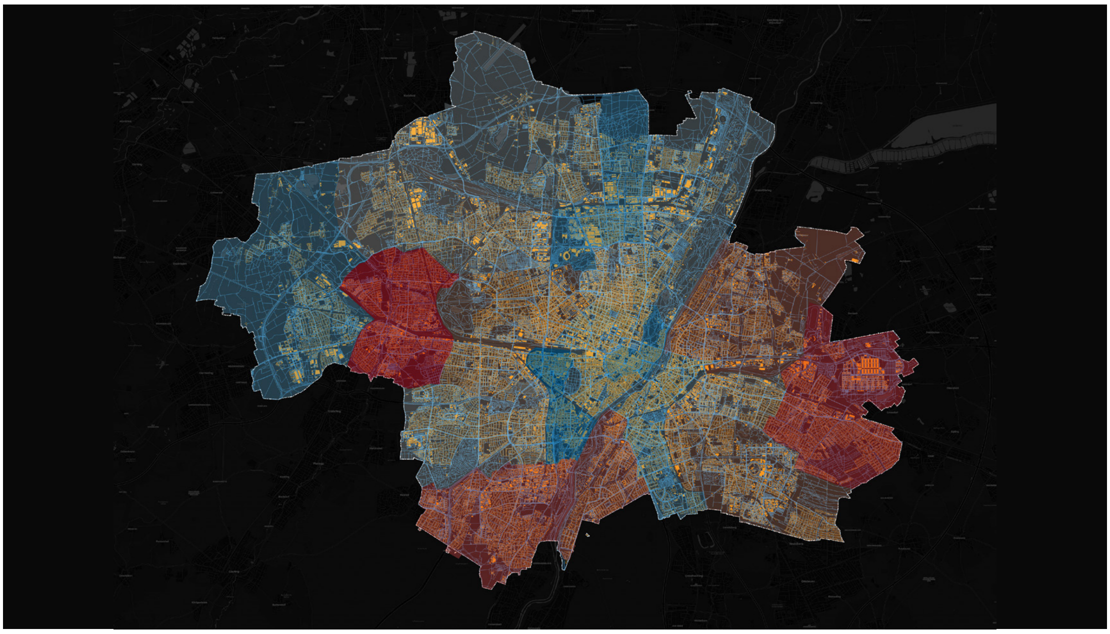
Betweenness	
Highest	**Lowest**
Back Bay, Beacon Hill	South Boston
Fenway Kenmore	Roxbury, West Roxbury
Downtown	Dorchester
Seaport	Jamaica Plain
Cambridge	Roslindale

Figure 11. City Form Betweenness Gradient (Boston)



Munich

Figure 12. City Form Fractality Gradient (Munich)



City Form Typologies:

- Small World: Altstadt-Lehel
- Monumental-Small World: Schwanthalerhöhe, Ludwigsvorstadt-Isarvorstadt, Schwabing-West
- Fractal: Maxvorstadt
- Fractal-Garden: Bogenhausen
- Radial/Garden/Organic: Au-Haidhausen
- Garden-Organic: Untergiesing-Harlaching
- Linear: Allach-Untermenzing, Schwabing-Freimann, Berg am Laim
- Monumental- Garden: Neuhausen-Nymphenburg, Sendling
- Garden: Pasing-Obermenzing, Trudering-Riem, Thalkirchen- Obersendling- Forstenried- Fürstenried- Solln, Hadern, Aubing-Lochhausen-Langwied, Feldmoching-Hasenbergl, Ramersdorf-Perlach
- Organic: Sendling-Westpark, Moosach, Laim, Milbertshofen-Am Hart, Obergiesing-Fasangarten, Milbertshofen-Am-Hart

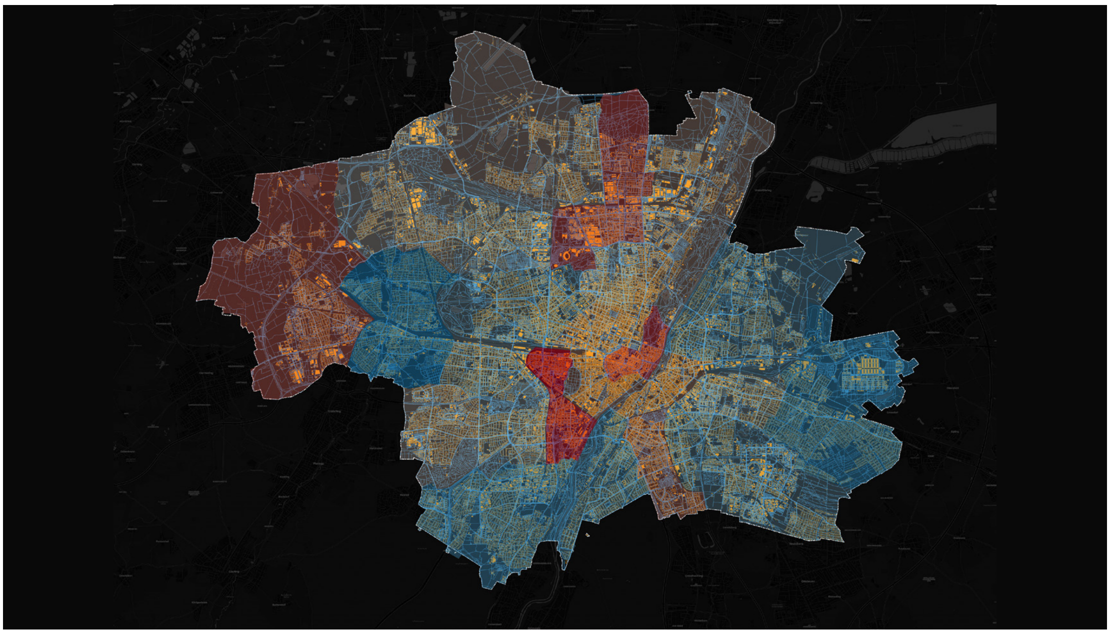
Table 7. City Form Fractality at the District and Neighborhood Scale Comparison (Munich)

Fractality	
Highest	**Lowest**
Schwanthalerhöhe	Pasing-Obermenzing
Sendling	Trudering-Riem
Milbertshofen-Am-Hart	Thalkirchen-Obersendling-Forstenried-Fürstenried-Solln
Aubing-Lochhausen-Langwied	Untergiesing-Harlaching
Schwabing-West	

Table 8. City Form Betweenness at the District and Neighborhood Scale Comparison (Munich)

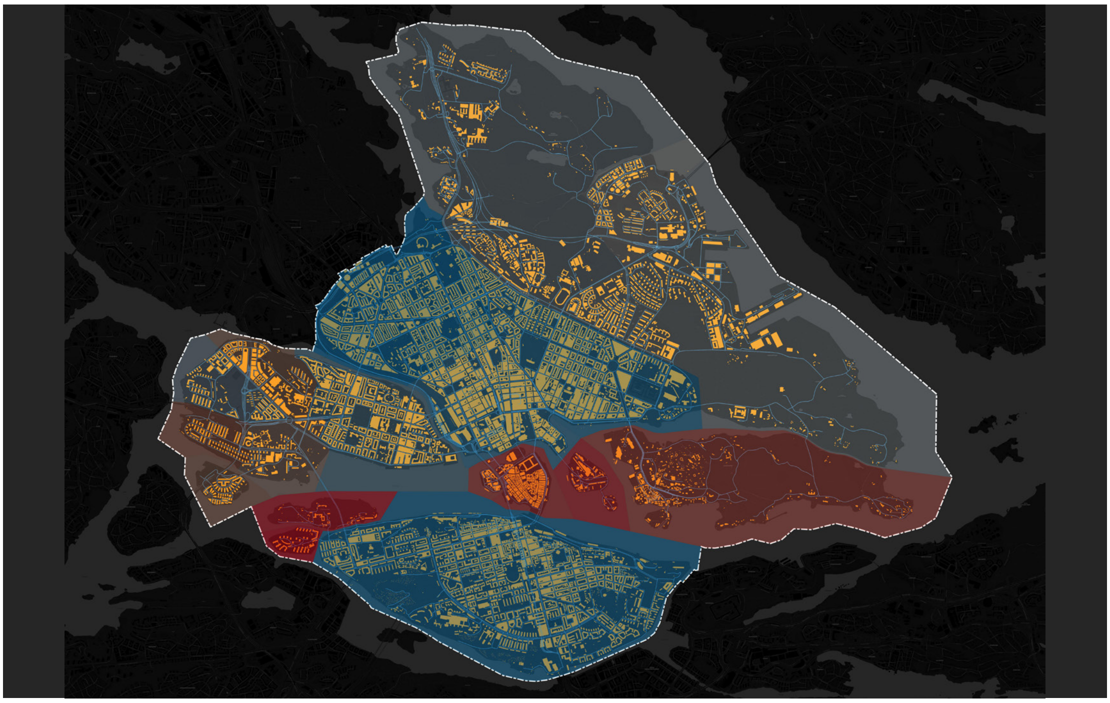
Betweenness	
Highest	**Lowest**
Maxvorstadt	Bogenhausen
Sendling	Trudering-Riem
Obergiesing-Fasangarten	Ramersdorf-Perlach
Altstadt-Lehel	Pasing-Obermenzing
Moosach	Thalkirchen-Obersendling-Forstenried-Fürstenried-Solln

Figure 13. City Form Betweenness Gradient (Munich)



Stockholm

Figure 14. City Form Fractality Gradient (Stockholm)



City Form Typologies:

- Fractal: Norrmalms, Södermalms, Kungsholmens, Östermalms
- Small World- Monumental: Gamla Stan
- Organic: Farsta, Skärholmens, Hässelby-Vällingby, Skarpnäcks, Enskede-Årsta-Vantörs, Spånga-Tensta, Rinkeby-Tensta
- Garden: Hägersten-Liljeholmens, Bromma, Älvsjö

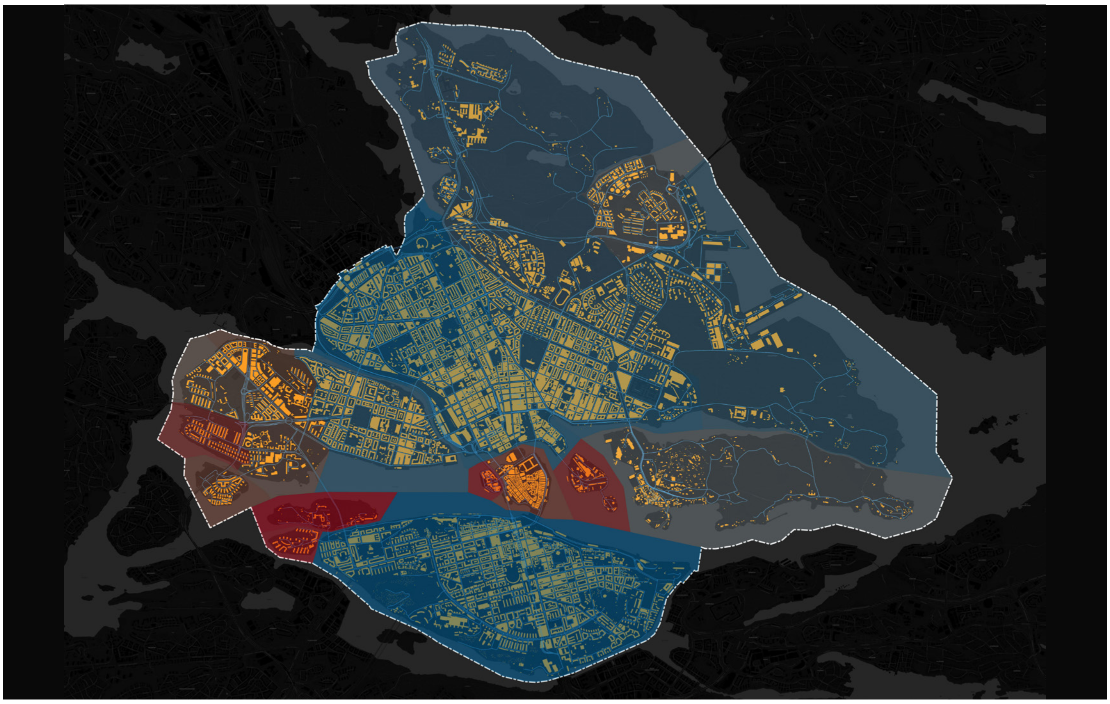
Table 9. City Form Fractality at the District and Neighborhood Scale Comparison (Stockholm)

Fractality	
Highest	**Lowest**
Norrmalm	Farsta
Vasastaden	Stadsholmen
Kungsholmen	Skeppsholmen
Östermalms	Djugarden
Södermalms	Langholmen

Table 10. City Form Betweenness at the District and Neighborhood Scale Comparison (Stockholm)

Betweenness	
Highest	**Lowest**
Norrmalm	Farsta
Vasastaden	Stadsholmen
Kungsholmen	Skeppsholmen
Östermalms	Langholmen
Södermalms	Lilla Essingen
Ladugardsgardet	Marieberg

Figure 15. City Form Betweenness Gradient (Stockholm)



Analytical Results: Insights from Benchmarking Across Five Global Cities

Comparative Analysis: Amsterdam, Barcelona, Boston, Munich, and Stockholm

To evaluate the degree of success of urban design and economic development policymaking, we built city digital twins of the selected cities: Amsterdam, Barcelona, Boston, Munich, and Stockholm. This opened the door to empirically measure their ability to create prosperity, provide quality access to urban services and amenities, facilitate the consolidation of sustainable mobility systems, and propel healthy, dynamic social interaction patterns. Performing city science analyses on the five cities provided numerous yields.

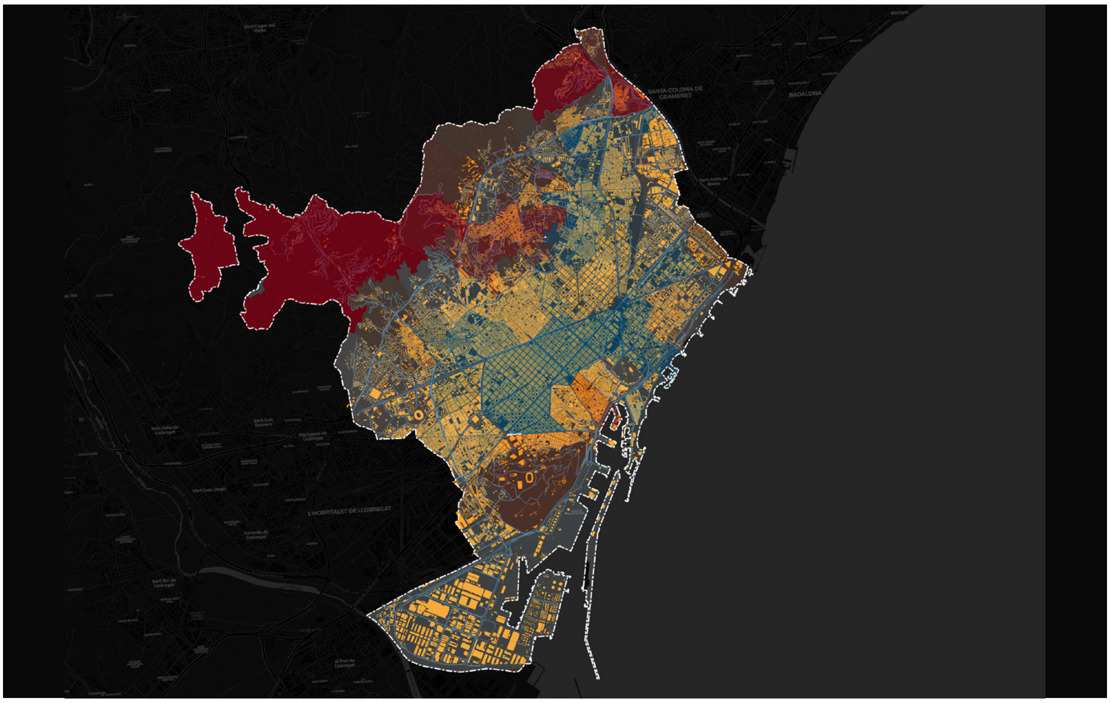
By decomposing the respective cities into 2,512 analogous, comparable, and benchmarkable urban units, we were able to rank each and every city, district, neighborhood, and small urban unit and distill the areas that were systematically outperforming the others as well as the inherent, common features and characteristics shared by the most outstanding environments to inform best practices across five main urban life dimensions:

- Sustainable urban development
- Economic complexity and smart specialization
- Innovation, research, and talent
- Housing and the 15-minute city standards
- Mobility and logistics

Urban Design Analysis

We deployed city form-urban performance analysis for each of the 2,512 analogous urban units across Amsterdam, Barcelona, Boston, Munich, and Stockholm. The city form and urban performance KPIs reflect the fundamental variables necessary for defining and evaluate the urban and economic performance of each city and neighborhood. Because the data were produced for regions with similar population size, it is possible to compare respective KPIs. The maps display the range of values for each KPI, with feature underlays, such as the buildings, roads, and borders, to provide the necessary context for interpretation. The colors of the choropleth maps are scaled with less desirable values shaded in red and desirable or positive values shaded blue. Each variable is locally scaled to the specific city to emphasize the internal gradient and range of values within a given municipality. Therefore, the maximum and minimum values may vary for each city, even though they may be dark red and blue. Nevertheless, the selected metrics were benchmarked across all five cities in the same way, here based on the exact same empirical value measurement procedures for each urban unit or polygon.

Figure 16. City Form Straightness Index (Barcelona)



The City Form Straightness Centrality Index presents clearly perceived gradients, directly signaling the empirical, perceived impact of different urban design typologies across distinct neighborhoods. By way of example, an observer may clearly perceive the structurally higher straightness values present in the areas directly informed by the 1859 Eixample Plan designed by Ildefons Cerdà.

The results of the city form KPI evaluation are summarized in the following benchmarking table:

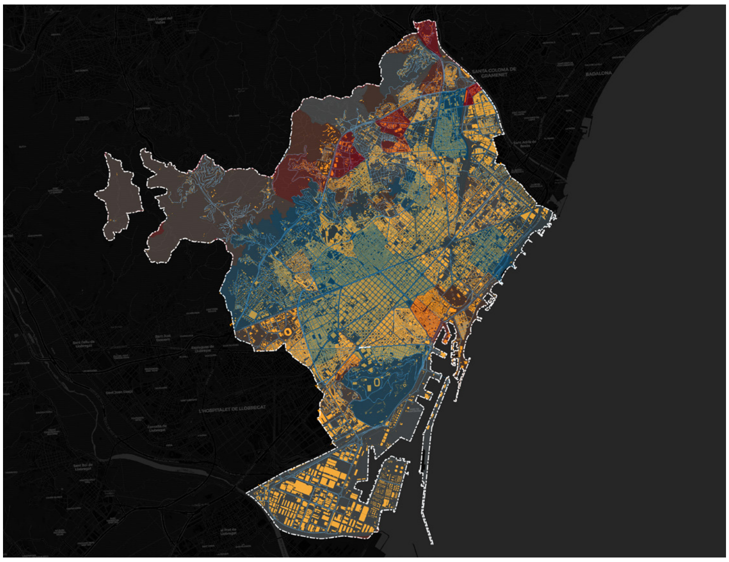
Table 11. City Form KPI Benchmarking (Global Cities)

City	City Form Fractality Index	Urbanization Efficiency	Avg City Form Betweenness	Avg City Form Straightness	Global Closeness	Avg City Form Entropy
Amsterdam	62%	64%	0.1232	0.65	0.059	49%
Barcelona	67%	72%	0.1292	0.72	0.065	52%
Boston	63%	65%	0.1057	0.67	0.059	42%
Munich	51%	54%	0.0972	0.64	0.051	64%
Stockholm	71%	75%	0.1905	0.58	0.072	45%
Target	**>85%**	**>80%**	**>0.15**	**0.85 – 0.95**	**>0.085**	**≈50%**

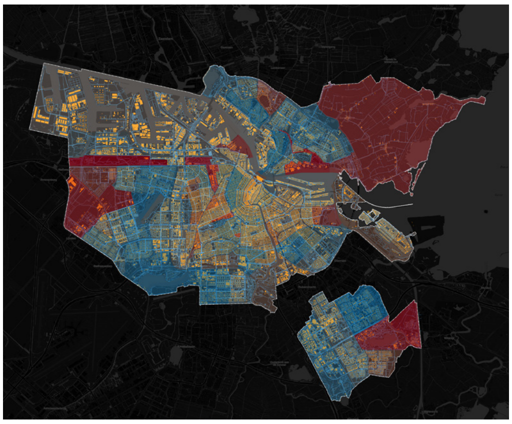
Figure 17. City Form Fractality Gradient Benchmarking

City Form Fractality

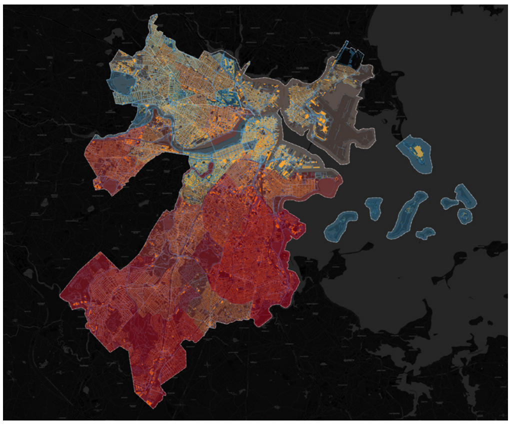
Barcelona



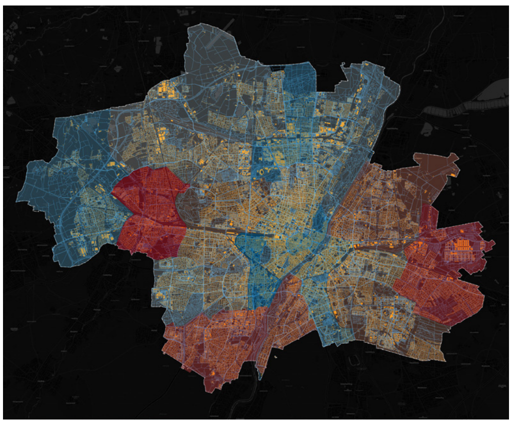
Amsterdam



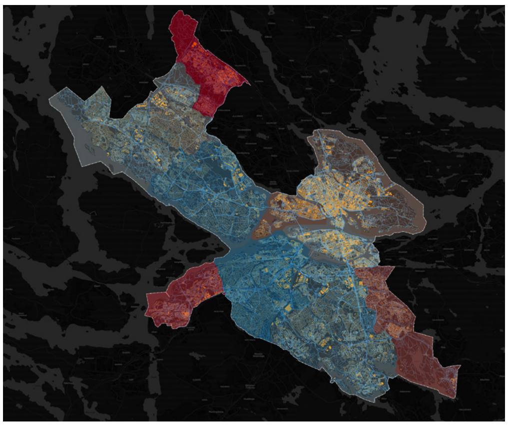
Boston



Munich



Stockholm

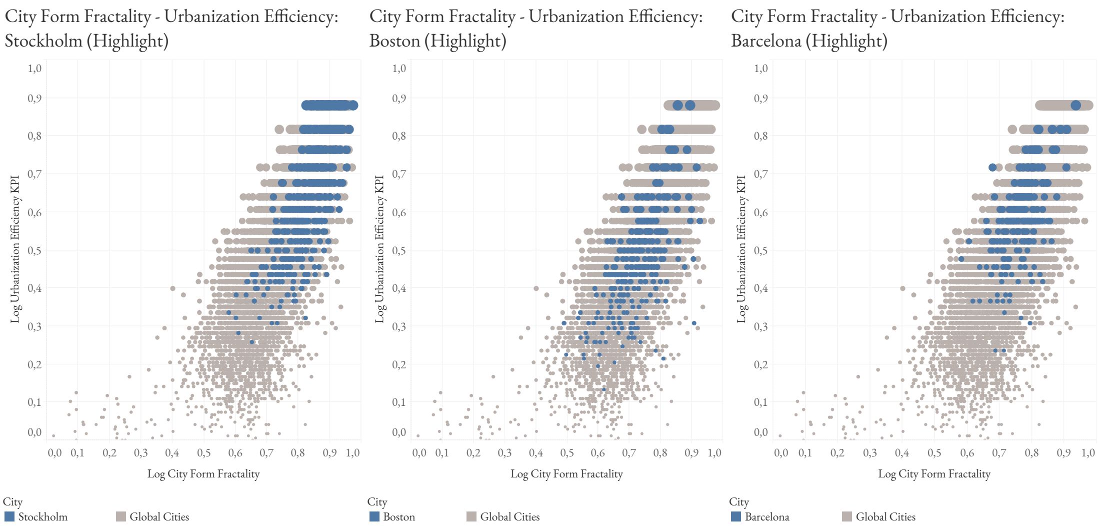


Insights—Envisioning a Sustainable Urban Design Strategy

Insight 1: City Form Fractality Facilitates Fruitful Human Interaction

City form fractality is the most salient and analytically informative urban design feature when it comes to predicting urbanization efficiency. City form fractality presents a nonlinear, positive relationship with urbanization efficiency: We observe that, when we double city form fractality (2x growth in absolute values), on average, there is a 32% superlinear increase in urbanization efficiency and social interaction superlinearity, including the multiplying effects of the knowledge economy, all else being equal. Hence, highly self-similar urban design patterns (urban fractality >70%, ideally >85%) are recommended to foster highly fruitful and fertile human dynamics within urban environments. A combination of 2D topological and 3D morphological features as well as thoughtful self-similar space programming and zoning strategies, here replicating nested hierarchies of urban life, can help achieve highly fractal architecture and urban design configurations.

Figure 18. City Form Fractality - Efficiency Benchmarking (Barcelona, Boston, and Stockholm)

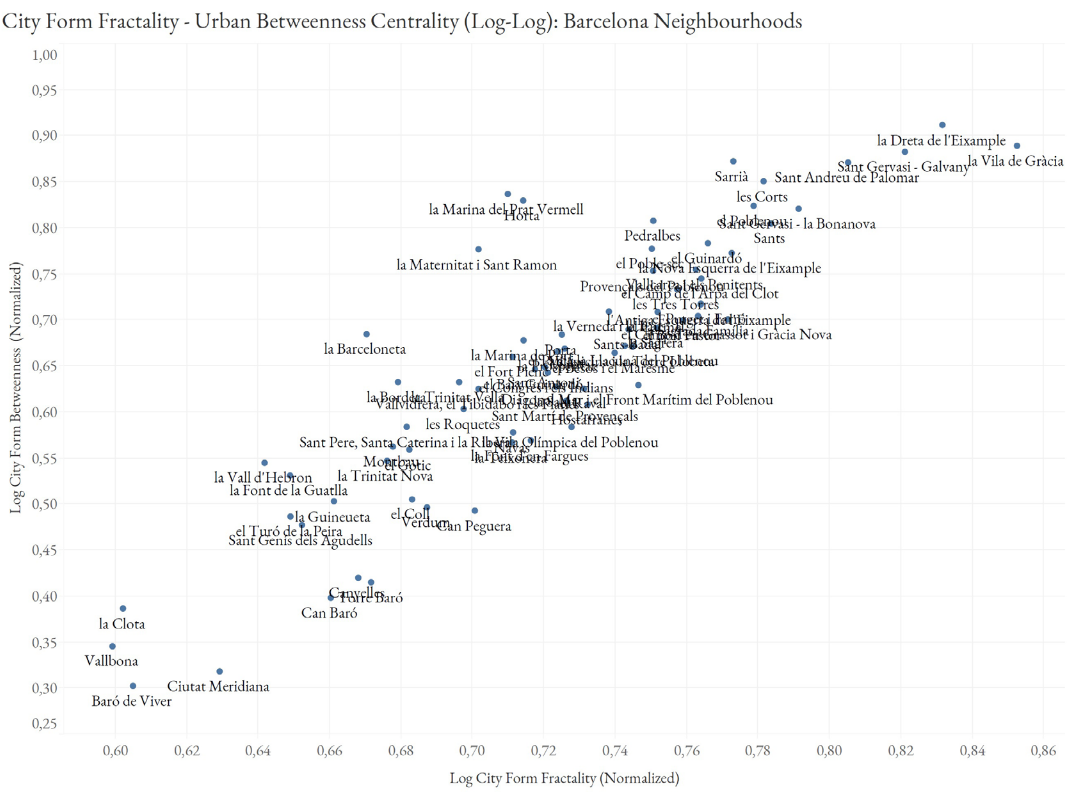


The log-log analysis between city form fractality and urbanization efficiency reveals the positive, nonlinear nature of the relationship between morphological self-similarity and intelligent use of material resources in the urban space. By way of illustration, the ranking of average city form fractality across all five selected cities is as follows: Stockholm, Barcelona, Boston, Amsterdam, and Munich. Some of the higher levels of morphological harmony can be perceived in neighborhoods such as Norrmalms, Södermalms, Kungsholmens, and Östermalms, often reaching values as high as 87%, 91%, and even 94% in their fractal dimension and normalized urbanization efficiency values upwards of 80% in districts that interestingly present a primarily fractal typology. In notable contrast to these areas, we find the neighborhoods of Farsta or Hässelby-Vällingby as presenting values ranging between 37% and 65% in morphological self-similarity and urbanization efficiency scores between 20% and 35%.

In a similar vein, we observe a high degree of internal heterogeneity within Barcelona, with urbanization efficiency values spreading across a wide range of figures, from 29% in Baró de Viver, up to 91% in La Dreta de l'Eixample, at the very center of the Cerdà expansion plan of 1859. It is worth noting that areas directly affected by the notable nineteenth-century design plan tend to outperform their peers: La Dreta de l'Eixample (91%), Sant Martí- El Poblenou (78%), La Nova Esquerra de l'Eixample (78%), or L'Antiga Esquerra de l'Eixample (73%) as well as their neighboring Sant Gervasi- Galvany (82%) and Sant Gervasi- La Bonanova (80%), for instance, present remarkably higher self-similarity metrics than Ciutat Meridiana (62%, with 31% of urbanization efficiency) or Vall d'Hebron (64%, with 55% urbanization efficiency). In physical terms, we can derive that the central areas of Eixample in Barcelona are approximately 540% more materially efficient (0.21 in absolute urbanization efficiency) than their lowest performing counterparts (0.0131 in absolute urbanization efficiency) within the city.

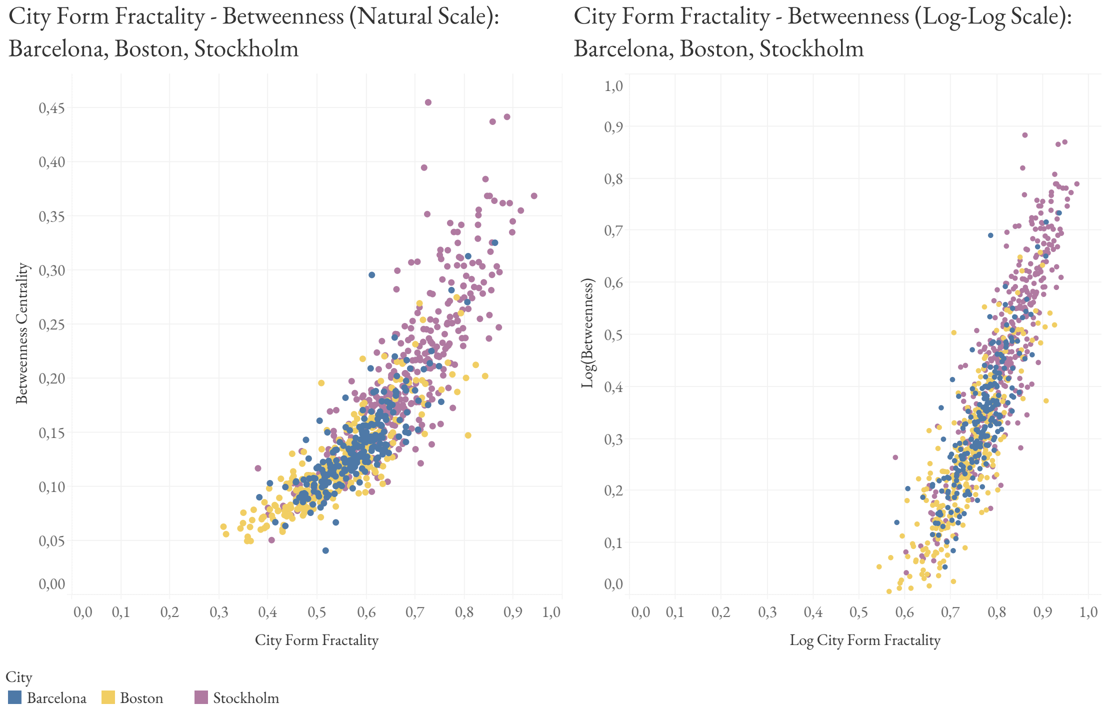
In other words, the better designed areas are almost seven times more efficient than the worst designed areas of Barcelona.

Figure 19. City Form Fractality—Urban Betweenness Centrality (Barcelona)



We should also notice the nonlinear, positive, power law relationship between city form fractality and betweenness centrality. Provided that network betweenness centrality is a highly accurate predictor for pedestrian flows and social interaction, we can deduce that city form self-similarity tends to have a structural effect on human dynamics and socialization patterns.

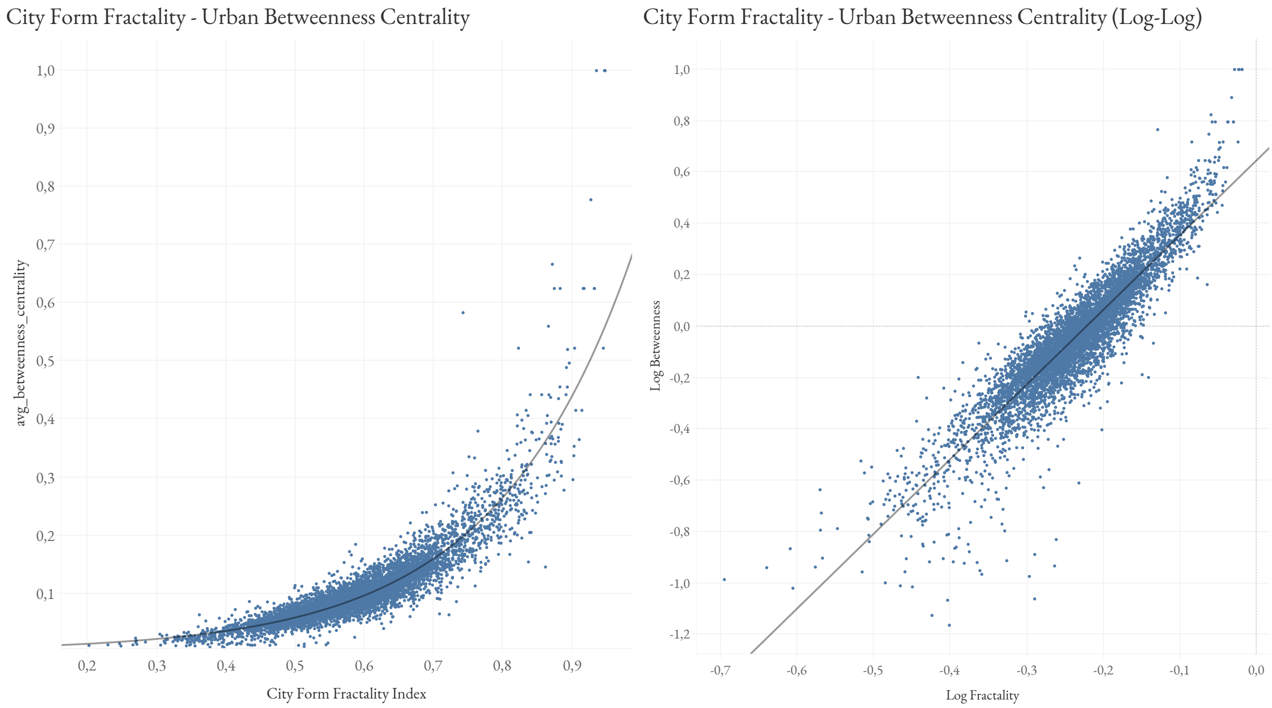
Figure 20. City Form Fractality—Betweenness (Barcelona, Boston, and Stockholm)



An eloquent comparison across some of the selected cities reveals the internal variance across different neighborhoods and districts in terms of betweenness centrality and their relationship with fractality. The natural scale evaluation of normalized values presents a power law distribution, whereas the log-log scale analysis reveals the slope of the nonlinear relationships. To illustrate this concept, we must notice that the least fractal areas of Barcelona (39%) present absolute values of around 0.0411 betweenness centrality, whereas the most fractal areas (86%) reach up to 0.3256 in betweenness centrality; this signals that some areas facilitate human interaction almost eight times more than others when comparing neighborhoods within the same city.

The positive, nonlinear nature of the relationship between city form fractality and urban form KPIs, such as urbanization efficiency, betweenness centrality, straightness centrality, and closeness centrality, confirms the following: The greater the urban design excellence we aim for, the greater the potential for positive results. These results may be in terms of material sustainability (achieving the same or more results with fewer resources) and/or the surplus associated with human interaction, here whether in terms of economic output, environmental impact, access to services, or even casual, healthy socialization patterns between fellow citizens. In other words, doubling the city form fractality in absolute values or increasing 5% of the normalized fractality score presents higher yields in the upper ranges than in the lower ranges. This striking insight creates a clear incentive for striving for excellence in urban design and space programming, aiming to increase the quality of life of citizens.

Figure 21. City Form Fractality—Urban Betweenness Centrality (natural scale, log-log scale)



A continued evaluation of fractality shows a positive, nonlinear relationship between urban form fractality and urban betweenness. The left graph shows a natural scale, nonlinear, exponential relationship, while the right shows a log-log relationship.

Figure 22. City Form Fractality—Urban Betweenness Centrality (Barcelona vs. Global Cities)

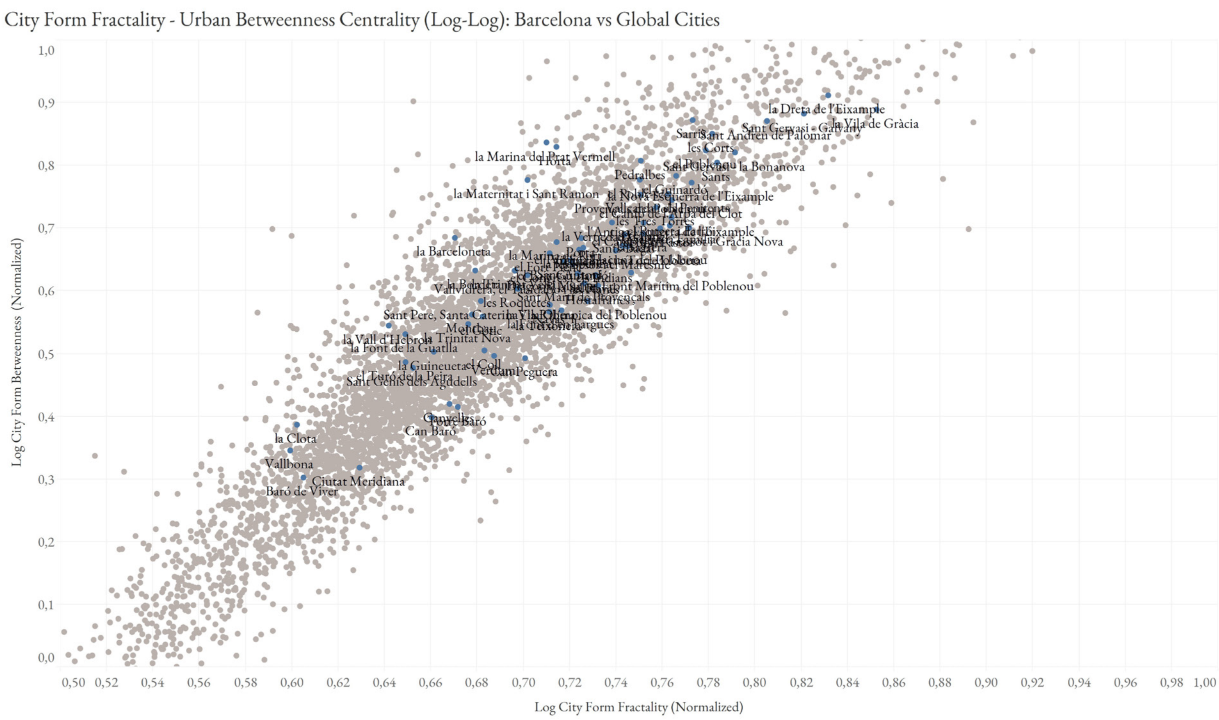


Figure 23. Network Closeness, Circuity, and Centrality

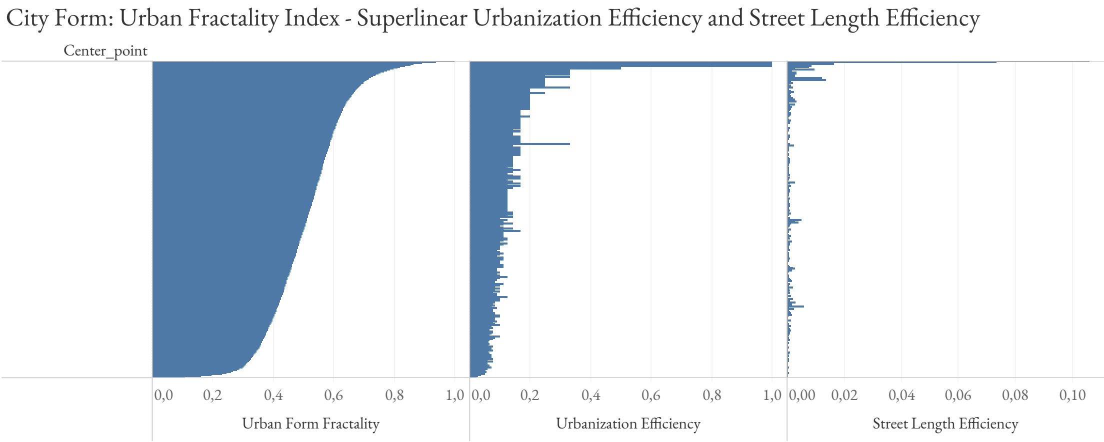
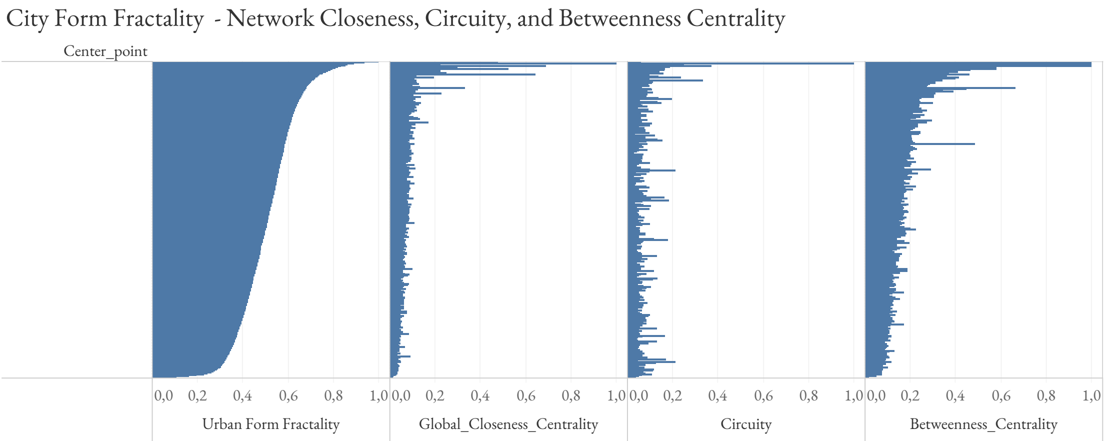


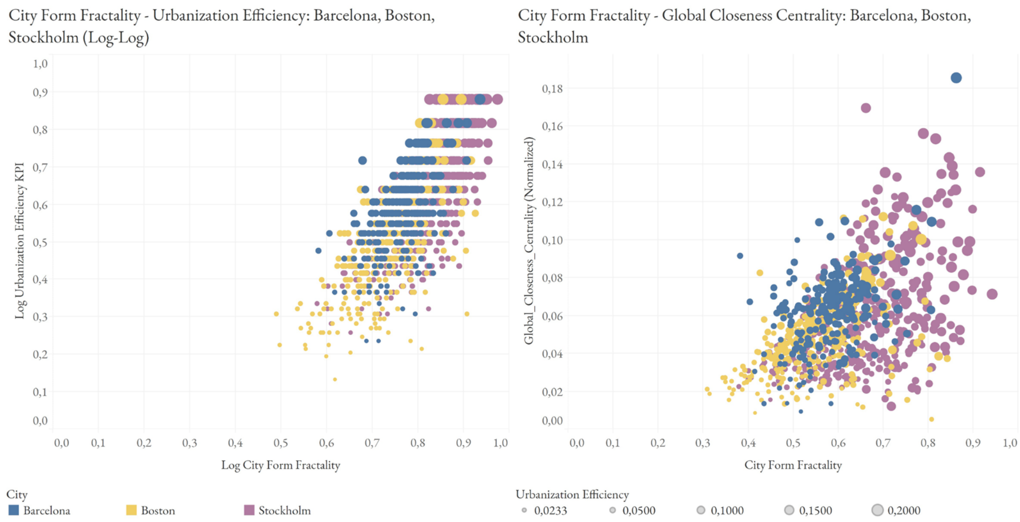
Figure 24. Urban Fractality Index vs. Urbanization Efficiency



City form fractality, quality, or harmonic polycentrism is the utmost predictor of urban design excellence, and its analysis can reveal highly insightful patterns at multiple scales, whether operating at the metropolitan, city/district, or architectural levels of aggregation. From urbanization efficiency all the way through street length efficiency, betweenness centrality, circuity, or closeness centrality, the network dynamics and emerging properties associated with this specific feature can help inform the aesthetic, morphological, and functional design strategies.

A comparison of Barcelona's neighborhoods with those of other cities reveals the internal heterogeneity and the overall higher scores perceived in Barcelona when compared with its global counterparts.

Figure 25. City Form Fractality: Urbanization Efficiency (Barcelona, Boston, Stockholm)



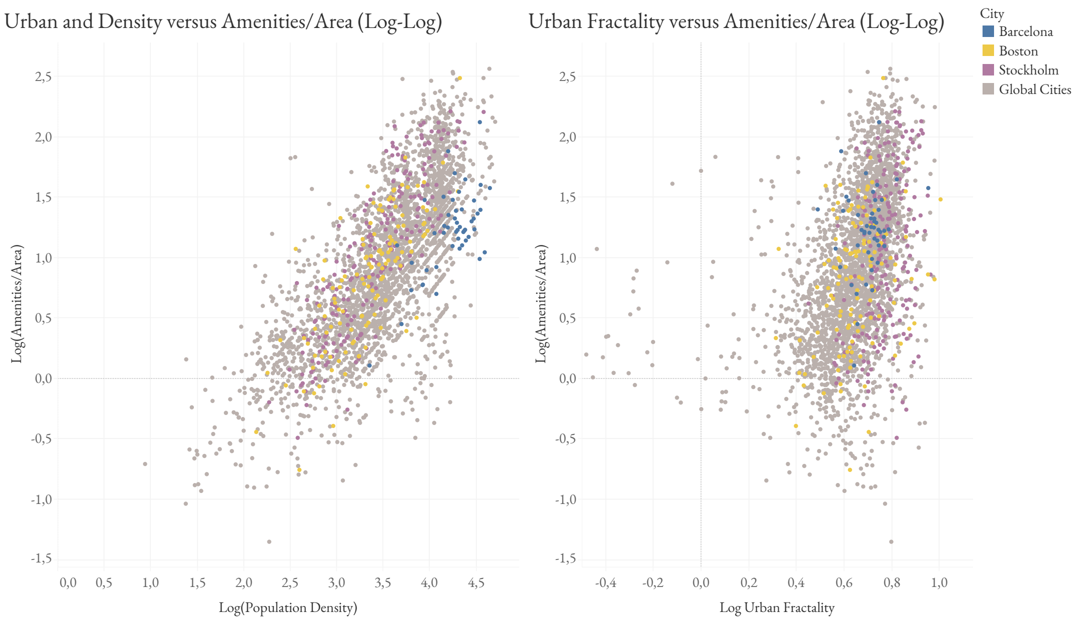
The urban areas or nodes with high closeness centrality can quickly interact with all other nodes, making them efficient spreaders of information or resources. Hence, the positive, nonlinear nature of the relationship between self-similarity and city form centrality becomes even more relevant.

In summary, the most efficient environments across all of the cities include areas that were recently developed during periods of urban development trends focusing on highly self-similar, harmonic, or fractal three-dimensional city form layout patterns. We can observe this phenomenon in many of the maps presented in this section. The top performing urban areas present high levels of city form fractality but also high levels of betweenness, straightness, and closeness. Often, these areas also have higher counts of amenities and public transportation options.

Insight 2: Desirable Urban Density Ranges Can Be Estimated for Each City and Context

The evaluation of urban density provided fruitful analytical yields: There is a positive, nonlinear relationship between urban density, urbanization efficiency, and access to services and amenities. The first factor to be taken into account is that, as a population increases, its demand for urban services and amenities also increases in a natural, 1:1 fashion. However, the level of urban density of a given urban environment structurally impacts the material infrastructure efficiency, the social interaction patterns, and the ability for citizens to reach critical services within walkable distance. The cost savings derived from increased density/scale are remarkable: Every time we double population density (2x growth), we observe on average a 19% sublinear increase in economies of scale in terms of access to amenities, all else being equal.

Figure 26. Urban Density and Fractality vs. Urbanization Efficiency (Log-Log)



By way of example, the areas with the highest density levels within Barcelona permit casual wanderers to access approximately 110 times more services and amenities. However, there are physical limits to urban density, and we considered the research efforts led by Ekmekci, Kalvo, and Sevtsuk (2016) when assessing the optimal building block size, according to the total population of a given city or urban continuum. Generally speaking, there is an incentive to adhere to compact urban design patterns, characterized by medium–high-density levels. Yet we can estimate desirable or optimal ranges of urban density, according to the total area and population of any given municipality.

The combination of the nonlinear relationships observed between urban density and urbanization efficiency, with the physical constraints or limits extracted from the academic studies of fellow researchers allowed for identifying desirable urban density values for each of the selected global cities. When analyzing the results of the density KPIs there are some key takeaways: The largest city by population is Barcelona, and the smallest is Boston. The largest city by area is Munich and the smallest is Barcelona. The most densely populated city is Barcelona, and the least is Amsterdam. However, when looking at future development, it is clear that many of the cities need to significantly increase their density. Munich should approximately triple its density. Amsterdam should grow around two and half times larger. Stockholm could potentially double its average density, particularly in areas currently dominated by single family housing or garden city development patterns. Boston should grow around one and half times larger, and Barcelona should remain at its current density levels. To achieve these results, it is critical to consider not just growth for the sake of growth but strategic growth that aligns with the economic and innovation metrics.

Table 12. Urban Density per City

City	Population	Area in km²	Density Population/km²	Desirable Density
Amsterdam	900,144	219	4,110	≈12,000
Barcelona	1,660,122	102	16,275	≈17,200
Boston	652,944	125	5,224	≈11,800
Munich	1,592,708	311	5,121	≈16,800
Stockholm	975,546	188	5,189	≈12,500

The nonlinear, convex pattern extracted from the analysis enables estimating desirable urban density ranges for each of the 160 municipalities across the Barcelona metropolitan region. Given that the ongoing Pla Director Urbanístic (PDU) contemplates demographic growth patterns in the order of 676,000 citizens and 475,000 new residential dwellings between 2024 and 2050, we estimated the desirable density ranges for each and every municipality across the seven *comarques*. The results shed light on the differential between desirable density values and current, legacy population density across the entire metropolitan region.

Overall, Barcelona presents density values relatively close to the ideal or target reference goals, yet the rest of the metropolitan region presents a high degree of heterogeneity. Some municipalities within the first urban belt or inner core of the metropolitan area (most notably, e.g., L'Hospitalet de Llobregat, Santa Coloma de Gramenet, Cornellà de Llobregat, or Badia del Vallès) present abnormally high-density values, remarkably higher than their optimal or desirable target values.

Figure 27. Current Population (Barcelona)

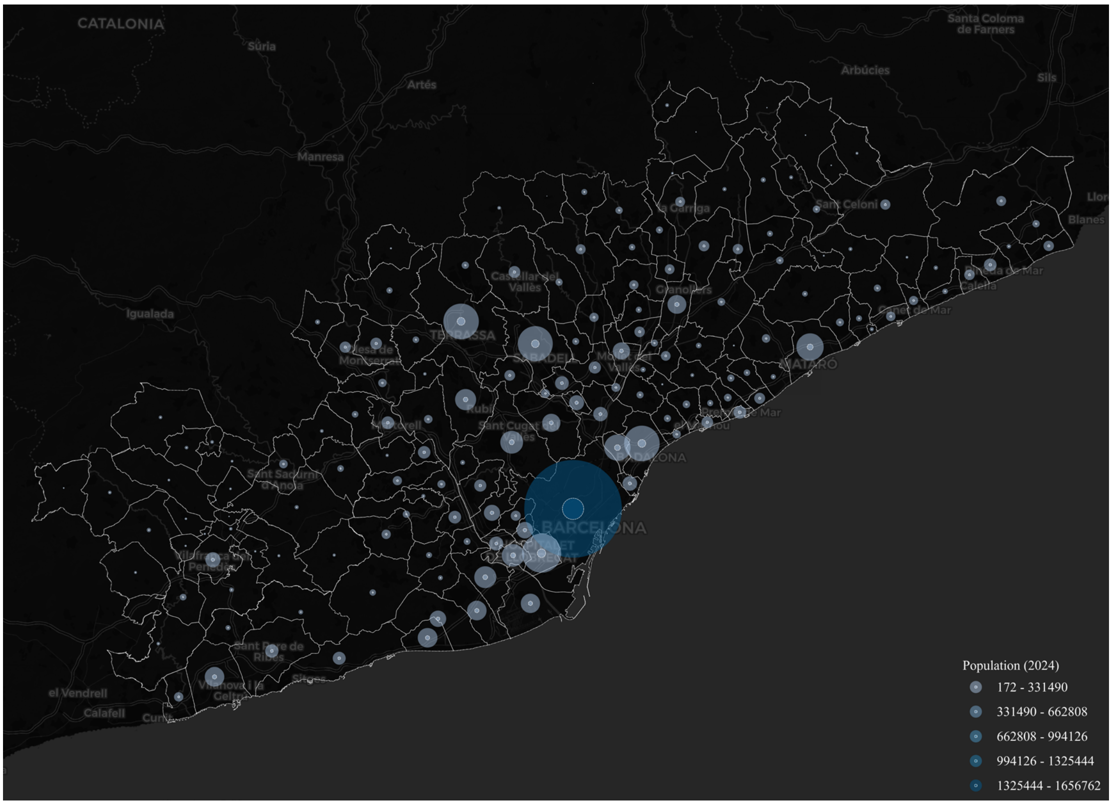


Figure 28. Ideal Population 2050 (Barcelona)—Current Density Differential

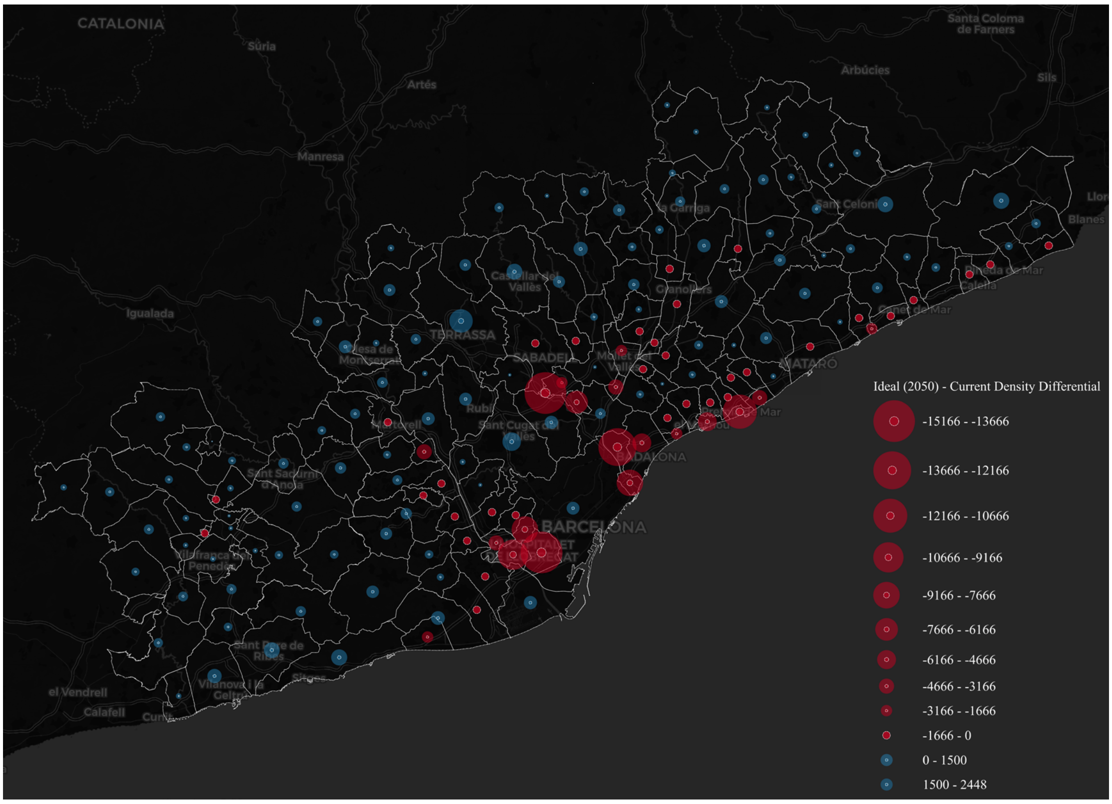


Figure 29. Ideal Population Growth Pattern (2024–2050, Barcelona)

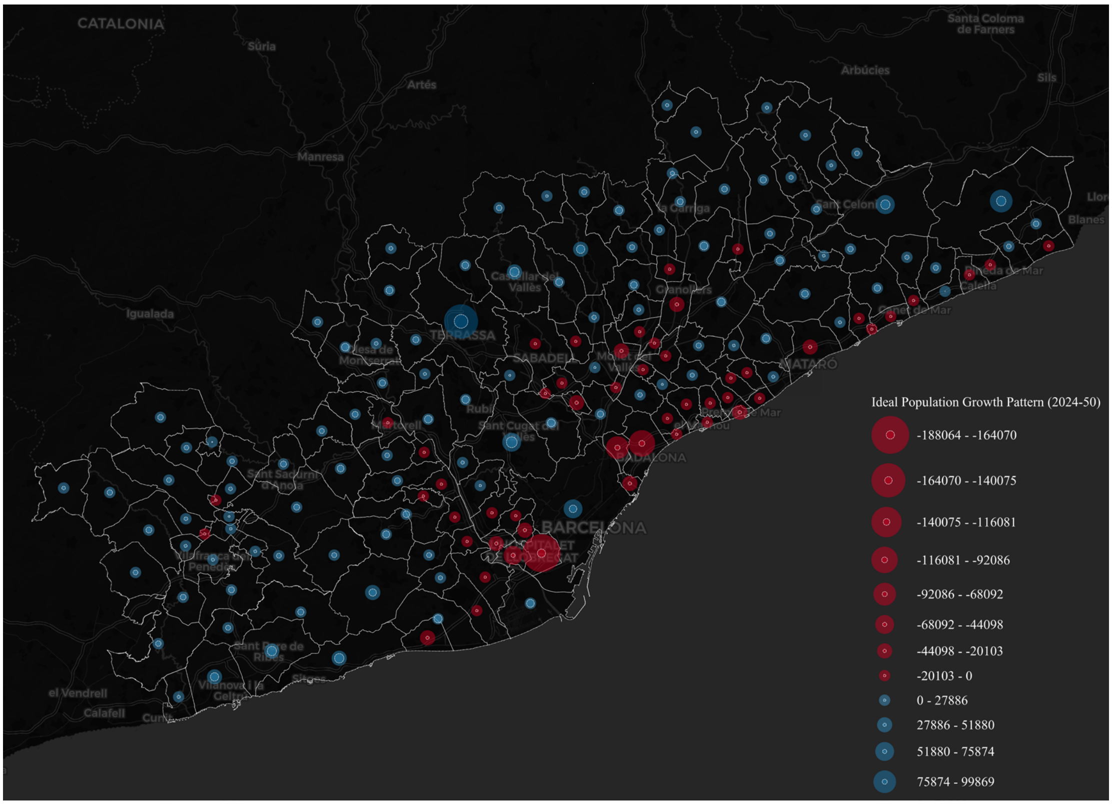


Figure 30. Ideal Target Population (2050, Barcelona)

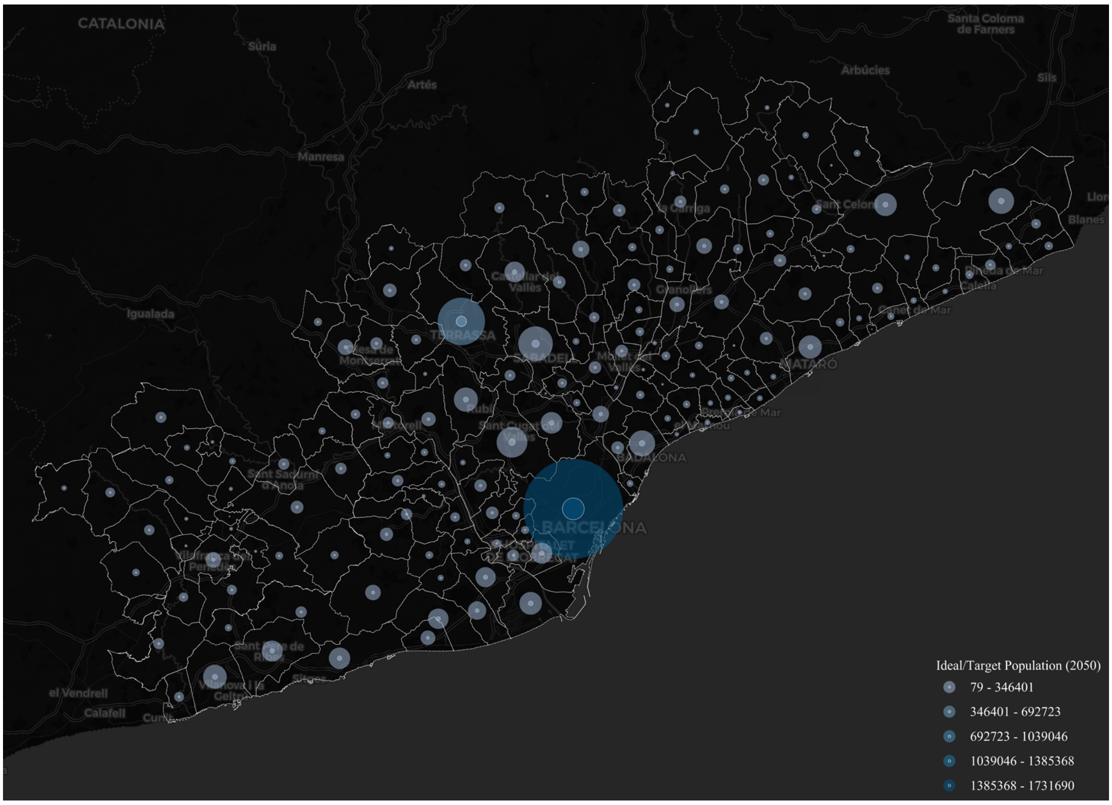
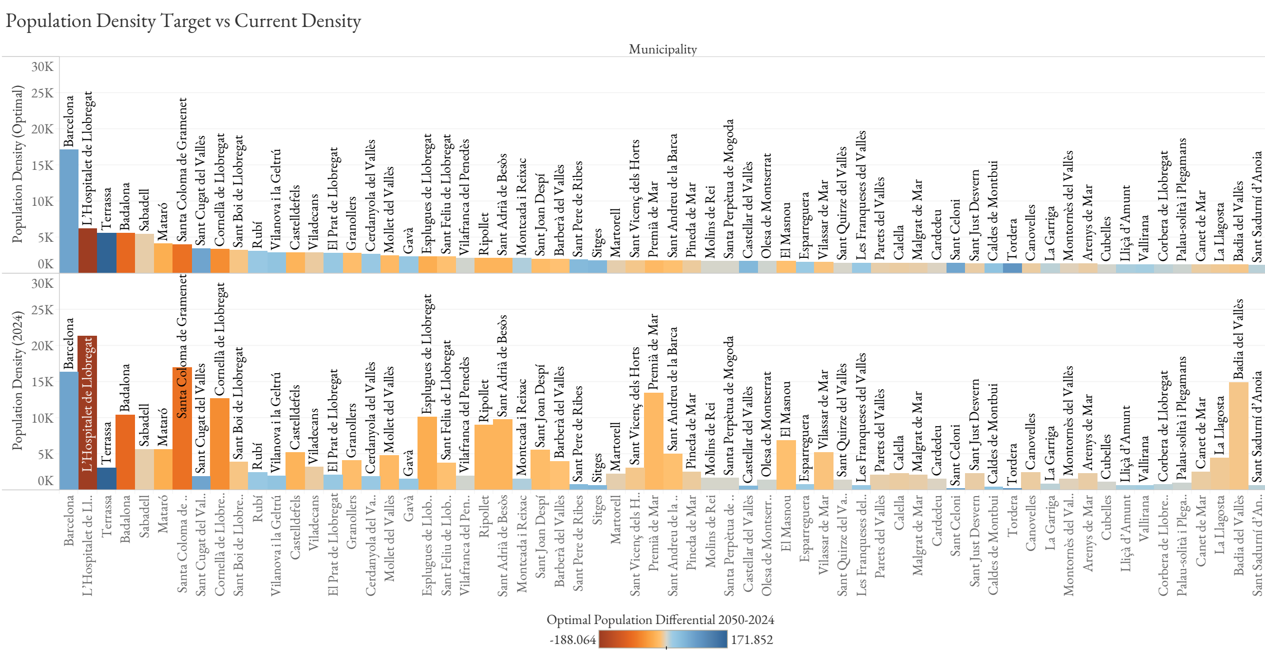


Figure 31. Desirable or Optimal Population Density vs. Current Density



On the other hand, some municipalities, primarily those belonging to the second urban belt, such as Sant Cugat del Vallès, Terrassa, Sant Celoni, Tordera, Sitges, Sant Pere de Ribes, or Begues, still present ample room for raising urban density levels to reach their ideal urban development goals.

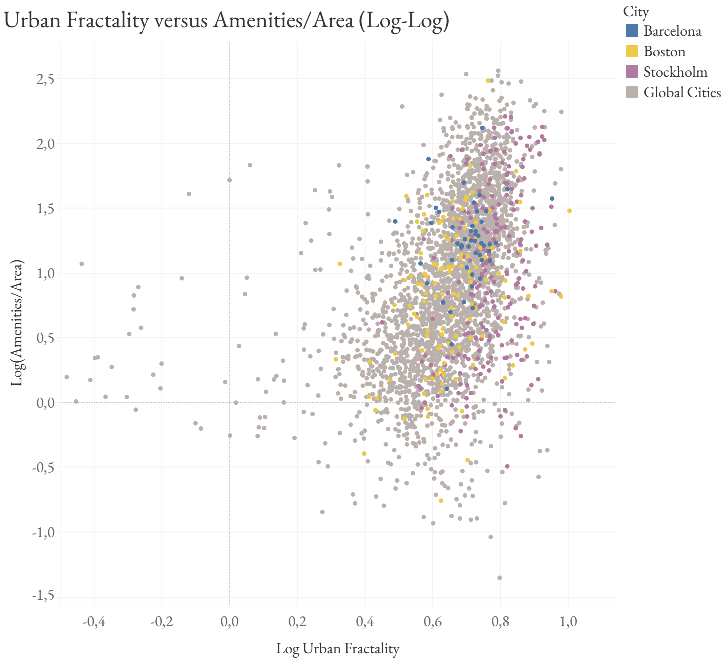
In conclusion, urban compactness tends to have vast structural effects on the subjective urban experience, yet there are some physical limitations to social interaction, depending on the total population size. Every time we double population density, we obtain an average of 19% gains in urbanization efficiency by means of economies of scale and higher access to urban services and amenities.

Insight 3: Urban Form Self-Similarity Increases Accessibility to Urban Services

From an urban sustainability standpoint, it is critical to discern the morphological patterns that can provide the most efficient use of scarce resources while mitigating negative externalities associated with urban development. When comparing the relationship between access to amenities with city form fractality, by doubling city form self-similarity or harmony, we can attain the same degree of access to critical urban services while deploying only 76% of the material resources. This reflects a savings of 24%, potentially diminishing the environmental impact associated with urban development. Furthermore, the fractal layout is the most sublinear of all typologies in terms of material infrastructure. This implies that it is the most efficient in terms of the use of space and materials for construction. This revelation is fundamental when deploying space programming and zoning policymaking strategies: If new districts are designed in a fractal or related typology style, it is possible to attain remarkably higher access to urban amenities—in the areas of education, healthcare, culture, leisure and entertainment, retail and commerce, green areas, among others—for the same or analogous level of built area.

Therefore, sustainable urbanization efficiency also grows with fractality. The chart depicted in this section describes the super linear effect. This is because of the fact that the geospatial organization of highly self-similar city planning systems allows for increased access to all nodes (or in an urban planning context, buildings and street intersections) by means of an intelligent, harmonious system of nested hierarchies of services. The embedded network properties allow for more route choices and close proximity of amenities to places of work or interest.

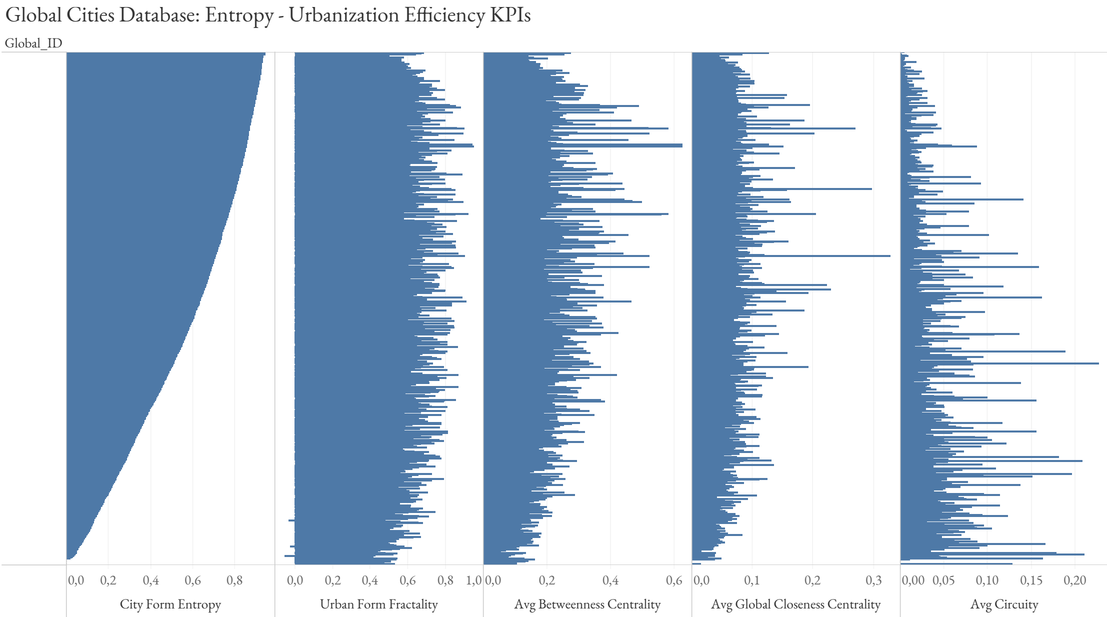
Figure 32. City Form Fractality—Amenities/Area (Log-Log)



Insight 4: Intermediate Urban Form Entropy Attains Maximum Material Efficiency

The Urban Form Entropy Index is correlated with urban development efficiency metrics; this this case, intermediate levels of city form entropy, around 50% in the normalized scale, and can achieve the maximum/optimal degrees of urbanization efficiency. The overall degree of city form regularity or specificity can be estimated by means of the urban form entropy metric. Highly rigid three-dimensional urban design patterns characterized by simple replicable patterns present low levels of entropy, whereas highly idiosyncratic, unique, and unpredictable city design morphologies present high entropy levels.

Figure 33. City Form Entropy vs. Urbanization Efficiency KPIs



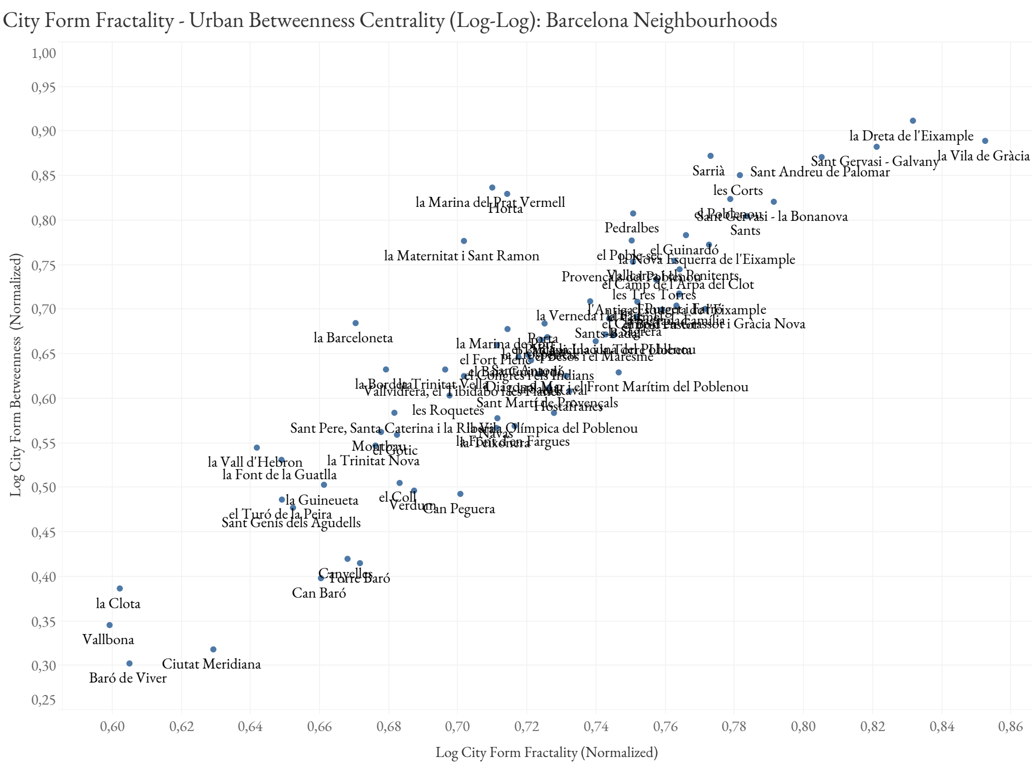
By evaluating the evidence-based relationship between urban form entropy and various urbanization efficiency KPIs, we can see that city planning patterns presenting an intermediate degree of city form entropy outperform both extremely high or low city form regularity values regarding urbanization efficiency patterns. Intermediate levels of urban form entropy (Shannon entropy order) present the optimal levels of urbanization efficiency, global closeness centrality, betweenness centrality, and urban form fractality. However, entropy is inversely correlated with network circuity, implying that a more rigid or highly ordered street layout pattern may contribute to increased overall mobility efficiency. In other words, a balanced combination of underlying distributed network regularity with a polycentric node and edge distribution presents the optimal features to maximize citizens' quality of life.

Insight 5: Nested Hierarchies of Innovation Spaces Create Prosperity

Urban design self-similarity structurally facilitates the types of social interactions required to drive a knowledge economy. Through a geospatial analysis of knowledge-intensive activities across an urban area, we can identify the core hotspots for intellectual advancement in a community. By measuring innovation KPIs across the cities of Amsterdam, Barcelona, Boston, Munich, and Stockholm, we can estimate the relative strength of each of the main three phases of innovation (research, technology transfer, and advanced production). Next, we can distill the missing ingredients and dynamics that would contribute to a high-functioning innovation environment that nurtures local talent and boosts a community's prosperity.

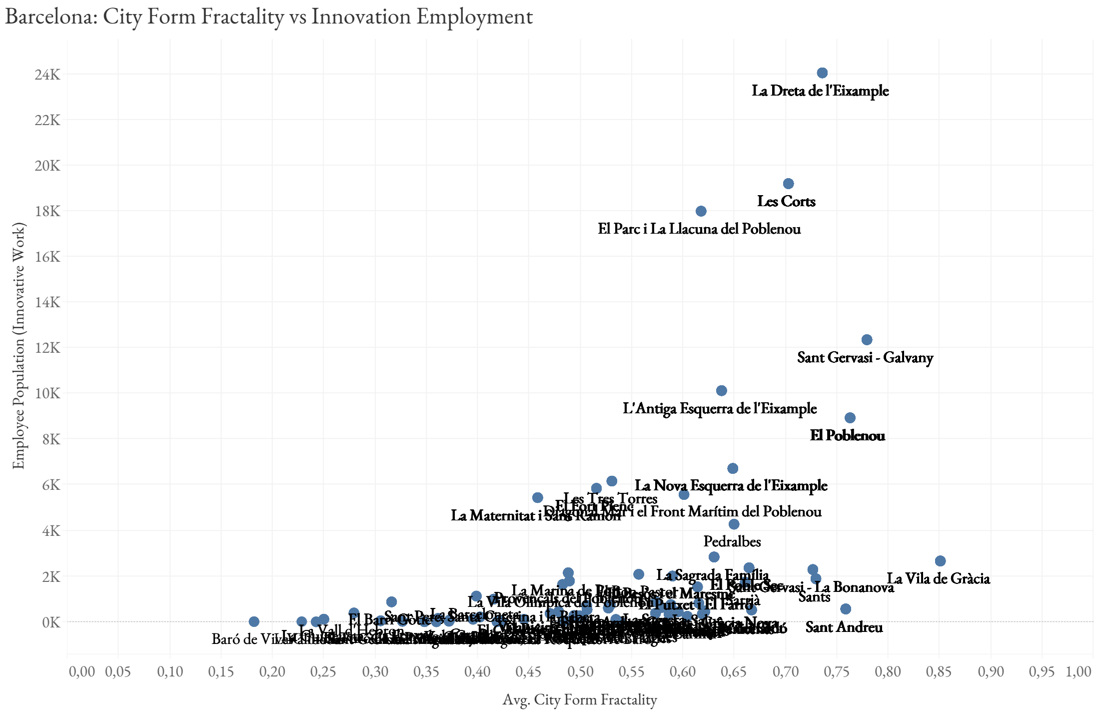
As explored in the *Atlas of Innovation Districts* (2019), the geographic concentration of knowledge-intensive activities, combined with an urban design strategy that provides support across the multiple phases of innovation and knowledge transfer mechanisms tends to facilitate the realization of the multiplying effects of the innovation ecosystem. The higher the urban design quality of a setting, the more dynamic and fruitful the social interaction patterns.

Figure 34. City Form Fractality Innovation Intensity Log-Log (Barcelona)



An analysis of the geospatial distribution of knowledge-intensive activities at the natural scale and city form fractality innovation shows a positive, nonlinear relationship between city form fractality and innovation performance.

Figure 35. City Form Fractality Innovation Intensity (Barcelona)



Goals and Strategies: Envisioning a Sustainable Urban Design Strategy

Goal and Strategy 1:

The first goal was to conceive of a fractal metropolis urban design vision for the Barcelona metropolitan region composed of self-similar morphological patterns and nested hierarchies of network edges (streets, roads, boulevards) and nodes (architectural spaces), aiming to reach average city form fractality of 75% and raising the average urbanization efficiency up to >80%.

A Vision for Barcelona's Future: Aspiring to Become the First Fractal Metropolis Worldwide

An urban design vision aiming to establish the very first fractal metropolis in the world will help the city, the metropolitan area, and broader region perform at their highest, drawing a three-dimensional urban fabric characterized by a high degree of morphological and land use self-similarity.

The underlying scale-free network patterns will provide the Barcelona metropolitan region with two major advantages: 1) a widespread, universal, egalitarian network that enables rapid commutes and accessibility to critical services and 2) nested hierarchies of architectural spaces and buildings allowing for realizing the multiplying effects of social interaction in urban settings. These spaces may encompass higher education institutions, high complexity hospitals and healthcare centers, commerce and trade, or logistics and supply chain management entities. Through the development of a shared vision, public–private partnerships (PPPs) can help multiple stakeholders work together effectively, aligning their incentive schemes and retrofitting collaborations.

How can a highly self-similar morphological pattern be achieved? An important approach is through scale-free networks that have self-similar morphological patterns. These emerge from mixed-use development strategies, where residential dwellings coexist with economic activity, commerce, and a vibrant local cultural scene.

Fractal Nodes Architectural Spaces	Fractal Edges Roads, Streets, and Walkways
Tier 1 Nodes: • Top tier research and academic centers, healthcare, commerce, cultural hotspots	**Tier 1 Edges:** • Metropolitan avenues • Global accessibility
Tier 2 Nodes: • Public administration and general interest private centers, providing district-level support	**Tier 2 Edges:** • Metropolitan streets • Boulevards that reinforce the centrality of the main nodes of the network
Tier 3 Nodes: • Leading private business hubs, by knowledge area, operating at the neighborhood/district scale	**Tier 3 Edges:** • Partially reticulated access and distribution network for essential services
Tier 4 Nodes: • Local service companies operating at the neighborhood scale	**Tier 4 Edges:** • Street network at neighborhood/district scale
Tier 5 Nodes: • Small and medium-sized companies • Constellation of suppliers and providers, operating at the street level scale	**Tier 5 Edges:** • Local network of pedestrian areas and walkways connecting architectural spaces that present synergies

An urban design vision for the Barcelona metropolitan region based on harmonious polycentrism can truly be transformative for the future economic and social growth of the area. By studying urban land use systems, economic geography and transport network connections, it is possible to identify new areas of the city that remain optimal for redevelopment as well as identify areas that will require specific urban design interventions, densification, infrastructure renewal, maintenance, and refurbishment, all of which will help meet the needs and demands of citizens and visitors.

To understand the latent potential economic development opportunities, we mapped the economic geography of the cities, here describing the economic diversity and innovation performance of each city, district, and neighborhood. When combined with real estate and land use analysis, it is possible to identify suitable areas for different types of interventions: street redesign, conceptual architectural design, redistribution of uses, densification, location of open spaces, and public transport nodes.

By way of example, some urban development interventions that would greatly benefit from the fractal metropolis vision, include, among others the following:

- The PDU “avingudes metropolitans” would become Tier 1 Metropolitan Avenue edges by reinforcing their centrality, connecting Tier 1 mixed-use development urban hubs.
- The PDU “carrers metropolitans” would become Tier 2 Metropolitan Street edges by reinforcing their centrality, connecting Tier 2 mixed-use development urban hubs.
- Northwestern urban renewal efforts: The up-and-coming migration of the top hospital in Catalonia, Hospital Clínic de Barcelona, from its current and outdated site in Eixample to the Alta Diagonal area, paired with the upcoming Esplugues innovation district.
- Southeastern urban renewal: Sant Adrià del Besòs and Badalona industrial fabric renewal.
- Besòs area industrial manufacturing regeneration: Bon Pastor, Torrent de l’Estadella, la Verneda and Verneda Industrial, Montsolís, La Sagrera.
- Representative Tier 1 architectural spaces devoted to regional-scale activities that are planned to be demolished or redesigned may include, among others, the following:
  — former Model prison complex in Carrer Entença
  — former University of Barcelona sports complex in Avinguda Diagonal
  — former Fira de Barcelona complex in Plaça Espanya
  — former Mercedes industrial complex in Bon Pastor-Sagrera manufacturing area
  — former Tres Xemeneies del Paral·lel
  — vacant singular spaces in the Eastern stripe of 22@ innovation district

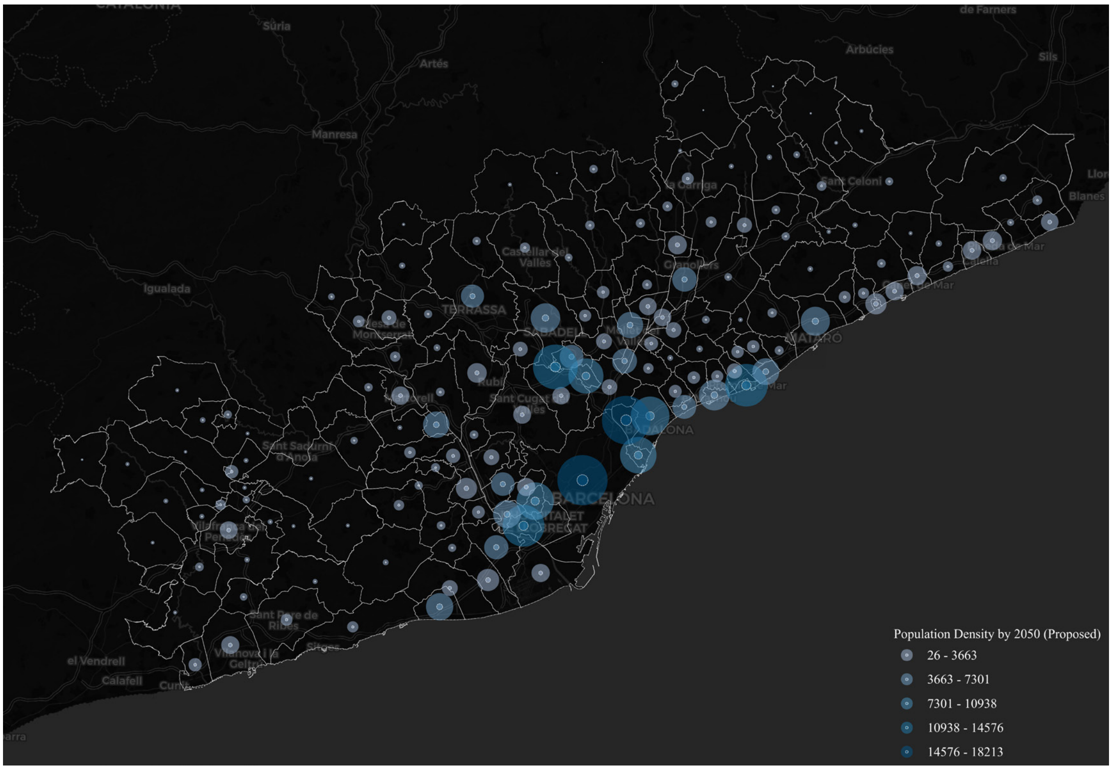
Table 13. City Form KPIs—Urban Design Desirable Target Values

City Form KPI	Desirable Range of Values
Urban Form Fractality	> 75% City Form Fractal Dimension (City Average) > 85% City Form Fractal Dimension (Tier 1 areas)
Urbanization Efficiency	> 80% City Form Fractal Dimension (City Average) > 90% City Form Fractal Dimension (Tier 1 areas)
Shannon Entropy	Between 0.4 and 0.6 Normalized Shannon Entropy Order
Avg. Betweenness Centrality	> 0.15
Avg. Global Closeness Centrality	> 0.085
Avg. Circuity Centrality	> 0.05
Avg. Straightness Centrality	Between 0.85 and 0.95
Avg. Building Tessellation Area	Approx 10–15
Avg. Building Tessellation Orientation	Approx 10–20

Goal and Strategy 2:

Urban density optimization: Envision a geospatial growth pattern tailored for each of the 160 municipalities of the metropolitan area, aiming to accommodate 676,000 citizens and 475,000 dwellings, following sustainable growth patterns and informing smart allocation of new residential areas. Currently, 51 municipalities exceed their optimal density, and 109 present substandard values.

Figure 36. Proposed Population Density (2050, Barcelona)



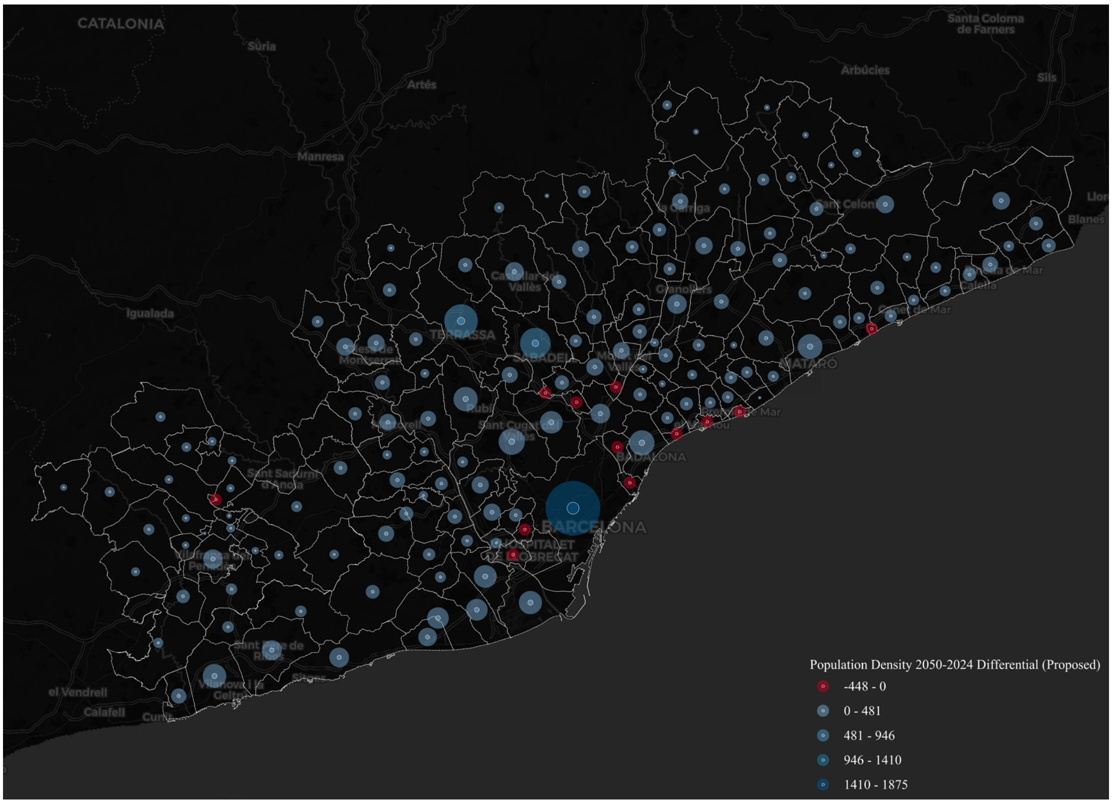
To meet the need defined by the demographic projection of the *Pla Director Metropolità* (2023) to provide 475,000 new residential dwellings for 676,000 citizens between 2024 and 2050, we performed a resource allocation optimization.

The optimization simulation we carried out indicated that approximately 51 of the 160 municipalities of the Barcelona metropolitan area currently exceed their optimal/target density values. In fact, some of them far exceed their desirable values, such as the following:

- L'Hospitalet de Llobregat: 21,300 instead of optimal 6,200 residents / km^2
- Santa Coloma de Gramenet: 17,000 instead of optimal 3,900 residents / km^2
- Badia del Vallès: 14,900 instead of optimal 1,900 residents / km^2
- Premià de Mar: 13,400 instead of optimal 1,800 residents / km^2
- Sant Adrià del Besòs: 9,800 instead of optimal 1,900 residents / km^2

The recommended strategy for optimal density is the result of integrating the optimization model with constraints imposed by the legacy infrastructure and urban development mismanagement and malpractice carried out in recent decades. Because the newly proposed development financial efforts could ascend up to 150B euros between 2024 and 2050, it is critical to carefully allocate the growth to balance the current inequalities and unsustainable practices. Assuming that the massive demolition of currently inhabited buildings may represent an unlikely and highly controversial scenario, at least in the short term, an alternative strategy has been proposed that aims to attain figures closer to the theoretical ideal for the cities that still have ample room for densification while mitigating the most conflictive cases.

Figure 37. Proposed Population Density Differential (2050–2024, Barcelona)



Key urban density recommendations include the following:

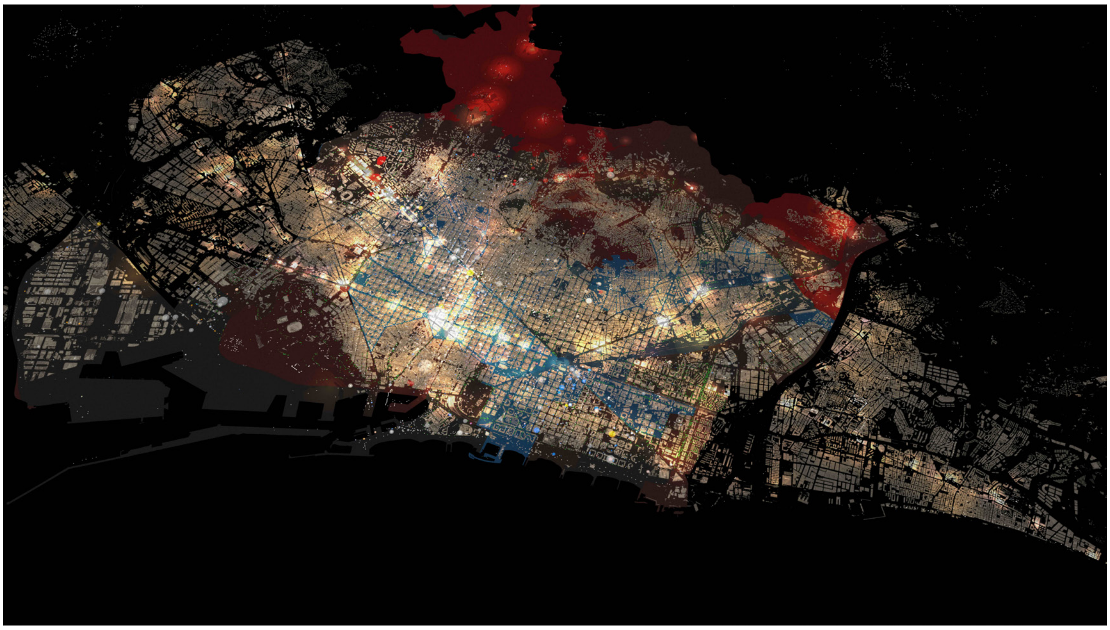
(1) Increase the level of density of Barcelona from the current 16,339 up to 18,214 by 2050.

(2) Stabilize, freeze or diminish density ranges in cities already exceeding its optimal, particularly in the first urban belt and coastal area (such as l'Hospitalet, Santa Coloma, or Badia).

(3) Increase the density of the second urban belt, such as Terrassa (from current 3,142 up to its optimal 3,848), Sant Cugat del Vallès (from current 1,888 up to its proposed 2,323), Tordera (from current 205 up to 400), Sitges (from current 669 up to 915), and Sant Celoni (from current 275 up to 472), among others.

Goal and Strategy 3:

Activity Programming and Zoning: Establish a zoning and programming strategy following a scale-free geospatial distribution, with amenities of order 1 located in tier 1 areas; subsequently, the more sophisticated and complex the activity, the more concentrated it will be.



From a sustainability standpoint, the more self-similar an urban design configuration is, the more enhanced the social interaction will be. At the same time, resource consumption and future emissions will be reduced. Hence, the key design criteria for achieving the proposed objectives include the alignment of the fractal distribution of the urban form (topology, morphology, entropy, self-similarity) and services of a "self-similar" nature, where services are reproduced in different scales geospatially.

This assumes a balanced or harmonious distribution of services offered to the population that can help optimize and minimize value creation (freedom, interaction, opportunity) and value capture (equal distribution of critical services and sustainable development). In addition, urban topology design criteria can help reinforce the mobility and accessibility strategy, thus increasing sustainable mobility. Urban morphology can be measured to strategically design the nested hierarchies of architectural spaces, here based on intermediate levels of entropy and high compactness to combine the efficiency of urbanization with flexible socialization. This strategy will help support the knowledge economy based on innovation value chains that are rooted in comparative advantage and wider access to critical services while increasing sustainable development practices by reducing air pollution, travel times, car dependency, and more efficient energy/water systems.

Representative examples of nested hierarchies of zoning and activity programming can be described as follows:

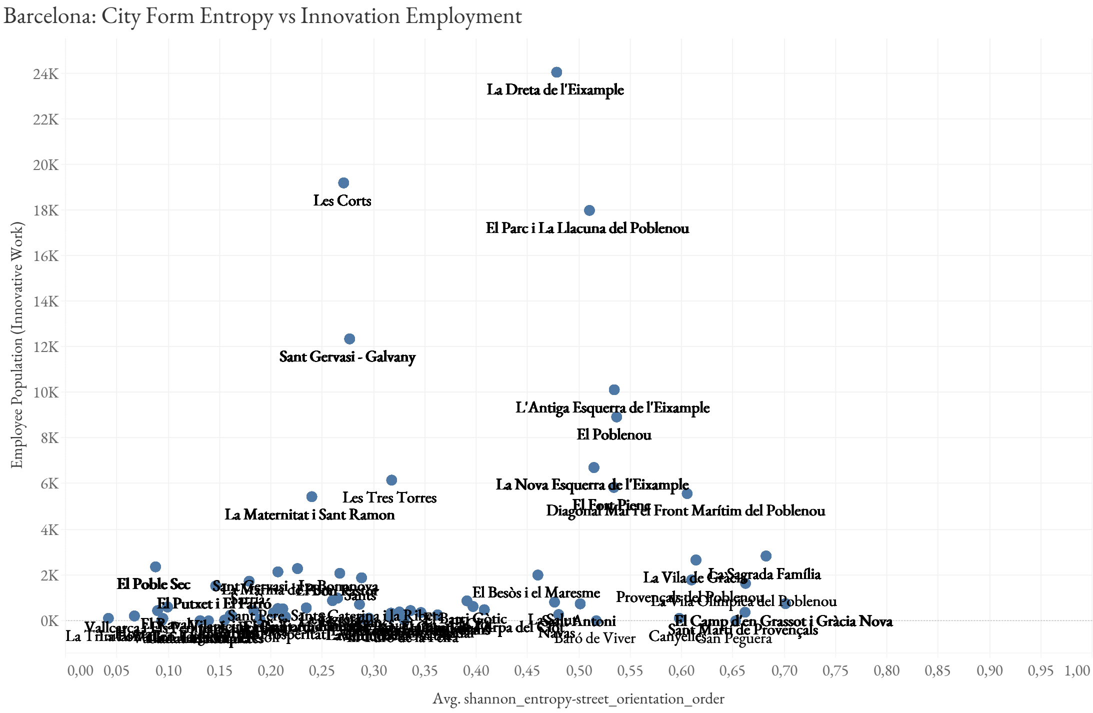
- Education
  - Tier 1: World-class research agencies and academic support infrastructure
  - Tier 2: Applied research centers, laboratories, and medical research institutions
  - Tier 3: Universities and professional training centers
  - Tier 4: High schools and secondary education
  - Tier 5: Local kindergarten, primary schools
- Healthcare
  - Tier 1: World-class hospitals and medical facilities
  - Tier 2: Top general clinics
  - Tier 3: Socio-sanitary and topic-specific clinics
  - Tier 4: Mental health centers
  - Tier 5: Primary care centers and facilities
- Culture
  - Tier 1: World-class cultural and exhibition centers
  - Tier 2: Top art galleries and museums
  - Tier 3: City-level cultural venues and historic landmarks
  - Tier 4: District-level cultural centers, libraries, and theaters
  - Tier 5: Neighborhood level cultural centers, libraries, and theaters
- Businesses and Innovation
  - Tier 1: World-class innovation institutions, whether public or private
  - Tier 2: Topic-specific business leading firms and corporations
  - Tier 3: City-level private companies
  - Tier 4: District-level businesses and services
  - Tier 5: Local service businesses, suppliers, and providers

Generally speaking, the more basic or less complex the activity, the more territorially widespread it should be distributed to provide universal access to all citizens. The more sophisticated the activity, the more geographically concentrated it needs to be to benefit from agglomeration and complex network dynamics around topic-specific hubs.

Goal and Strategy 4:

Entropy: Create an urban design strategy embedding intermediate urban entropy values between 45% and 55% in all new urban developments and resource allocation strategies.

Figure 38. City Form Entropy vs. Innovation Intensity (Barcelona)

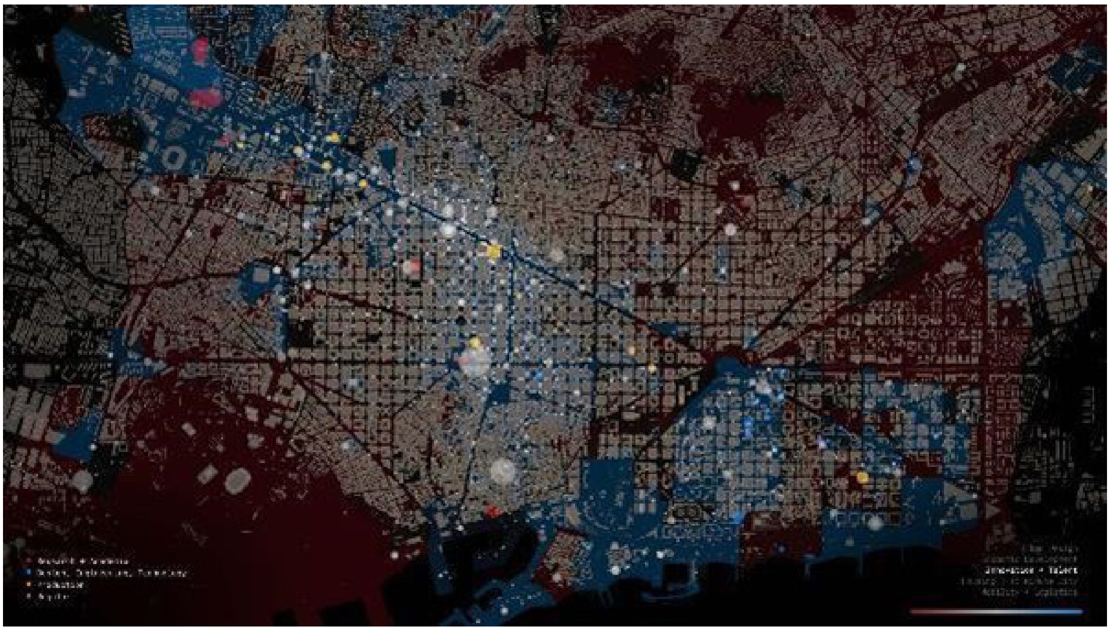


The analysis of the various city form entropy values observed within the different Barcelona neighbourhoods reinforces a core city science hypothesis: when assessing the optimal / desirable urban form entropy values between 0 (highly rigid reticular street layouts such as Barceloneta, Gràcia, or Camp d'en Grassot) and 1 (highly loose street layouts and building form , such as Guinardó, Putxet, Raval, or Ciutat Meridiana), we observe the most efficient urban configurations tend to present intermediate degrees of city form entropy: approximately 48–52% in terms of Shannon Entropy index. In other words, urban areas presenting intermediate city form entropy values (representing a balance between liberty and order, such as Dreta de l'Eixample, Parc i Llacuna del Poblenou, L'Antiga Esquerra de l'Eixample, Sant Gervasi and Bonanova) systematically outperform neighborhoods with extremely high or low entropy values, whether we refer to highly rigid reticular grid or highly loose networks following organic growth patterns.

Harmonically integrating intermediate levels of city form entropy with highly fractal design patterns will dramatically increase the overall quality of the urban design solutions and the proposed configurations.

Goal and Strategy 5:

Urbanism propelling prosperity and the knowledge economy: Create a network of innovation districts that are strategically located near the top research centers, hosting the physical spaces providing support to raise knowledge employment from 125,000 up to 200,000 in the upcoming years.



As we can observe, currently, there is a highly unbalanced geospatial distribution of knowledge-intensive activities. On the one hand, during the first phase of innovation, research is highly concentrated in the upper diagonal area yet is essentially disconnected from the second phase (tech transfer, design, engineering, technology), which is currently clustered around the 22@ innovation district in Sant Martí- Poblenou. Finally, the third phase—advanced production—is scattered around legacy manufacturing sites (Besòs area industrial clusters, legacy 22@ areas, Port of Barcelona area, among others), being exceedingly distant from any physical interconnectivity principle. Finally, even the respective industrial sectors are highly atomized. The main pharmaceutical companies are distributed across multiple distant sites, such as Ronda del General Mitre, l'Hospitalet, Badalona, and the Besòs area, among others. We can observe similar patterns in traditional sectors such as automobile manufacturing and mobility, urban design and construction, food production, and industrial design and manufacturing services. Hence, it does not come as a surprise, as we describe in the following sections, that the knowledge economy scene in Barcelona is highly disjointed and struggles to realize the multiplying effects associated with successful innovation ecosystems that support the local talent.

Envisioning, conceiving, designing, planning, building, and nurturing a constellation of strategically located innovation districts would allow the Barcelona metropolitan region to revamp its knowledge economy, hence balancing the territorial unevenness and creating tens of thousands of high value-added job opportunities for its citizens. The most promising candidates for hosting innovation districts include the following:

- Esplugues- Porta de Barcelona (110 Ha), which links the new development with pre-existing institutions across the Sarrià-Bonanova area between Esplugues and Barcelona. The Zona Alta diagonal/Esplugues area holds great promise in becoming the top research/academic innovation district in Catalonia and a world-class talent magnet able to liberate latent economic development forces and create distributed prosperity.
  - Esplugues: Porta de Barcelona corridor crossing Can Cervera, Can Pelegrí, Can Vidalet, Can Clota, Can Oliveres, and Finestrelles
  - Barcelona: New Hospital Clínic campus in Diagonal Avenue, with connections with public and private research institutions in Pedralbes, Sarrià, Bonanova
  - Masterplan: Masterplan i Estratègia de desenvolupament urbanístic i econòmic de l'àmbit d'oportunitat Porta de Barcelona, Esplugues de Llobregat (2023)
- Barcelona-Besòs area (140 Ha): Urban regeneration of five industrial clusters (Bon Pastor, La Verneda, Verneda Industrial, Montsolís, Torrent de l'Estadella) between Barcelona and Sant Adrià del Besòs. The Barcelona-Besòs River area is undergoing a substantial urban redesign and renewal process in the Bon Pastor and Sagrera areas. The Besòs area currently hosts four clusters of industrial manufacturers that present a level of outdated urbanization and strong limitations in terms of accessibility and common workspaces necessary to generate synergies between companies and institutions. The Besòs area can become a new high impact innovation district for the city.
  - Bon Pastor, Torrent de l'Estadella, Montsolís, La Verneda, La Verneda Industrial
  - Masterplan: Masterplan – Estudi d'Estratègies de Desenvolupament Urbanístic i Econòmic dels Teixits Productius i Teixit Industrial del Besòs del Municipi de Barcelona (2022)
- Badalona i les Tres Xemeneies (240 Ha): Urban regeneration of legacy industrial parks: Polígon Sud, El Sot, les Tres Xemeneies, Polígon Nord. The Badalona and Tres Xemeneies area is also a privileged area for redevelopment as well as for certain properties on the city's seafront.
  - Polígon Sud, El Sot, les Tres Xemeneies
  - Polígon Nord, Les Guixeres, BCIN Complex
  - Montigalà, Bonavista, Pomar de Dalt, IGTP/Josep Carreras/IrsiCaixa/Guttmann
  - Masterplan: Masterplan Urbanístic i Econòmic de la Ciutat de Badalona Servei de redacció del treball de definició de la transformació econòmica i urbanística de Badalona

Urban Development Supporting the Knowledge Economy—Benchmarks and Estimates

Table 14. Proposed Urban Development Benchmarks (Barcelona Area)

Barcelona-Besòs Innovation District	• 140 Ha • 451,950 m^2 of new development • Aggregate annual urban area GDP to grow from — €1.25B (2024) up to €5.5B by 2040–45 • Capex investment: approximately €7B
Badalona Innovation District	• 240 Ha, with a particular focus on 120 Ha in P. Sud and 3X • 735,180 m^2 of new development • Aggregate annual City GDP to grow from — €4.32B up to €8.87B by 2040–45 • Capex investment: approximately €6B
Esplugues **Porta de Barcelona** **Innovation District**	• 109 Ha • 761,550 m^2 of new development • Aggregate annual urban area GDP to grow from — €1.43B up to €6.12B by 2040–45 • Capex investment: approximately €6B
Summary	• €21B to generate approx. 75,000 new employment opportunities and approx. 60% innovation-intensive jobs (upwards of 50,000), hence contributing to raising knowledge-intensive employment from 125,000 up to 200,000.

Challenge 2:

Nurturing Urban Economics and Prosperity

Challenge 2: Nurturing Urban Economics and Prosperity

Economic Development and Smart Specialization

The field of knowledge economics has experienced a major revolution in recent years. Significant scientific advances have been made since the turn of century by the Harvard Kennedy School's Growth Lab, led by Ricardo Hausmann together with the MIT Collective Learning group, and later at the Artificial and Natural Intelligence Toulouse Institute, led by César Hidalgo, here in collaboration with world-class researchers such as Albert-László Barabási and Ron Boschma, among others.

The economic complexity field is a revolutionary data science domain aiming to characterize the collective knowledge of communities worldwide, compare them in an analogous manner, trace their evolution over time, and extract decision-making recommendations based on best practices. The model has been eloquently depicted in the *Atlas of Economic Complexity* (Harvard University) and the *Observatory of Economic Complexity* (Massachusetts Institute of Technology), which highlight the core strengths of countries and nations around the globe through the lens of network theory.

Building on this solid framework, the Aretian team developed a city-scale economic complexity analysis methodology. This methodology expands the original approach by territorializing the analysis at the city scale and combines HS (product exports) with NAICS industry classification datasets of geospatially based business datasets (service) by deploying artificial intelligence modeling techniques at the urban scale. The urban economic complexity methodology is illustrated in *City Science: Performance Follows Form* (2023) and *the Atlas of Innovation Districts* (2019).

The methodology starts from the perspective that economic growth requires the accumulation of capabilities. The neoclassical theory of economic growth assumes that these capacities can be aggregated in an additive fashion, hence building stock. The larger the stock, the larger the flow of output in a given period. This theory has some drawbacks. In the first place, data show that sustained economic growth can be explained mostly by technological improvements instead of factor accumulation. Second, knowledge stock is more complex than additive theory and must consider the complementarities in the accumulation of human capital. One solution comes from the application of network theory. Knowledge is distributed across people. Technology is not an aggregate value but a combination of this distributed knowledge. As a result, countries or regions with more knowledge can produce a larger variety of products; they will be more diversified. In the same fashion, few countries and regions will be able to produce complex products. These regions will have more knowledge and higher diversification than those producing less complex products. As a result, there is an inverse relationship between the diversification of a region and the complexity of its exports. Regions with a larger stock of knowledge have more diversity and produce goods that are more complex and less ubiquitous (produced by few regions).

A community's network science-based collective knowledge is reflected by service (NAICS codes) and export-oriented industrial manufacturing products (HS codes). There are two major predictors of economic success in terms of collective know-how: 1) levels of diversity and 2) sophistication of products and services produced by a given community. A combination of a highly diverse (resilient, adaptive, flexible) economic base with highly complex (sophisticated, unique, non ubiquitous) products and services is an extremely reliable predictor of the prosperity of any community.

Economic Complexity and Evidence-Based Smart Specialization

Economic complexity (PCI) is a measure of sophistication and value added by industry. A firm with a high value in economic complexity produces a service or product that is internationally competitive, is relatively unique, and exports more than its fair share when compared with other competitors. As a result, economic complexity correlates strongly with niche and sophisticated products and is a predictor of future growth. There are 848 4-digit NAICS service codes describing the entire economic base of any city and up to 775 4-digit HS codes describing the total range of export-driven manufacturing products. We can compute for each city the Product Complexity Index (PCI) specific to that area, signaling the level of refinement or sophistication achieved by that sector or subindustry.

Product proximity (Product Density Index, PDI) conveys the distance between the current portfolio of industries surrounding any city and those industries that are "within reach" to currently activated nodes within the network. Product proximity or density estimates the density of an industrial value chain. For instance, the BMW automobile complex in Bayern, Germany, is well known for concentrating over 70% of its value chain, particularly the most sophisticated and complex activities, within less than 50 km of Munich. This approach allows the automobile sector in Munich to present a long value chain—from industrial designers, manufacturers, automobile part suppliers, and mobility software engineers to engine experts. Generally speaking, the higher the PDI, the stronger the supply chain, and the easier to accumulate and expand the collective know-how by leveraging the benefits of information and knowledge exchange across multiple phases of the production value chain.

The smart specialization strategy (SS) illuminates strategic sectors within any city and its broader environment as desirable targets for the foreseeable future. To this end, we classify industries according to two main metrics—economic complexity and proximity—which will allow for the identification of successful and high performing industries.

An **RCA** summarizes the level of global competitiveness of any industry. Generally speaking, the larger the critical mass (economies of scale), the product density values (economies of scope), and the product complexity indicators (refinement/uniqueness of the service or product), the stronger the competitiveness of that industry in the global arena will be.

A **four quadrant analysis** enables the visualization of the relative position of any sector and subindustry within the overall economy, providing insights into both the overall service industry scene (NAICS codes) and the export-oriented manufacturing scene (HS codes).

- 1st quadrant: Thriving industries, combining high complexity (PCI>0) and density (PDI>0); these are the best sectors for continued growth and leading economic development and prosperity creation. Quadrant 1 sectors are destined to lead the economy of any city and smart specialization efforts.
- 2nd quadrant: Traditional and stagnant; these are often legacy industries that may not be the most sophisticated, but they provide a solid foundation, combining high degrees of density (PDI>0) with relatively low complexity (PCI<0). They can potentially be at risk if they do not invest in innovation efforts.
- 3rd quadrant: Emerging industries; these are typically relatively young sectors that combine high complexity (PCI>0) with relatively underdeveloped density (PDI<0). Reinforcement of industries' value chains and critical mass growth tend to be prerequisites for 3rd quadrant industries to grow.
- 4th quadrant: At-risk industries; these are typically industries that combine low complexity (PCI<0) with low density (PDI<0). Therefore, these industries could potentially be exposed to major risks, such as outsourcing or aggressive commoditization. A combination of complexity efforts (innovation investment) and density efforts (value chains) can activate and dynamize these industries.

We can analyze, evaluate, and rank the (NAICS) industries available in Amsterdam, Barcelona, Boston, Munich, and Stockholm according to the PCI and PDI metrics, selecting the subset of industries that are both high in economic complexity and proximity. The results are shown in the figures below. There is a significant overlap between the strategic industries in Barcelona and the other four cities. They are strategic because they use many of the capabilities and resources that are abundant in the area and also provide high value added for the economy because of their economic complexity. As a result, these are attractive sectors to consider both from a growth and low-risk perspective.

Figure 39. Product Space-Network Visualization of Economic Sectors and their Interrelationships

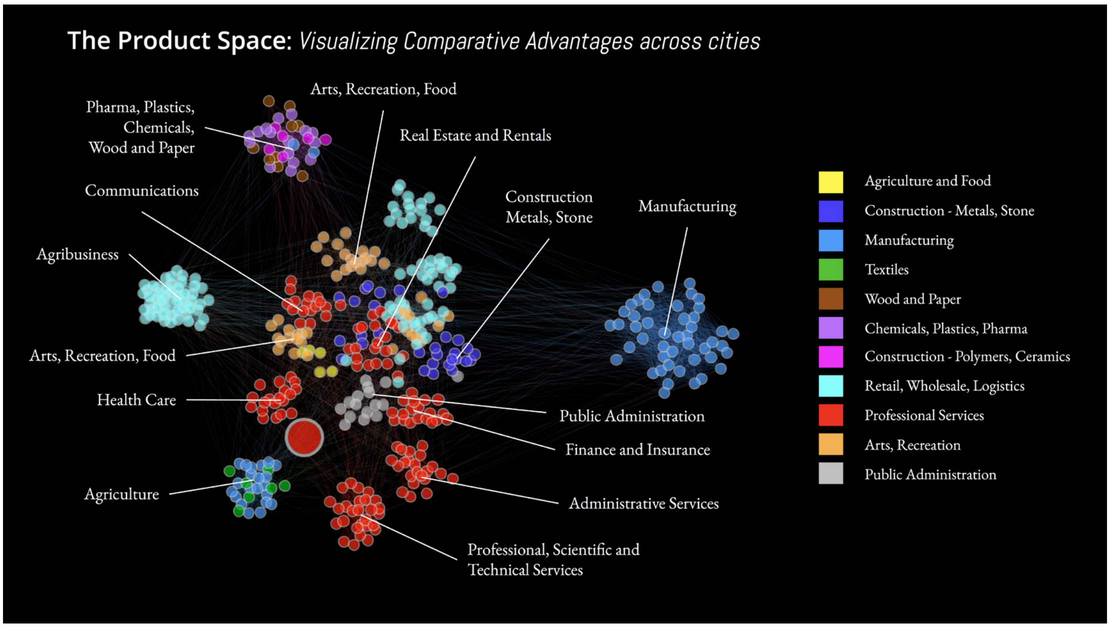
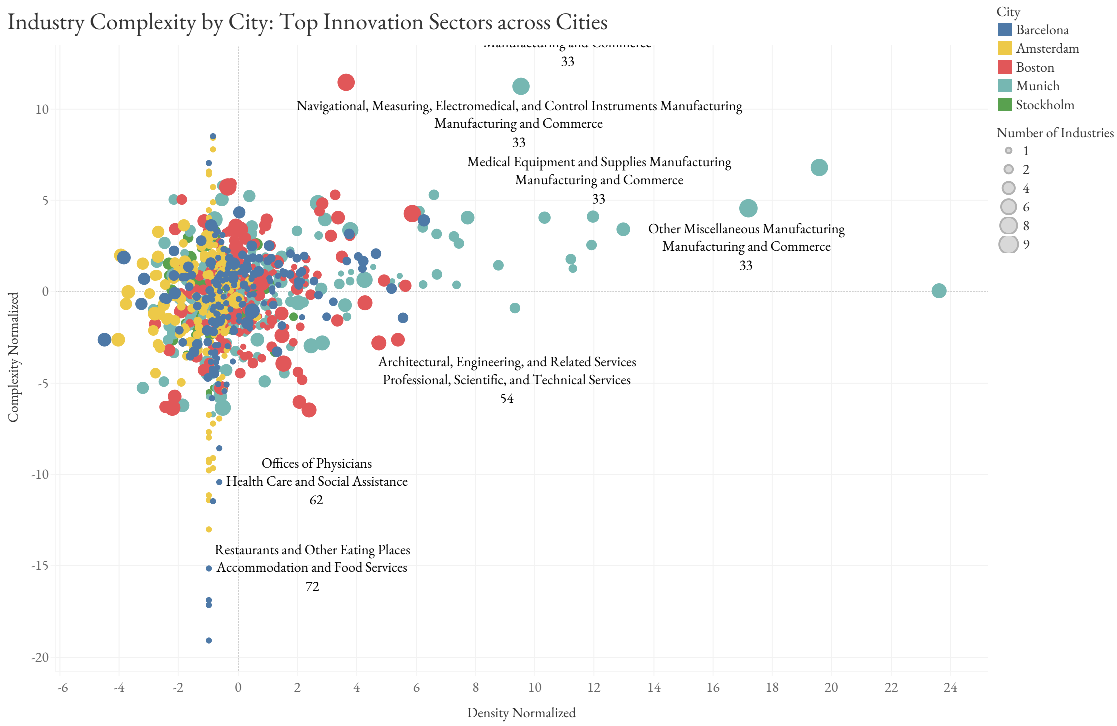


Figure 40. Smart Specialization—Scatter Plot Visualization Describing the Relationship Between Economic Complexity and Industry Density Across Cities



Insights - Nurturing Urban Economics and Prosperity

Insight 1: High Product Density and Complexity Generates Sustained Prosperity

A combination of a highly diversified economy (PDI, resilience, adaptability) and sophisticated/complex (PCI) products and services creates the optimal combination to achieve global competitiveness (RCA), increase exports, well-remunerated employment, and prosperity.

The five strategic cities and their main identified strengths are detailed in the table below. The results of the economic complexity analysis allow for classifying any industry within a city across density, complexity, revenue, and RCA. As a result, recommendations can be tailored for each sector and city.

Table 16. 5 Global Cities—Summary

Barcelona	The largest city in the group by urban and metropolitan population, Barcelona, presents a widely diverse manufacturing scene, holding the promise of becoming a design, technology, biomedical, and advanced manufacturing export and commerce hub thanks to its strategic location and latent knowledge base in maritime trade. However, in relative terms, Barcelona ranks 5th and last when compared with Amsterdam, Boston, Munich, and Stockholm.
Munich	Also a large city by population and extension, Munich has an important technological hub including IT, software development, and electronics. In addition, the automotive, finance, and insurance sectors are also noteworthy. Munich is the leading city of the selected global cities in terms of economic complexity and diversity and can serve as a source of inspiration for best practices.
Boston	Boston is famous for the presence of globally prestigious universities that feed the pool of talent of the city. In particular, education and healthcare are thriving economic sectors, along with finance and technology and biotechnology and life sciences.
Amsterdam	Amsterdam has thriving creative and technology sectors, such as design, advertising and media, and software development. At the same time, Amsterdam is a prominent financial and business hub, hosting the Amsterdam Stock Exchange and being the headquarters for various international companies.
Stockholm	The capital of Sweden, Stockholm, is known for its vibrant tech and innovation ecosystem. The city is home to numerous startups, tech companies, and innovation hubs. Stockholm has a well-developed financial sector, including banking and financial services and a strong presence in the life sciences and biotechnology sectors.

Amsterdam

Figure 41. Product Space (Amsterdam)

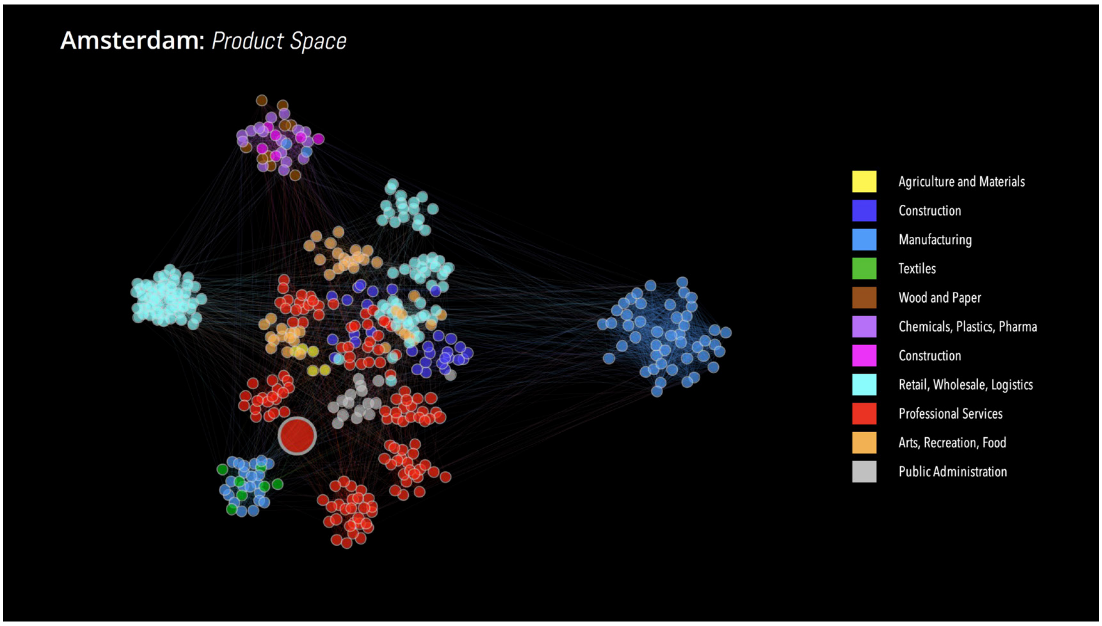
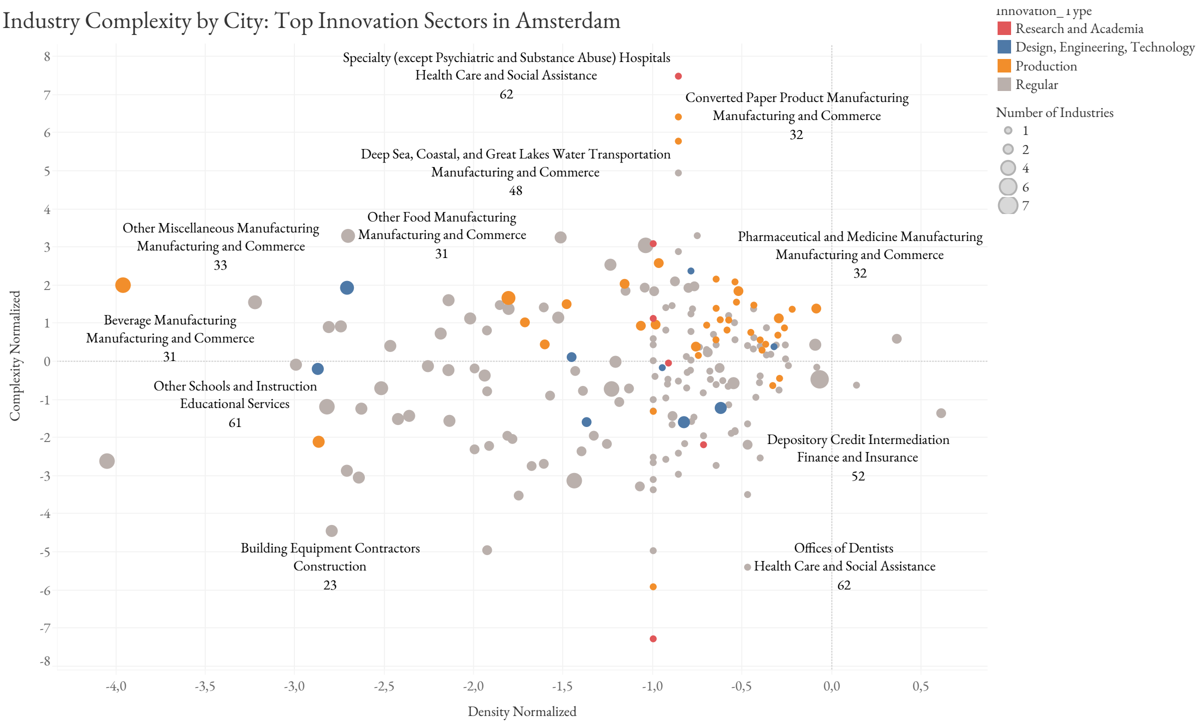


Figure 42. Smart Specialization (Amsterdam)



Economic Base Overview

Amsterdam presents an ecosystem composed of 345 industries and 84 innovative industries:

- Total Service Industries: 345 out of 848 total number of potential industries
- Total Revenue: €90.701M
- Total Innovative Industries: 84 out of 184 innovative industries
- Total Innovative Revenue €29.024M (32% of total revenue)

Economies of Scale

- Top Industries in Revenue:
  — Management of Companies and Enterprises
  — Wholesale Trade
  — Professional, Scientific and Technical Services
  — Finance and Insurance
  — Manufacturing and Commerce

Economies of Scope

- Top Industries in Product Density
  — Wholesale Trade
  — Information and Software
  — Professional, Scientific and Technical Services
  — Manufacturing and Commerce
  — Real Estate

Industrial Innovation Strategy

- Top Industries in Product Complexity or Sophistication
  — Information Technology and Software
  — Manufacturing and Commerce
  — Finance and Insurance
  — Infrastructure and Waste Management Services
  — Professional, Scientific and Technical Services

Smart Specialization Strategy

- Top Industries in RCA
  — Management of Companies and Enterprises
  — Mining, Quarrying, and Oil and Gas Extraction
  — Real Estate
  — Information Technology
  — Finance and Insurance

Barcelona

Figure 43. Product Space (Barcelona)

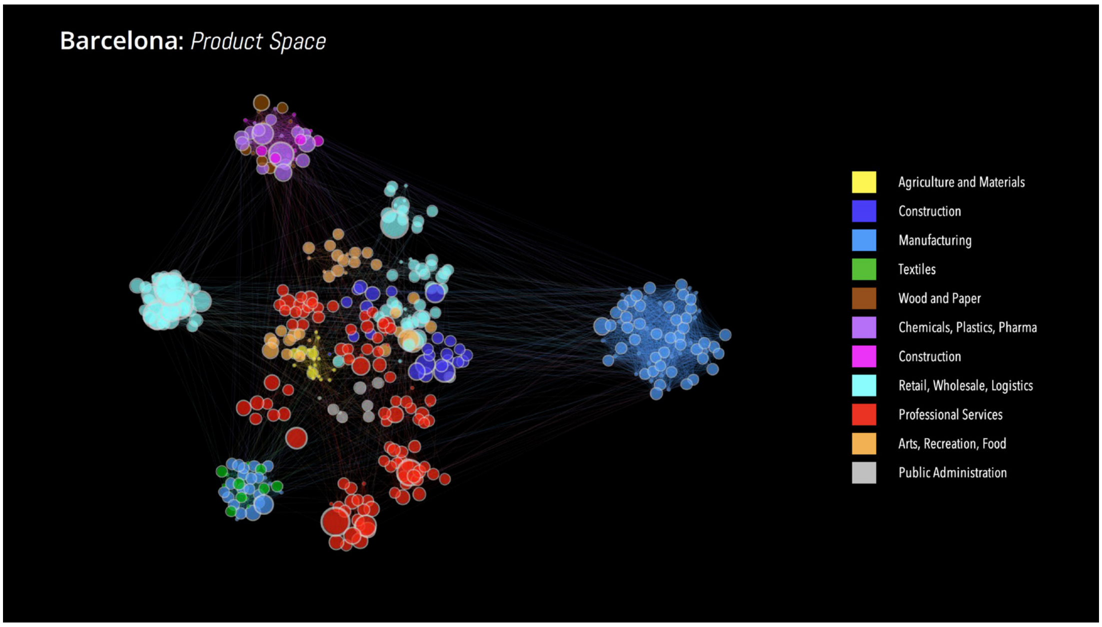
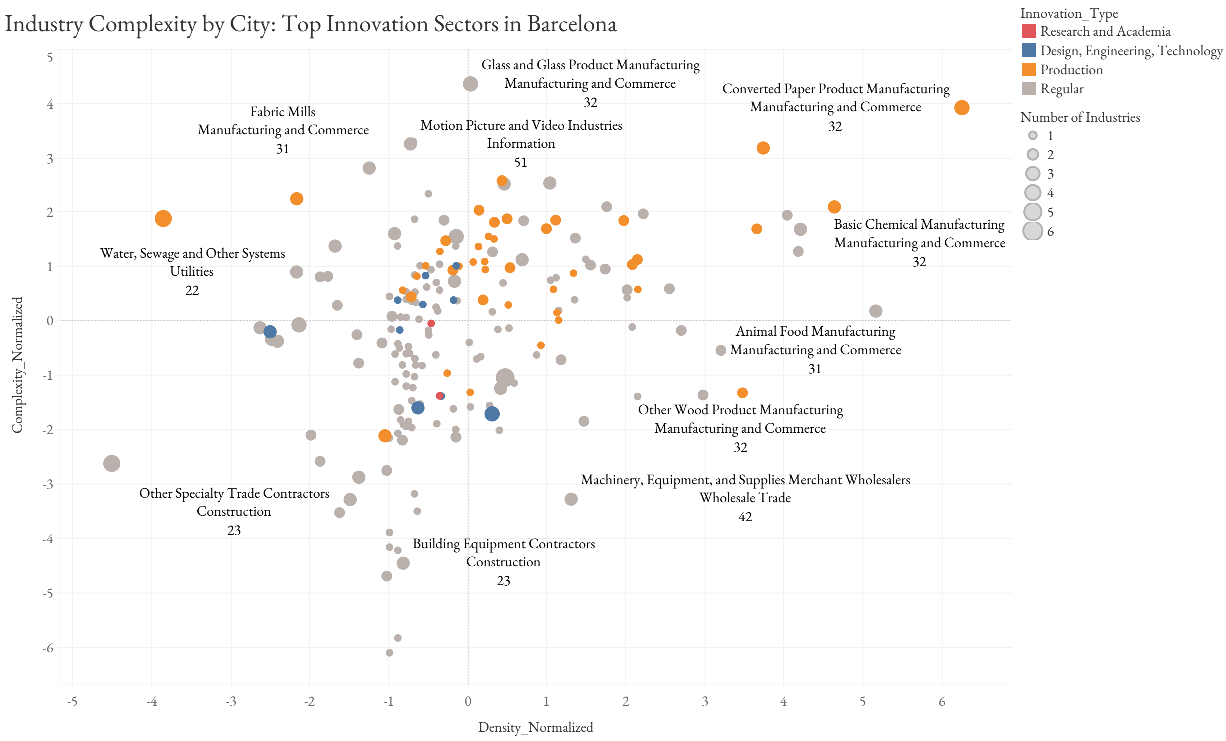


Figure 44. Smart Specialization (Barcelona)



Economic Base Overview

Barcelona presents an ecosystem composed of 321 industries and 92 innovative industries:

- Total Service Industries: 321 out of 848 total number of potential industries
- Total Revenue: €125.823M
- Total Innovative Industries: 92 out of 184 innovative industries
- Total Innovative Revenue €29.882M (24% of total revenue)

Economies of Scale

- Top Industries in Revenue:
  - Manufacturing and Commerce
  - Wholesale Trade
  - Professional, Scientific, and Technical Services
  - Construction
  - Infrastructure and Waste Management Services

Economies of Scope

- Top Industries in Product Density
  - Manufacturing and Commerce
  - Wholesale Trade
  - Construction
  - Management of Companies and Enterprises

Industrial Innovation Strategy

- Top Industries in Product Complexity or Sophistication
  - Information and Software
  - Manufacturing and Commerce
  - Infrastructure and Waste Management
  - Manufacturing and Commerce
  - Management of Companies and Enterprises

Smart Specialization Strategy

- Top Industries in RCA
  - Manufacturing and Commerce
  - Wholesale Trade
  - Construction
  - Infrastructure and Waste Management
  - Professional, Scientific, and Technical Services

Boston

Figure 45. Product Space (Boston)

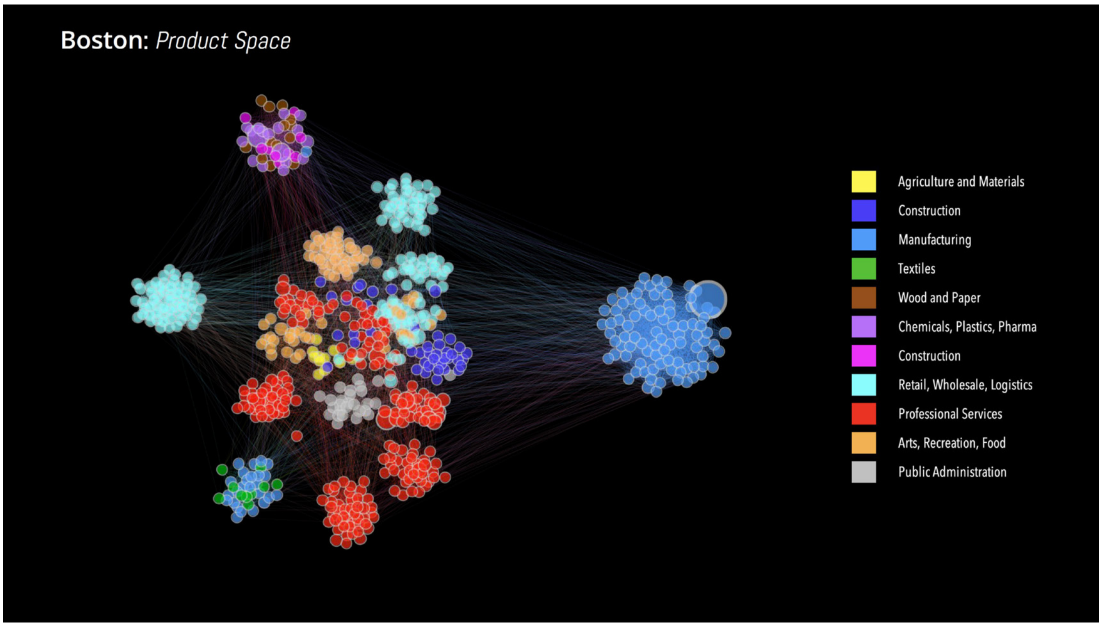
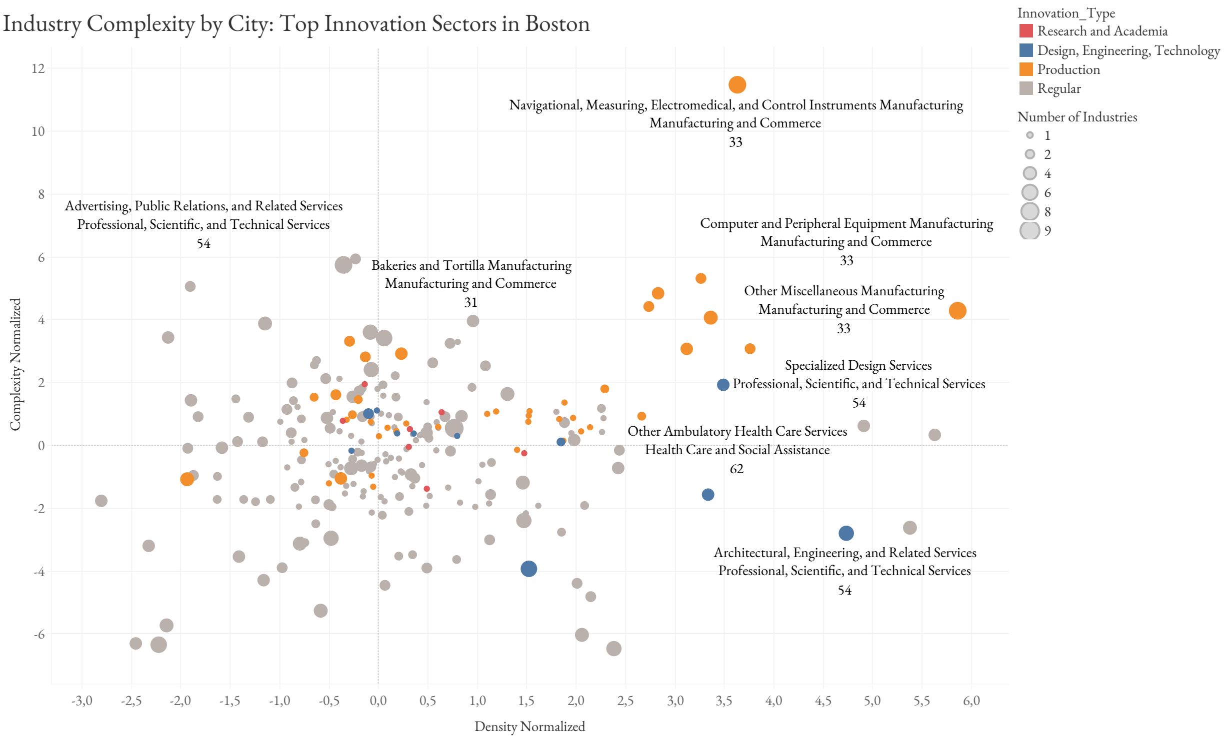


Figure 46. Smart Specialization (Boston)



Economic Base Overview

Boston presents an ecosystem composed of 557 industries and 132 innovative industries:

- Total Service Industries: 557 out of 848 total number of potential industries
- Total Revenue: €160.176M
- Total Innovative Industries: 132 out of 184 innovative industries
- Total Innovative Revenue €75.547M (47% of total revenue)

Economies of Scale

- Top Industries in Revenue:
  — Manufacturing and Commerce
  — Finance and Insurance
  — Health Care and Social Assistance
  — Professional, Scientific, and Technical Services
  — Educational Services and Research

Economies of Scope

- Top Industries in Product Density
  — Manufacturing and Commerce
  — Professional, Scientific, and Technical Services
  — Health Care and Social Assistance
  — Infrastructure and Waste Management Services
  — Finance and Insurance

Industrial Innovation Strategy

- Top Industries in Product Complexity or Sophistication
  — Manufacturing and Commerce
  — Information and Software
  — Educational Services and Research
  — Finance and Insurance
  — Management of Companies and Enterprises

Smart Specialization Strategy

- Top Industries in RCA
  — Educational Services and Research
  — Manufacturing and Commerce
  — Health Care and Social Assistance
  — Finance and Insurance
  — Professional, Scientific, and Technical Services

Munich

Figure 47. Product Space (Munich)

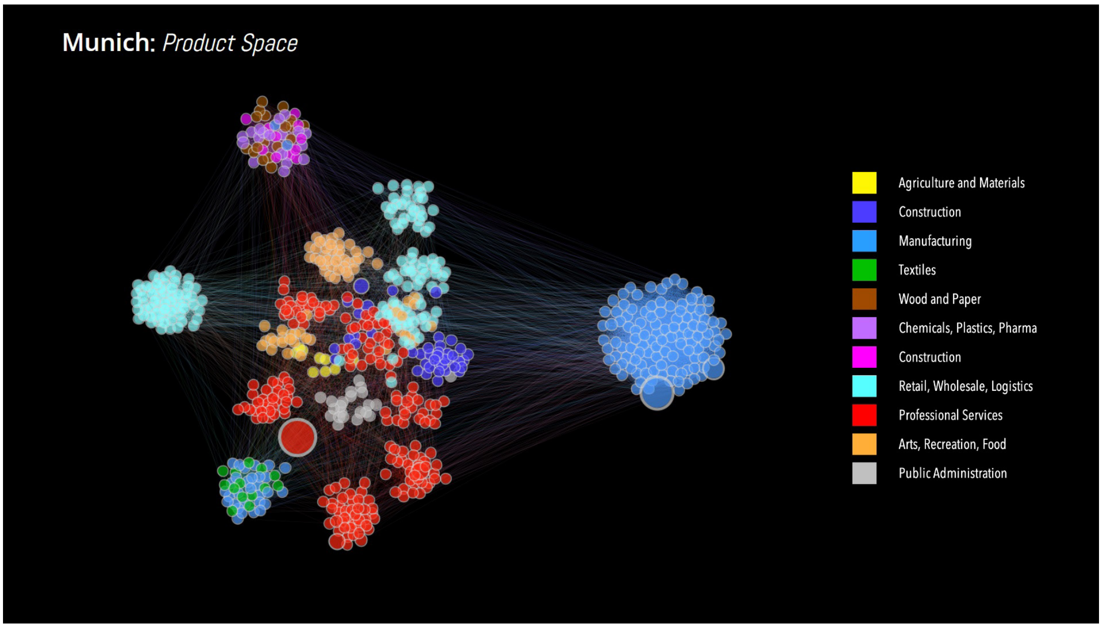
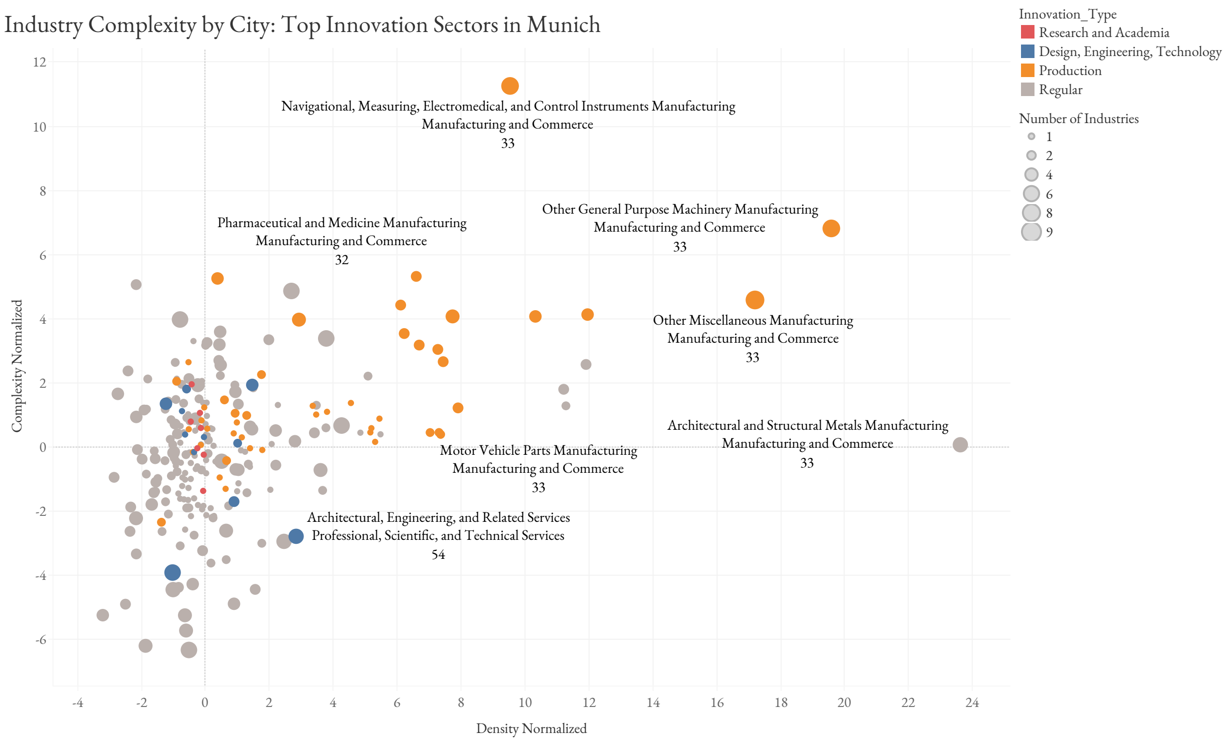


Figure 48. Smart Specialization (Munich)



Economic Base Overview

Munich presents an ecosystem composed of 567 industries and 149 innovative industries:

- Total Service Industries: 567 out of 848 total number of potential industries
- Total Revenue: €150.854M
- Total Innovative Industries: 149 out of 184 innovative industries
- Total Innovative Revenue €39.642M (26% of total revenue)

Economies of Scale

- Top Industries in Revenue:
  - — Manufacturing and Commerce
  - — Management of Companies and Enterprises
  - — Professional, Scientific, and Technical Services
  - — Wholesale Trade
  - — Infrastructure and Waste Management Services

Economies of Scope

- Top Industries in Product Density
  - — Manufacturing and Commerce
  - — Wholesale Trade
  - — Infrastructure and Waste Management Services
  - — Professional, Scientific, and Technical Services
  - — Construction

Industrial Innovation Strategy

- Top Industries in Product Complexity or Sophistication
  - — Manufacturing and Commerce
  - — Information and Software
  - — Finance and Insurance
  - — Educational Services and Research
  - — Wholesale Trade

Smart Specialization Strategy

- Top Industries in RCA
  - — Manufacturing and Commerce
  - — Wholesale Trade
  - — Infrastructure and Waste Management Services
  - — Professional, Scientific, and Technical Services
  - — Construction

Stockholm

Figure 49. Product Space (Stockholm)

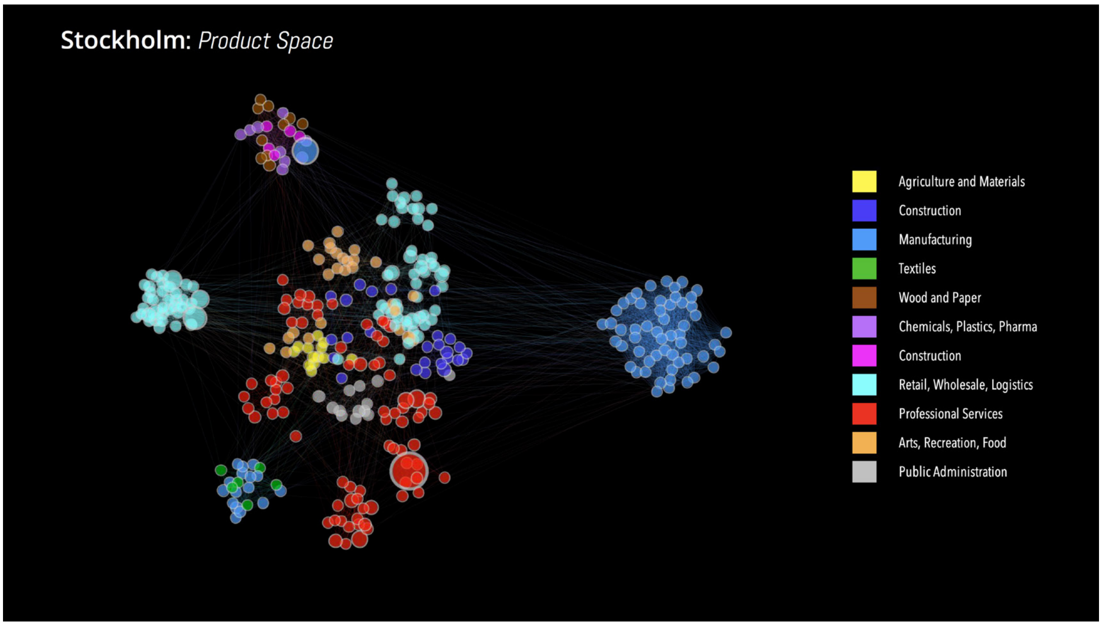
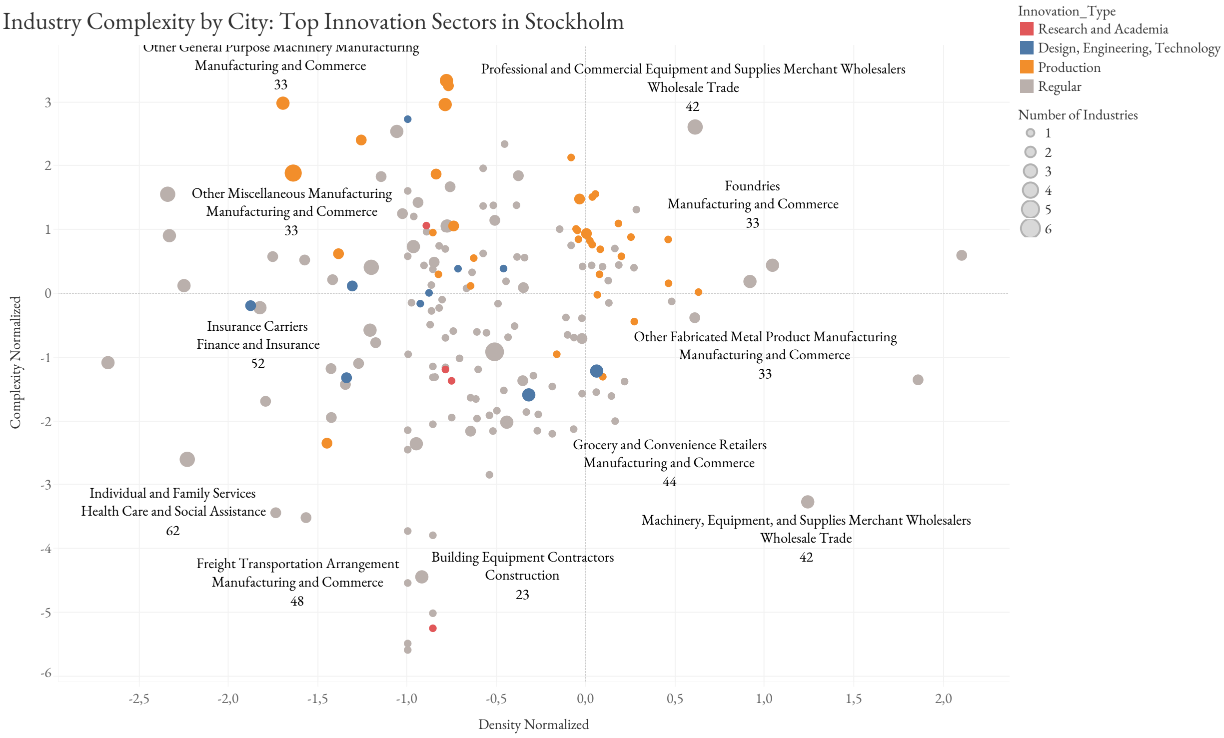


Figure 50. Smart Specialization (Stockholm)



Economic Base Overview

Stockholm presents an ecosystem composed of 275 industries and 75 innovative industries:

- Total Service Industries: 275 out of 848 total number of potential industries
- Total Revenue: €125.357M
- Total Innovative Industries: 75 out of 184 innovative industries
- Total Innovative Revenue €28.816M (23% of total revenue)

Economies of Scale

- Top Industries in Revenue:
  — Wholesale Trade
  — Infrastructure and Waste Management Services
  — Manufacturing and Commerce
  — Professional, Scientific, and Technical Services
  — Finance and Insurance

Economies of Scope

- Top Industries in Product Density
  — Wholesale Trade
  — Management of Companies and Enterprises
  — Information and Software
  — Agriculture, Forestry, Fishing, and Hunting
  — Educational Services and Research

Industrial Innovation Strategy

- Top Industries in Product Complexity or Sophistication
  — Manufacturing and Commerce
  — Information and Software
  — Arts, Entertainment, and Recreation
  — Infrastructure and Waste Management
  — Management of Companies and Enterprises

Smart Specialization Strategy

- Top Industries in RCA
  — Manufacturing and Commerce
  — Wholesale Trade
  — Construction
  — Infrastructure and Waste Management
  — Professional. Scientific, and Technical Services

Insight 2: City-Level Economic Complexity Analysis Reveals Industry-Specific Needs

The results of the economic complexity analysis allow for classifying any industry within a city across density, complexity, revenue, and RCA, hence tailoring the recommendations for each sector and city. The strategic industries for each city have a major overlap with the current strengths highlighted in the introduction of this section. Barcelona, the largest city, has a diversified product portfolio associated with advanced manufacturing, design, technology, and export and commerce. Munich showcases an important technological hub, an automotive cluster, and finance and insurance sectors. Boston has strengths in healthcare, education, finance and technology, and life sciences. Amsterdam shows thriving creative and technology sectors, and a prominent financial and business hub. Finally, we identify Stockholm's vibrant tech and innovation ecosystem, which includes biotechnology and financial sectors.

An analysis of Barcelona's economic development suggests that the city may be "boiling the ocean", trying to achieve global competitiveness by spreading efforts too much, without necessarily acquiring a level of excellence necessary to become an international leader. We can perform a quantitative measurement of specialization by counting the total number of possible nodes (industries or services) and those nodes that are actually present in each country. Presence is defined by the relative weight of a sector in a city compared with other cities. It provides a measurement of how many sectors a given city has a comparative advantage in. Barcelona is the largest city in the group; however, it does not have the largest total for present industries. In this regard, it lacks the sufficient differentiation of its leading sectors to compete in the international comparison. This would be equivalent to the strategy of "boiling the ocean," which is when a large city has multiple different relatively successful economic sectors but there is no specialized group that can compete internationally at the highest level in terms of high-value-added jobs and premium products and services. An alternative way of estimating the same phenomenon is looking at the number of innovative industries based on the number of innovative employees and innovative products involved. We again observe that Barcelona does not have the highest number of innovative industries.

Table 17. 5 Global Cities—Industry Presence and Benchmarking

City	Total Potential Industries	Total Present Industries	Total Service Industries	Innovative Industries
Amsterdam	848	115	345	84
Barcelona	848	304	321	92
Boston	848	331	557	132
Munich	848	322	567	149
Stockholm	848	213	275	75

Insight 3: Product Complexity Can Be Raised by Strengthening Innovation Ecosystems

The overall economic complexity ranking is (in order) as follows: Munich, Boston, Stockholm, Amsterdam, and Barcelona. Challenges such as geospatial dispersion of industries across multiple industrial clusters, short value chains (low PDI), feeble critical mass (low revenue), and excessive reliance on low value-added services (such as tourism, accommodation, low PCI) and manufacturing sectors weaken the overall competitiveness of Barcelona's economic base.

Economic Development Strategy: Industries with a Global Comparative Advantage

An economic development strategy involves identifying and applying a series of specific smart specialization and placemaking interventions at the local level to propel the prosperity of a new city development or urban regeneration plan. More precisely, a successful economic development strategy can benefit from performing advanced analytics on the economic and innovation data gathered at the submunicipal, territorial scale, including information on production, exports, expenditures in innovation, patent creation, and firm-level data on production, employment, and innovation. The main goal of an economic development strategy is to provide a roadmap and recommendations to shape and nurture the local economies of a given city, conforming its growth with clear goalposts and benchmarks with other comparable cities and districts. The main components of the economic development strategy are the innovation pipeline strategy and the smart specialization strategy.

Table 18. Industry Growth, Diversification, and Sophistication Targets (Barcelona)

	Barcelona (2022)	Barcelona (Target)	Current versus Target	Required Delta
Total Service Industries	321	670	47.91%	108.72%
Total Present Industries	304	402	75.62%	32.24%
Innovative Industries	92	170	54.12%	84.78%
Total Manufacturing Industries	89	119	74.79%	33.71%
Innovative Manufacturing Industries	39	45	86.67%	15.38%

Informing a Successful Smart Specialization Strategy

The successful development of a given city requires taking into account the contributions that different industries and skills bring into the mix to create a fruitful innovation ecosystem. In this regard, analyzing the levels of diversification and economic complexity of the district and broader region can provide precise estimates that can help predict and shape the future diversification path. In addition, risk mitigation strategies can be informed to provide an assessment of potential pitfalls in the diversification strategy. Risk mitigation strategies should focus on potentially promising sectors that nevertheless are exposed to failure and industries that seem safe but have an underestimated risk component.

For Barcelona to positively converge with its per capita fair share, compared with Amsterdam, Boston, Munich, and Stockholm, the city would need to meet the following goals:

- Increasing the number of total NAICS service industries from 321 up to >670
- Increasing the number of total NAICS innovative industries from 92 up to >170
- Increasing the number of total NAICS present industries from 304 up to >403
- Increasing the number of total NAICS manufacturing industries from 89 up to >119
- Increasing the number of total NAICS innovative manufacturing industries from 39 up to >45

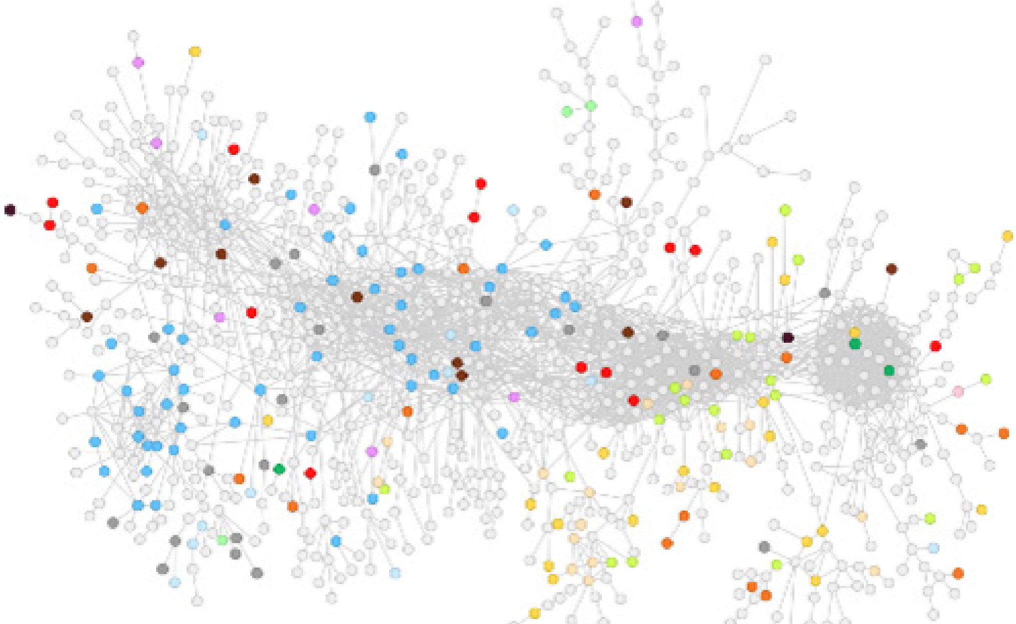
Insight 4: Four Quadrant Analysis Illuminates Sectors-Specific Policymaking

The four quadrant analysis of industry sectors classified sectors into high performing (Q1), traditional and stagnant (Q2), emerging industries (Q3), and at-risk sectors (Q4), hence informing the priorities tailored for each knowledge domain and activity.

Shaping a Highly Diversified and Sophisticated Smart Specialization Portfolio

By developing the knowledge economy ecosystem of the city, Barcelona would pivot toward a more prosperous model, attract local and international talent, and become a point of reference.

Figure 51. Product Space (Barcelona)



Product Space legend

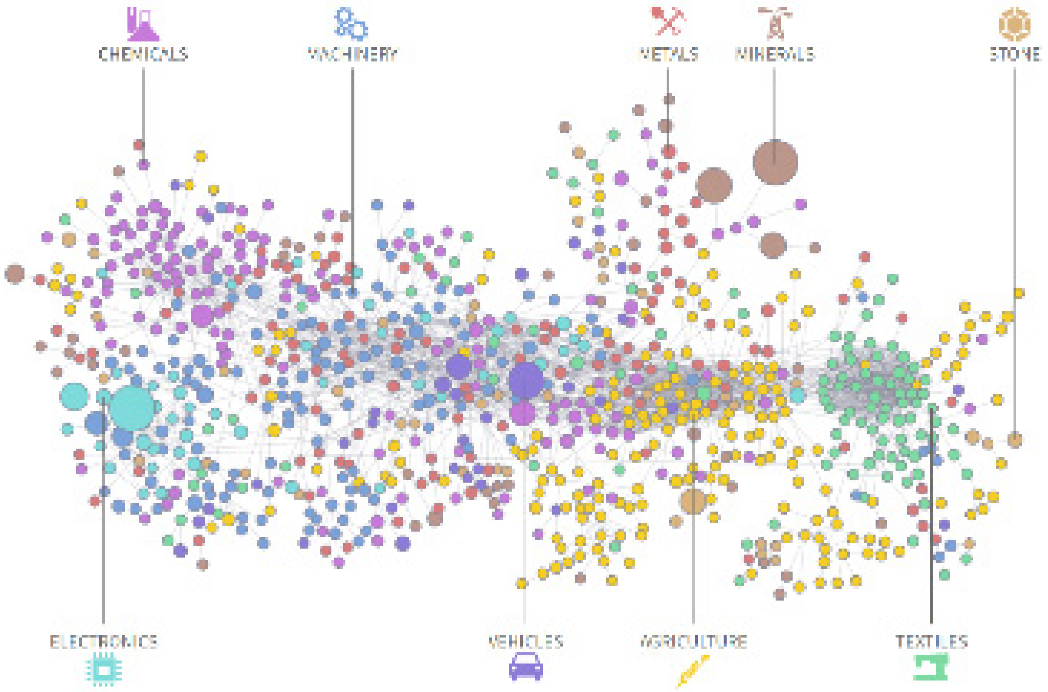


Figure 51 shows the main economic strengths of Barcelona by sector in a visualization called the Product Space. In each product space, each economic sector is depicted by a bubble or node, which is color coded according to the legend on the right of the figure. Economic sectors are related if they are linked to one another. Central nodes or sectors have more connections; these generally correspond to sophisticated and high value industries such as auto parts manufacturing and electrical equipment, while peripheral nodes correspond to less complex industries such as agricultural products and natural resources. When a node is highlighted, this implies that the region has a comparative advantage in that sector. Implicitly, the most revealing part is the availability of skills, knowledge, resources, and infrastructure that allow for a specific economic sector to thrive.

The Barcelona City product space shows 208 active nodes out of a total of 775 nodes available globally. This is partly because of the city's remarkable size, which allows a critical mass of talent and resources to develop multiple different industries, from automotive and electronic equipment manufacturing to creative industries and technology information-related sectors. However, even statistically controlling for the size of the city, Barcelona shows broad diversification of economic sectors that are not often observed in cities of the same size. This characteristic facilitates the creation of new industries and services because the city and its metropolitan area already have a significant critical mass of human and physical capital.

For example, the central blue nodes corresponding to electronic equipment/industrial machinery are highly connected to the rest of the economic network, implying that local talent can expand into other industries both in the manufacture of new materials and in the creative and digital industries. This same reasoning applies to industries such as pharmaceuticals and chemicals that also have a high level of connectivity with the rest of the economy.

Table 19. Four Quadrant Analysis and Specialization Goals—Manufacturing (Barcelona)

Manufacturing Total	Export-Oriented Manufacturing Industries	% of Total Sectors	Export Revenue (€M)	% of Total Export Revenue
Q1 Thriving Industries	162	34%	€12.828M	47%
Q2 Stagnant Industries	93	20%	€2.963M	11%
Q3 Emerging Industries	95	20%	€7.027M	26%
Q4 At-Risk Industries	125	26%	€4.591M	17%
Total	475	100%	€27.409M	100%

The strategic recommendation is to tailor the core priority for each of the quadrants:

- **Q1 industries:** Focus on product diversification and sophistication
- **Q2 industries:** Focus on strengthening the knowledge base and innovation/PCI
- **Q3 industries:** Focus on gaining critical mass and capitalizing the innovation edge
- **Q4 industries:** Combine intensive and extensive urgent measures to avoid commoditization/ global outsourcing

Smart Specialization Weaknesses and Challenges Facing the Barcelona Metropolitan Region

The Barcelona area presents a series of economic development shortcomings:

- **Lack of critical mass**: Barcelona currently has a critical mass deficit in terms of productive fabric. Despite the presence of some global companies, the overwhelming majority of sectors are stuck in medium-tech industries, with a small minority of activities meeting cutting-edge, world-class sophistication standards.
- **Territorial fragmentation:** The productive industrial and knowledge fabric of Barcelona is geographically atomized because of geographical and physical barriers. These include the major road axes, such as B-20, B-23, and N-340, as well as rivers/riverbeds and the Collserola mountains. In addition, numerous industries in the capital are highly dispersed, such as the pharmaceutical sector, without the concentration levels needed to consolidate a world-class knowledge hub. This fragmentation makes it difficult to establish concentrated knowledge fields, which would strengthen value chains and help ecosystems flourish that are capable of completing the seven phases of innovation. Geographically consolidating different ecosystems should be a priority.
- **Industry Atomization:** Barcelona presents 475 different types of business services around 208 families of globally competitive export products and a total of over 2,000 knowledge fields present in its area of influence. However, only a handful of sectors present innovation peaks in terms of product sophistication and service uniqueness. In relative terms, it is the least innovative of the five cities considered in the current study. Therefore, it is a strategic necessity for the municipality and the broader metropolitan region to consolidate complete value chains in those fields of knowledge that present the highest level of maturity and potential for generating prosperity.
- **Value chain weaknesses:** Much of the productive industry of the industrial services and manufacturing sector focuses on products and services of a medium technology level. Barcelona presents strong potential in 11 fields of knowledge, which should become the foundation of future innovation districts established in the territory.

Insight 5: Dense, High Value-Added Manufacturing Value Chains Create Stable Prosperity

Barcelona can extract lessons from long-term investment in high value-added manufacturing industries from Munich as well as high-tech sectors in the Boston area.

Learning from Munich: The Advanced Manufacturing Virtuous Cycle

The analysis reveals that, out of the five cities analyzed, Munich and Boston show the most diversified and sophisticated manufacturing base while presenting globally identifiable strengths in key sectors, such as technology, software development, IT, finance, and insurance. Munich also has a strong comparative advantage in advanced manufacturing, automotive, and electronics, whereas Boston shows an important presence in cutting-edge engineering, artificial intelligence and software, robotics, and the biotechnology, pharmaceuticals, and life sciences sectors. Stockholm and Amsterdam also present a high degree of diversification and sophistication in terms of industries with a comparative advantage. However, because these cities are significantly smaller than Barcelona, the comparison does not necessarily serve as the most valuable PPP policymaking benchmark in terms of best practices.

Munich—Top Manufacturing Industry Policymaking Strategies:

Economic development

- Industry clusters: These bring together companies, research institutions, stakeholders (automotive, aerospace, IT, healthcare) to promote collaboration, knowledge exchange, and innovation, driving economic growth and competitiveness.
- Research & innovation: Research institutions, innovations hubs such as TUM (Technical University of Munich) and LMU (Ludwig Maximilian University).
- Technology & Innovation Parks: MTZ (Munich technology Center), TUM-Tech.

Industrie 4.0 Vision

- Conceived in 2013, this aims to reinforce cross industry innovation in IoT & Industry.
- The government launched a program called "Industrie 4.0" in 2013, which aimed to promote the digitalization of manufacturing processes and the integration of new technologies such as the Internet of Things (IoT), Artificial Intelligence (AI), and Big Data.

Three key programs implemented by the State of Bavaria:

- The Future Bavaria Initiative in the 1990s
- The High-Tech Initiative in the early 2000s
- The 2006 Cluster Program

Smart Specialization Strategies

- Critical mass of public research activity in universities and public research institutes. Munich's specializations have developed because of close links between companies and teaching institutions and the availability of capital and technology transfer.

The "Munich Mix"

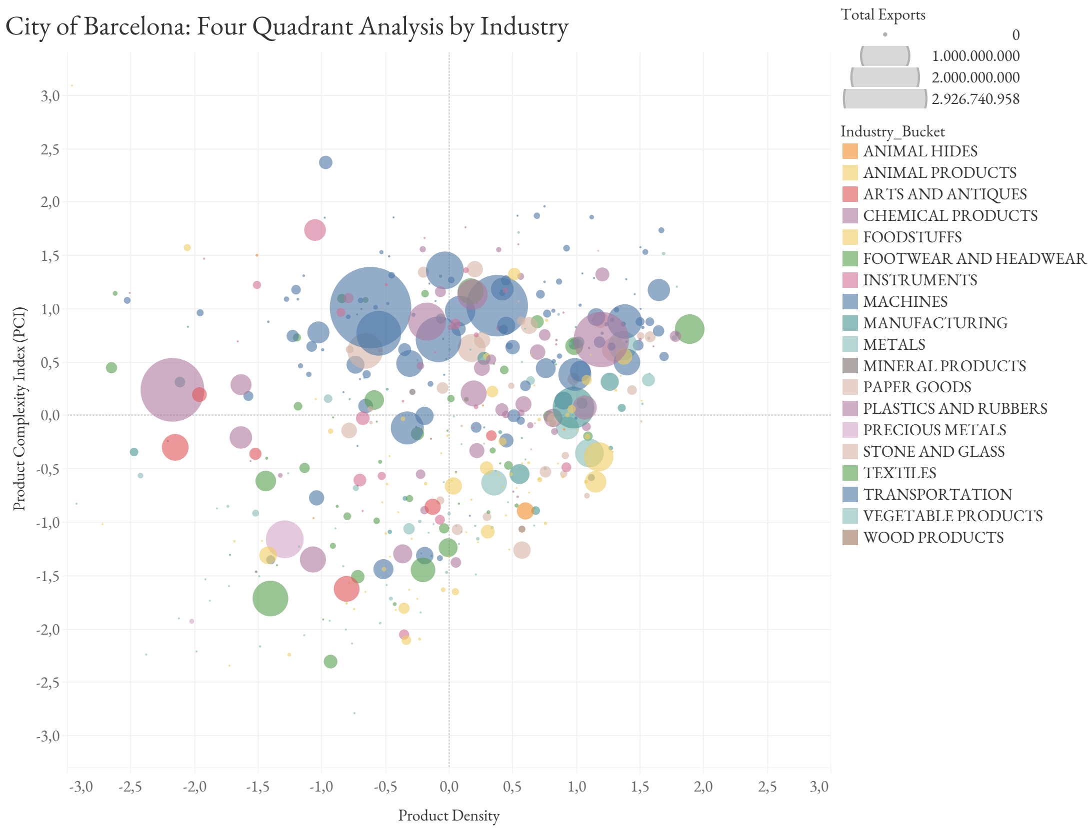
- Very diverse industrial structure helped produce institutional thickness. Key elements include strong institutions, high levels of interaction, sense of common purpose, coordinating activity. There is an interconnectedness of interests.
- Investments in connectivity/infrastructure: A recent study found that, out of Germany's seven largest cities, Munich has the best local public transport offering.
- Innovation hubs and technology parks are here.
- Regional development funds include Bavarian innovation funding.

Goals and Strategies - Nurturing Urban Economics and Prosperity

Goal and Strategy 1:

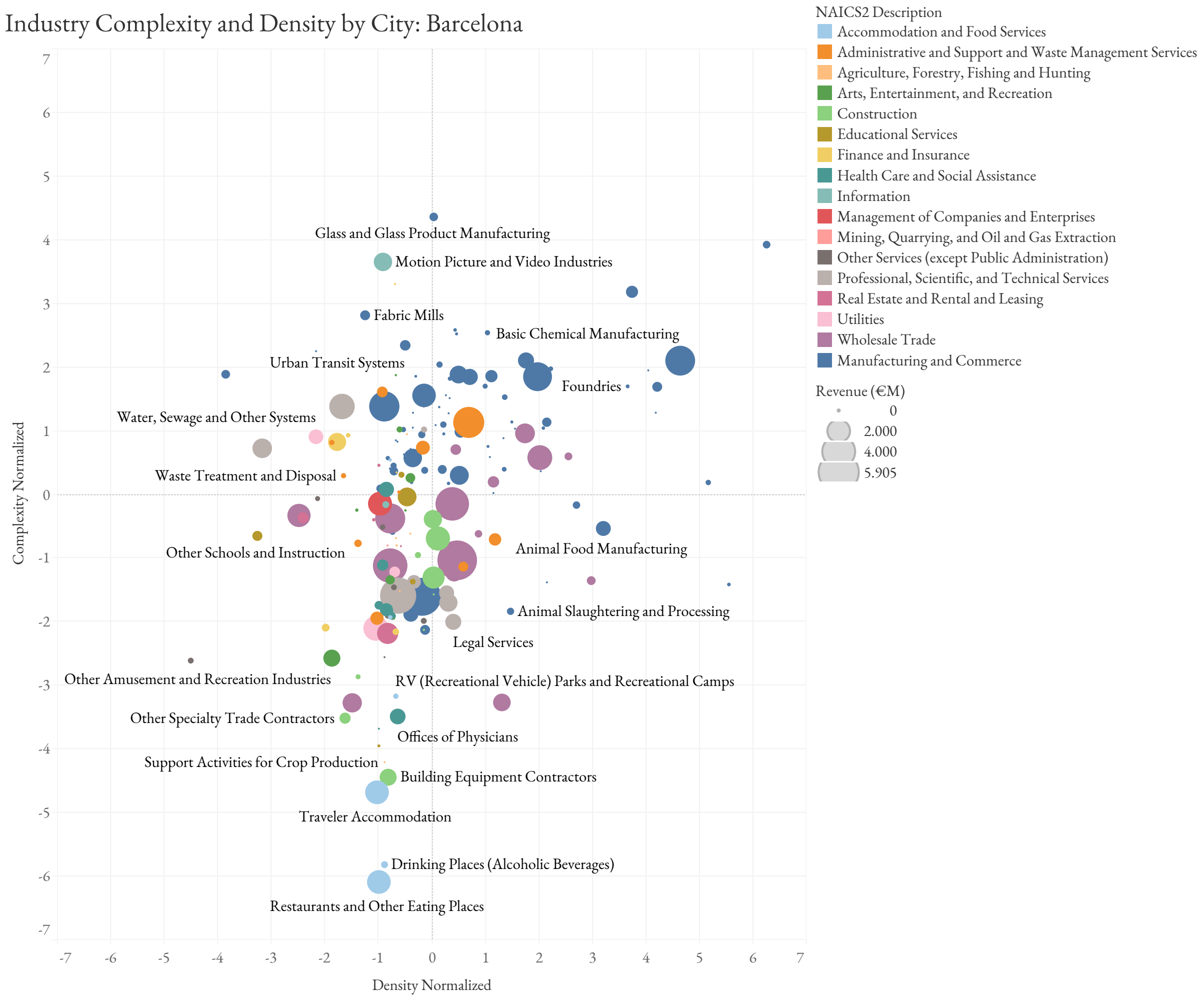
Economic Development Strategy: Raise the NAICS industry diversity and sophistication in Barcelona from 321 industries (92 innovative) up to 670 (170 innovative) and manufacturing industries from 89 (39 innovative) up to 119 (45 innovative). Strategy: Geospatial concentration by sector (pharmaceuticals, automobile, high-tech, precision instruments, machinery) by 2040.

Figure 52. Four Quadrant Analysis by Industry (Barcelona)



Barcelona is a highly diversified economy in both products and services. It showcases a high comparative advantage in sectors that are strategic at a regional but also at the global level: pharmaceuticals and healthcare, advanced manufacturing, engineering, and design. However, these sectors do not reach the peak level of quality and sophistication to compete successfully at a global level. The recommended strategy for Barcelona is to avoid the trap of "boiling the ocean," as mentioned before. Barcelona already has the advantage of being the largest economy in the region. There is sufficient supply of local talent to enrich its strategic industries and services. However, a set of policies aimed at narrowing the focus of specialization would be beneficial. The outcome of such policies would help meet benchmarks and Barcelona develop industries with greater global competitive advantage.

Figure 53. Four Quadrant Analysis of NAICS Services in Barcelona



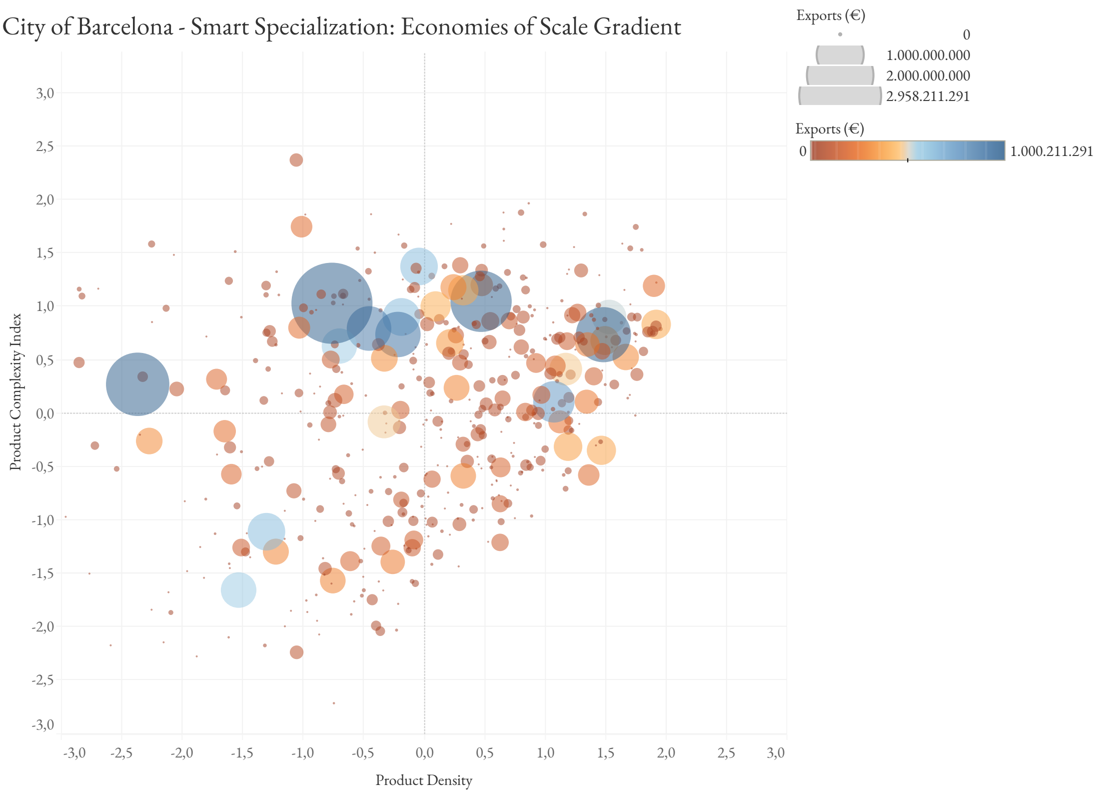
- Q1 Priority Service Industries: Chemical manufacturing for pharmaceutical products and construction, pharmaceutical and medicine manufacturing, paint and adhesive manufacturing, electronics, apparel and textile design, lumber and furniture, semiconductor manufacturing, motor vehicles manufacturing, and advanced construction manufacturing
- Q2 Traditional/Stagnant Service Industries (requiring a strong innovation impulse): Food manufacturing, beverage manufacturing, waste management, water infrastructure management, residential building construction, general construction, architectural, and engineering and related urban design services
- Q3 Emerging Service Industries (highly promising sectors): Motion picture and video industries, urban transit systems, scientific, professional and technical services, software and data science, gaming, and healthcare support services
- Q4 At-Risk Service Industries (very low sophistication/complexity): Tourism-related industries, travel accommodation, restaurants and other sustenance activities, colleges and universities, support activities for crop production, natural gas production, electric power generation, general freight trucking, chemical wholesalers, automobile dealers, and amusement and recreation industries

Goal and Strategy 2:

Economies of scale: Increase the total annual city revenue from €125.823M up to ≅€190.000M by 2040 and the innovation-related revenue from €29.882M up to ≅€60.000M.

Barcelona Product Economies of Scale Index (PESI) Analysis

Figure 54. Product Economies of Scale Index (PESI) Analysis (Barcelona)

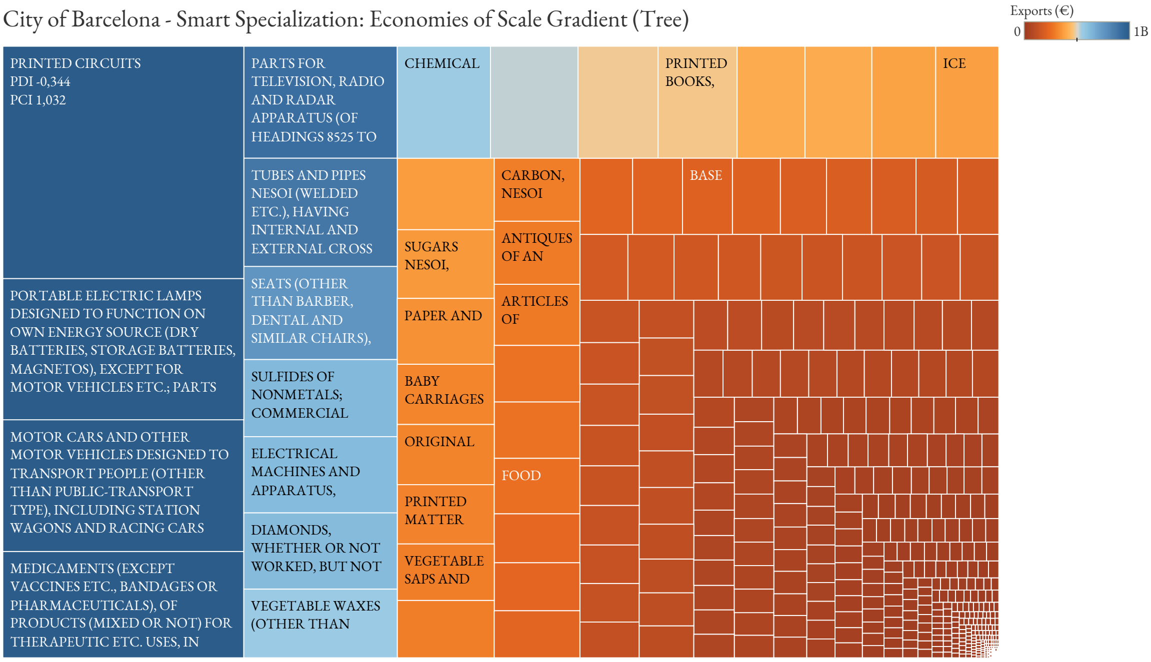


- Top industries in terms of revenue
  - — Printed circuits
  - — Motor cars and other motor vehicles designed for transport
  - — Medicaments or products for therapeutic uses
  - — Parts of television and radar apparatus
  - — Portable electric lamps
  - — Oxygen-function amino-compounds

- Bottom industries in terms of revenue
  - — Bituminous mixtures
  - — Cloves
  - — Ethyl alcohol

Barcelona Product Economies of Scale Index (PESI) Tree

Figure 55. Product Economies of Scale Index (PESI) Tree (Barcelona)



Sample Strategy: Pursue a geographic concentration of closely related sectors in clusters, particularly spread around the five industrial areas in the Besòs riverbed (Bon Pastor, Torrent de l'Estadella, Montsolís, La Verneda, Verneda Industrial) next to the upcoming Sagrera intermodal station.

Define a geographic-specific set of target industries for each of the major industrial cluster hubs within the Barcelona Metro Area to define sector-specific investment attraction priorities based on this rationale:

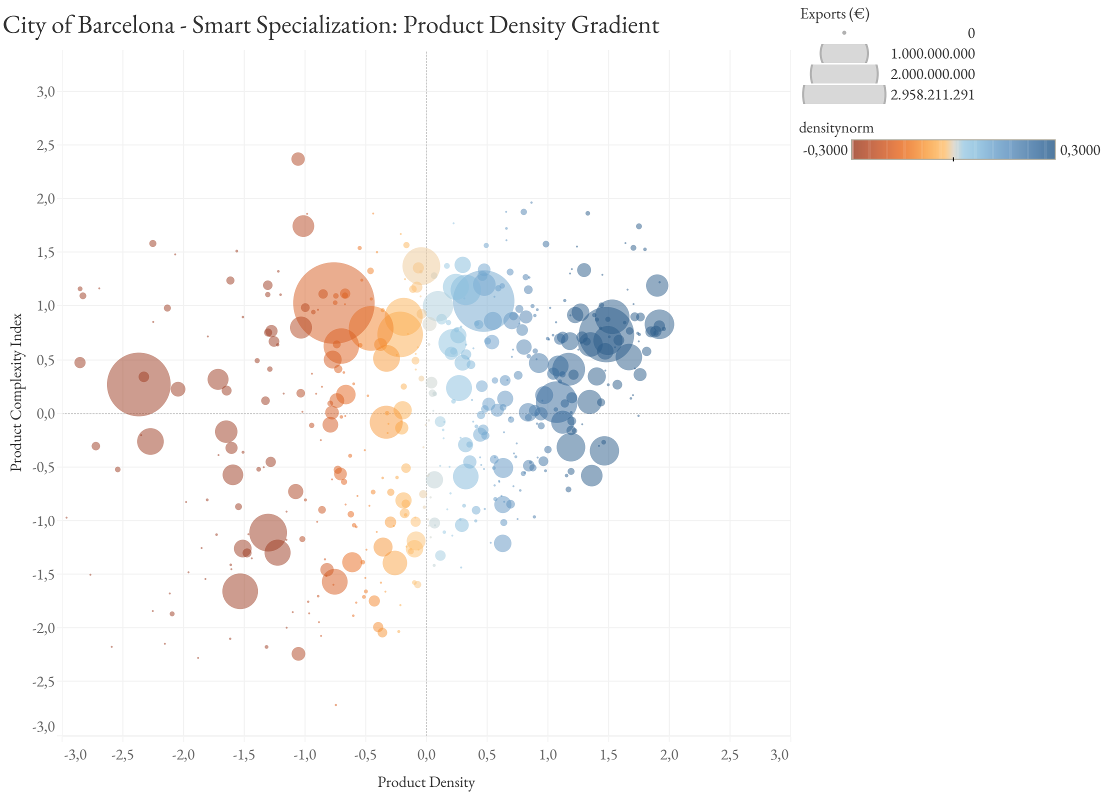
- Polígons de Barcelona- Besòs: Bon Pastor, Torrent de l'Estadella, Montsolís, Verneda and Verneda Industrial
- Polígons del Corredor de la C-245: Gavà, Viladecans, Sant Boi, El Prat, Castelldefels
- Polígon de la Zona Franca, ZAL del Port de Barcelona
- Polígons de Cornellà- L'Hospitalet, Fira de l'Hospitalet
- Polígons del Pla: Esplugues, Sant Just Desvern, Sant Joan Despí, Cornellà
- Polígons del Llobregat: Castellbisbal, Papiol, Molins de Rei, Pubí, Pallejà, etc.
- Martorell Seat automotive cluster: Martorell, Abrera, Esparraguera, Oleta, St Esteve
- Corredor del Vallès: Sabadell- Barberà- Sant Quirze, Sant Cugat- Rubí, Montcada- La Llagosta, Terrassa- Rubí,
- Badalona Sud: Polígon Sud, El Sot and Badalona Nord: Polígon Nord, Les Guixeres, BCIN
- Sant Adrià: Les Tres Xemeneies

Goal and Strategy 3:

Economies of Scope: Increase the density of industries from 255 out of 477 up to ≅350 in alignment with the other global cities. This can be carried out through vertical integration processes and by facilitating the establishment of longer value chains (multiple companies contributing to a final product within physical proximity, hence retaining the IP core).

Barcelona Product Density Index (PDI) Analysis

Figure 56. Product Density Index (PDI) Analysis (Barcelona)

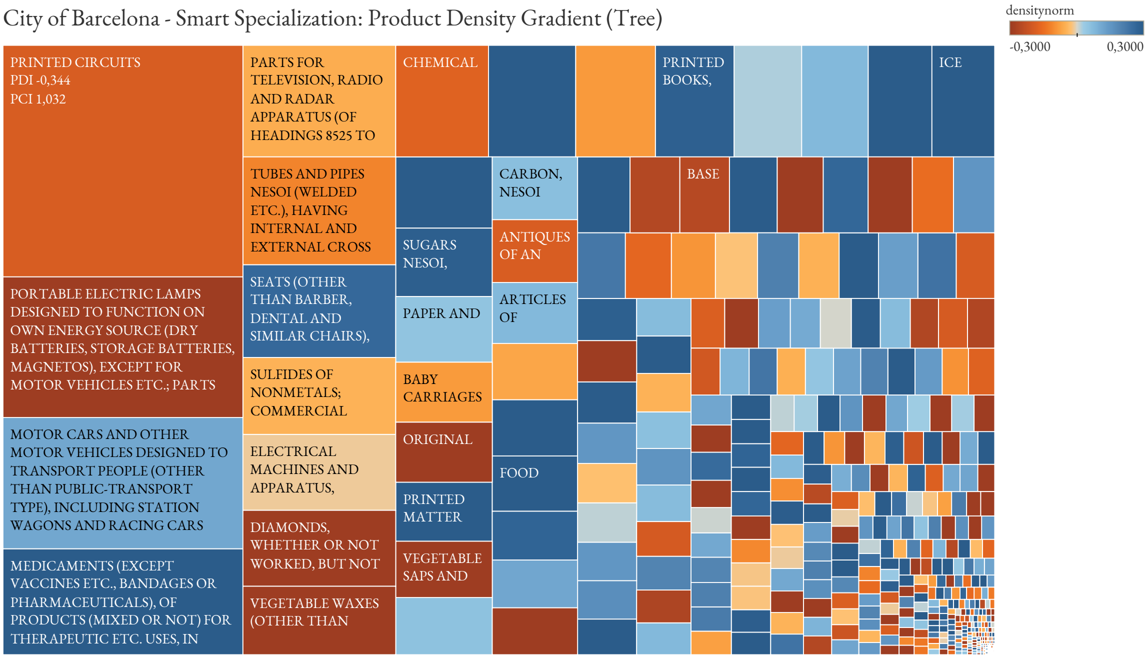


- Top industries in terms of product density include the following:
  — Parts of electric motors, generators, generating sets and rotary converters
  — Springs and leave of iron and steel
  — Articles of plastics, polymers, and resins
  — Parts of electrical apparatus for switching, electric circuits, panels, boards, and consoles
  — Parts and accessories for tractors, public transport passenger vehicles, motor cars, goods transport motor vehicles, and special transport vehicles

- Bottom industries in terms of product density include the following:
  — Portable electric lamps
  — Diamonds and precious metals
  — Vegetable saps and extract
  — Printed circuits

Barcelona Product Density Index (PDI) Tree

Figure 57. Product Density Index (PDI) Tree (Barcelona)



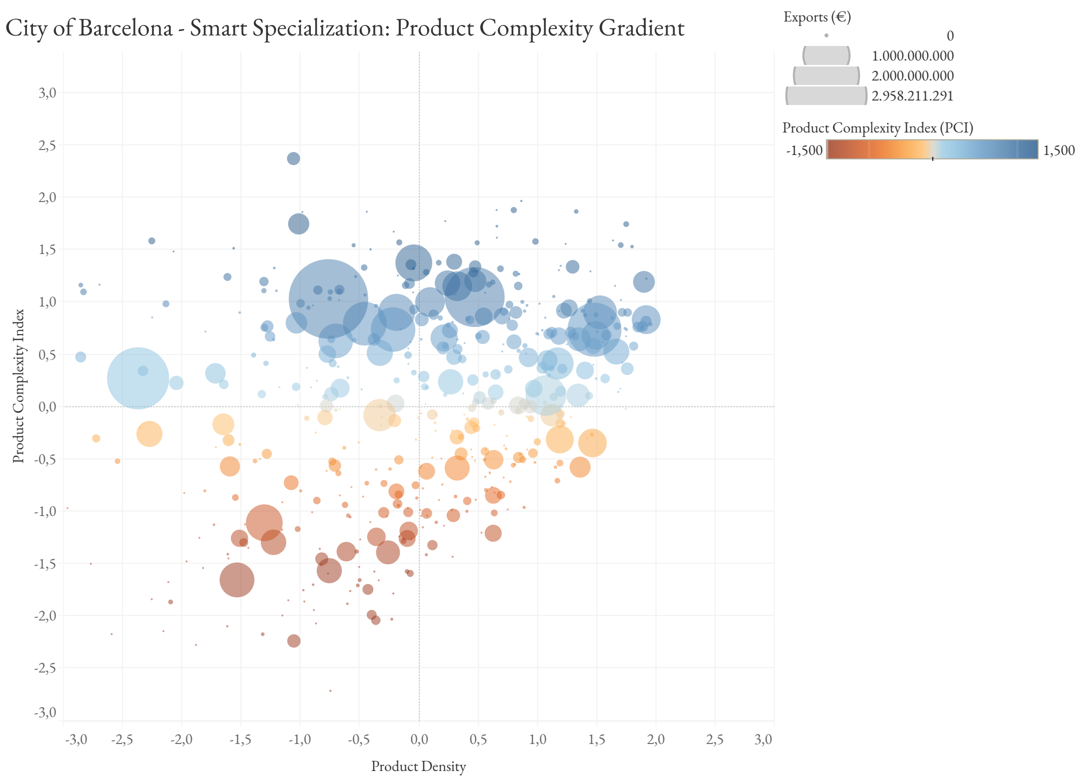
- The strengthening of industrial manufacturing value chains can greatly benefit the economic base of Barcelona. Some recommended strategies include the following:
  - — Geospatial clustering to increase the critical mass of the respective sectors.
  - — Emphasis on companies developing products or services with a high degree of product relatedness from an economic complexity standpoint.
  - — Building longer value chains within physical proximity, incrementally capturing the most value-added phases of the supply chain from product design, intellectual property (IP) core capabilities, technology stack, vertical integration of the critical manufacturing phases, secondary suppliers and providers and all the way through intermodal logistics and retail/commerce.

Goal and Strategy 4:

Industrial Innovation Strategy: to increase the number and knowledge-intensive sectors, focus on raising tech transfer across Q1, Q2 and Q3 sectors.

Barcelona Product Complexity Index (PCI) Analysis

Figure 58. Product Complexity Index (PCI) Analysis (Barcelona)

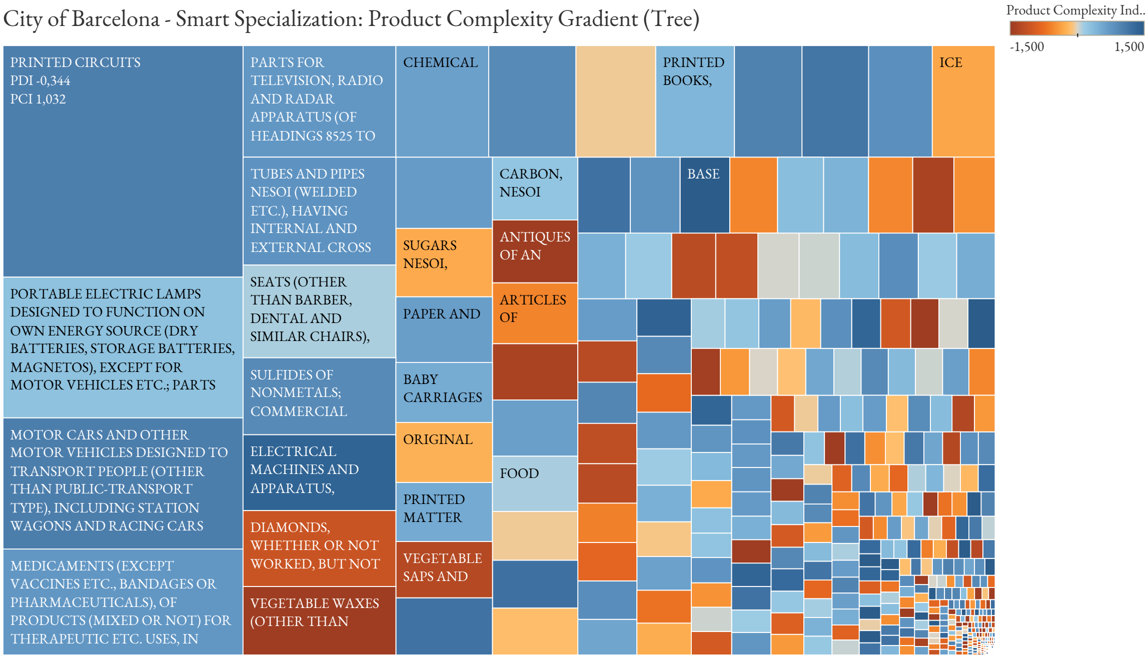


- Top industries in terms of product complexity or sophistication include the following:
  - — Electrical machines and apparatus
  - — Chemical elements doped for use in electronics, in the form of discs, wafers, and chemical compounds doped for use in electronics
  - — Printed circuits
  - — Motor cars and other motor vehicles designed for transport
  - — Calendering or other rolling machines, other than for metals or glass
  - — Electric laser, other light or photon beam, apparatus for soldering or welding, and electric machines for hot spraying of metals
  - — Industrial or laboratory electric furnaces and ovens, dielectric equipment

- Bottom industries in terms of product complexity or sophistication include the following:
  - — Vegetables waxes
  - — Natural gums, resins, and balsams
  - — Gold and precious metals

Barcelona Product Complexity Index (PCI) Tree

Figure 59. Product Complexity Index (PCI) Tree (Barcelona)



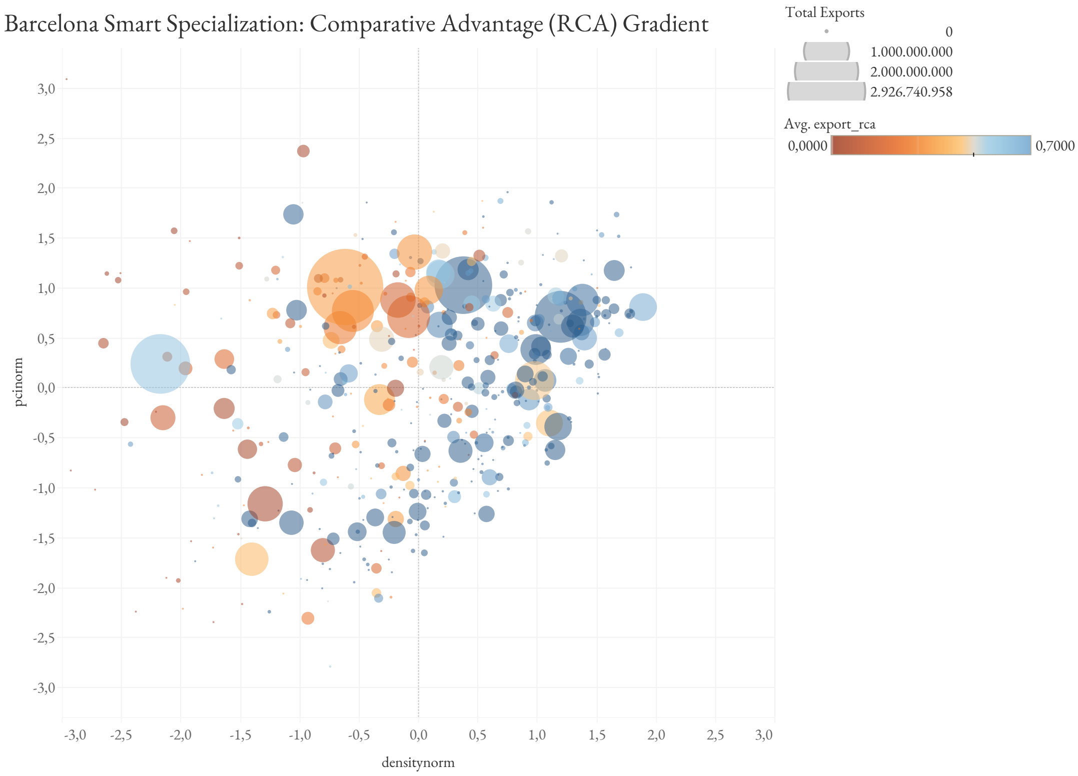
The recommended strategy to raise the overall level of product complexity is to invest in establishing a long-term viable and ambitious innovation strategy for the industries showing a comparative advantage. This would involve reinforcing university–industry relationships to transfer new knowledge to the private sector.

Goal and Strategy 5:

Smart Specialization Strategy: Place emphasis on Quadrant 1 industries, raising the number of industries with a global RCA from 255 up to ≅360 industries (out of 775) by 2040. This could be carried out by helping boost product sophistication in sectors with high knowledge levels.

Barcelona Product Revealed Comparative Advantage Index (RCA) Analysis

Figure 60. Product RCA Index (PRCAI) Analysis (Barcelona)

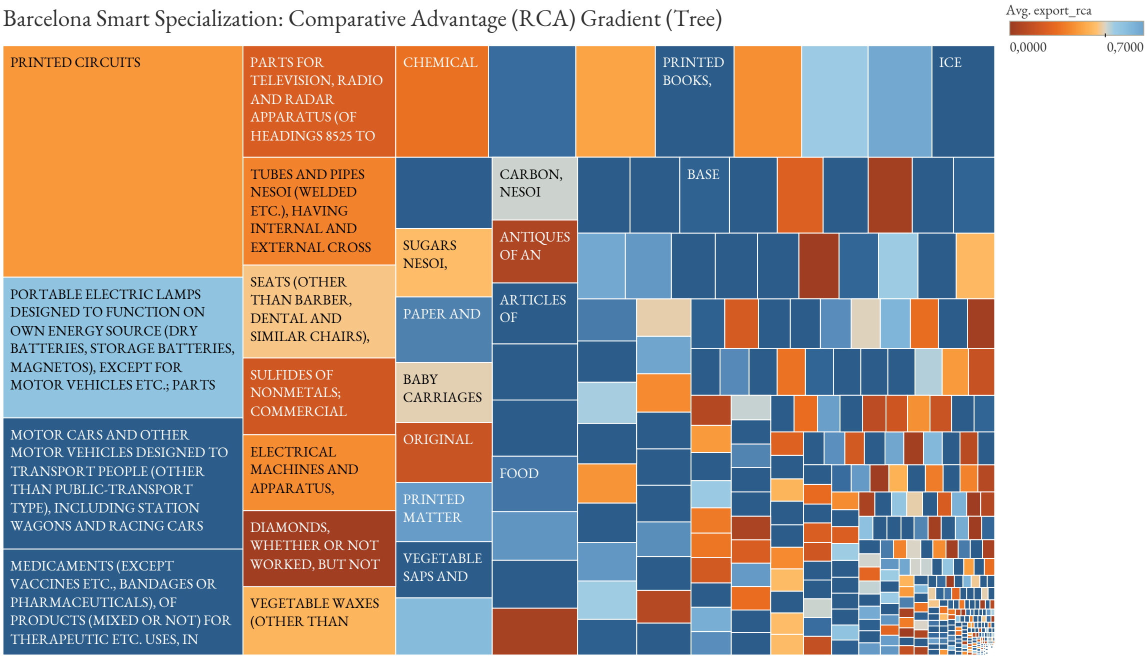


- Top industries in terms of RCA include the following:
  - Pharmaceutical products and medicaments for therapeutic use
  - Sulfides of nonmetals
  - Arts and antiques, original engravings, prints, and lithographs
  - Vehicles, other than tramway and railway
  - Vacuum flasks and other vacuum vessels
  - Aircraft, spacecraft, and parts thereof
  - Esters of inorganic acids
  - Iron ores and concentrates
  - Diphosforus pentaoxide

- Bottom industries in terms of RCA include the following:
  - Electric machinery, sound recorders and reproducers, television reproducers, and radio and radar apparatus
  - Natural or cultured pearls and precious metals

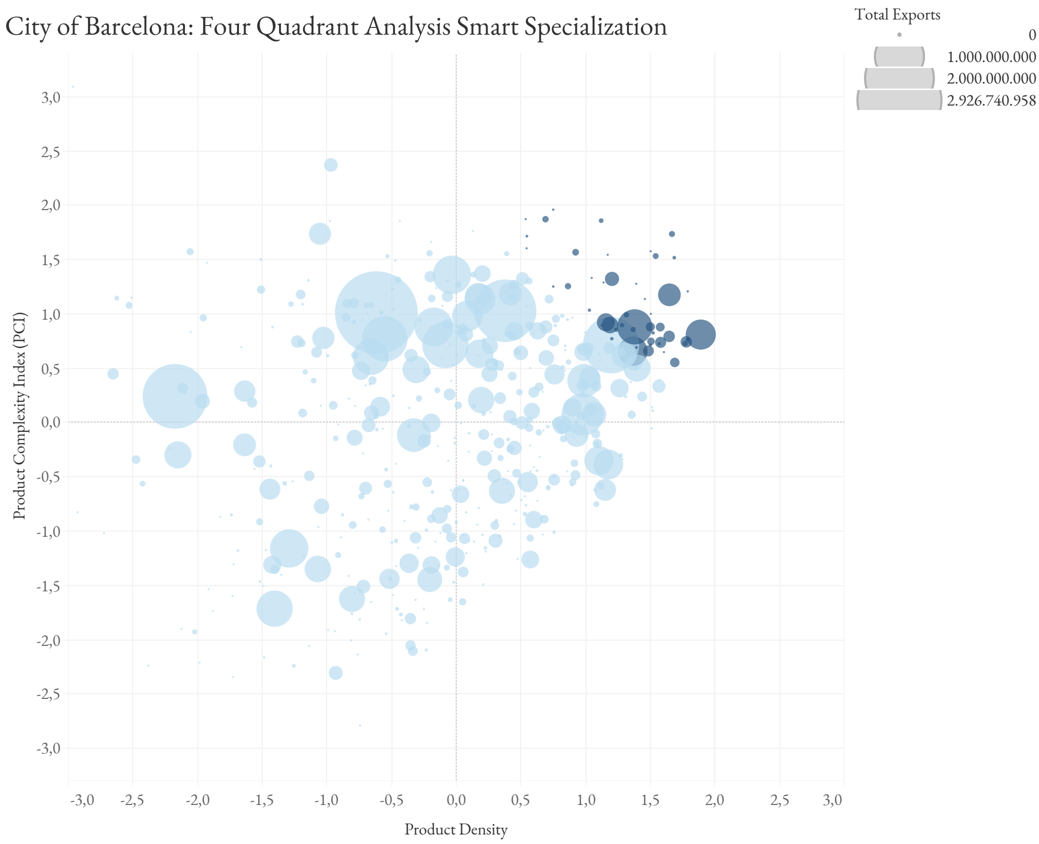
Barcelona Product RCA Index (PRCAI) Tree

Figure 61. Product RCA Index (PRCAI) Tree (Barcelona)



The revealed comparative advantage is the result of decision-making efforts impacting industry critical mass, product density, and product complexity. By raising the bar in terms of product diversification and sophistication strategies, we tend to observe a growing number of industries presenting a global RCA.

Figure 62. Smart Specialization Strategy (Barcelona)



- Top industries in terms of smart specialization include the following:
  - Electrical machinery and parts thereof, sound recorders and reproducers, television reproducers, and radio and radar apparatus
  - Articles of plastics and polymers
  - Electric laser, other light or photon beam, apparatus for soldering or welding, andelectric machines for hot spraying of metals
  - Vehicles, other than tramway and railway
  - Nuclear reactors, boilers, machinery, and mechanical appliances
  - Miscellaneous articles of base metal

Challenge 3:

Propelling Research and Innovation Ecosystems

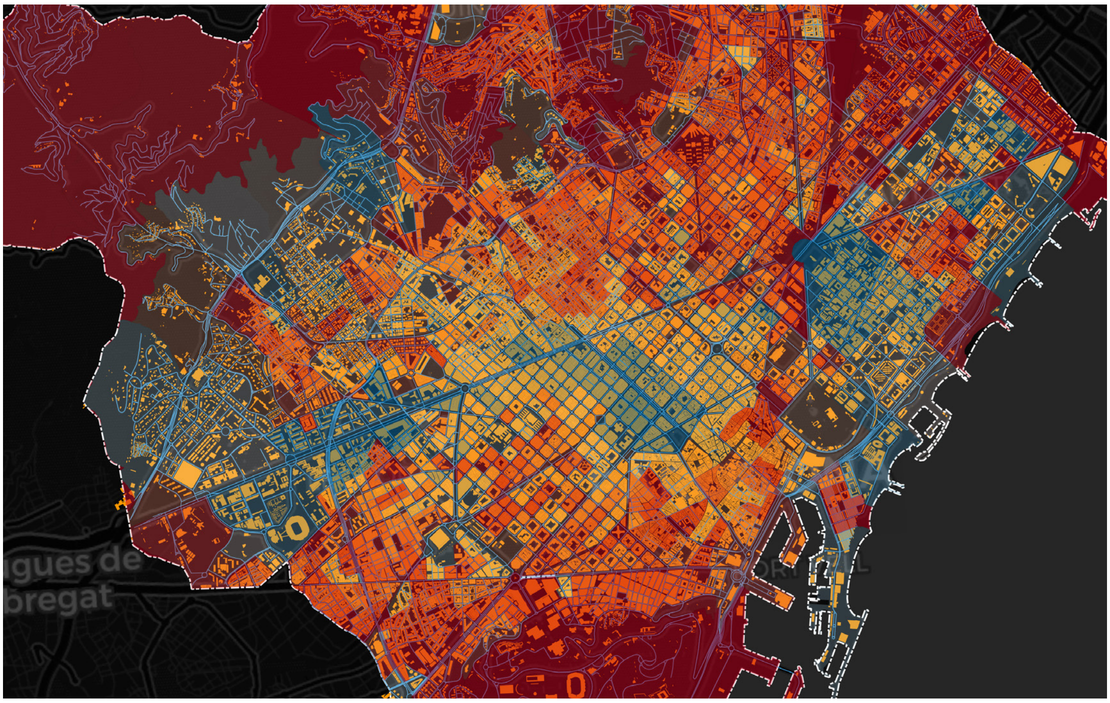
Challenge 3: Propelling Research and Innovation Ecosystems

Evaluating Urban Innovation Ecosystems

Through a geospatial analysis of knowledge-intensive activities through the lens of city science, we can perform accurate systems level diagnostics of the health of an innovation ecosystem. By comparing representative statistics on the urban innovation performance KPIs from notable innovation districts with those of the average block groups, we can understand the positive, super linear effects of such strategies in terms of job creation, wealth creation, knowledge advancement, and standards of living.

Three core innovation KPIs were the building blocks of the analysis: innovation intensity, innovation performance, and innovation impact. These KPIs allow us to quantitatively measure the differential impact of innovation districts and benchmark different typologies of innovation districts against one another and other non-innovation-intensive districts. Finally, we analyzed the superlinearity of innovation-related activities in a regression framework against population, city size, and other variables to benchmark our results against previous studies.

Figure 63. Geospatial Distribution of Innovation-Intensive Employment in Barcelona



The analysis revealed the concentration of innovation employment, innovative businesses, and sales throughout the cities' respective districts and neighborhoods. We could also observe the multiplying effects generated by the economic surplus generated by knowledge-intensive activities.

When a nascent innovation ecosystem reaches maturity, it tends to realize the multiplying effects of the geographic concentration and clustering of the knowledge economy dynamics. On average, the comparison between innovation intensity lognormal, innovation performance (Pareto/power law), and innovation impact (gamma) depicts the increasingly nonlinear amplifying effects of clustering knowledge-intensive activities.

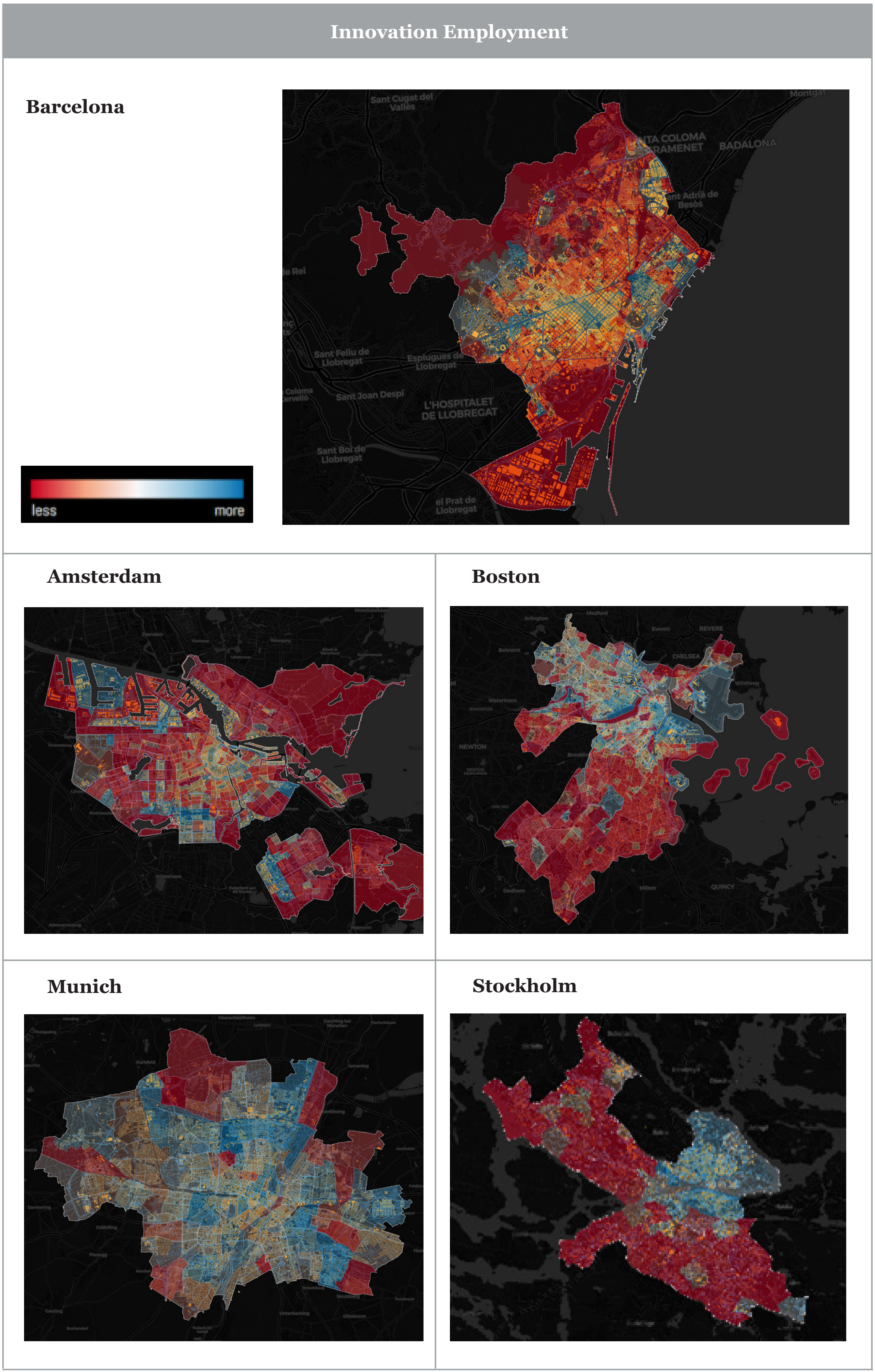
On average, innovation districts present a 2.8 times higher concentration of knowledge-intensive activities per employee once these districts reach maturity. This, in turn, produces four times higher innovation output per employee in terms of patents, new products, new services, new processes, and R&D, 16 times higher creation and availability of knowledge-intensive employment opportunities, and 25 times higher business revenue per resident.

To strengthen the knowledge economy, innovation district leaders should develop a new vision that focuses on innovation strategy. A key ingredient for the success of a given innovation district is to consider how to optimally connect sources of innovation (universities and research centers) with industry to help boost the internal production of new products and services. A strategic plan can be created by completing an assessment of the district's strengths, weaknesses, risks, and opportunities (SWOT).

A key tool to help in this process is Aretian's innovation pipeline. University research activities can be linked with local industries, thereby mapping out connections between innovations emerging from academia and the city's current economic performance. This will also show the gaps that might be filled by new industry or startups that might help diversify the economic performance of the city. In terms of innovative employment, we identified key areas in each city, hence shedding light on the most innovative areas.

Innovation Performance: KPIs and Best Practice Benchmarks

Figure 64. Innovation Employment Gradient Benchmarking



Innovation KPIs: Measuring the Impact of the Knowledge Economy

The measurement of the following innovation KPIs is critical for achieving success:

Innovation Intensity: This needs to be above 35%, with a critical mass of approximately 20,000 and innovation intensity above 50% in critical centers of innovation districts. The innovation intensity peaks observed in world-class innovation districts typically reach values between 70% and 85%.

Innovation Performance: This measures the tangible results of the collective effort deployed to create the advancement of knowledge. Innovation performance measures the tangible outputs of innovation created on an annual basis by the innovation community, preferably at the smallest possible census geographic aggregation level. Innovation performance measurements reflect the output of new products, services, and production processes, new patents and their associated revenues, scientific research papers, and other R&D outputs.

Innovation Impact: This measures the societal benefits of the collective effort deployed to create knowledge and innovation networks. The innovation impact describes the benefits to the broader community that result from the development of knowledge-intensive activities. The innovation impact is measured through a variety of contributing indicators, including the number of innovation-intensive employees in the district, the meritocracy index, the prosperity index, the inequality index, measurements of indirect employment generation, measurements of diversity, and industry alignment with the broader metropolitan area.

Ingredients and Dynamics for Success

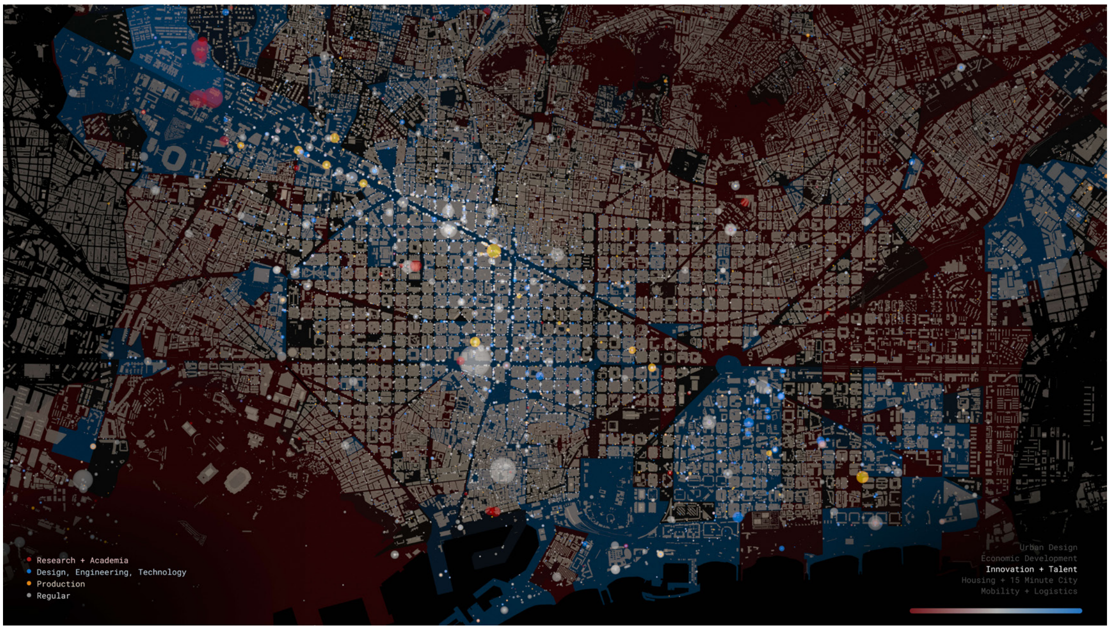
The Seven Phases of Innovation

The seven phases of innovation provide a framework for organizations to create support systems that can promote innovation efforts among startups and young companies. Creating startup competitions, accelerators, boot camps, and conferences will help increase excitement and provide opportunities for the creation of new companies. In addition, providing legal, IP, and financial advice and mentorship during the startup process will help remove obstacles, making it easier for individuals and teams to achieve their goals. Successfully nurturing this innovation-friendly environment will require the support of innovative organizations associated with the leading research institutions, coworking spaces, and industry professionals as well as state sponsorship to achieve its full potential. The following table provides an in-depth description of the seven phases of innovation in the network of talent:

Table 20. The Seven Phases of Innovation

(1) Idea Creation Inception	Idea creation inception corresponds to the different research areas leading to the inception of creative ideas with the potential for innovation development.
(2) Data Gathering	Data gathering is the step following the idea; it corresponds to the development of processes to gather data with the aim of confirming the validity of the idea itself.
(3) Hypothesis	Hypothesis is the confirmation and formulation following data gathering. Based on the available data, researchers and innovators formulate a hypothesis that they will test.
(4) Prototype	Prototype is the creation of processes, services, or goods that follow the previous steps and that test the innovative validity of the product being developed.
(5) Validation and Calibration	Validation and calibration are the steps during which the prototypes are consolidated, validated, and calibrated before the launch of the product.
(6) Minimum Viable Product	Minimum viable product is the first truly entrepreneurial step. It corresponds to the creation of startups based on the product that has been previously developed.
(7) Mass Production and Diffusion	Mass production and diffusion is the last step in the phases of innovation. Once a minimum viable product has been launched, mass production and diffusion are feasible. New products or services can then be created on top of the existing product to consolidate the company and lead it into the innovative company stage.

Geospatial Gradient of Innovation and Key Knowledge Economy Nodes in Barcelona



Insights - Propelling Innovation Ecosystems

Insight 1: Concentration of Innovation Networks Strengthens the Knowledge Economy

Innovation KPIs: The geospatial concentration of knowledge economy employment, paired with the fruitful knowledge exchange dynamics between academia, startups, and innovative firms, enables the realization of the multiplying effects of scale-free innovation network concentration.

The overall innovation ecosystem ranking is (in order): Boston, Stockholm, Amsterdam, Munich, and Barcelona. The Boston area presents the best practices examples of propelling the knowledge economy by integrating highly sophisticated innovation ecosystems with urban design strategies.

Innovation is a key driver for economic growth in cities. Therefore, it is important to measure all the necessary KPIs that describe the innovation economy. Below are charts and tables that describe the levels of innovation and key economic data.

Table 21. Demographics and Talent Benchmarking (Five Global Cities)

City	Population	Total Employment	Innovation Employment	Innovation Intensity	Ratio with Barcelona
Amsterdam	900,144	581,997	123,910	21.29%	141%
Barcelona	1,616,902	843,442	127,314	15.09%	100%
Boston	652,944	682,192	203,811	29.88%	198%
Munich	1,592,708	924,065	176,380	19.09%	126%
Stockholm	975,546	681,294	169,446	24.87%	165%

The lower-bound threshold to nurture a successful knowledge economy is for an innovation district to reach an innovation intensity above 35% and for the broader city to surpass 20% innovation intensity. Currently, Barcelona presents an average innovation intensity of approximately 15%, and its potential innovation districts rarely exceed 30% innovation intensity values.

Goals and Strategies—World-Class Innovation Ecosystem

Goal and Strategy 1:

World-Class Innovation Ecosystem: Raise the number of knowledge-intensive jobs from 125,000 up to 200,000 (hence, increasing innovation intensity from 15% up to 20%) between 2024 and 2040 by concentrating knowledge advancement hubs in strategic locations.

Table 22. Total Revenue and per Employee and Resident Ratios

City	Revenue Volume (€)	Revenue/ Employee (€)	Revenue/ Resident (€)	Ratio with Barcelona
Amsterdam	90,701,521,112	155,845	100,763	129%
Barcelona	125,823,619,404	149,179	77,818	100%
Boston	160,176,934,163	234,797	245,315	315%
Munich	150,854.033,448	163,250	94,715	122%
Stockholm	125,357,590,596	183,999	128,500	165%

Barcelona, with 127,000 innovation employees within the city, currently does not fully reach the necessary threshold for innovation employment. Barcelona would be able to achieve at least an average innovation intensity of 20% by adding 75,000 to 80,000 innovation employment over the next couple of decades. This would give the city a level of critical mass in knowledge-intensive activities that are able to generate the multiplying effects of innovation and compete globally.

Table 23. Unemployment Rate—Five Global Cities

City	Unemployment Rate
Amsterdam	4.8%
Barcelona	8.5%
Boston	2.7%
Munich	3.9%
Stockholm	6.8%

A desirable goal for Barcelona is to match Stockholm's standards within the coming years as much as possible so as to reach the same innovation metrics per capita. This can be achieved by learning from the city, establishing best practices, and forming working groups to share information in a productive way. Some of the best practices for building a successful innovation scene can be learned from evaluating the Greater Boston area's "Innovation Scene" or network of urban areas presenting a high degree of innovation concentration: a constellation of innovation districts. Boston has been very successful in creating new companies from academic research. In addition, the municipal government has been smart in its land use planning to create the space necessary for new innovative companies to thrive.

Amsterdam

Figure 65. Innovation Employment (Amsterdam)

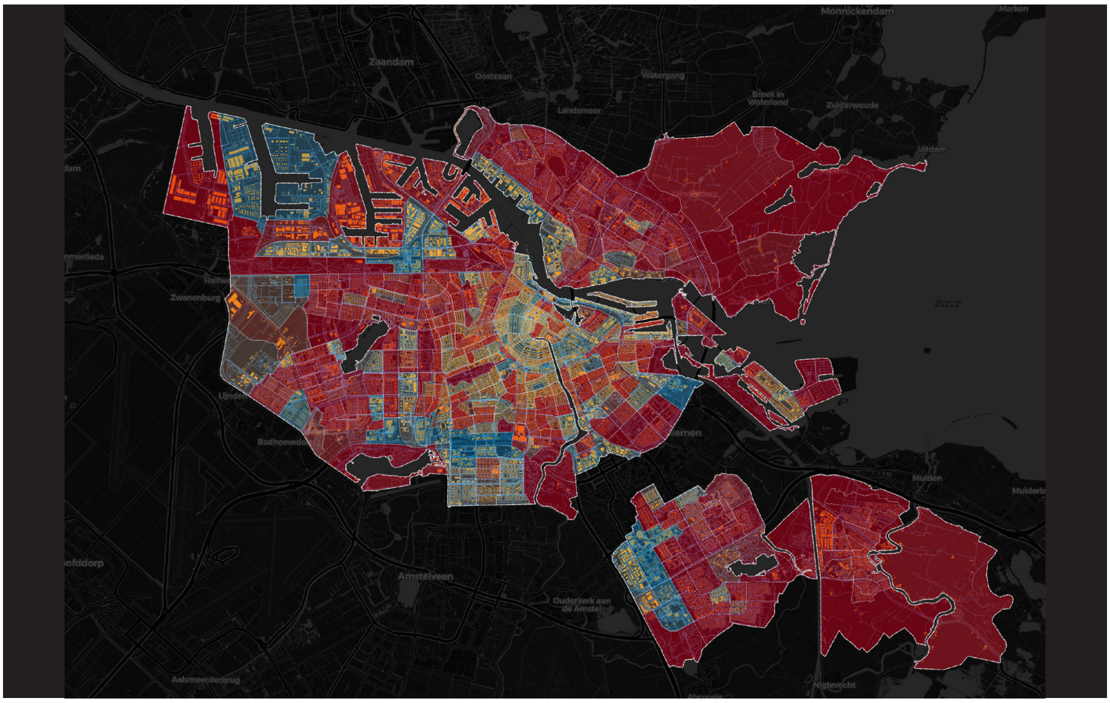
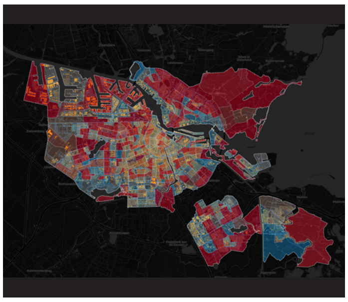
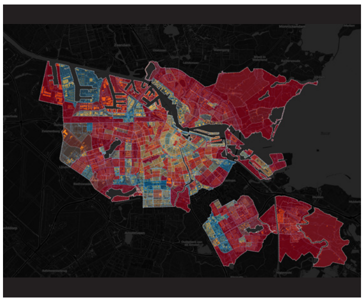
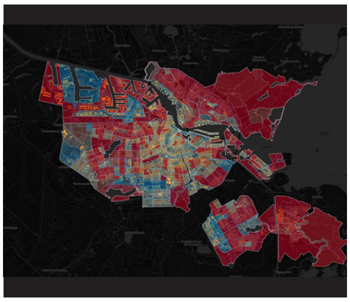


Table 24. Innovation Key Performance Indicators (Amsterdam)

Innovative Businesses	Innovation Employment	Innovation Revenue
		

Regarding Amsterdam, the city center and Zuidas area have a high concentration of innovative employment, with a focus on custom computing programming services and software, computer systems design services, general management of technology firms; engineering services; marketing research and public opinion polling; architectural services; colleges, universities, and research centers; crude petroleum extraction; and research in the physical, engineering and life sciences.

Barcelona

Figure 66. Innovation Employment (Barcelona)

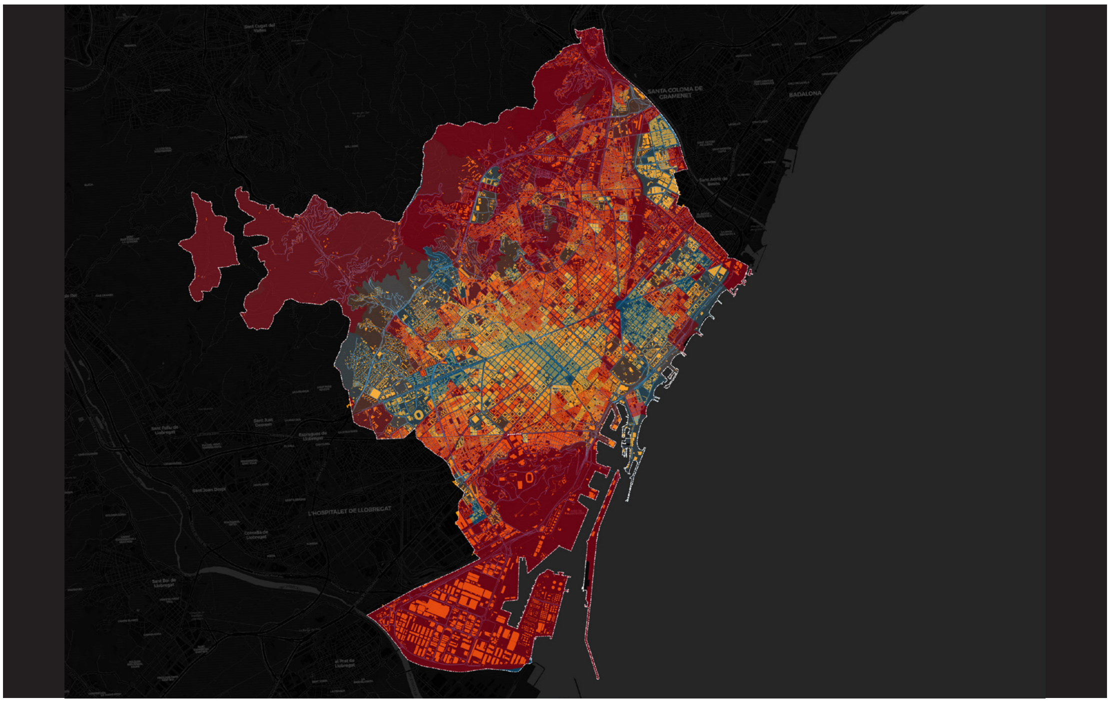
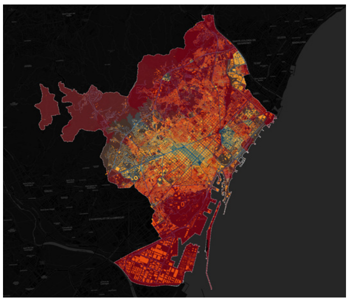
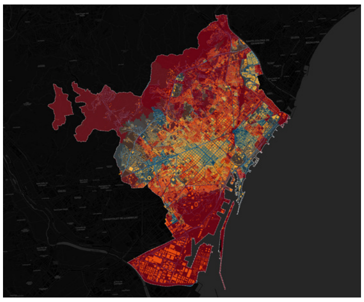
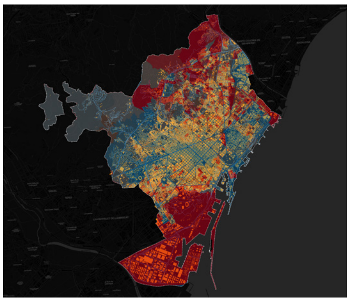


Table 25. Innovation Key Performance Indicators (Barcelona)

Innovative Businesses	Innovation Employment	Innovation Revenue
		

Barcelona's innovative employment is primarily located in the core areas of the Eixample district; the Sant Gervasi-Alta Diagonal area; and the Sant Martí and 22@ innovation district neighborhoods. We want to note, though, the relative lack of self-contained, self-sufficient innovation ecosystems: The largest academic and research activity concentration is located in the Alta Diagonal area yet disconnected from tech transfer centers in Poblenou and the manufacturing scene in the Besòs area.

Boston

Figure 67. Innovation Employment (Boston)

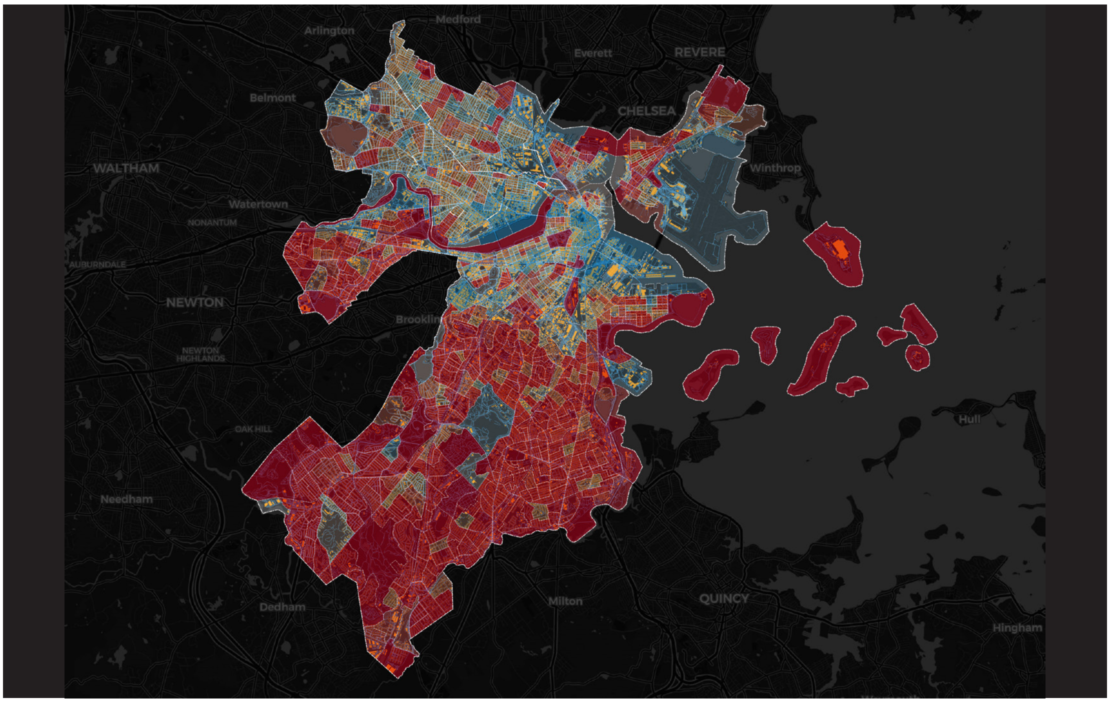
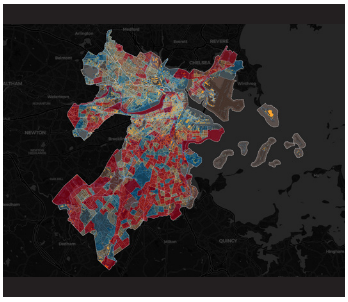
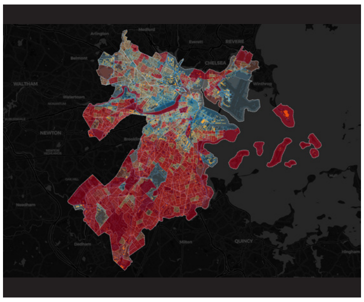
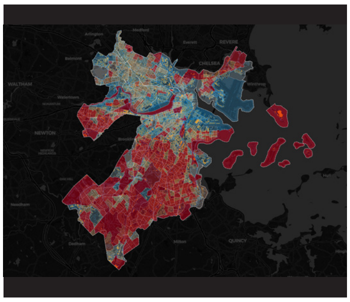


Table 26. Innovation Key Performance Indicators (Boston)

Innovative Businesses	Innovation Employment	Innovation Revenue
		

The most thriving innovation ecosystem in the Boston area is located in Kendall Square, which is propelled by a myriad of researchers and spin-off companies stemming from MIT and Harvard. Other remarkable areas can be located in notable innovation districts, including the Seaport innovation district, Harvard Square, the Longwood Medical Area, and the up-and-coming Union Square Innovation District in Somerville.

Munich

Figure 68. Innovation Employment (Munich)

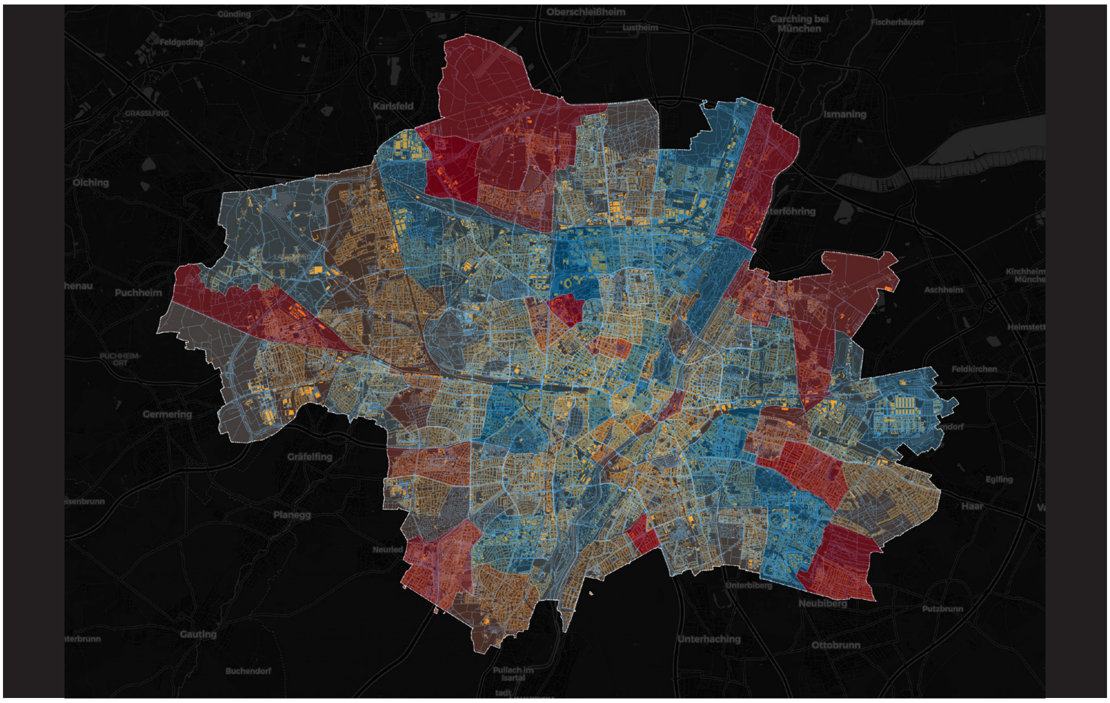
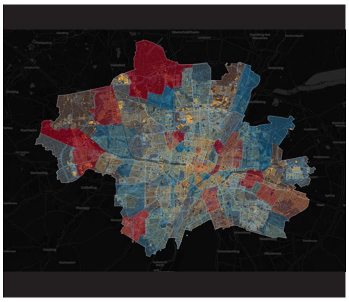
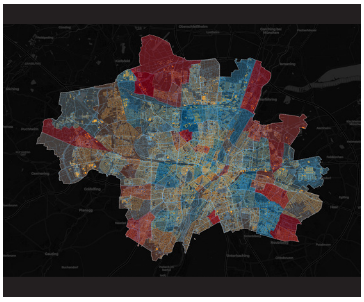
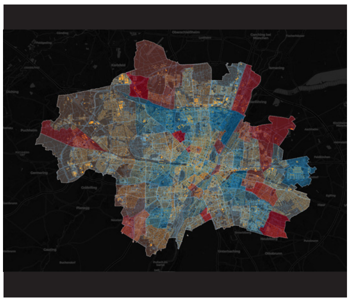


Table 27. Innovation Key Performance Indicators (Munich)

Innovative Businesses	Innovation Employment	Innovation Revenue
		

A careful examination of the innovative areas in Munich reveals the following knowledge economy hotspots: the Ludwigsvorstadt-Isarvorstadt district, which hosts several startups and innovation centers, the Maxvorstadt area, Alstadt-Lehel, and the Schwabing-Freimann district.

Stockholm

Figure 69. Innovation Employment (Stockholm)

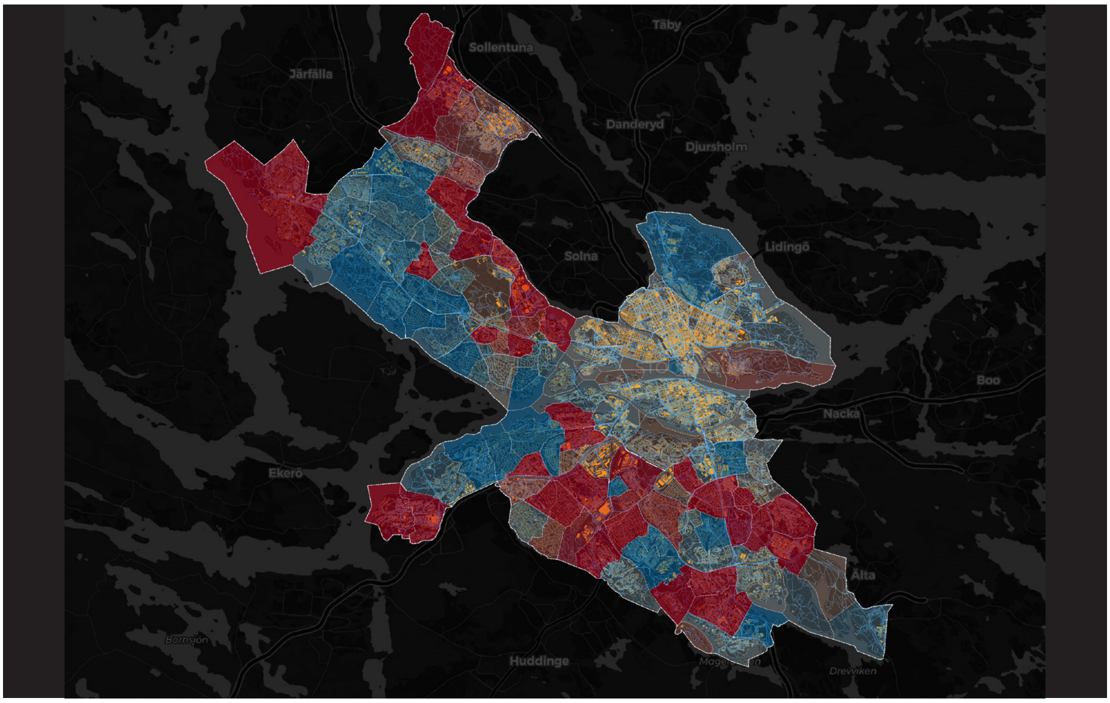
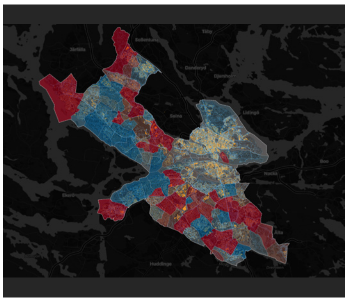
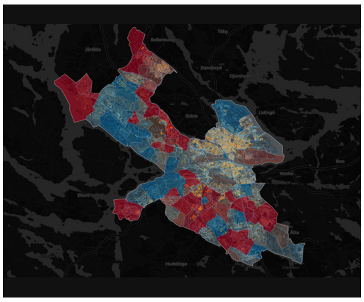
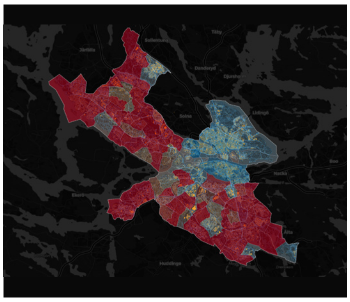


Table 28. Innovation Key Performance Indicators (Stockholm)

Innovative Businesses	Innovation Employment	Innovation Revenue
		

For Stockholm, the innovative areas are located in the center of Norrmalm and in Ostermalm, which host a vibrant startup scene, consolidated software and engineering companies, pharmaceutical and biotechnology firms, boutique consulting services, audiovisual and motion picture production corporations, and large energy, city planning/urban design, and construction corporations.

Insight 2: Innovation Districts Maximize the Multiplying Effects of Collective Knowledge

Successful Innovation Ecosystems: The Boston area presents a series of high-quality examples of successful innovation districts, including Kendall Square, Longwood, Seaport, and Harvard. The Boston area presents a magnificent example of how city leaders can contribute to shaping a long-term vision and giving birth to a world-class, highly successful innovation ecosystem. First and foremost, it is important to look at the main districts within Boston: Kendall Square, Harvard Square, the Longwood Medical Area, Boston Seaport, and two up-and-coming neighborhoods: Union Square in Somerville and Harvard Allston (Harvard's new Enterprise Research Campus extension).

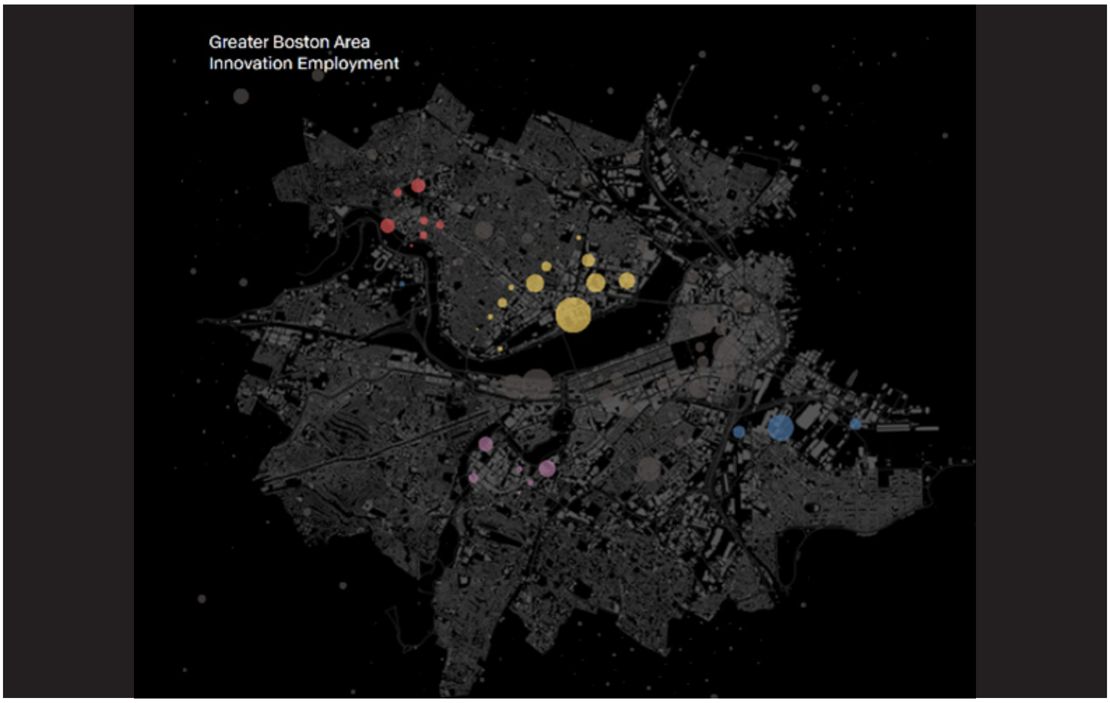
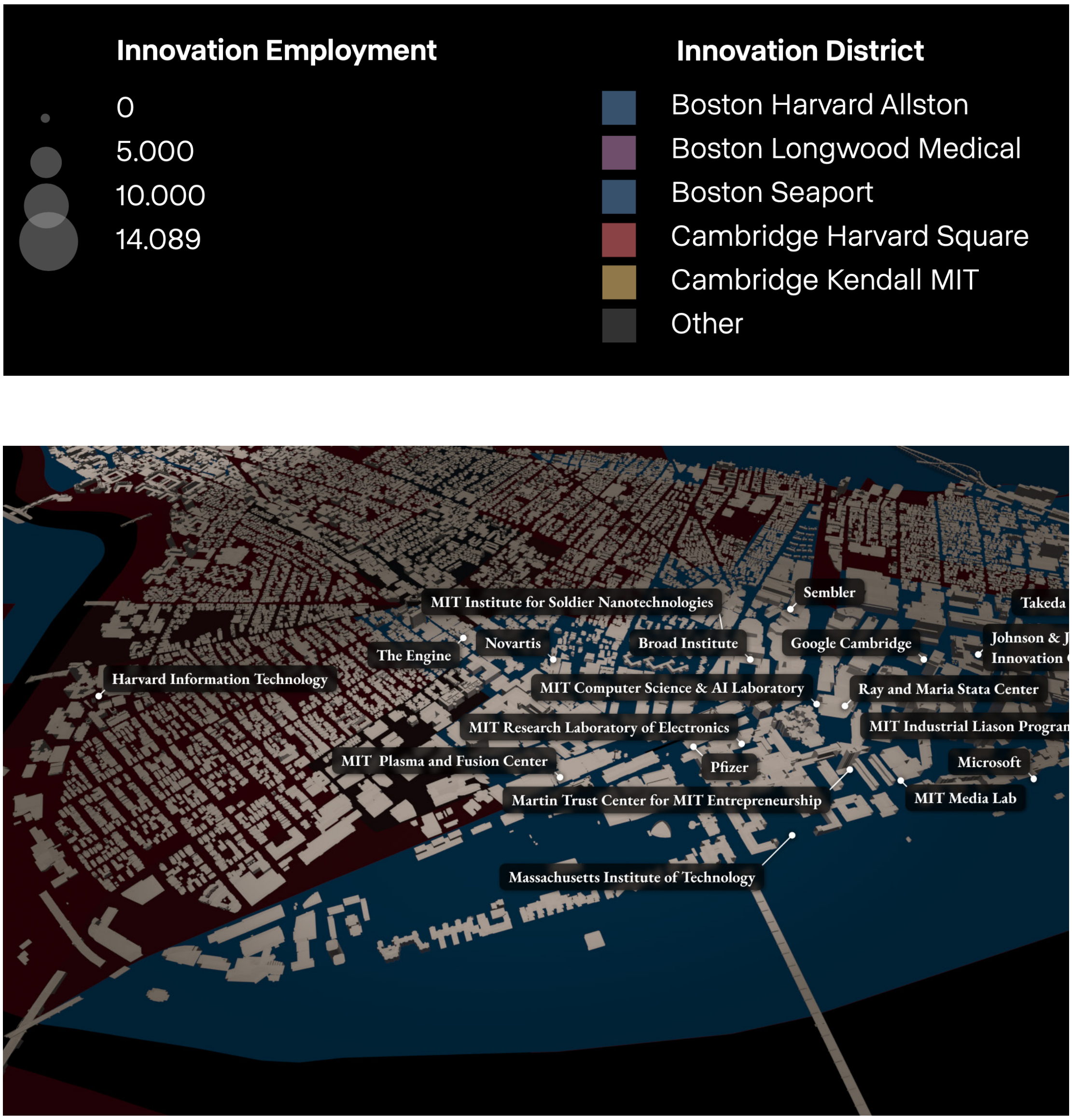


Figure 70. Innovation Districts and Knowledge-Intensive Employment (Greater Boston Area)



Goal and Strategy 2:

Innovation Pipeline and KPIs: Strengthen the three phases of innovation (research, tech transfer, and advanced production) to increase innovation intensity, performance, and impact of KPIs to raise revenue/employee from €149,179 up to ≅€200,000 and revenue/resident from €77,818 up to ≅€110,000 by 2040, here by means of providing support across the seven steps of innovation.

Kendall Square is well known for its close proximity to the MIT campus. Nearly 70% of Harvard students are also only two metro stops away from Kendall. The neighborhood hosts 45,000 employees and has an 84% innovation intensity peak with an average of 45% throughout the neighborhood. The square has a series of specific buildings that are programmed to support the innovation process, along the seven steps of innovation. Research is conducted at MIT and Harvard while applied research is done in conjunction with industry. Harvard and MIT have incubators to support the creation of new ideas while innovation centers/tech transfer facilities help take these ideas into Minimum Viable Products or MVPs and early-stage companies. The presence of numerous coworking facilities and startup incubators such as the Cambridge Innovation Center (CIC), which started in Kendall Square, was one of the first coworking business hospitality companies in this sector. Kendall has one of the lowest vacancy rates of 1–2% because all major technology companies want to be within this ecosystem. The result is a thriving district that has many visitors, supporting the hospitality industry, numerous law firms, CPAs, business advice, and supporting industries that help keep the innovation companies thriving by providing the necessary services.

Boston Seaport is a relatively mature innovation district, though presenting a lower degree of innovation intensity than Kendall, because it focuses a bit more on commercial activities than hosting innovative companies. However, the new buildings provide attractive new real estate to rent for firms looking to attract top talent. Many large firms have been located in the seaport area, including Amazon. The developing neighborhoods of Union Square, which is located in Somerville, will house new companies located at the end of the Green Line Station, a Metro line. The Harvard Allston Enterprise research campus will be a major addition to Boston's innovation ecosystem with a large number of new buildings located next to the Harvard Business School and School of Engineering and Applied Sciences.

Harvard Square is one of the foremost talent magnets around the globe. Despite its growing innovative scene, it has been lagging behind Kendall Square because of office space scarcity. Nevertheless, a significant number of IT and pharmaceutical companies are located around Harvard Square. Significant space scarcity prompted Harvard entrepreneurs to gravitate toward Kendall Square, whose startup scene is composed of 70% of tech firms with at least one Harvard graduate as the founder or cofounder. Being next to Harvard allows for easy access to students and research opportunities. Finally, the Longwood Medical Area is a cluster of some of the world's top medical research centers, healthcare facilities, and prestigious doctors. The geographic clustering of advanced life sciences activities allows for patients to be seen by multiple different specialists, allowing Longwood to focus on highly challenging medical conditions. It also attracts some of the best talent, with Harvard Medical School being located in the heart of the campus.

Barcelona and Boston: Innovation Ranking Comparison

An evaluation of the innovation-related industries across Barcelona and Boston presents a series of revealing insights. Despite its remarkably larger population, Barcelona presents comparatively fewer innovative industries. Furthermore, the innovative sectors ranging across the three phases of innovation tend to present, on average, substantially lower PCI or industry-specific Product Complexity Index.

Figure 71. Innovation Ranking (Barcelona)

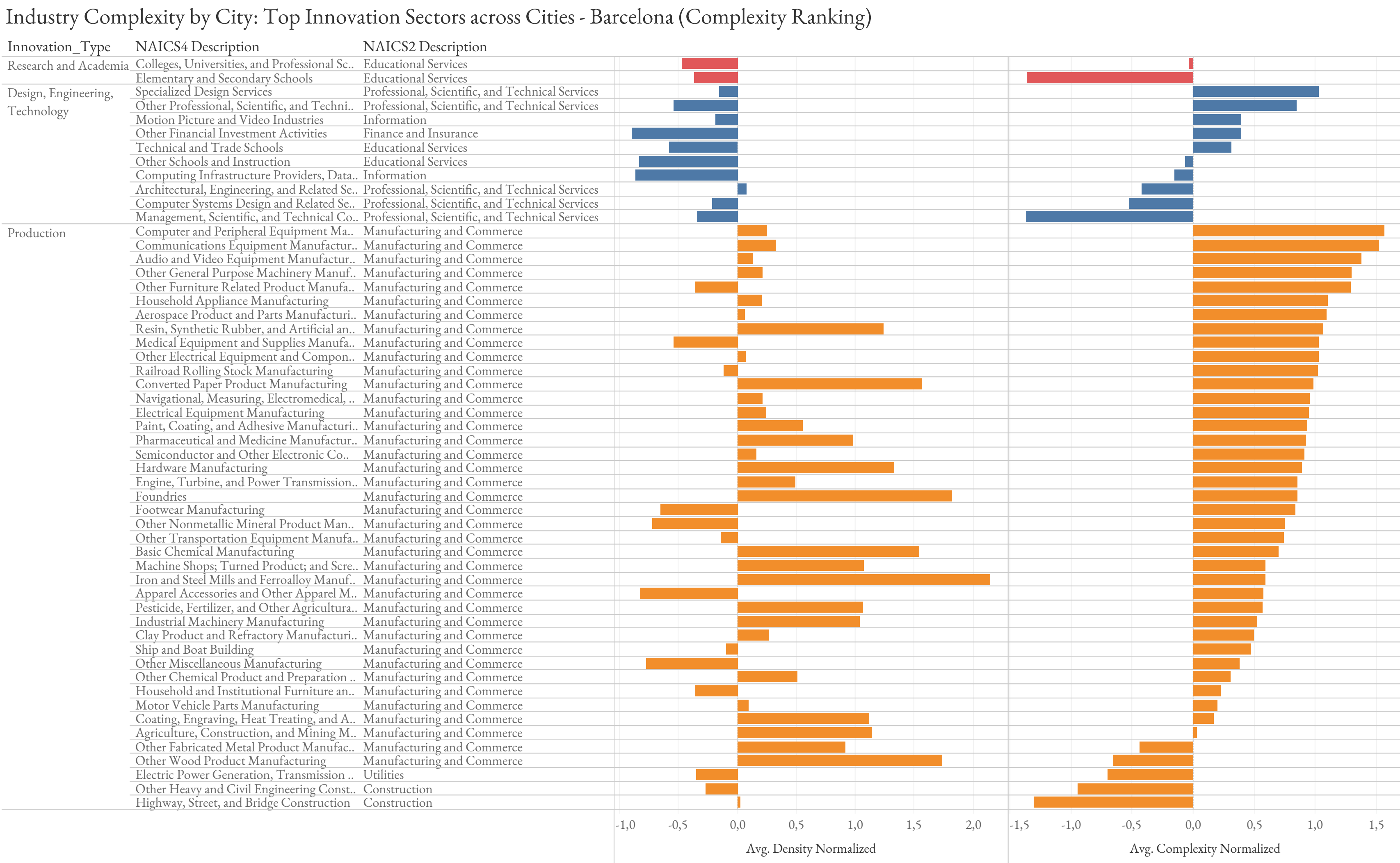
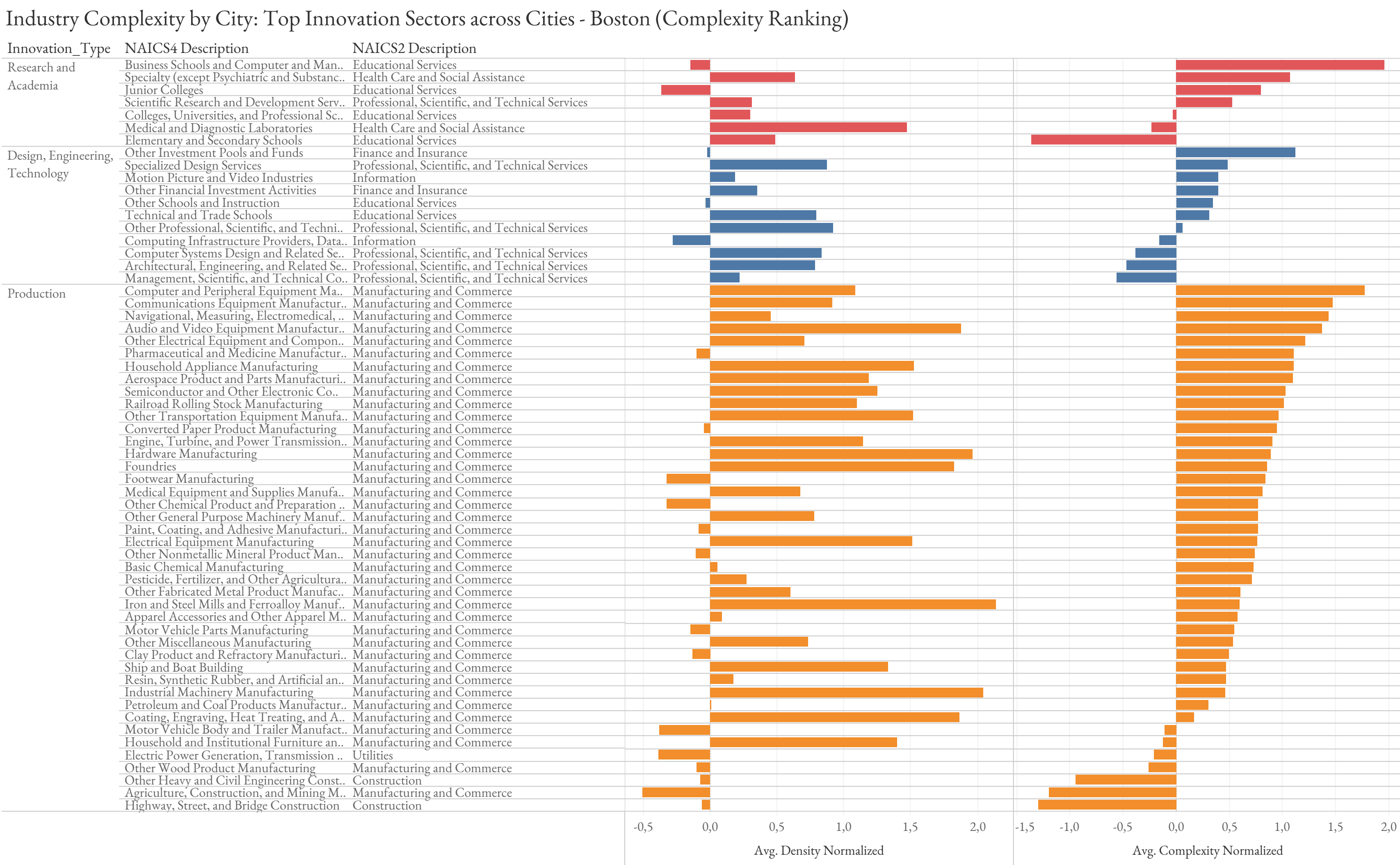


Figure 72. Innovation Ranking (Boston)

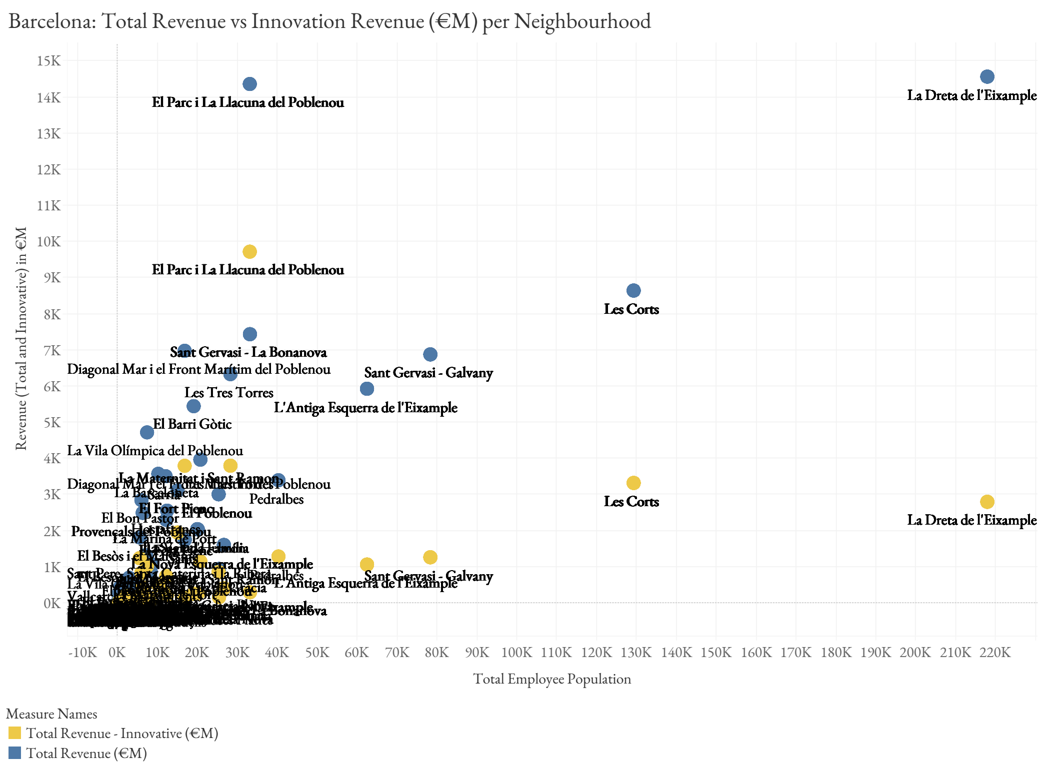


It is also worth noting that the applied research sectors are particularly weak in Barcelona, which is in stark comparison with Boston. Moreover, the knowledge transfer sectors present a higher degree of density (stronger value chains) in Boston compared with Barcelona. Industries such as specialized design services, computer systems design, software, civil engineering and architecture design, or professional, scientific, and technical services (boutique consulting) present a remarkably higher level of industry density in Boston than in Barcelona.

In sum, the location of innovative districts next to innovative institutions and universities will foster greater innovation in both realms. This will create a path to creating a world-class innovation ecosystem in Barcelona, with network dynamics that can harness citizens' potential while generating long-term effects for driving innovation across key industries.

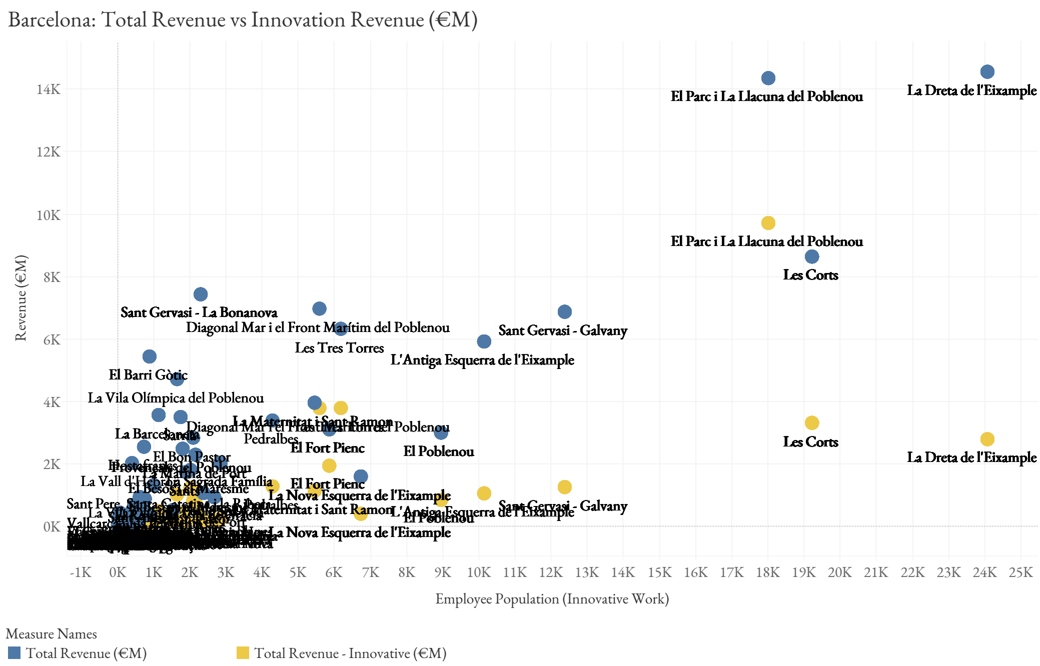
It should be noted that the 22@ innovation district has created one of the most dynamic economic centers of Barcelona. Although it has a much smaller employment base than Les Corts/Alta diagonal or even Dreta de l'Eixample, the district has been able to generate a similar revenue per year as Dreta de l'Eixample (approximately €14B). A key factor has been the higher degree of innovation concentrated around Parc i la Llacuna del Poblenou. This has generated an exchange of intellectual capital that has led to the multiplying effects of the knowledge economy.

Figure 73. Innovation and Total Revenue vs. Intensity (Barcelona)



The high concentration of innovation employment at the very core center of 22@ innovation district enables the generation of a larger revenue surplus per employee when compared with the traditional Central Business District of Dreta de l'Eixample, which is structured around major central avenues such as Rambla de Catalunya and Passeig de Gràcia. A key takeaway is that investing in innovation pays off and provides generous yields that can generate quality employment.

Figure 74. Total Revenue and Innovation Revenue (Barcelona)



Insight 3: Industry Physical Atomization and Lack of Knowledge Transfer Platforms Hinder the Innovation Potential of a Community

Innovative sectors: Physical atomization and lack of proper tech transfer platforms across innovation phases prevent the benefits of creative tension between universities and industries.

Barcelona Recommendations: A Network of Thriving Innovation Districts

The Barcelona metropolitan area has the potential to create a new thriving innovation ecosystem composed of selected innovation districts and industry-specific knowledge economy hubs. This would place Barcelona as an economic and knowledge powerhouse in Europe and abroad. The ongoing efforts to support the consolidation of a nascent and highly promising innovation scene in Barcelona present immense opportunities for the region to harness the potential of its citizens, increase the quality of life across the region, and generate sustained and distributed prosperity cycles.

Barcelona area institutions should strive to conceive, shape, nurture, support, and develop a constellation of strategically located knowledge economy hubs. These hubs should aspire to serve city citizens by creating quality jobs and attractive economic development anchor sites. These hubs can be developed by following strategic guidelines, employing new urban analysis tools, and analyzing relevant data sets and KPIs.

Weaknesses in the Innovation Ecosystem

- **Phase 1 – Research**. Currently, we observe a shortage of successful R&D projects stemming from applied research centers from a myriad of over 2,000 knowledge fields across 11 main research domains present in the Barcelona area.
- **Phase 2 – Knowledge Transfer**. There is currently no consolidated knowledge and technology transfer center in Barcelona in any field of knowledge. This provides the opportunity to strategically design and locate new centers, potentially in line with pre-existing institutions or with other national or international ones.
- **Phase 3 – Anchor Innovation Companies.** Leading innovative companies operating in the geographical areas of intervention tend to be midsized or regional offices for multinational corporations, rarely concentrating their core knowledge concentration hubs in the Barcelona area.
- **Phase 4 – Startup Incubators**. There is a scarcity of consolidated startup incubation centers in the Barcelona area because only 19% of the 2,000 startups in the area can be considered truly knowledge-intensive and having R&D high value-added activities.
- **Phase 5 – Industry Verticals**. Industry verticals are currently highly atomized territorially so that value chains are excessively short and rarely exceed two or three stages of the production chain. In the future, they should aim to cover a minimum of five phases of the production chain.

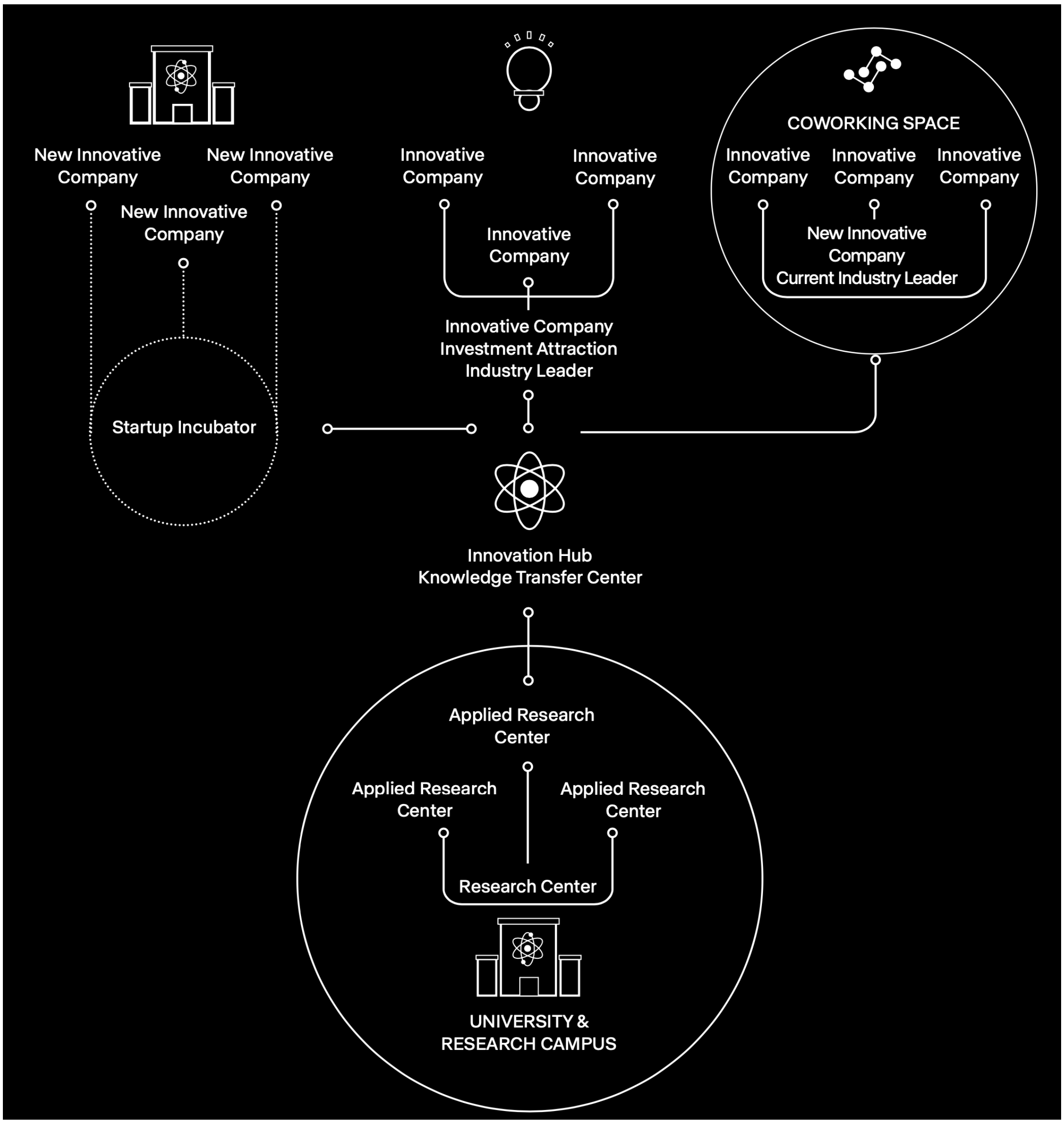
Innovation pipeline diagrams help identify the most critical needs of a given community. On the left side of the diagrams and quantitative measures, representative university research centers are presented, whereas, on the right side the startups, most of the dynamic businesses and high value-added industries are placed. Between these two groups lie the connecting institutions that can support the technology transfer process.

The goal of this exercise is to determine what types of physical and intangible support would be the most beneficial to the community based on the identification of promising new research and design of buildings and architectural spaces, here as tailored to the industry and activity needs, to help transfer that new knowledge into a product aligned with market needs.

To best identify the key drivers of innovation within the community, the creation of research network graphs allows for the visualization of publications and patents within the academic community. By describing each innovation production process step by step, the natural hierarchies will emerge and help inform the knowledge economy vision.

Below is a representative network map of researchers throughout a university research community. This generalizable framework allows for identifying the strengths, weaknesses, risks, and opportunities of the research community while informing space design, location intelligence, activity programming, and organizational strategies aiming to propel the local knowledge economy ecosystem. The increasing super linearity of innovation associated with population growth is further exacerbated by local urban and economic development interventions such as nurturing well-thought-out innovation districts.

Figure 75. Innovation Ecosystem

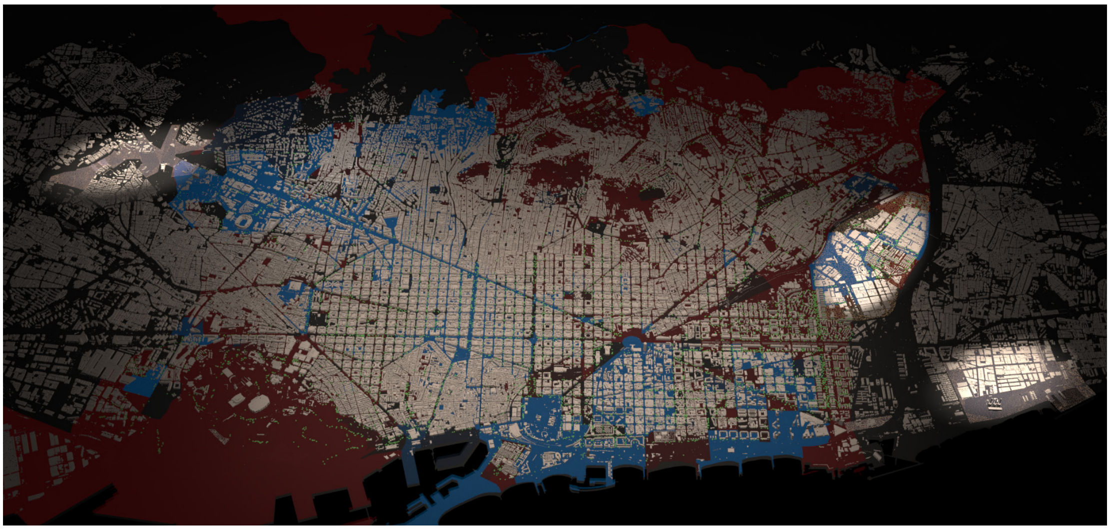


We should acknowledge that Barcelona and its broader metropolitan region have been attracting numerous innovation-related investments in recent years, amounting to approximately 140 knowledge-intensive centers and generating approximately €2.5B in 2023. Those centers include the Barcelona Supercomputing Center, the nuclear accelerator Sincrotró Alba, the HP Digital Design Hub, and Sanofi's AI center, among others. It must be noted, however, that the lack of a mature knowledge and technology transfer ecosystem currently hinders the realization of the latent potential of the region in terms of prosperity creation.

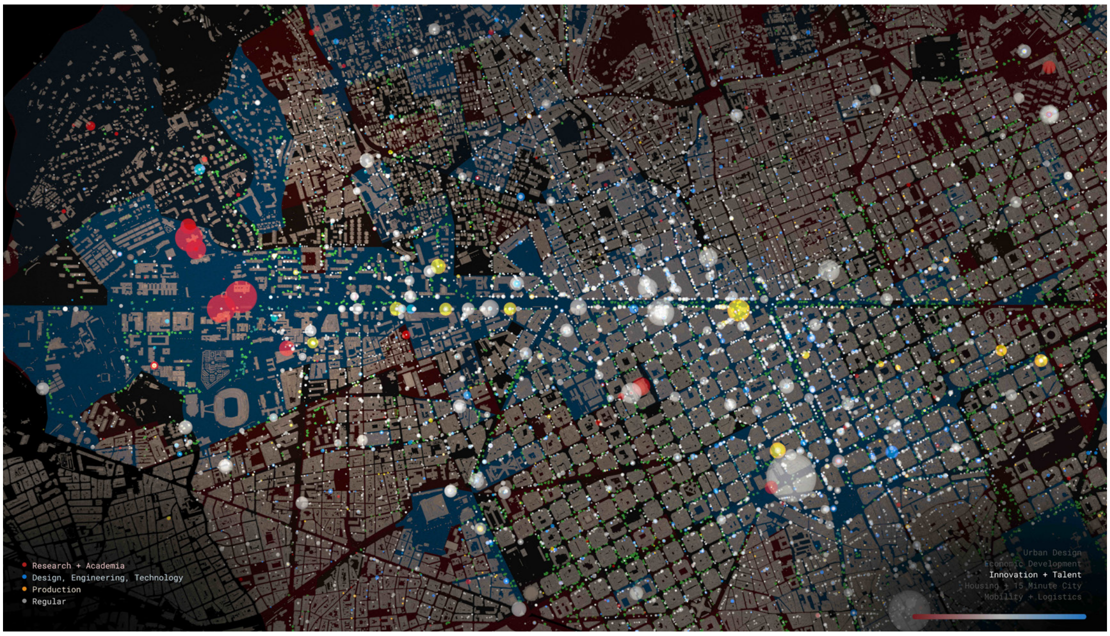
Goal and Strategy 3:

A Thriving Network of Innovation Districts: Strategically located in the Esplugues-Alta diagonal (109 Ha, potentially 23,000 new employees), Barcelona-Besòs (140 Ha, potentially 24,000 new employees), and Badalona i les Tres Xemeneies (190 Ha, potentially 27,500 new employees) while having innovation intensity ranging from 40% up to 60% and hosting dedicated applied research areas, innovation centers, startups incubators, coworking, and industry liaison.

Figure 76. The Three Innovation Districts Called to Galvanize the Knowledge Economy in the Barcelona Area



Innovation districts are defined as urban neighborhoods or districts purposely designed, nurtured, and supported to concentrate and promote innovation-related activities in dense urban areas. These districts leverage the nonlinear effects of the geographic concentration of knowledge-intensive activities.



A high concentration of research institutions in the Alta Diagonal area presents a strategic opportunity to bridge the gap between the different phases of innovation by linking applied research with knowledge-intensive industries via technology transfer centers and startup incubators.

Barcelona-Besòs Innovation District

Center 1: UrbanTech

The UrbanTech field presents great potential synergies between the schools of Civil Engineering, Architecture and Urbanism at BarcelonaTech, with sectors that have a strong tradition and presence in the city and the Besòs estates, such as Ciència de les Ciutats, GIS /GIS, digital design, intelligent construction and advanced construction procedures, urban mobility, and the real estate sector.

Research Areas:
- Civil engineering (153 researchers)
- Architecture (123 researchers)
- Urban planning (37 researchers)
- Informatics and computing (79 researchers)
- Mathematics (144 researchers)
- Graphic engineering and design (26 researchers)

University–Industry Synergistic Development Potential:
- Construction: Construction companies, structures, carpentry, interior design, and glass and crystal
- Mobility: Design and manufacture of cars, motorcycles, heavy vehicles, logistics, and technological solutions for urban mobility
- Real estate: Civil engineering design, architecture, town planning, GIS, and consulting

University Startup Scene Synergistic Development Potential Areas:
- Prop tech, sustainable mobility (automation, AI and mobility), travel tech & leisure, design for civil engineering and architecture, GIS/city science models, green energy technologies, data science and logistics, and advanced construction

Center 2: Robotics and Advanced Manufacturing

The robotics and advanced manufacturing field presents great potential synergies between the schools of Industrial Engineering, Computing, Telecommunications, and Physics, with sectors such as industrial machinery, industrial design and robotics, electronic equipment, semiconductors, and wood products and the paper.

Research Areas:
- Systems engineering, automation and industrial informatics (55 researchers)
- Industrial engineering and Information and Communications Technology (48 researchers)
- Engineering of machines and thermal engines (25 researchers)
- Electronic engineering and signal theory (160 researchers)
- Engineering (29 researchers)
- Computing (79 researchers)

University–Industry Synergistic Development Potential:
- Technological devices for medicine/pharmacy/dentistry, precision instruments, photonics, manufacturing of automotive parts and motor vehicles, electronic components, metal products for the war industry, manufacturing of paints and varnishes, robotics products, manufacturing of clothing and footwear, electrical energy distribution, and household appliances

University Startup Scene Synergistic Development Potential Areas:
- Automation of hardware, automation of processes for renewable energies, cosmetics, data centers, and machinery for sustainable mobility

Center 3: Nanotechnology and Advanced Materials

The nanotechnology and advanced materials field presents great potential synergies between the schools of Physics, Chemistry, and Materials Science with sectors such as plastics and resins, textiles and fashion design, chemical products, medical products, and pharmaceuticals.

Research Areas:

- Physics (120 researchers)
- Chemical engineering (85 researchers)
- Materials science and technology (60 researchers)
- Optics and optometry (37 researchers)
- Quantum physics (43 researchers)

University–Industry Synergistic Development Potential:

- Textile industry, fashion, shoes, plastics and resins, chemical products (fashion, cosmetics, leather, skins), and medical and pharmaceutical products

University Startup Scene Synergistic Development Potential Areas:

- Fashion design, recycling for the textile sector, beauty and cosmetic products, health digitalization, frontier materials for renewable energies, and photonics

Center 4: Agri-Food and Sustainability

The field of agritechnology presents great potential synergies between the schools of Chemistry, Agriculture, and Agricultural Engineering, and Industrial Engineering with sectors such as gastronomy, manufacturing of agri-food products, chemical products, renewable energy, and sustainability and waste management.

Research Areas:

- Agricultural engineering and biotechnology (37 researchers)
- Nutrition, food sciences (25 researchers)
- Chemical engineering (85 researchers)

University–Industry Synergistic Development Potential:

- Agri-food products, bread and derivatives, cosmetics and health, manufacture of equipment for gastronomic production, industrial machinery for renewable energy, waste management, trade in electric energy, seeds, and precision instruments for agriculture

University Startup Scene Synergistic Development Potential Areas:

- AI for food tech, additive manufacturing for the agri-food sector, sensors for agriculture, nutrition and dietetics, bioengineering, frontier materials for the pharmaceutical sector, and intelligent management of industrial waste

Center 5: Data Science and Software

The data science and software field presents great potential synergies between the schools of Computing, Mathematics, Civil Engineering and Numerical Methods, Industrial Engineering, Business Organization, Telecommunications, BSC, with sectors such as business intelligence, data science for business management, digital design, arts, logistics, and mobility.

Research Areas:

- Computing (79 researchers)
- Mathematics (144 researchers)
- Civil engineering and numerical methods (70 researchers)
- Industrial engineering, business organization (48 researchers)
- Telecommunications (160 researchers)

University–Industry Synergistic Development Potential:

- AI and data science for business management consulting, AI for industrial processes, computer programming, market studies and surveys, cinema and audiovisual, and media and marketing

University Startup Scene Synergistic Development Potential Areas:

- ICT and mobile telephony, IoT and sensors, AI for business management, AI for eCommerce, AI for design and gaming, AI for genetics and medicine, AI for fashion, cloud computing, adtech (marketing and ads), and hardware

Esplugues-Porta de Barcelona Innovation District

Ecosystem 1: Medical Research & Biotech

- General medicine, pediatrics, surgery and medical-surgical specialties, genetics, microbiology and statistics, clinical sciences, clinical fundamentals, diagnosis and detection of diseases, biomedicine, child and youth mental health, and immune and respiratory dysfunction in children

Ecosystem 2: Healthcare, Lifestyle, Pharma, Agritech, Food, Sports

- Nutrition, food sciences and gastronomy, biomedicine, genetics, microbiology and statistics, evolutionary biology, ecology and environmental sciences, pharmacy and pharmaceutical technology, pharmacology, toxicology and therapeutic chemistry, agritechnology, food science, and sports health sciences

Ecosystem 3: Urban Tech and Sustainable Development

- Civil and environmental engineering, architecture technology, architectural projects, urbanism and territorial planning, project and construction engineering, industrialized and sustainable building, and mobility and logistics

Ecosystem 4: Product Design, AI for Business Development

- Applied mathematics and AI, computer science, mathematics and computer science, and research in media technologies

Ecosystem 1: Medical Research & Biotech

- Total New Employment: 9,675 employees
- Total Innovation Employment: 8,925 employees
- Total Broader Ecosystem: 18,450 employees
- Innovation Intensity (%): 39%
- Real Estate Development: 357,950 m^2
- Leading institutions:
  — Sant Joan de Déu, Hospital Clínic, UIC, Clínica Diagonal, Dexeus
- Core Research:
  — Pediatrics, medical research, genetics, and rare diseases
- Core Industries:
  — Hospital services, pediatrics, surgery, pharmaceuticals, and biotech
- Core Startups:
  — Health tech, business services and software, and beauty and personal care

Ecosystem 2: Healthcare, Lifestyle, Pharma, Agritech, Food, Sports

- Total New Employment: 3,050 employees
- Total Innovation Employment: 2,640 employees
- Total Broader Ecosystem: 11,100 employees
- Innovation Intensity (%): 24%
- Real Estate Development: 185,400 m^2
- Leading institutions:
  — Universitat de Barcelona, URL, UAB, UdLL, URV, UdG, UVic, and UPC
- Core Research:
  — Nutrition, food, sports, lifestyle, public health
- Core Industries:
  — Food, agritech, nutrition, packaging and labeling, sports, apparel and textile, lifestyle, public health, cosmetics, and pharma
- Core Startups:
  — Food tech, agritech, sports, green and energy tech, pharmaceuticals, and cosmetics

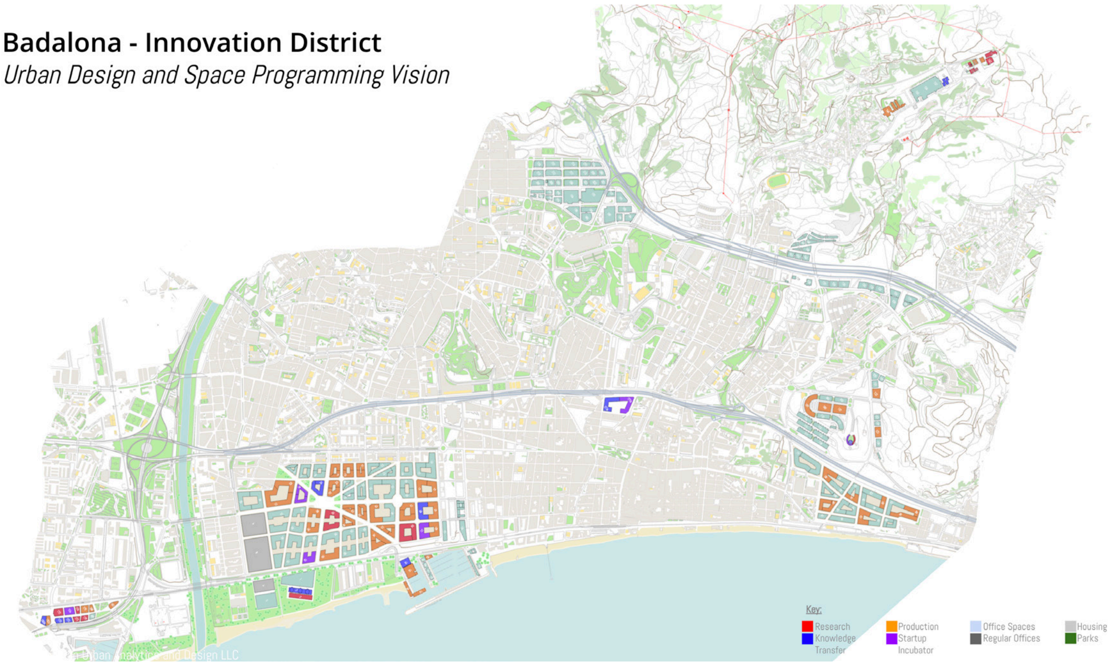
Ecosystem 3: Urban Tech and Sustainable Development

- Total New Employment: 7,260 employees
- Total Innovation Employment: 6,500 employees
- Total Broader Ecosystem: 15,250 employees
- Innovation Intensity (%): 43%
- Real Estate Development: 141,150 m^2
- Leading institutions:
  — BarcelonaTech-UPC, BSC, La Salle, UIC, IQS, Esade, and IESE
- Core Research:
  — Urbanism, civil engineering, architecture, mobility, and sustainability
- Core Industries:
  — Construction, urban development, energy, cleantech, advanced materials, and mobility and logistics
- Core Startups:
  — Business services and software, travel tech and leisure, digital content and media, and green and energy tech

Ecosystem 4: Product Design, AI for Business Development

- Total New Employment: 3,035 employees
- Total Innovation Employment: 4,150 employees
- Total Broader Ecosystem: 6,725 employees
- Innovation Intensity (%): 62%
- Real Estate Development: 77,050 m^2
- Leading institutions:
  — BarcelonaTech-UPC, BSC, La Salle, IQS, Esade, IESE
- Core Research:
  — Computer science, electrical engineering, supercomputing, and industrial engineering
- Core Industries:
  — Data science, software development, digital design, AI consulting, and supercomputing
- Core Startups:
  — ICT and mobile, FinTech, AdTech, EdTech, digital content and media, and business services and software

Badalona i les Tres Xemeneies Innovation District



Center 1: Media, Digital Design, VR/AR

Research Areas:

- Department of Visual Arts and Design (54 researchers)
- Department of Graphic Engineering and Design (26 researchers)
- Computer science, multimedia and telecommunication studies (16 researchers)
- Informatics and computing (79 researchers) and mathematics (144 researchers)

University–Industry Synergistic Development Potential:

- Media and art, entertainment and audiovisual production, sports, gaming, virtual and augmented reality, graphic and digital design, product prototyping, and audiovisual technology

University Startup Scene Synergistic Development Potential Areas:

- AdTech
- Business services and software
- Community and social network
- Digital content and media
- Ecommerce
- EdTech
- FinTech
- Gaming
- Hardware
- ICT and mobile

Center 2: Medical, Biomedical, and Pharmaceutical

Research Areas:
- Department of Medicine- Germans Trias i Pujol Research Institute (28 researchers)
- Department of Clinical Sciences, Translational Medicine (23 researchers)
- Department of Experimental and Health Sciences, Germans Trias i Pujol Research Institute (16 researchers)
- Department of Biosciences- Germans Trias i Pujol Research Institute (16 researchers)
- Cancer- Department of Clinical Sciences (14 researchers)
- Department of Dentistry, Translational Medicine (7 researchers)
- Josep Carreras Leukemia Research Institute (14 researchers)
- IrsiCaixa AIDS Research Institute (24 researchers)

University–Industry Synergistic Development Potential:
- Technological devices for medicine/pharmacy/dentistry, chemical products, and paints and adhesives
- Plastics and resins, cosmetic products, and medical and pharmaceutical products

University Startup Scene Synergistic Development Potential Areas:
- Health tech, disease detection, disease treatment, pharmaceutical startups, medical and biomedical products, clinical trials, food tech, and cosmetics and beauty

Center 3: Advanced Manufacturing and High-Performance Materials

Research Areas:
- Advanced Manufacturing
  - Department of Systems Engineering, Automation and Industrial Informatics (55 researchers)
  - Department of Mining, Industrial and ICT Engineering (48 researchers)
  - Department of Mechanical Engineering (46 researchers)
  - Department of Thermal Engines and Machines (25 researchers)
  - Institute of Robotics and Industrial Informatics (18 researchers)
  - Department of Nautical Science and Engineering (17 researchers)
- High-Performance Materials
  - Department of Physics (120 researchers)
  - Department of Chemical Engineering (85 researchers)
  - Materials Science and Engineering Department (60 researchers)
  - Department of Optics and Optometry (37 researchers)
  - Department of Materials Science and Physical Chemistry Institute of Theoretical and Computational Chemistry of the University of Barcelona (28 researchers)
  - Department of Chemical Engineering and Analytical Chemistry (25 researchers)
  - Department of Applied Physics, Institute of Nanoscience and Nanotechnology (20 researchers)
  - Department of Condensed Matter Physics, Institute of Nanoscience and Nanotechnology (18 researchers)

University–Industry Synergistic Development Potential:
- Manufacturing of automotive parts and motor vehicles (heavy vehicles, cranes, special vehicles), precision instruments and photonics, electronic components (home appliances, televisions, screens, computers, tablets, mobile phones), metal products and robotics, metals precious (jewelry, luxury products, fashion accessories), naval industry, and clothing and footwear manufacturing

University Startup Scene Synergistic Development Potential Areas:
- AI and digitization for graphic and industrial design, business services and software, community and social network, ecommerce, EdTech, fashion and design, FinTech, hardware, legal tech, and sports

Center 4: Sustainability

Research Areas:

- Electronic Engineering Department (105 researchers)
- Department of Signal Theory and Communications (93 researchers)
- Department of Computer Architecture (85 researchers)
- Department of Telematics Engineering (50 researchers)
- Department of Electrical Engineering (50 researchers)
- Road Engineering (153 researchers)
- Architecture (123 researchers), Urban Planning (37 researchers)
- Informatics and Computing (79 researchers)
- Mathematics (144 researchers)

University–Industry Synergistic Development Potential:

- Energy and Electronics
  - — Energy management and transition of water resources
  - — Waste management
- Urban Tech
  - — Construction: Construction companies, structures, carpentry, interior design, glass, and crystal
  - — Mobility: Design and manufacture of cars, motorcycles, heavy vehicles, logistics, and technological solutions for urban mobility
  - — Real estate: Civil engineering design, architecture, town planning, GIS, and consulting

University Startup Scene Synergistic Development Potential Areas:

- Clean tech/green energy technologies, energy transition, PropTech, sustainable mobility (automation, AI and mobility), travel tech and leisure, design for civil engineering and architecture, GIS/city science models, data science and logistics, and advanced construction

Insight 4: The Analysis of the Innovation Pipeline Reveals Liaison Opportunities Between Research and Industry for Each City and Context

Research networks: The analysis of the three innovation phases across cities and districts and the seven steps of innovation in Barcelona reveals that there are numerous applied research domains presenting attractive opportunities for knowledge transfer.

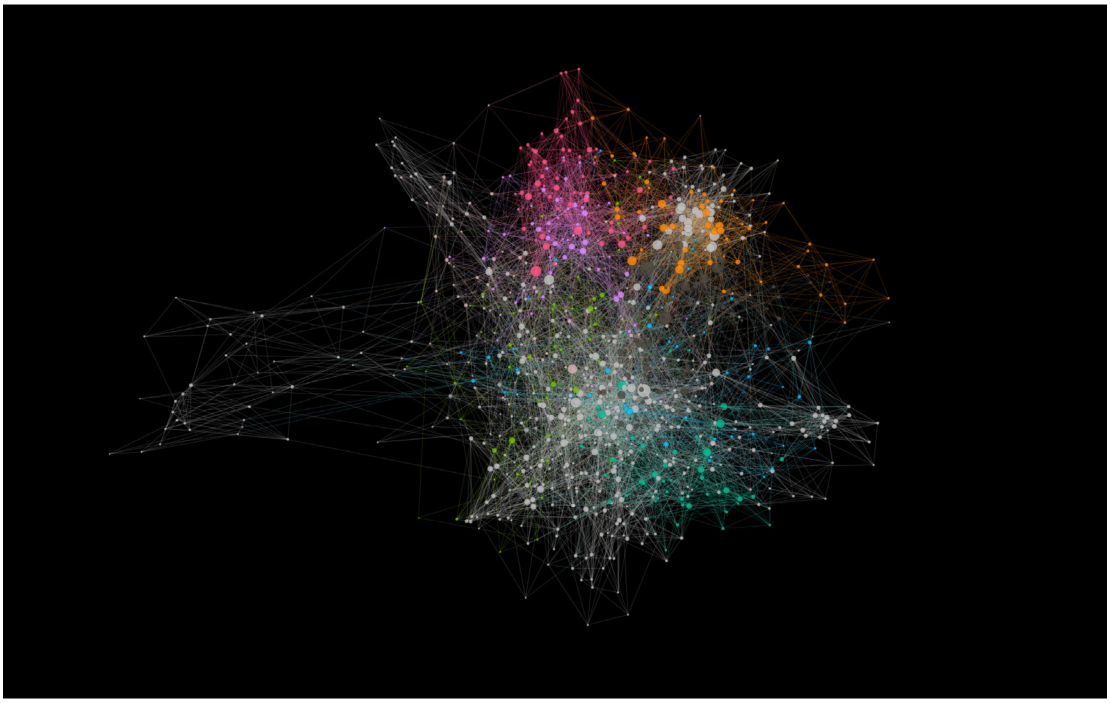
Goal and Strategy 4:

Applied Research Knowledge Transfer Focus: Define a vision to align the roughly ≅1,500 applied research fields across all universities and research centers with the 98 innovative sectors (four in research, 17 in tech transfer, and 77 in production) to codify the mutual knowledge exchange and knowledge advancement and realize the multiplying effects of innovation (potentially 4x more innovations per capita, 15x more knowledge employment, and x25 more revenue per resident).

Barcelona Area—Research Networks

BarcelonaTech

Figure 77. Research Network—Degree (BarcelonaTech)

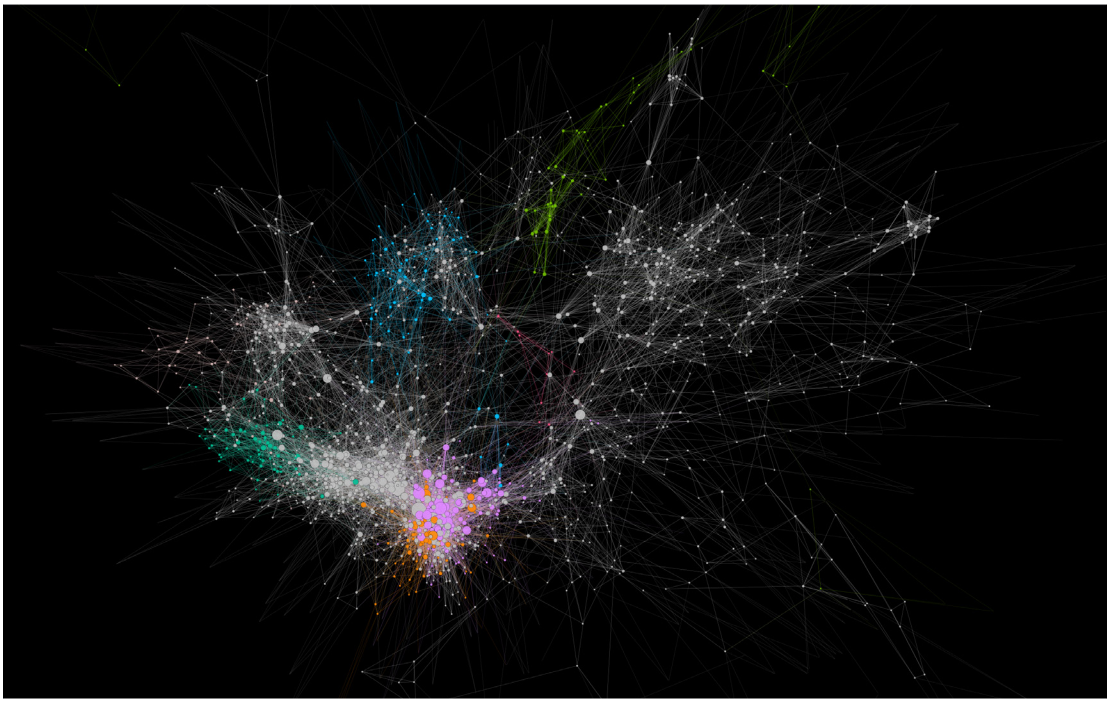


BarcelonaTech intellectual production and industrial liaison potential summary:

- Active Researchers: 2,415
- Publications: 112,000 (aggregate)
- Scientific Articles: 47,139
- Books: 3,736
- Top Research Departments: Civil and Environmental Engineering, Mathematics, Computer Science, Materials Science, Chemical Engineering, Computer Architecture, Architecture, Urban Planning and Design, Electronics, Systems Engineering, Materials Science, Telematics, Mechanical Engineering, Optics and Optometry, Agri-food, Statistics, Information Systems, and Graphic Design
- Top Research Areas: soil mechanics, construction engineering, high-performance materials, high precision instruments, molecular engineering, high-performance materials, advanced control systems, environmental engineering, structural engineering, synthetic polymers, molecular biology, remote sensing, language processing technology, agribusiness development, and computation
- Potentially Related Startups: AI and big data, cloud and edge computing, urban tech, IoT and sensors, automation, connectivity, digital health, AR/VR, robotics, recycling and recovery
- Potentially Related Industries: Computer systems design, architectural and civil engineering design, automation and robotics, chemical manufacturing, telecommunications, chemistry, electronics, materials science, industrial computer science, robotics, nutrition and biotechnology, smart construction, smart mobility, and advanced computation

Universitat de Barcelona (UB)

Figure 78. Research Network—Degree (Universitat de Barcelona)

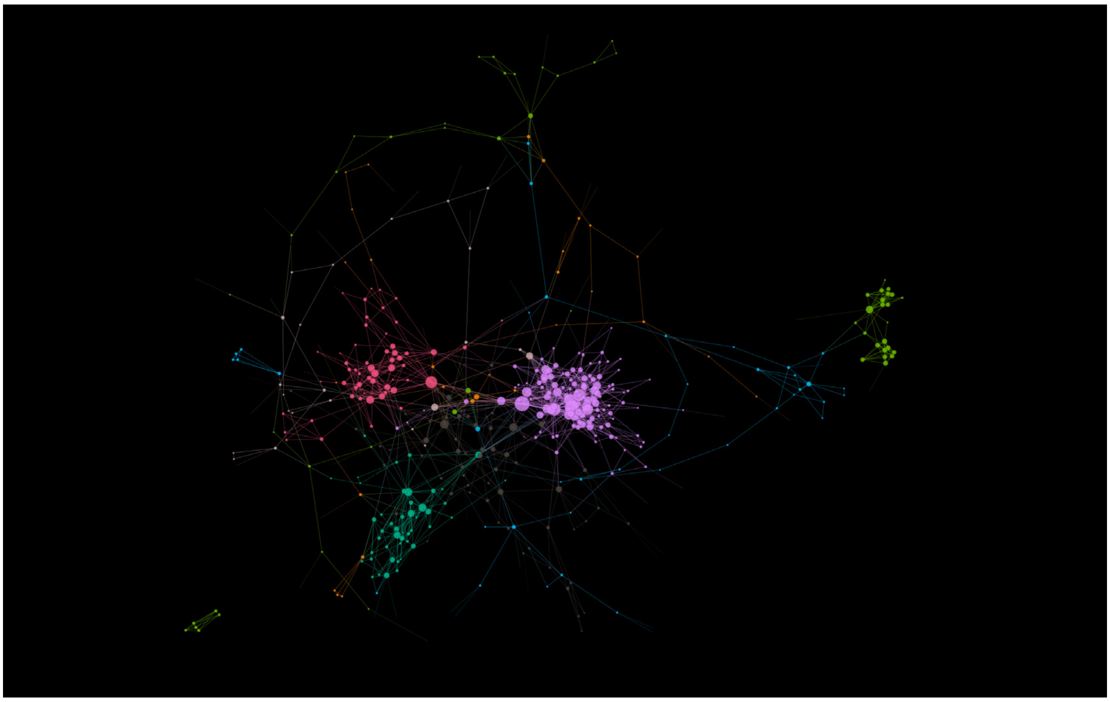


Universitat de Barcelona intellectual production and industrial liaison potential summary:

- Active Researchers: 3,090
- Publications: 182,841
- Scientific Articles: 133,682
- Books: 11,421
- Top Research Departments:
  — Medical School, Neurosciences, Surgery and Medical Procedures, Biomedicine, Molecular Biochemistry, Pharmaceutical Research, and Biology
- Top Research Areas:
  — Endocarditis, cardiovascular infections, chronic liver disease, respiratory diseases, molecular modeling and bioinformatics, endocrinology, gynecology and human reproduction, genetics, oncology and cancer research, viral pathologies, respiratory diseases, hepatic oncology, muscular and mitochondrial function, brain and blood vessel-related, obesity and diabetes, bone diseases, arrhythmia, lymphoma, and maternal reproduction
- Potentially Related Startups: Health tech, pharmaceuticals, AI, and data science
- Potentially Related Industries: Health practitioners, medical equipment and supplies manufacturing, pharmaceutical and medicine manufacturing, therapeutic chemistry, specialty medical clinics, disease diagnostics, clinical trials, surgery, medical equipment, and materials science

Universitat Pompeu Fabra

Figure 79. Research Network—Degree (Universitat Pompeu Fabra)

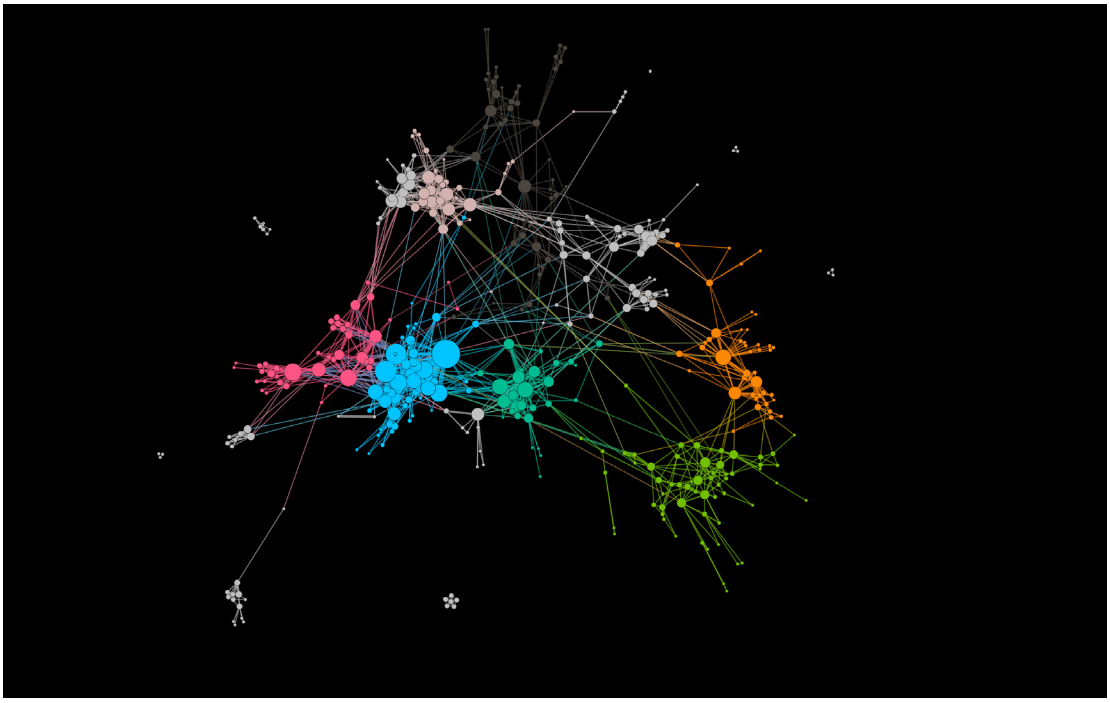


Universitat Pompeu Fabra intellectual production and industrial liaison potential summary:

- Active Researchers: 984
- Publications: 65,268
- Scientific Articles: 33,293
- Books: 3,578
- Top Research Departments:
  — Healthcare and Experimental Sciences, Political Science, Communications and Media, Law, Information Technology, Language and Translation, Business, Humanities
- Top Research Areas:
  — Healthcare services, pharmacology, myogenesis, inflammation and muscular functions, cardiology, childhood and environment, computational neuroscience, lung cancer, genomics, infection biology, protein chemistry, constitutional law, and environment
- Potentially Related Startups: Health tech, pharmaceuticals, omics sciences, surgery procedures, disease detection, and environmental studies
- Potentially Related Industries: Management, scientific, and technical consulting services, professional, scientific, and technical consulting services, financial investment, and information services

IGTP + IrsiCaixa + ILJC + Institut Guttmann de Badalona

Figure 80. Research Network—Degree (IGTP Badalona)

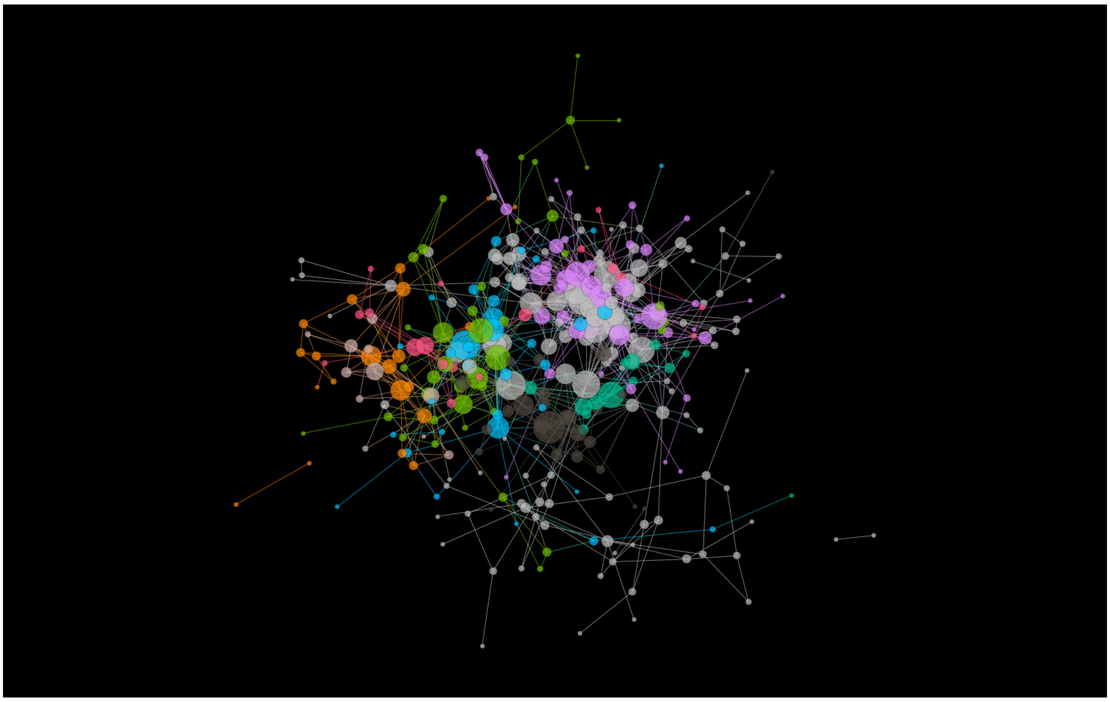


Can Ruti / IGTP/IrsiCaixa/ILJC/Guttmann intellectual production and industrial liaison potential summary:

- Active Researchers: 540 IGTP, 103 IrsiCaixa, 79 IRL Josep Carreras
- Publications: 5,615 IGTP, 1,145 IrsiCaixa, 611 IRL Josep Carreras
- Scientific Articles: 11,808
- Books: 32
- Top Research Departments:
  — Medicine, Translational Medicine, Biosciences, Leukemia, Viral Research, Odontostomatology, Surgery, Physiology, Oncology, Clinical Trials, and Neuroscience
- Top Research Areas:
  — Healthcare services, dynamic systems in medicine, HIV research, pharmacology, hereditary cancer, ocular inflammation, physiopathological mechanisms in respiratory diseases, arteriosclerosis, cardiac insufficiency, neuroplasticity and regeneration, hypophysis, Parkinson's disease, infection biology, and nutrition and aging
- Potentially Related Startups: Health tech, omics sciences, clinical trials, and bioengineering
- Potentially Related Industries: Oncology research and clinical treatment, leukemia research and development, viral disease research and development, clinical trials, pharmaceutical R&D, and medical and pharmaceutical manufacturing

Universitat Ramon Llull

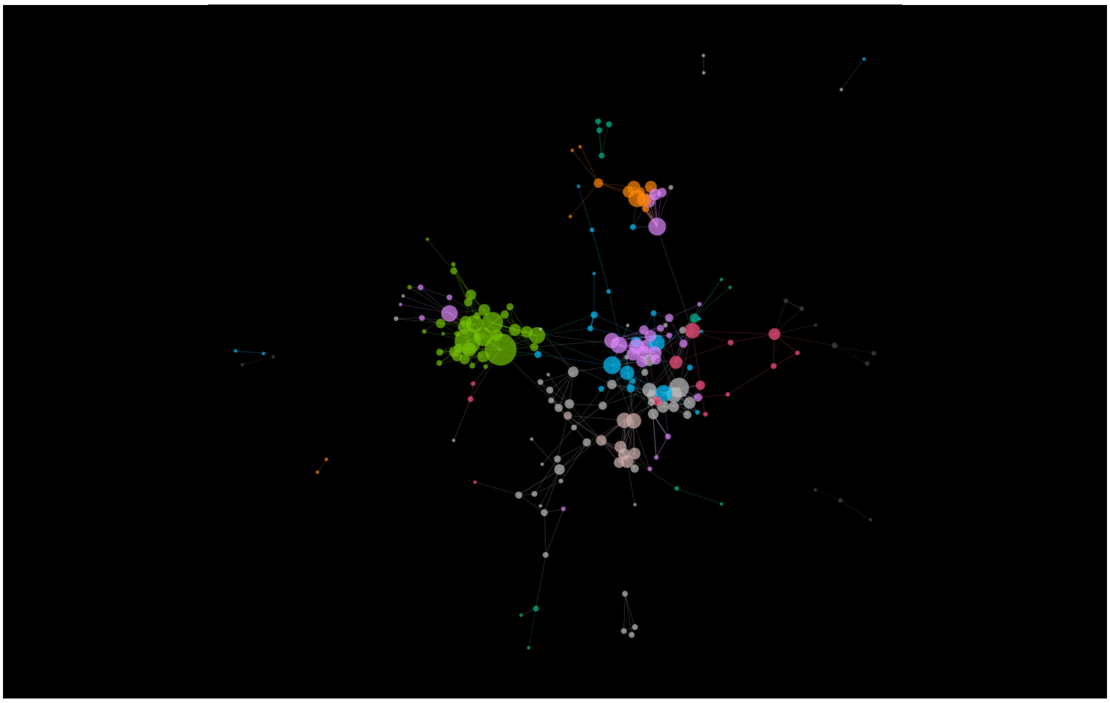
Figure 81. Research Network–Degree (Universitat Ramon Llull)



Universitat Ramon Llull intellectual production and industrial liaison potential summary:

- Active Researchers: 543
- Publications: 18,330
- Scientific articles: 11,460
- Books: 1,635
- Top Research Departments:
  — Engineering, Education Sciences, Psychology, Physical Education and Sports, Communications and International Relations, Infirmary, Humanities, Chemistry, Nutrition and Pharmaceuticals, Chemical Engineering and Materials Science, General Management, and Bioengineering
- Top Research Areas:
  — Pharmaceutical chemistry, IT-supported pedagogy, healthcare and sports, engineering simulation for environmental studies, sports and society, psychology, media technologies, and internet and cloud computing
- Potentially Related Startups: Sports tech, cloud computing, and materials science
- Potentially Related Industries: Sports and healthcare, materials science and chemical engineering, bioengineering, media and audiovisual, bioengineering, psychology, and pedagogy

Figure 82. Research Network—Degree (UIC)



Universitat Internacional de Catalunya intellectual production and industrial liaison potential summary:

- Active Researchers: 437
- Publications: 12,160
- Scientific articles: 7,603
- Books: 590
- Top Research Departments:
  — Basic Sciences, Odontology, Medicine, Architecture, Law, Physiotherapy, Humanities, Communication Sciences, Education, Economics, Infirmary, and Multilingualism
- Top Research Areas:
  — Pharmaceutical chemistry, physical activity and sports, internet technologies, media technologies, architecture and engineering, globalization, development and conflict, IT-supported pedagogy, digilab, and data science for the digital society
- Potentially Related Startups: Healthcare, bioengineering, and digital health
- Potentially Related Industries: Pharmaceutical, odontology, medicine, sports and physical activity, architecture, education, humanities, and media and audiovisual

Insight 5: Innovation Pipeline Support Structures Can Raise the Quality of the Startup Scene

Multiplying effects: Only 279 out of 1,902 Barcelona startups are knowledge intensive. The geospatial atomization of the three main phases of innovation across Barcelona—with research primarily clustered around the Alta Diagonal area, tech transfer clustered around 22@ district, and production mostly located in manufacturing enclaves—hinders the ability for sector-specific knowledge areas to complete the innovation pipeline. This pipeline starts with basic research and then continues to applied research, moving all the way through innovation and technology platform centers before finally connecting with industry verticals of each specific knowledge domain. Hence, a very small number of self-identified startups in the Barcelona area are R&D-based: only 14% of all startups. Specifically, only 10% of service startups are truly innovative, and only 30% of product-based startups can be considered to contribute to the advancement of the frontier of knowledge.

Goal and Strategy 5:

Focus on Technology Industries with a Global Comparative Advantage: Place emphasis on aligning traditional sectors with cutting-edge research and development. Regarding the startup scene, aim to increase the number of R&D-driven startups from 279 out of 1,902 up to more than 750 R&D-driven startups by 2040.

A key factor limiting the consolidation of a dynamic, world-class innovation scene in Barcelona is the relatively weak startup scene. Although it is true that the Barcelona area has witnessed the rise of a significant number of so-called startups in recent years (1,902), the vast majority of them do not rely on knowledge-intensive R&D products and services but on support services to digitization processes and other secondary economic activities. Only 279 out of 1,902 startups in the area can claim to present R&D-driven solutions. Specifically, out of 1,510 service-oriented startups, only 156 are R&D-derived, primarily in healthcare, ICT and mobile technologies, FinTech, and digital content and media. Out of the 392 product development and manufacturing startups in the Barcelona area, only 123 are R&D driven around healthcare, hardware, green and energy tech, food tech, and ICT and mobile technologies. In summary, notably sophisticated high tech-related startups are relatively scarce in the Barcelona area.

When evaluating the breakdown of startups by core technology, the main service-oriented R&D-driven startups by core technology are: AI and Big Data (53), cloud and edge computing (20), IoT and sensors (11), AR/VR (10), and bioengineering and regenerative medicine (10). The breakdown of advanced manufacturing innovative startups by technology presents the following ranking: automation/robotics (24), bioengineering (17), IoT (14), and AI and Big Data (14).

A key takeaway when moving forward is that a stronger pool of highly innovative startups could contribute to consolidating a world-class innovation scene in the Barcelona area. Facilitating the collaboration between applied research spin-off companies and traditional sectors would play a critical role in this process.

Figure 83. Barcelona Startup Scene—Innovative and Noninnovative Startups (Services and Products) by Industry

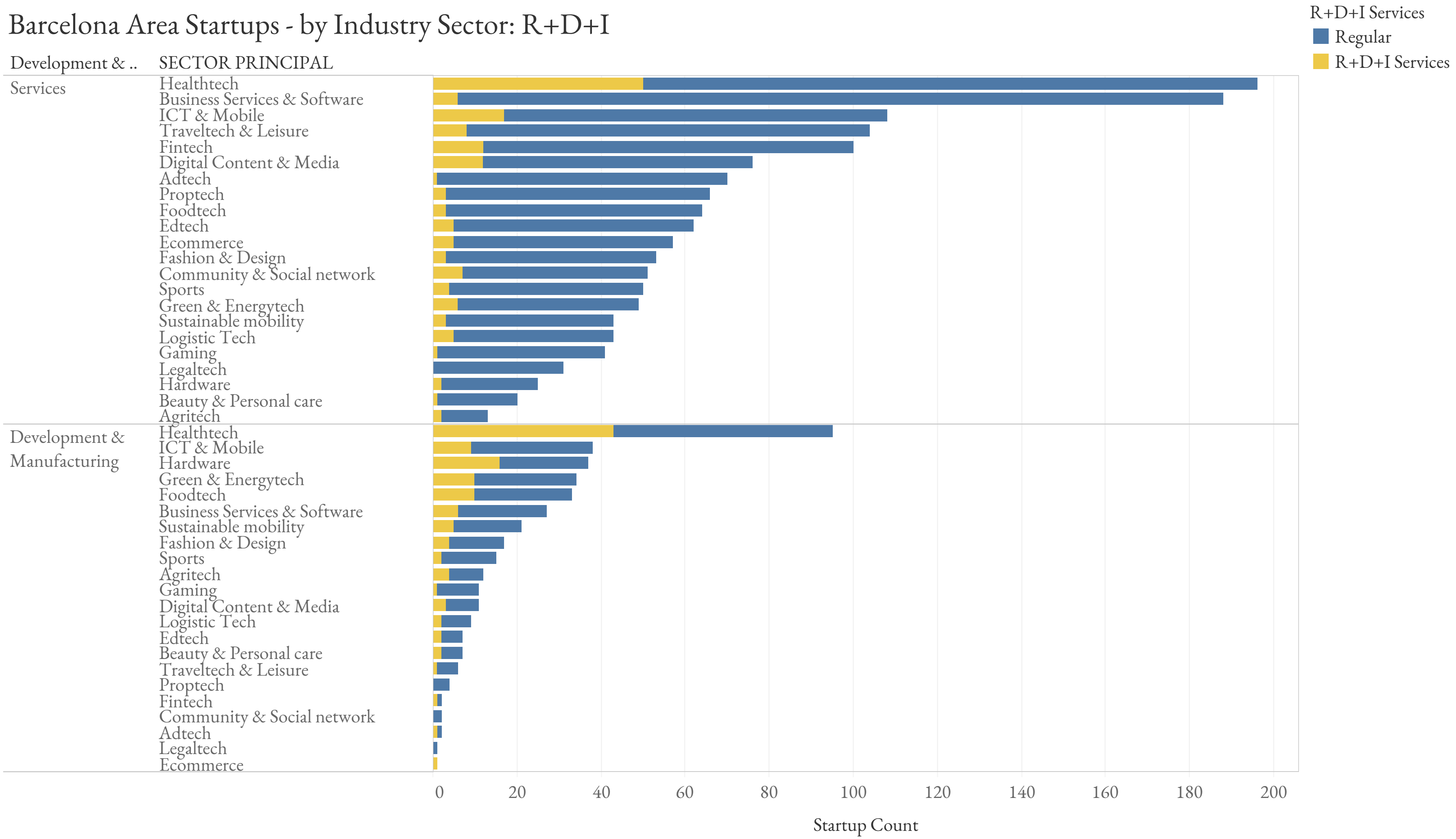
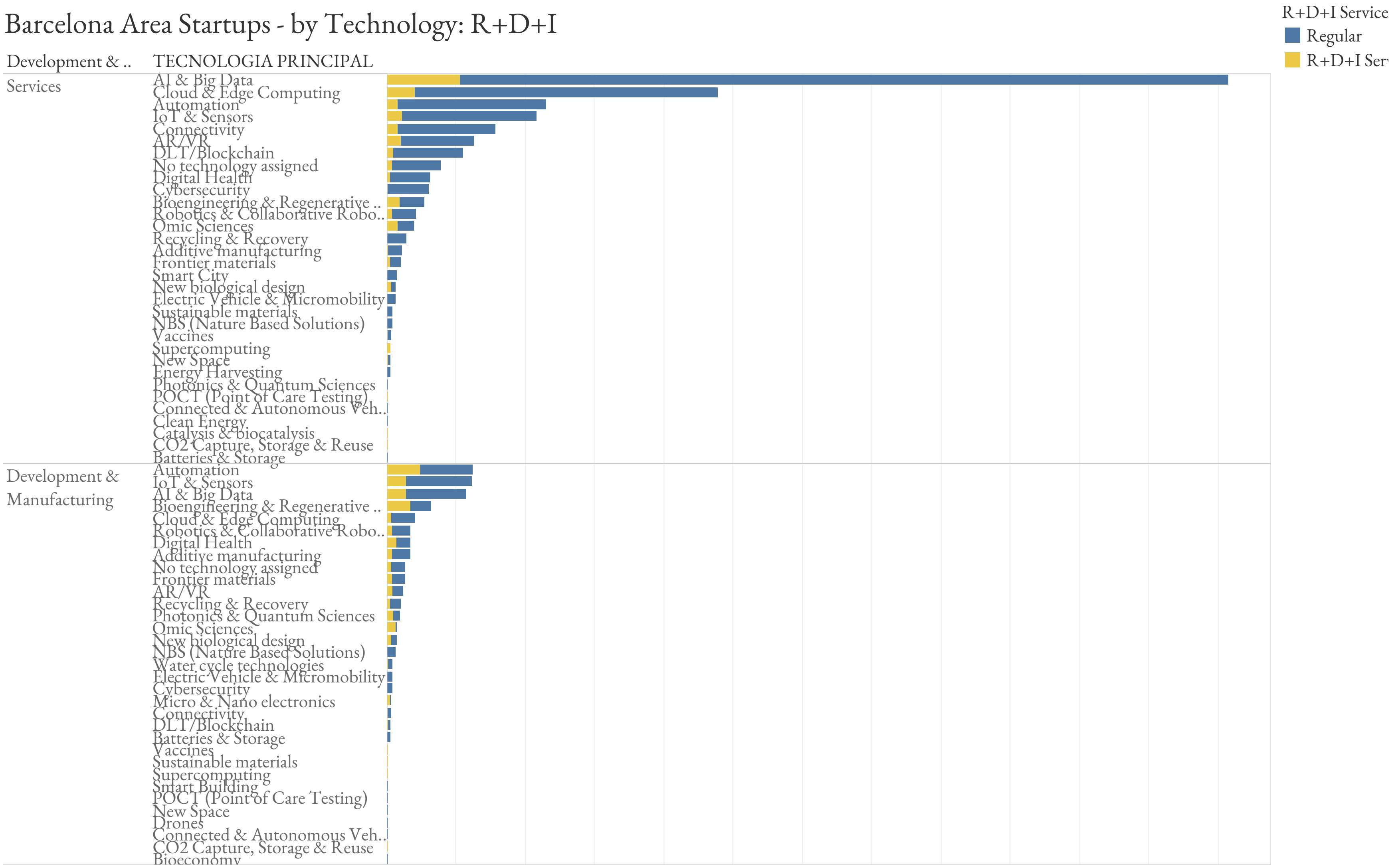


Figure 84. Barcelona Startup Scene—Innovative and Noninnovative Startups (Services and Products) by Core Technology



Challenge 4:

Providing Quality Housing and Standard of Living

Challenge 4: Providing Quality Housing and Standard of Living

Evaluating the Quality of Housing and Access to Urban Amenities

We evaluated the geospatial distribution of citizens across the five cities to understand their urban density levels and access to urban services and amenities. The central aim was to evaluate the cities according to 15-minute city quality standards, which emphasize proximity-based planning. Following these standards, urban neighborhoods are planned to accommodate an optimal density that would have access to basic essential services within a 15-minute walking or cycling distance.

We performed detailed analyses of reach and gravity for the Greater Barcelona area, including Barcelona city, the metropolitan area, and the metropolitan region. We first evaluated the current status of access to urban services and amenities by type and then compared the results with the best practices based on an analysis of our 100 global cities study.

Numerous insights emerged from these detailed studies. First, we found that Barcelona satisfies the 15-minute city standards in approximately 42% of areas within the city. Second, we identified that the metropolitan area is a slightly underserved area to the detriment of the 36 municipalities within the Barcelona Metropolitan Area. There is a need to balance the distribution of amenities and offer better access in general. Finally, we noted that the metropolitan region significantly underperforms, suffering from macrocephaly from the city core.

Our city science analysis aimed to inform the decision-making process on a case-by-case basis, offering sets of recommendations to reach the 15-minute city quality standards. Scenario evaluation was performed to estimate the optimal allocation of residential dwellings across the Barcelona metropolitan region between 2024 and 2050.

Strategies need to be implemented to meet the 15-minute city standards in the underserved areas of Barcelona as well as the metropolitan area and region. Our recommendations focus on promoting higher density, high degrees of city form of fractality, medium levels of city form entropy, and displaying a self- similar or harmonic distribution of services by following a nested hierarchy rationale.

Figure 85. Urban Amenities by Type Plotted Across the Barcelona Metropolitan Region

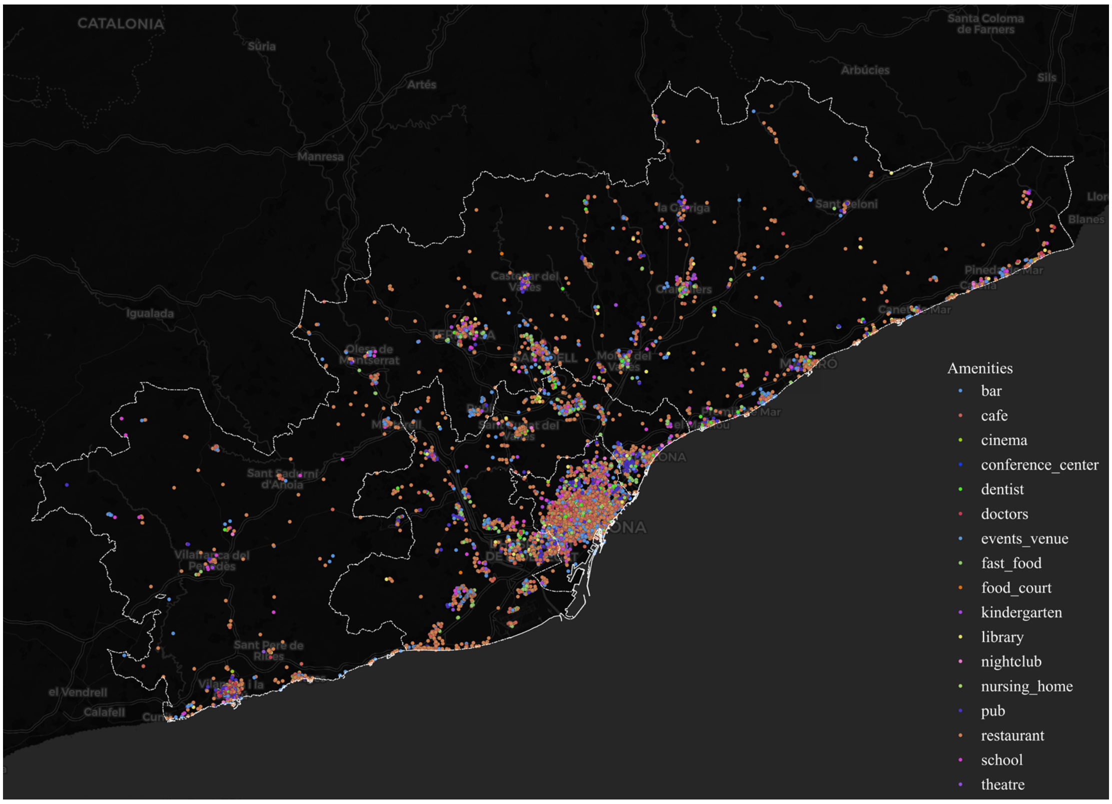
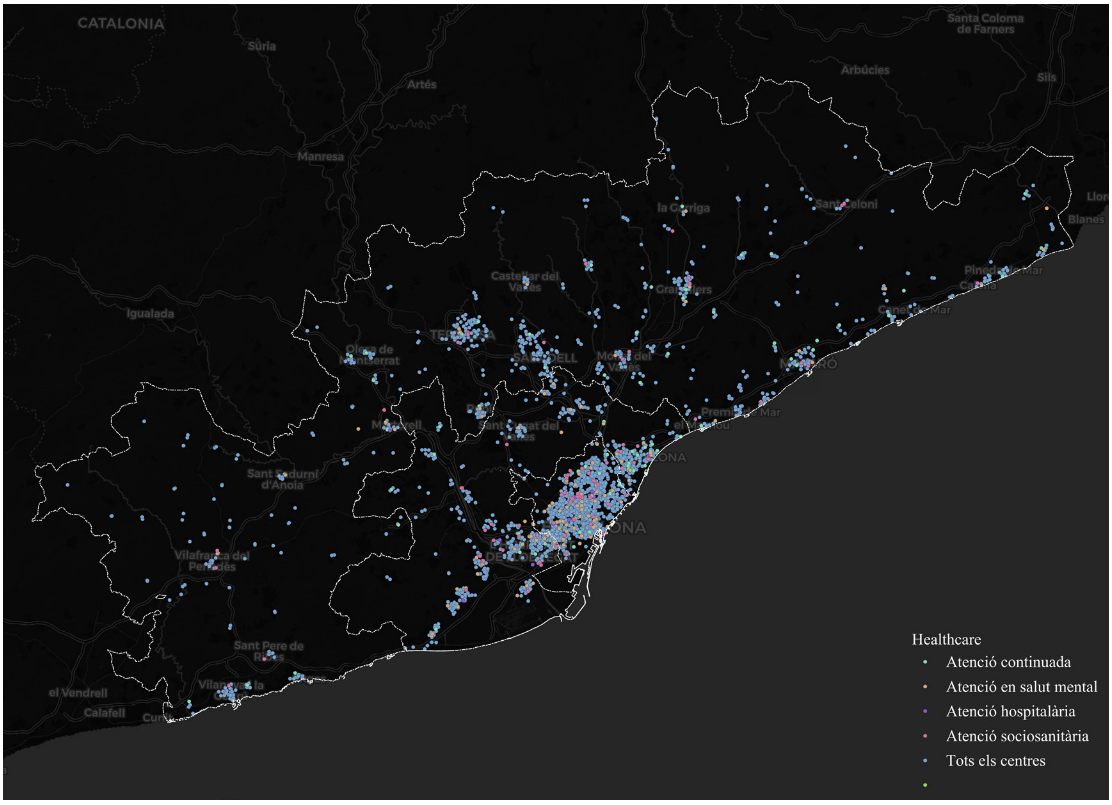


Figure 86. Healthcare Amenities by Type Plotted Across the Barcelona Metropolitan Region



Housing and 15-Minute City Quality Standards: KPIs

The State of Housing and Geospatial Distribution of Residential Areas

Following our thorough study of numerous cities around the world, we can extract a couple of key facts. When conducting the log-log analysis at the urban subunit level for all the cities (Seccions Censals for Barcelona, Buildings Groups for Boston, etc.), we identified that doubling population density results in a 19% improvement in material infrastructure efficiency and social interaction patterns. This would lead to greater access to services and amenities, fewer material resources used, and greater physical proximity, resulting in reduced commuting times for citizens.

In terms of housing and the geospatial distribution of residential areas, Barcelona has positive density. The city has 16,340 residents per km^2, and its optimal and desirable range lies at approximately 18,200 residents per km^2. However, the current average density of the metropolitan area of Barcelona is quite low and substantially lower for the metropolitan region.

15-Minute City Standards

Definition of 15-Minute City Standards: Evaluating the Quality of Urban Life

We have envisioned a city science methodology to evaluate the 15-minute city standards across cities and evaluate the quality of urban life. The methodology follows a number of steps, including the first critical step of dividing each of the five cities into small subunits (*Seccions Censals* for Barcelona, Building Groups for Boston, etc.). The division of the cities into urban units allows for mapping different KPIs, shedding light on the performance of the city's infrastructure. This includes mapping the topology, morphology, and urban activities, including services and amenities. By means of network science, we can evaluate the access to key KPIs such as amenities per km^2, the average distance to reach a first amenity, and the compared values with lower-bound thresholds from the 100 global cities study as highlighted in this report and in our city science book.

Amenities: 15-Minute City Standards

The 15-minute city standard metrics are defined by the following:

Analyzing amenities as both a ratio per area (km^2) and per capita results in the following metrics.

Access to Urban Amenities: Sustenance (Restaurants and Cafeterias)

Number of representative facilities within a given polygon of analysis: bars, cafes, fast food establishments, food courts, pubs, and restaurants.

Access to Urban Amenities: Education

Concentrations of libraries, schools, and kindergartens are relatively high around new development. This aligns with the fact that many of the neighborhoods are residential. The expansion of the innovation district can maintain these levels to continue to promote education in the neighborhoods.

Access to Urban Amenities: Healthcare Services

Number of representative facilities within a given polygon of analysis: clinics, dentists, doctors, hospitals, nursing homes, and pharmacies.

Access to Urban Amenities: Entertainment

Number of representative facilities within a given polygon of analysis: arts centers, cinemas, community centers, conference centers, events venues, nightclubs, social centers, and theaters.

Access to Urban Amenities: Mobility and Transportation

Number of representative facilities within a given polygon of analysis: bus stations, taxis, bicycle parking, bicycle rental, car rental, and car sharing.

Figure 87. Amenities (Barcelona—City)

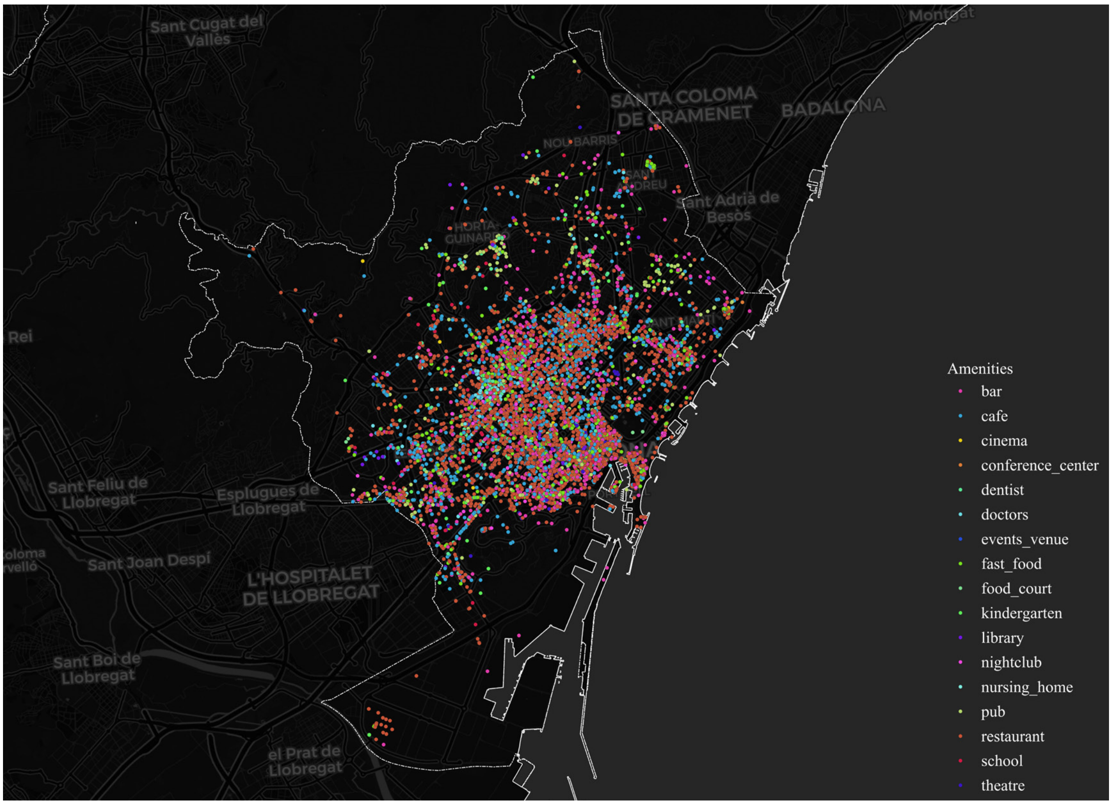


Figure 88. Amenities (Barcelona—Metropolitan Area)

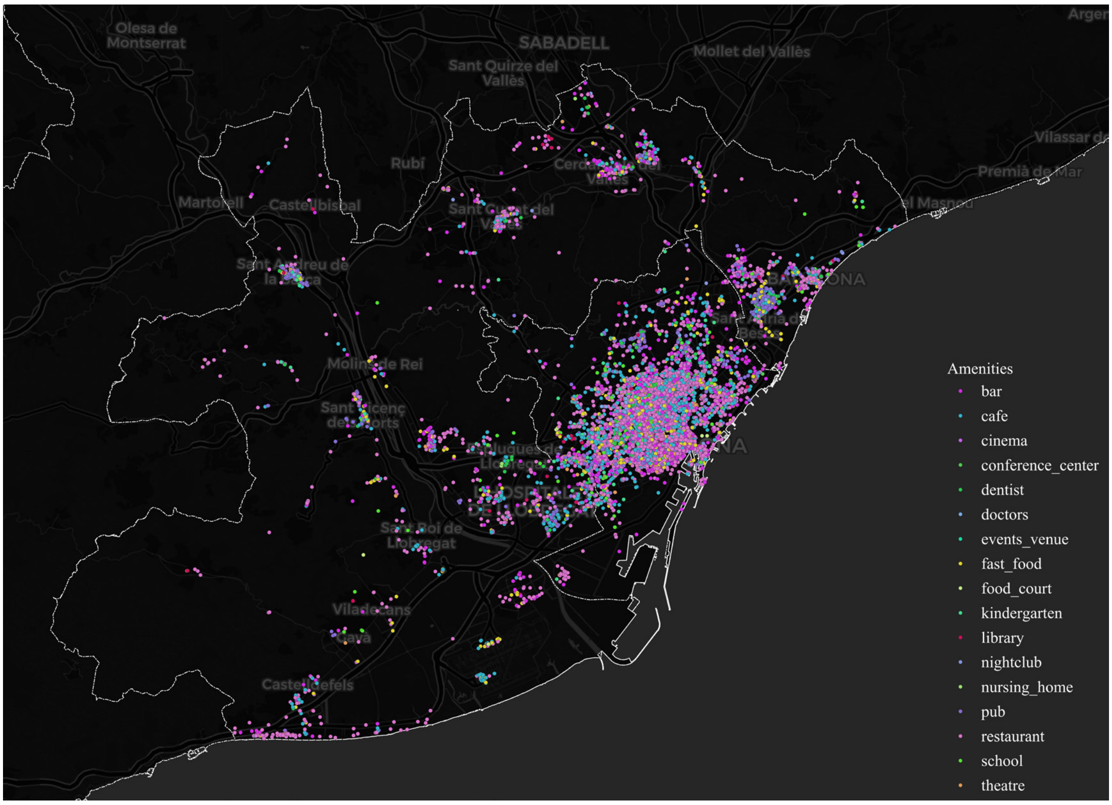


Figure 89. Healthcare (Barcelona—City)

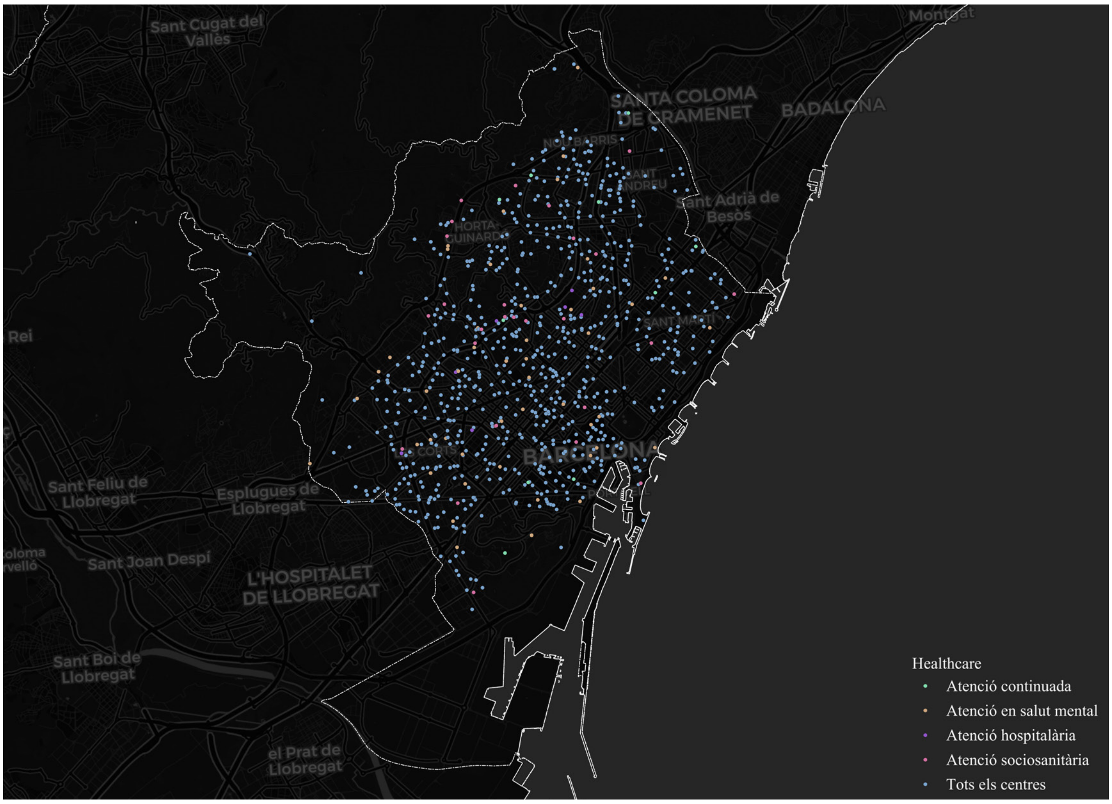
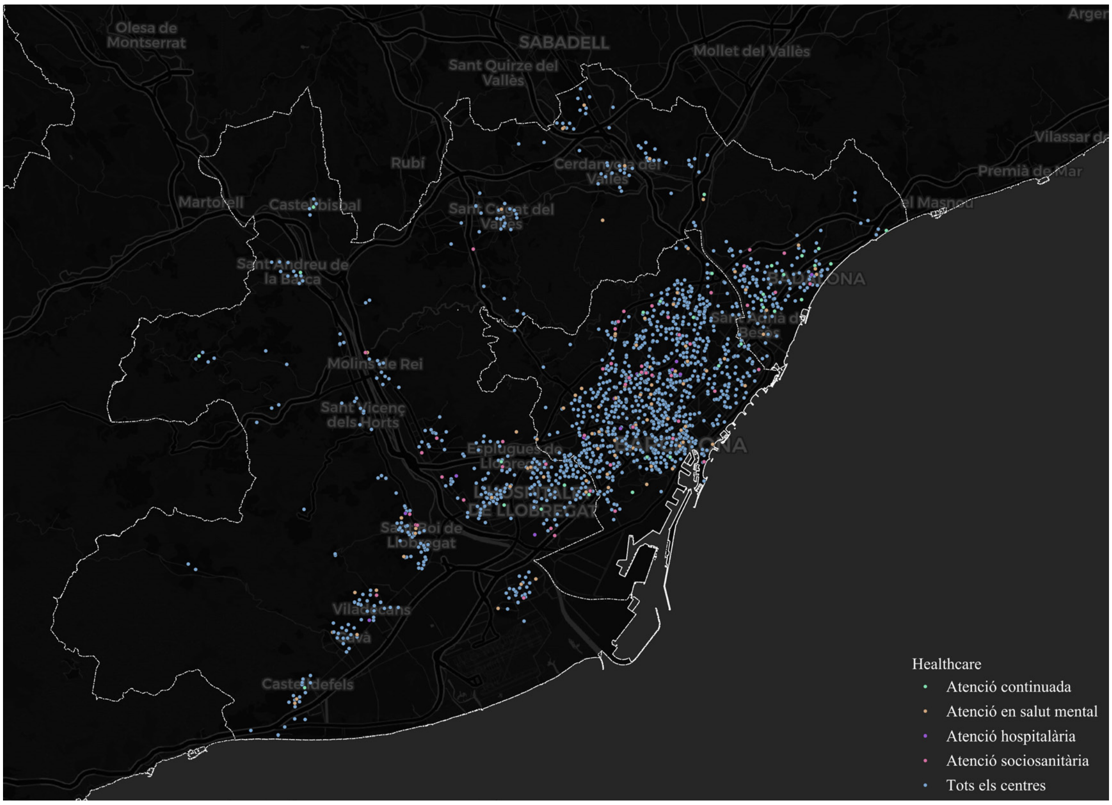


Figure 90. Healthcare (Barcelona—Metropolitan Area)



Barcelona's Eixample and Sant Martí districts represent a pre-eminent example of a fractal city typology. The geospatially even distribution of amenities is made possible by neighborhoods that were designed in this style. Certain neighborhoods, such as the Eixample district and Sant Martí, present a remarkably fractal nature. Comparatively, Ciutat Vella follows a small world city structure, Nou Barris presents a radial-organic pattern; Sants a linear city pattern; Gràcia a grid-organic pattern; and Les Corts a monumental pattern.

When evaluating the 15-minute city quality standards for cities across the globe, we can see striking differences. For example, Barcelona's districts of Eixample and Sant Martí show a much higher number of amenities, and their spatial breakdown presents a highly egalitarian nature in terms of widespread distribution and accessibility to critical services. Other districts, such as Sant Gervasi or Ciutat Vella, denote a more uneven distribution of amenities.

Figure 91. Average Distance to the Closest Amenity Gradient Benchmarking

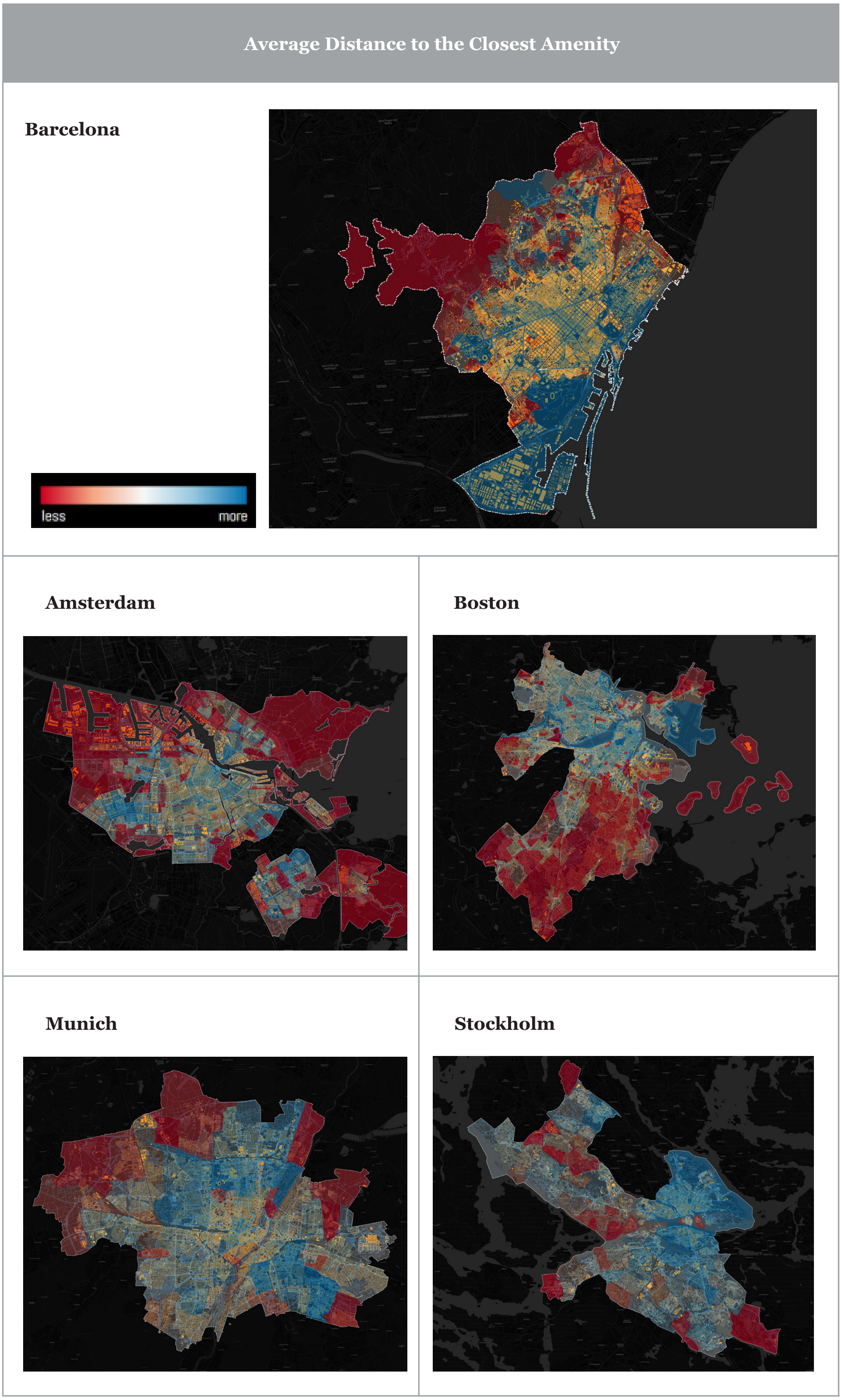
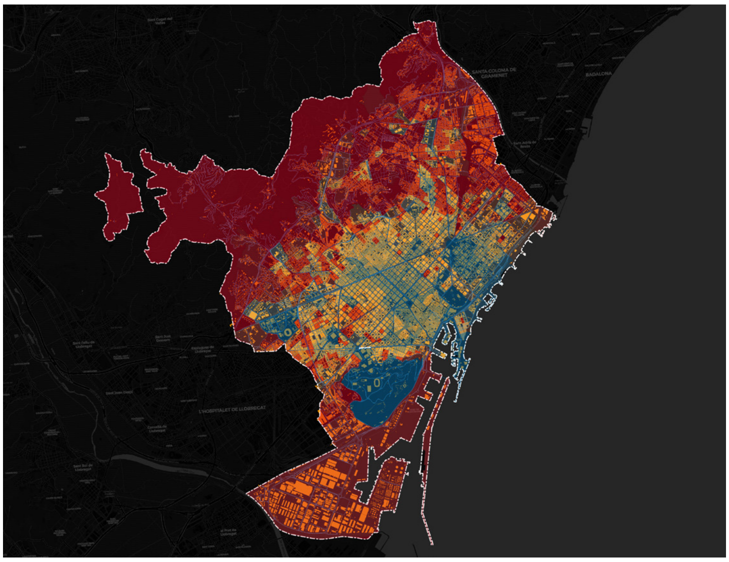


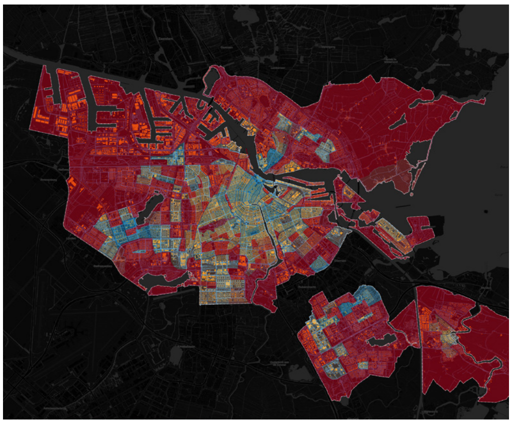
Figure 92. Average Distance to the 5th Closest Amenity Gradient Benchmarking

Average Distance to the 5th Closest Amenity

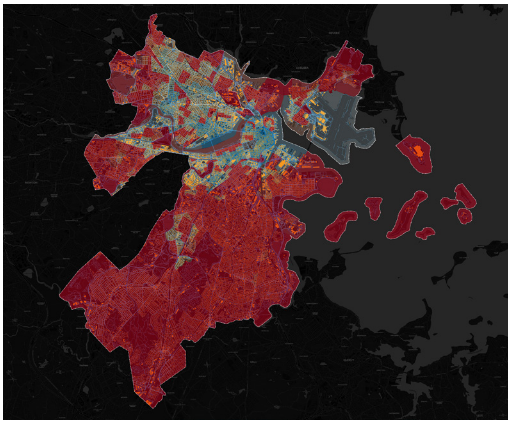
Barcelona



Amsterdam

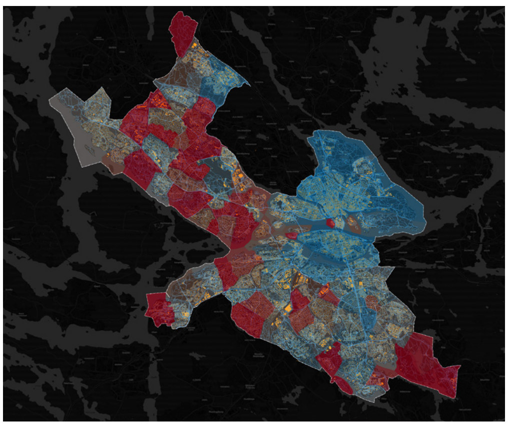


Boston



Munich

Stockholm



Benchmarks: High-Quality 15-Minute Standards

Amenity densities are evaluated to determine benchmarks, hence providing crucial insights into the distribution and accessibility of various amenities within a given area. Setting benchmarks for amenity densities allows for the qualification of areas into desirable ranges. This analytical approach reveals insights on spatial arrangement and availability of key services.

Table 29. The 15-Minute City Quality Standards for Cities Over 1M Citizens

Avg. Population Density	> 15,000 residents / km^2
Avg. All Amenities	Approx 80–100 amenities per km^2
Avg. Amenities/Population	0.0062 amenities per resident
Avg. All Amenities / Area	30 amenities / km^2
Avg. Avg Distance to 1st Amenity (m)	< 150m
Avg. Avg Distance to 5th Amenity (m)	< 500m
Avg. education_count	> 3 education centers per km^2
Avg. entertainment_count	> 1.5 entertainment centers per km^2
Avg. healthcare_count	> 7 healthcare centers per km^2
Avg. sustenance_count	> 50 sustenance centers per km^2
Avg. transportation_count	> 35 transportation nodes per km^2

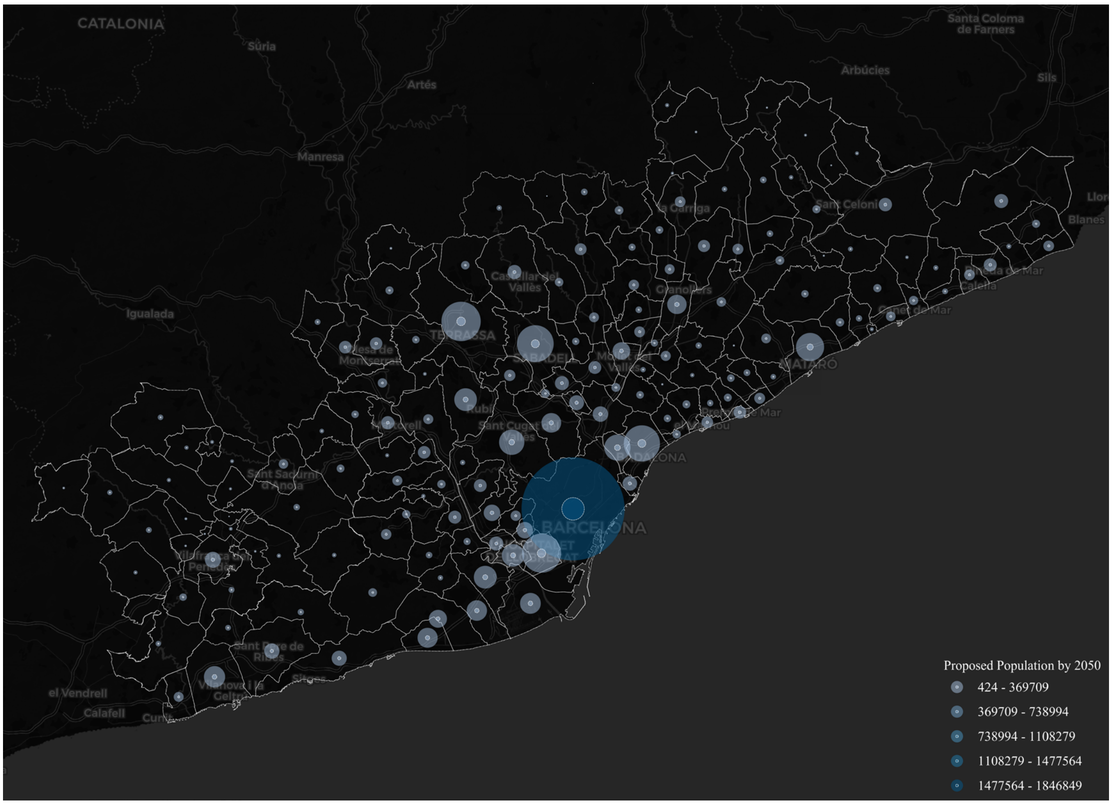
Cities with an average population density of more than 10,000 residents and approximately 5,000 employees per km^2 have intense levels of human activity. Amenity density analysis provides a quantitative breakdown of the relationship between the region, the users of the region, and its infrastructure.

Insights—Providing Quality Housing and Standard of Living

Insight 1: Desirable Housing Allocation Patterns Can Be Informed Via City Science

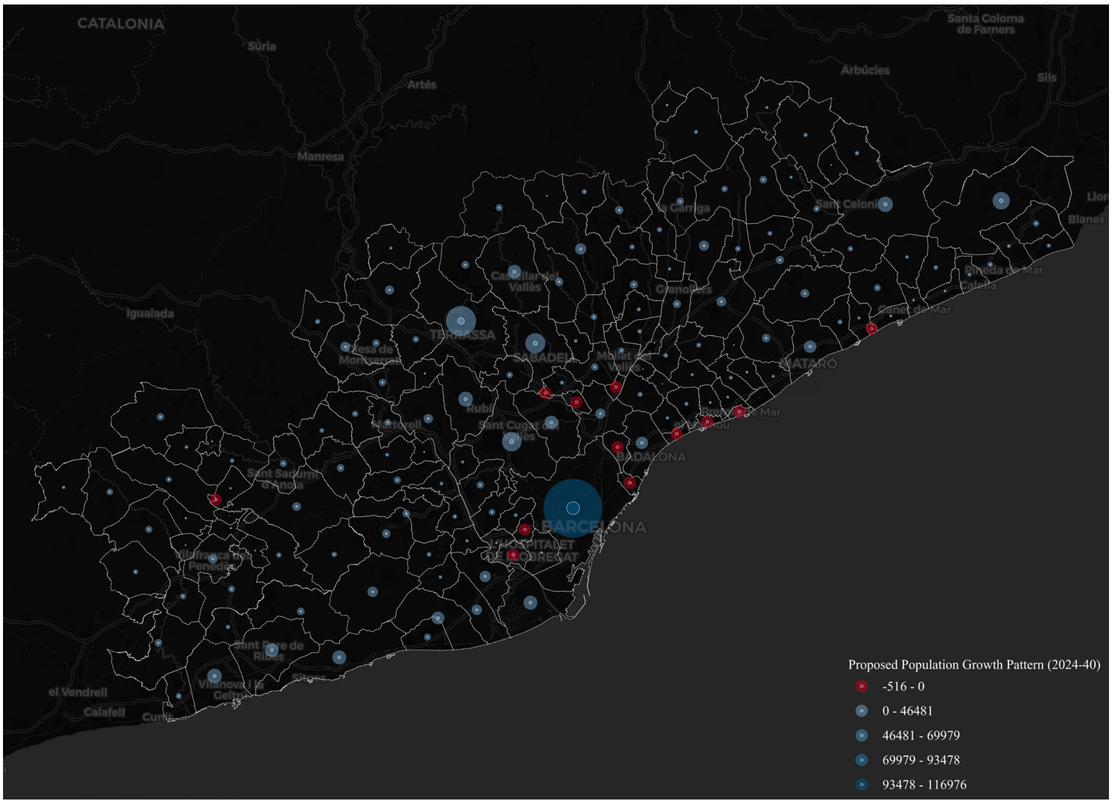
Housing: A target distribution of 475,000 new residential dwellings was identified based on the optimal population density and morphological best practices. A new vision to balance the current territorial model is needed because of inherited deficiencies (51 municipalities present much higher density than the optimal).

Figure 93. Proposed Population (2050, Barcelona Metropolitan Region)



The proposed distribution of new residential units and population by 2050 is the result of combining urban form density optimization (identification of desirable ranges of population density per municipality) with the need to accommodate the growth established by the Pla Director Metropolità and the physical constraints inherited from the legacy inefficiencies embedded in the system, which have mostly been driven by the 51 municipalities that exceed their desirable density. As a result, the population ranking by 2050 is as follows: Barcelona (1,846M), Terrassa (270K), L'Hospitalet (265K), Sabadell (235K), Badalona (229K), Mataró (137K), Santa Coloma de Gramenet (119K), Sant Cugat del Vallès (112K), Sant Boi de Llobregat (91K), and Rubí (89K).

Figure 94. Proposed Population Growth Pattern (2024—2040, Barcelona Metropolitan Region)



An intermediate scenario for 2040 can help inform short-term housing policymaking at the metro level and help integrate organic growth patterns with the desirable scenario envisioned for 2050. The metropolitan area of Barcelona (AMB) can play a crucial role in modulating and harmonizing new housing dwellings through zoning classifications and building permit management. By merging an assessment of city form density optimization across the metropolitan region with the need to accommodate the growth established by the Pla Director Metropolità while considering the embedded physical constraints inherited from the legacy inefficiencies embedded in the system, we can devise a proposed distribution of new residential units and population by 2040. The new dwellings distribution ranking by 2040 is as follows: Barcelona (1,774M), L'Hospitalet (265K), Terrassa (252K), Sabadell (227K), Badalona (225K), Mataró (133K), Santa Coloma de Gramenet (118K), Sant Cugat del Vallès (104K), Sant Boi de Llobregat (88K), and Rubí (85K).

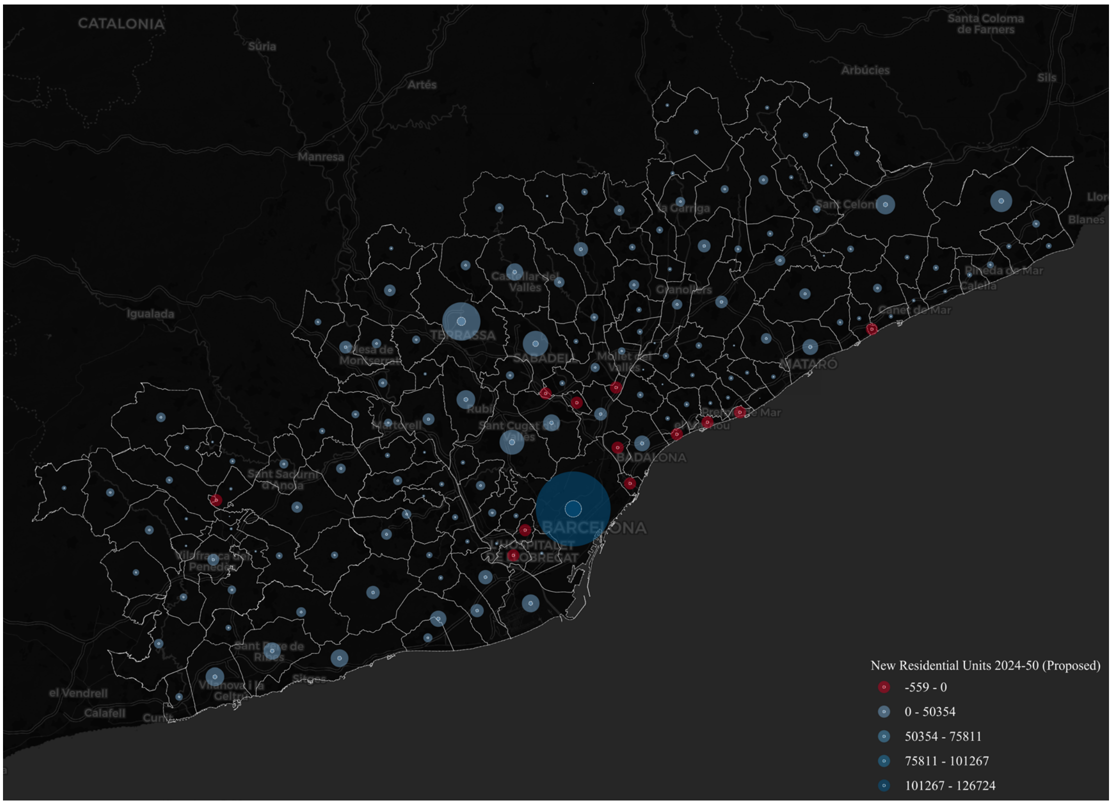
Goals and Strategies—Providing Quality Housing and Standard of Living

Goal and Strategy 1:

Residential dwellings: Proposed distribution of 475,000 new residential dwellings across the 160 municipalities of the metropolitan region, here based upon an integrated model combining inherited rigidness and design optimization.

- Barcelona: Accommodate ≅77,000 new dwellings by 2040 and up to 126,000 by 2050 for a total of 190,000 new citizens.
- Limit growth in overcrowded cities: L'Hospitalet, Santa Coloma, Badia del Vallès, and so forth.
- Increase housing and services: Terrassa and Sant Cugat del Vallès, among others.

Figure 95. Proposed New Residential Units (2024–2050, Barcelona Metropolitan Region)



As noted previously, the proposed distribution of new residential units and population by 2050 is the result of combining urban form density optimization (identification of desirable ranges of population density per municipality) with the need to accommodate the growth established by the Pla Director Metropolità and the physical constraints inherited from the legacy inefficiencies embedded in the system, which have mostly been driven by the 51 municipalities that exceed their desirable density. As a result, the new residential dwellings distribution ranking by 2050 is as follows: Barcelona (126K), Terrassa (33K), Sabadell (15K), Sant Cugat del Vallès (14K), Tordera (11K), Sant Celoni (8.5K), Vilanova i la Geltrú (8K), Rubí (8K), Sitges (7.5K), and El Prat (7K).

Figure 96. Proposed Population Growth Pattern (2024–2050, Barcelona)

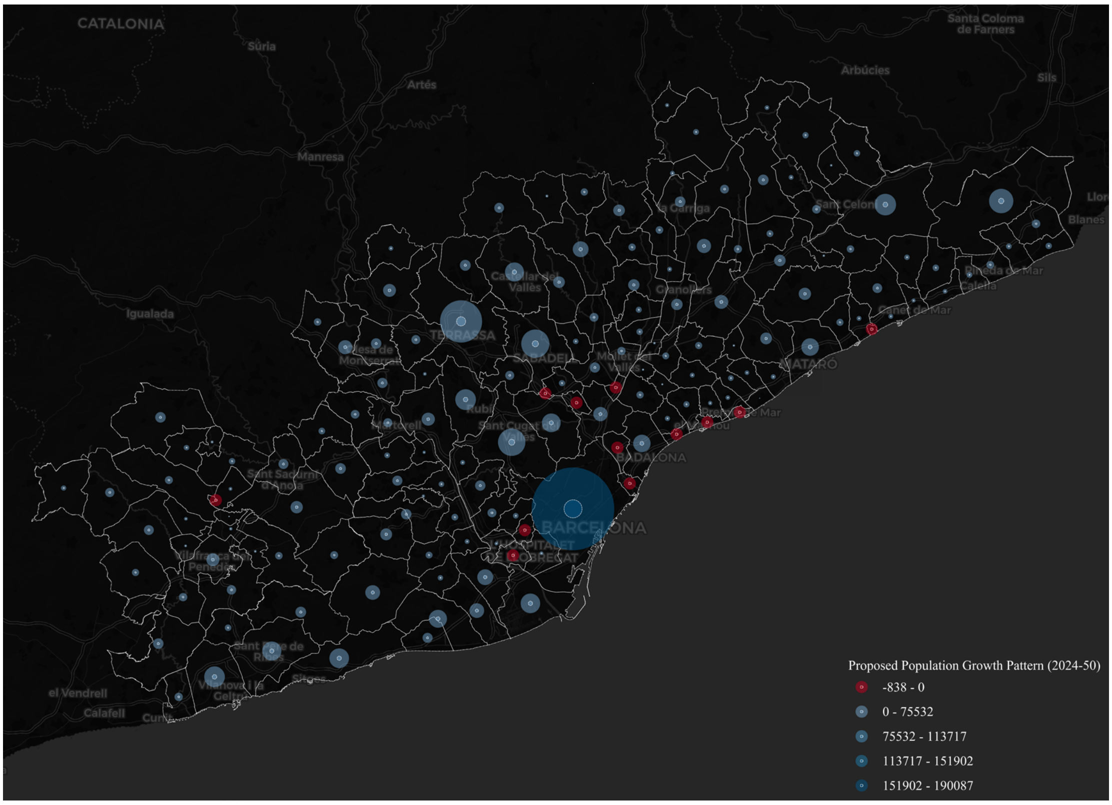
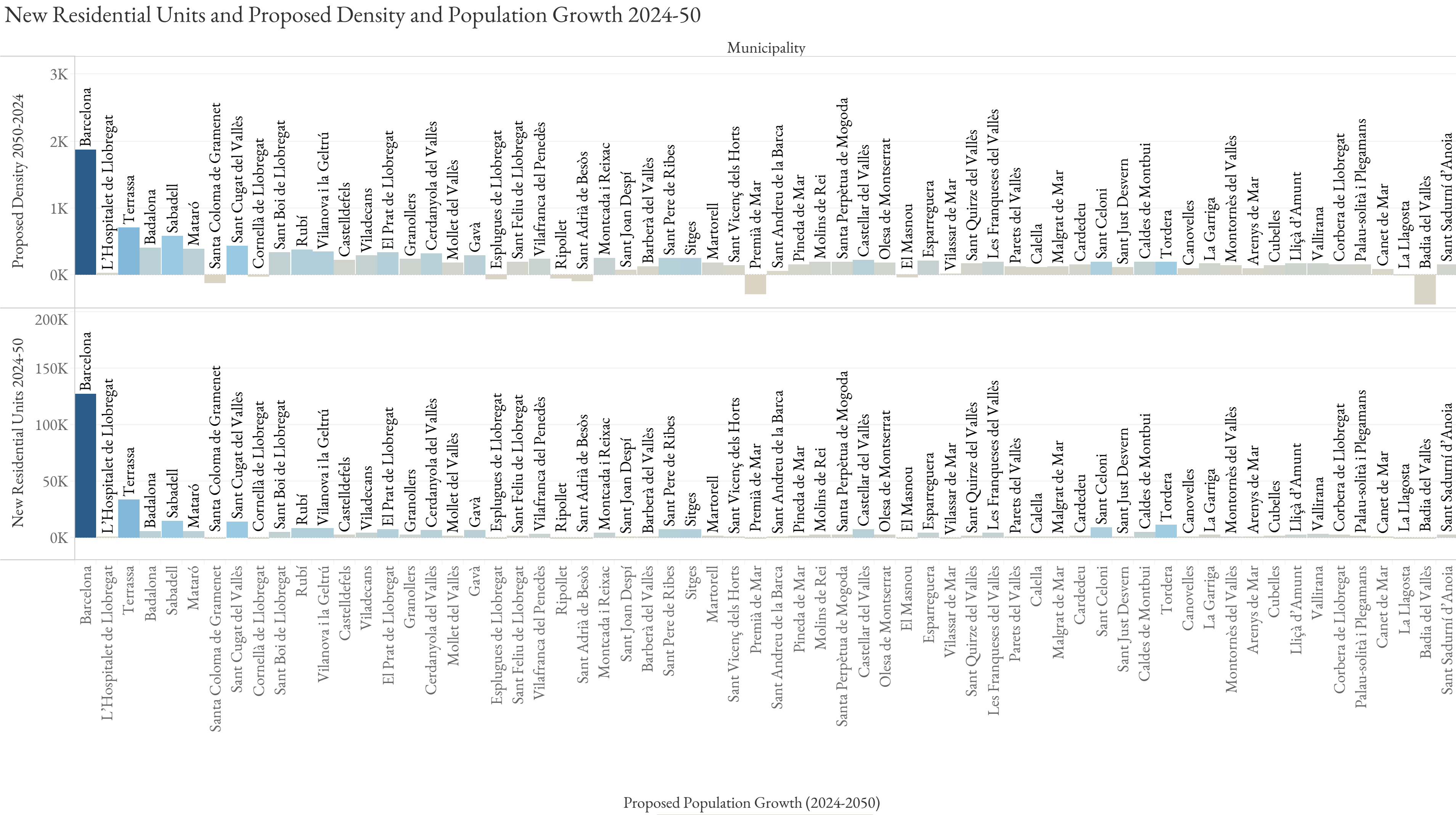


Figure 97. New Residential Units and Proposed Density and Population Growth 2024–2050



Insight 2: Desirable Density, Self-Similarity, and Allocation Can Help Attain the 15-Minute City Quality Standards Across a Given Metropolitan Region

15-Minute City Standards: High-quality 15-minute city standards can be derived from evaluating multiple cities. The amenity ranking is as follows (in order): Barcelona, Stockholm, Amsterdam, Boston, and Munich, though none of the cities satisfy the 15-minute city quality standards.

Goal and Strategy 2:

Resource Allocation Strategy to Attain the 15-Minute City Standards: Conceive of nested hierarchies of education and healthcare amenities that are strategically located to achieve universal access to critical services across the metropolitan region.

After empirically analyzing and comparing the cities, none of the five selected cities satisfy the 15-minute city standards. However, some cities are performing quite close to the standards but in different categories. Barcelona is ahead when it comes to amenities because the total amenities per km^2 is 68,32 and its target value aims to be superior to 80. In fact, Barcelona is not meeting the required criteria, but it is closer to its desirable value compared with other cities, such as Amsterdam, with a total amenities per km^2 of 18,44 and a target value superior to 60. The high score in amenities for Barcelona can be explained by the fact that Barcelona has a high density and good geospatially distributed amenities thanks to its highly fractal nature (42%), particularly in Eixample, Sant Marti (Poblenou and 22@), and parts of Sant Gervasi and Les Corts. The fractal identity of Barcelona provides a nested hierarchy of services, leading to an egalitarian system, serving residents all across the city. **Table 30** shows the amenities analysis of the five cities in detail, comparing the city's current scenario, desirable scenario, and target.

Table 30. Amenities Density—Five Global Cities

City	Amenities	Area in Km^2	Amenities/ Km^2	Target Amenities/ Km^2
Amsterdam	4039	219	18.44	>60
Barcelona	6962	102	68.32	>80
Boston	2224	125	17.79	>50
Munich	6118	311	19.67	>80
Stockholm	3535	188	18.80	>60

Table 31 enables a deeper analysis of the different amenities available within the five cities. Four categories are taken into account: sustenance, education, healthcare, and entertainment.

Insight 3: Network Analysis Reveals Unmet Urban Amenity Needs Across the Region

Amenity Distribution: Barcelona remarkably outperforms the other selected cities in terms of widespread accessibility to critical urban services and amenities: sustenance amenities per km^2 (53,61, exceeding desirable 50) and in healthcare centers per km^2 while falling short on entertainment (1.14<1.5) and education (1.68<3). Resource allocation efforts should be devoted to improving the standards with respect to education and cultural amenities.

Goal and Strategy 3:

Amenity Distribution: Raise the geospatial presence of education and entertainment amenities, particularly in nontourist areas within the city from 68.32 to 80 per km^2.

Table 31. Urban Amenities by City and Type (Selected Global Cities)

Empirical Values	Total Amenities	Sustenance	Education	Healthcare	Entertainment
Amsterdam	4,039	3,463	217	240	119
Barcelona	6,962	5,463	171	1,212	116
Boston	2,224	1,709	312	147	56
Munich	6,118	3,916	735	1,330	137
Stockholm	3,535	2,949	229	259	98

A comparison between cities can also be done by looking at the target values in total amenities per square kilometer and the values within the four categories per km^2. As previously mentioned, Barcelona is ahead in total amenities per km^2, especially when looking at sustenance and healthcare (scoring, respectively, at 53.61 for a target value superior to 50 and scoring 11.89 for a target value superior to 7). For education, Boston and Munich are ahead with respective scores of 2.50 and 2.36 for a target value superior to 3.

Table 32. Amenities Types and Density—Five Global Cities

Target Values	Total Amenities/Km^2	Sustenance/ Km^2	Education/ Km^2	Healthcare/ Km^2	Entertainment/ Km^2
Amsterdam	18.44	15.81	0.99	1.10	0.54
Barcelona	68.32	53.61	1.68	11.89	1.14
Boston	17.79	13.67	2.50	1.18	0.45
Munich	19.67	12.59	2.36	4.28	0.44
Stockholm	18.80	15.69	1.22	1.38	0.52
Target Values	**>80**	**>50**	**>3**	**>7**	**>1.5**

Insight 4: Urban Service Macrocephaly Weakens the Appeal of Metropolitan Cities

The evaluation of the geospatial distribution of amenities across the Barcelona metropolitan area reveals that there is a relatively balanced distribution of healthcare centers, yet education and cultural amenities fall short of satisfying the 15-minute city standards in most areas across the region.

Currently, Barcelona, with a population of 1.7M citizens, hosts 6,817 amenities, whereas the broader metropolitan area, with twice the population (3.4M), hosts 9,067 amenities. A data-driven strategy, tailored for each of the seven *comarques* and 160 municipalities and infused by empirically driven analyses can help raise the standards of living of the other 35 municipalities across the metropolitan area.

Goal and Strategy 4:

Creating an evidence-based territorial strategy to meet the needs of the Barcelona metropolitan area in terms of spatial distribution of amenities presents a powerful opportunity to raise the standards of living for citizens. This would help even out the excessive concentration present in Barcelona and increase amenities present across the area from 9,067 up to ≅15,000 by 2040.

Insight 5: The Barcelona Metropolitan Region Dramatically Falls Short in Terms of Accessibility to Urban Services and Amenities

Education and cultural amenities dramatically fall short of satisfying the 15-minute city standards in the overwhelming majority of areas across the metropolitan region, which comprises 160 municipalities. We found limited access to education, healthcare, culture, and entertainment. In contrast, sustenance retail is relatively distributed, with 15-minute city standards being met in the category of restaurants and cafeterias.

Goal and Strategy 5:

Regional Distribution of Amenities: Capitalize on the opportunity to raise the standards of living of citizens by balancing out the traditional macrocephaly of Barcelona and increase amenities in the region from 12,233 up to ≅20,000 by 2040.

The 15-minute city quality standards are met across many areas within Barcelona, primarily because of the highly self-similar nature of central districts such as Eixample. The city outperforms its peer cities in most categories, though there is room for improvement. Some neighborhoods such as Nou Barris and Sants, along with certain areas within Sant Andreu and Sant Martí, could be enhanced.

In comparison, both the metropolitan area and metropolitan region are underperforming. They suffer from the macrocephaly effect of Barcelona city. The metropolitan region is particularly underperforming in most critical services, including healthcare, sustenance, education, and entertainment. **Table 33** illustrates the healthcare amenities and its subcategories for Barcelona city, its metropolitan area, and metropolitan region.

Table 33. Healthcare Count by Type (Barcelona)

Healthcare	Barcelona City	Metropolitan Area	Metropolitan Region
Hospital Centers	14	25	35
Continuous Care Centers	17	49	94
Socio-Sanitary Care	52	90	138
Mental Health Care	78	141	197
All Centers	1,176	1,930	2,846
TOTAL	**1,323**	**2,210**	**3,275**

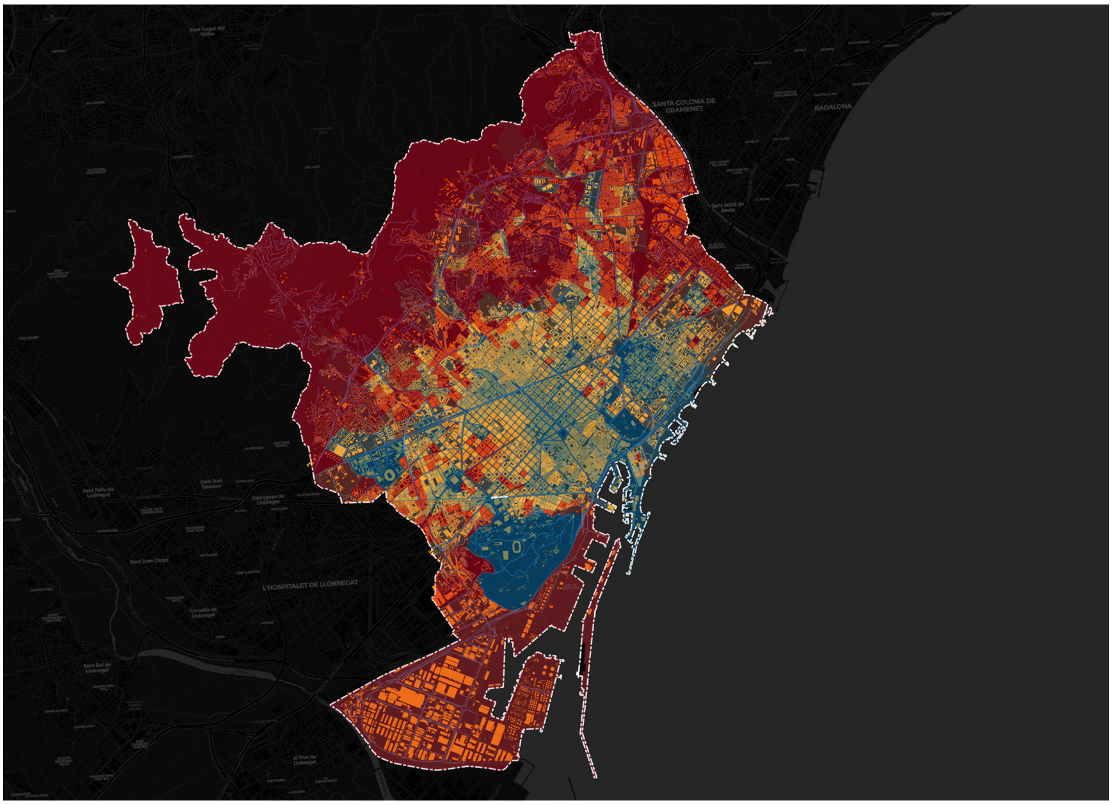
Table 34 illustrates the sustenance and education amenities and its subcategories for Barcelona city, its metropolitan area, and metropolitan region. There is a need to increase the territorial balance of amenities. The Barcelona metropolitan area has a population of 3.2 million people and the Barcelona metropolitan region of 5.2 million people, gathering 2,250 and 3,166 amenities nodes, respectively. These numbers are significantly lower than the total number of amenities in Barcelona, which has 6,817 nodes for a population of only 1.7 million people.

The Urban Form Fractality Index is positively and super linearly correlated with access to urban services and amenities. Fractal grids achieve a more egalitarian distribution of services than other network types. The higher the fractality, the higher the urbanization efficiency. A key takeaway is that doubling the fractality increases access to urban services and amenities by 31%, boosting the chances of attaining the 15-minute city standards. A combination of high density and high fractality can also lead to meeting the 15-minute city standards. As noted, fractality is the best predictor of urban design efficiency, which, in turn, leads to greater access to amenities.

Table 34. All Amenities (Barcelona)

Amenities	Barcelona City	Metropolitan Area	Metropolitan Region
Bar	984	1,238	1,663
Café	1,233	1,595	1,912
Cinema	20	33	43
Conference_center	1	1	1
Dentist	99	186	285
Doctors	118	129	312
Events_venue	1	6	13
Fast_food	517	729	914
Food_court	7	9	21
Kindergarten	75	98	130
Library	46	72	123
Nightclub	56	65	100
Nursing_home	2	5	8
Pub	264	636	932
Restaurant	3,253	4,059	5,445
School	88	136	230
Theater	53	70	101
TOTAL	**6,817**	**9,067**	**12,233**

Figure 98. Barcelona (City)—Average Distance to 5th Closest Amenity



Barcelona Insights: 15-minute City Challenges and Opportunities

As previously mentioned, certain areas within Barcelona, such as central Eixample, Sant Gervasi, parts of the 22@ district, and the southern part of Gràcia, are not far from attaining the 15-minute city quality standards. Several recommendations can be made for reaching these standards. Barcelona should focus on achieving high density and high fractality, including high betweenness, closeness, circuity, and straightness. It should also aiming for medium entropy. The city should also study success factors that have led to 42% of Barcelona already meeting 15-minute city standards to continue geospatially distributing housing and amenities effectively.

Challenge 5:

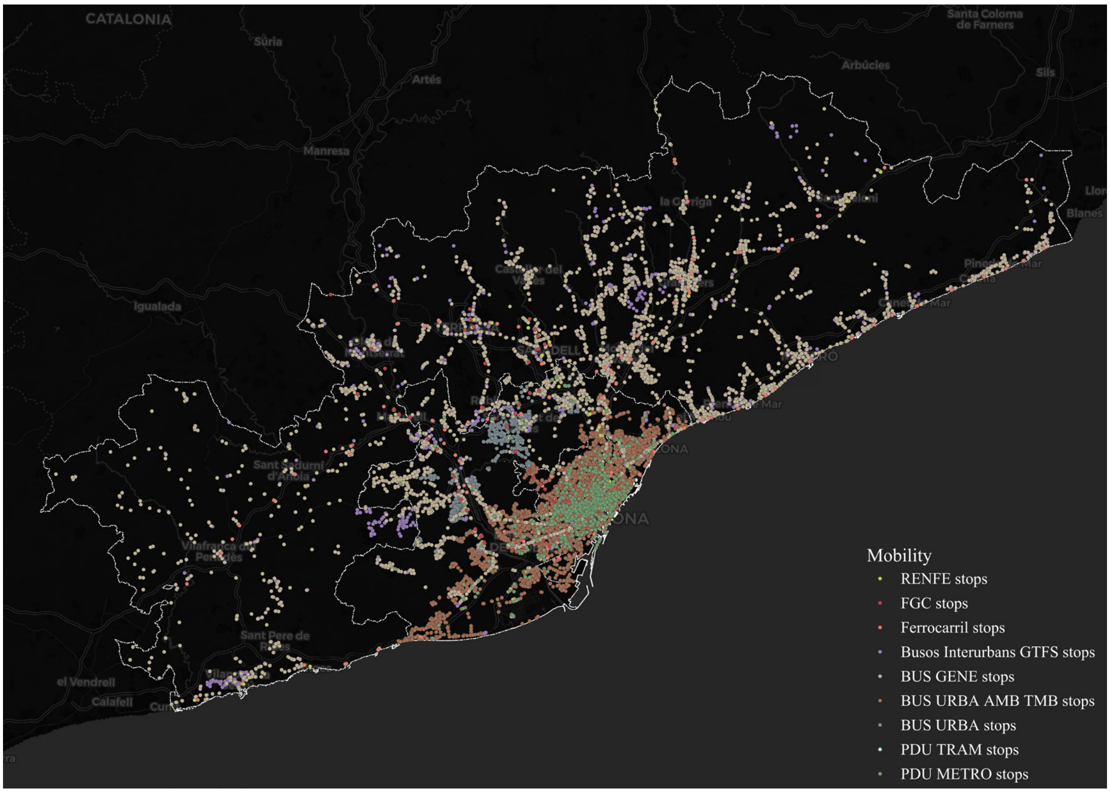
Shaping a Sustainable Mobility and Logistics Strategy

Challenge 5: Shaping a Sustainable Mobility and Logistics Strategy

Access to Urban Mobility Services

A comprehensive analysis of the mobility and logistics landscape of Barcelona is essential for understanding its performance. We carried out a multifaceted exploration of this area, focusing on the public urban transit systems. Through precise mapping, we visualized and interpreted the densities of public transportation modes across the urban area. This shed light on patterns of usage, accessibility, and potential areas for optimization. It also provided a snapshot of the current state of Barcelona's mobility infrastructure while providing strategic insights for enhancing the overall efficiency and sustainability of the city's transportation network.

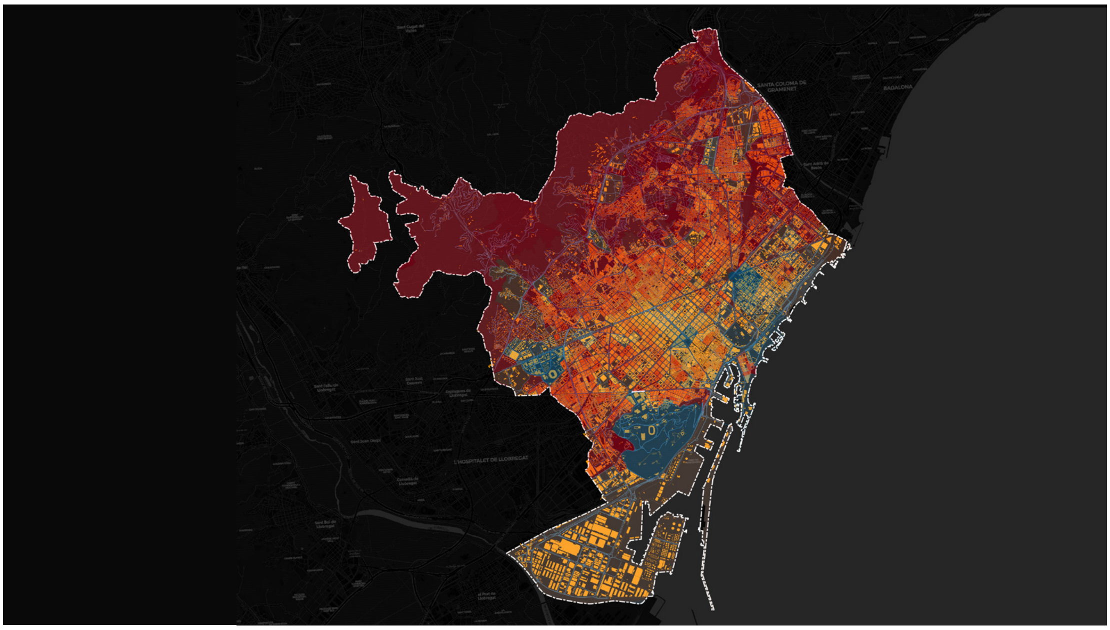
Figure 99. Mobility—Barcelona (Metropolitan Region)—Geospatial Distribution of Public Transit Station Across the Broader Barcelona Metropolitan Region



Urban Mobility Benchmarking

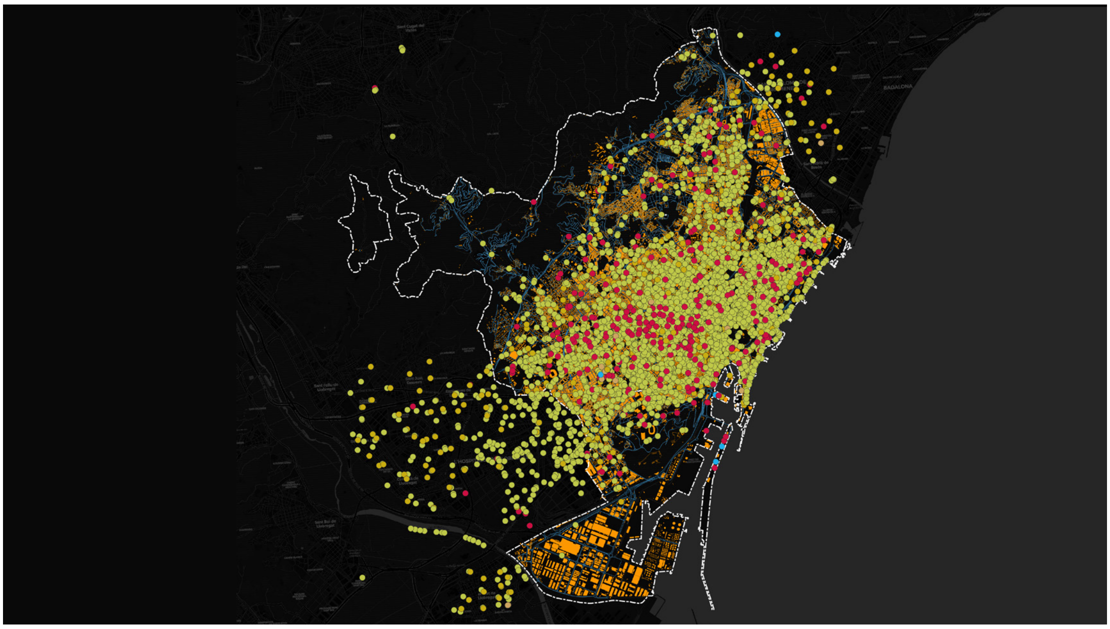
Defining Best Practices in Urban Public Transit to Support Sustainable Mobility

Figure 100. Barcelona Transportation Heatmap



A density analysis of the various public transportation services that the city provides

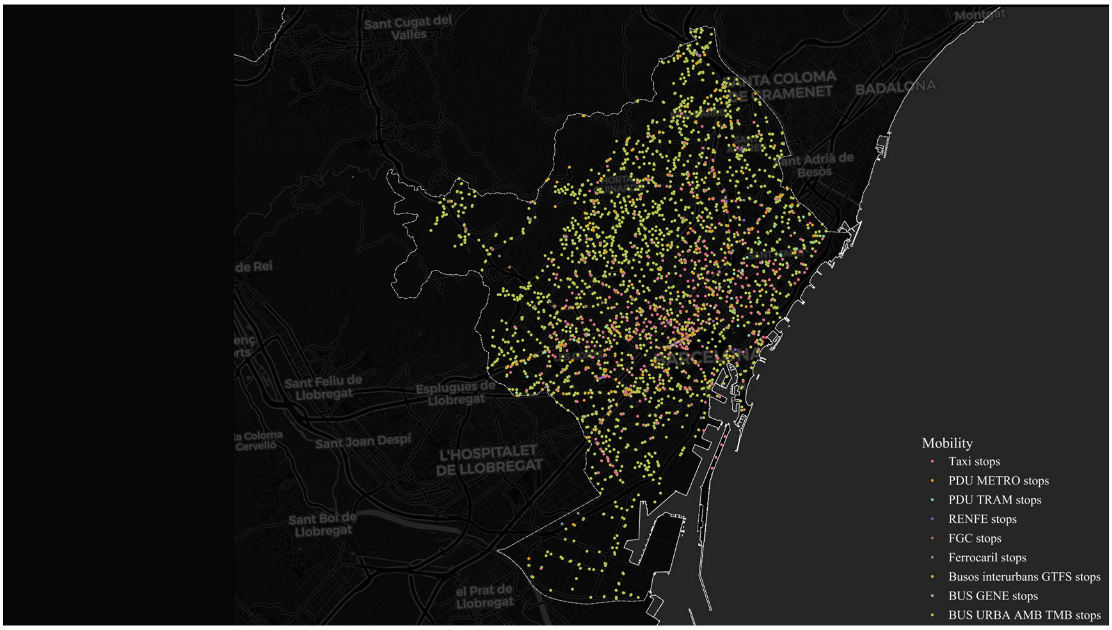
Figure 101. Barcelona Transportation Plotted



A plotted view of the various public transportation services that the city provides

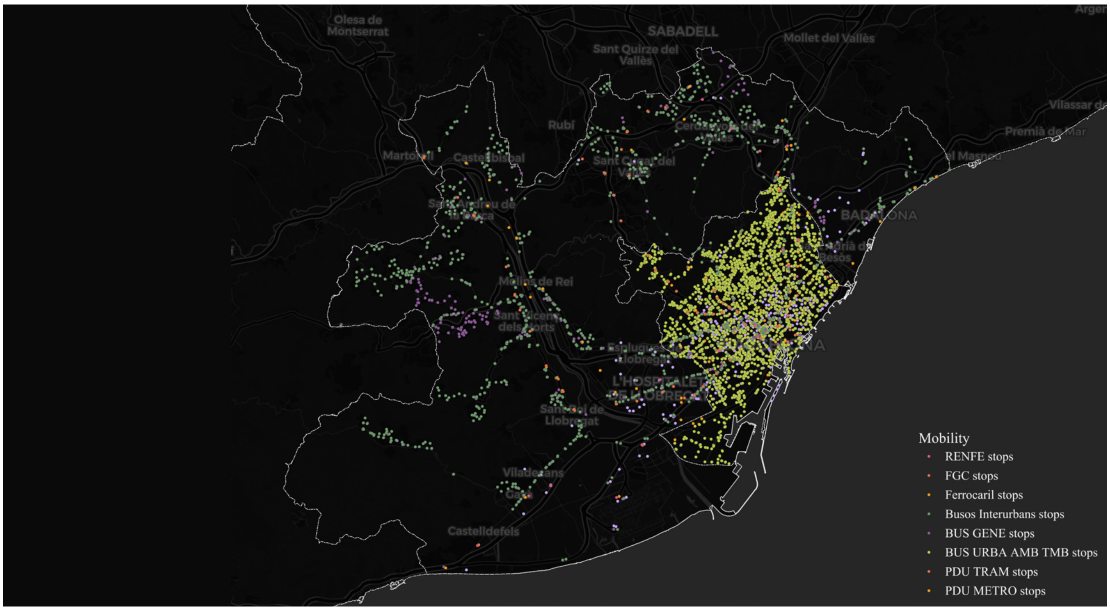
As seen in **Figure 100**, public transport services follow a predictable pattern, generally being concentrated toward the city center. This pattern of public transport density is a well-documented aspect of urban planning and transportation systems globally, primarily being driven by factors such as higher population density in central areas, the concentration of commercial and economic activities, well-developed infrastructure and connectivity, and an emphasis on accessibility and walkability. These considerations are a key aspect in determining and analyzing the performance of a city.

Figure 102. Mobility—Barcelona (City)



Mobility nodes refer to the key points or locations within a transportation network where various modes of transportation converge or intersect. The concept of mobility nodes is crucial in urban planning and transportation management for enhancing accessibility, reducing travel times, and improving the overall effectiveness of a city's mobility infrastructure. Public transit stations across Barcelona show generally even geospatial distribution. This contributes to a high degree of sustainable mobility regarding internal mobility flows. In Barcelona, up to 74% of mobility comprises walking, biking, and public transit. In contrast, the broader metropolitan area and region show much lower levels of sustainable mobility, with higher degrees of car-centric dependency.

Figure 103. Mobility—Barcelona (Metropolitan Area)



A higher number of public transport services and greater sustainable mobility near the city center is an enduring legacy of hyper-centralism, which affects many cities globally. This is driven by factors such as high population densities, a concentration of commercial and economic activities, well-developed infrastructure and connectivity, and an emphasis on accessibility and walkability.

These considerations are key for examining a city's performance. Because the overall density in Barcelona's metropolitan area is relatively higher than that of other cities, there is a strategic opportunity to reinforce the public transit system. This can be done by systematically introducing the following:

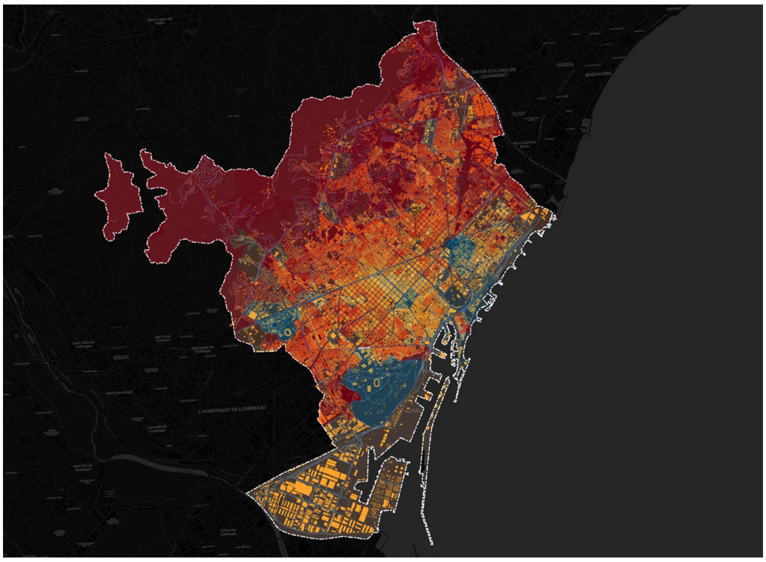
- Evidence-based infrastructure investment prioritization
- Whole life cycle asset management strategies (WLCAM)
- Data-driven fleet sizing
- AI-based transition from a traditional or tabulated asset maintenance toward a condition-based maintenance asset management regime

Condition-based maintenance is a revolutionary trend in urban mobility asset management that aims to dramatically reduce asset maintenance operational costs (opex) and asset replacement and refurbishment capital investment costs (capex) by tracking critical infrastructure data, such as asset age, condition, capacity utilization, pressure and temperature conditions, demand seasonality patterns, and incident cause, to inform unsupervised learning asset management policies that help achieve two major goals: (1) dramatically reducing costs while (2) remarkably raising performance standards and commuter service satisfaction.

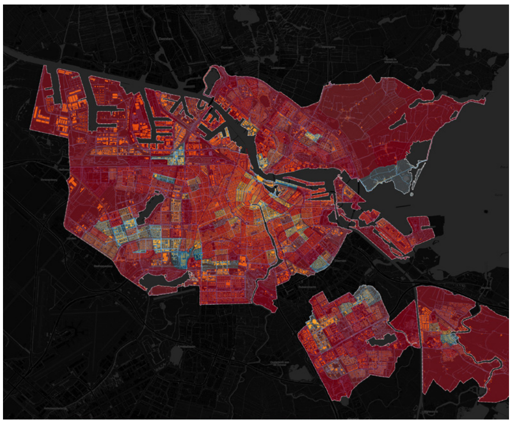
Figure 104. Transportation Service Density Heatmaps Gradient Benchmarking

Transportation Service Density Heatmaps

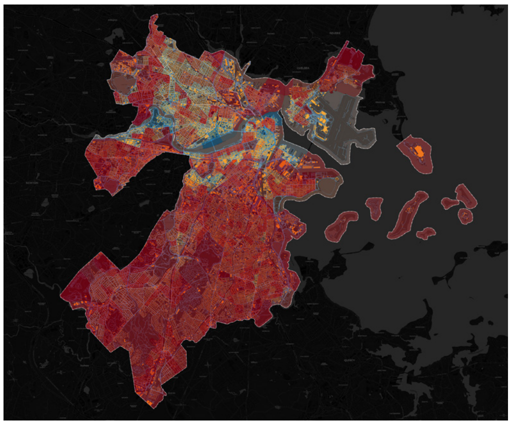
Barcelona



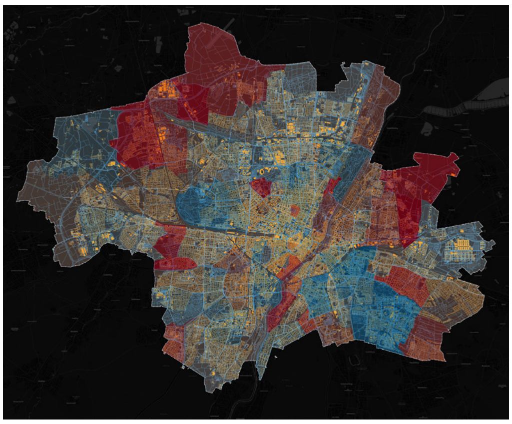
Amsterdam



Boston



Munich



Stockholm

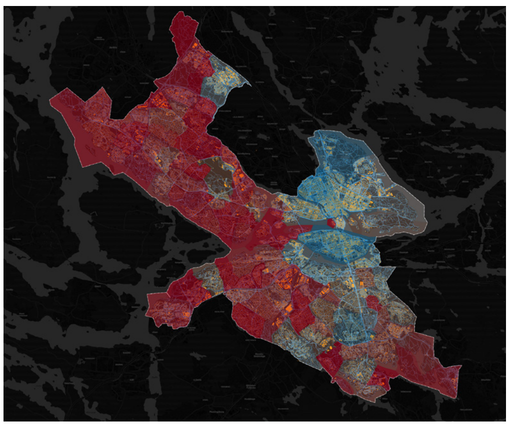
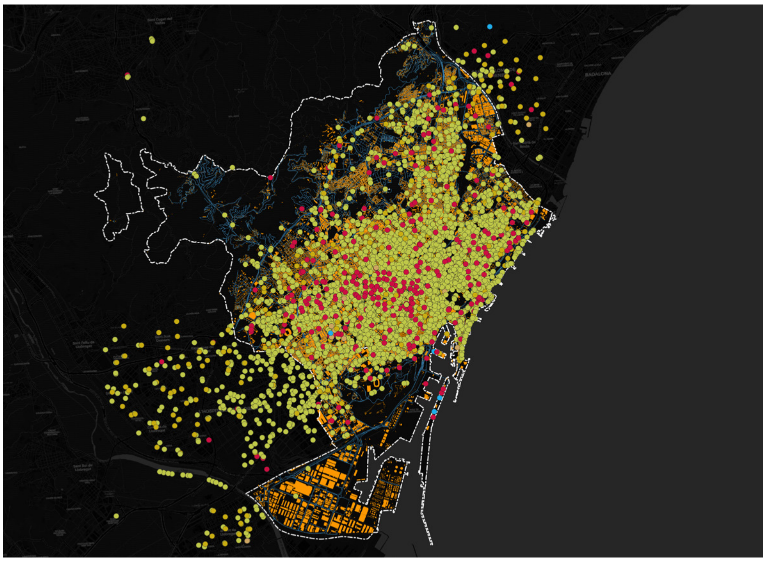


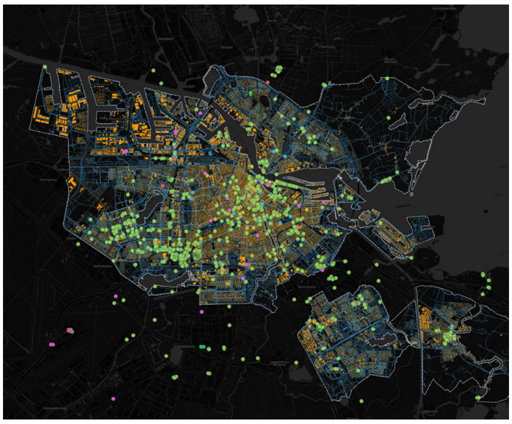
Figure 105. Transportation Services Plotted Gradient Benchmarking

Transportation Services Plotted

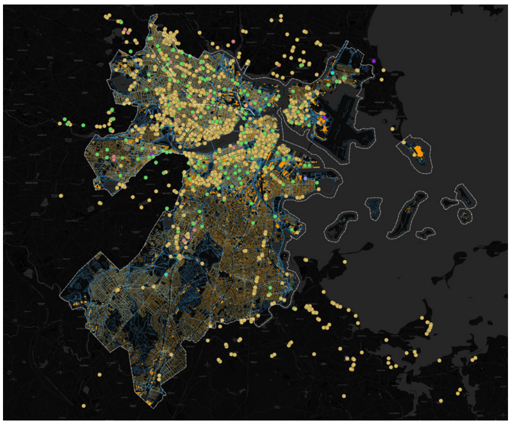
Barcelona



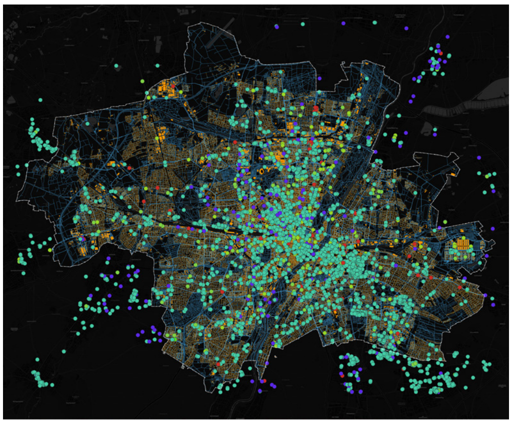
Amsterdam



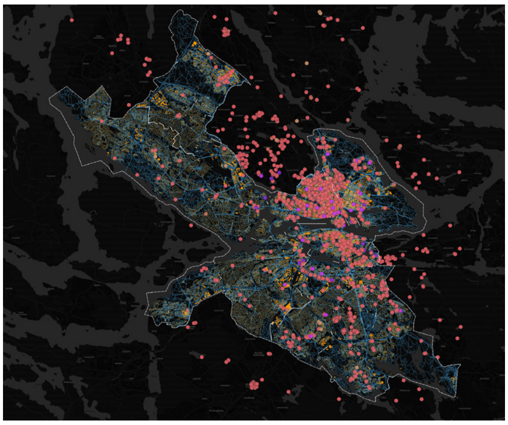
Boston



Munich



Stockholm



Insights—Shaping a Sustainable Mobility and Logistics Strategy

Insight 1: Opportunity to Raise the Sustainable Mobility Index From 74% up to 80%

Sustainable Mobility Assessment: The sustainable transport ranking is led by Amsterdam and Barcelona (74%), followed by Stockholm (68%), Munich (63.5%), and Boston (51%), for internal flows.

When analyzing the mobility results, Barcelona is the only city that attains the desirable mobility value because the number of mobility nodes per km^2 is 70, while it has a target number of 35 nodes per km^2. Boston and Munich are not achieving the desirable value, but they are performing well because their mobility nodes per km^2 are 24.18 and 21.83, respectively, for a target number of 30 and 35 nodes, respectively.

Stockholm and Amsterdam are not performing as well, with mobility nodes far below the target value, 13.34 and 8.73, respectively, with a target of 30 nodes. However, these two cities are pioneers in sustainable mobility, focusing on low-emissions and natural transportation modes such as biking and walking, hence fostering pedestrian environments.

Table 36. Mobility—Five Global Cities

Empirical Values	Total Mobility	Area in km^2	Mobility/km^2	Target Mobility
Amsterdam	1,912	219	8.73	>30 Nodes/Km^2
Barcelona	7,072	102	70.02	>35 Nodes/Km^2
Boston	3,022	125	24.18	>30 Nodes/Km^2
Munich	6,789	311	21.83	>35 Nodes/Km^2
Stockholm	2,507	188	13.34	>30 Nodes/Km^2

An analysis of the distribution of public transit stations reveals that Barcelona is well positioned among the five cities in terms of sustainable mobility networks and the density of public transit stations per km^2. However, there is an opportunity to further advance toward the UN SDGs, building on the current infrastructure network.

Goals and Strategies—Shaping a Sustainable Mobility and Logistics Strategy

Goal and Strategy 1:

Sustainable Mobility Ratio: Raising the sustainable mobility ratio (public transit, pedestrians, and individual mobility devices) from 74% up to 80% by 2040 through infrastructure deployment, data science of services and asset management, and investment prioritization.

Learning from Amsterdam, Munich, and Stockholm

The average sustainable mobility index for inner city flows across Europe is approximately 58.5%, including pedestrian flows, bicycles, scooters, and public transit systems.

- Amsterdam: Presents a sustainable mobility index of 73%. The city government's plans aim for cycling to account for 35% of all trips made in the city by 2030.
- Barcelona presents a sustainable mobility index of 74% for the city proper, remarkably reduced to 54.7% for the metropolitan area. The superblock program includes 245 km (152 miles) of cycling lanes that make the city appealing for cyclists. City science and complex systems modeling could be applied to understand the underlying causal mechanisms between public transit policies and mobility efficiency measures. Seven new metro stations are expected to be built by 2025, which should help with station density challenges as part of the city's vision is to have 65% of all trips be made via public transportation.
- Boston presents a sustainable mobility index of 50.9%, with plans to roll out 25% more bus services between 2023 and 2028.
- Munich presents a sustainable mobility index of 63.5%. Munich's plan to have 80% of roadways reserved for bicycles, public transport, and electric vehicles by 2035 helped land it in the top 10 of the sustainable mobility subindex
- Stockholm presents a sustainable mobility index of 68%. The city estimates between 75% and 80% of commutes are taken by public transit, cycle, or pedestrians.

Insight 2: Compact Development, Higher Density, High Fractality, Intermediate Entropy, and a Self-Similar Distribution of Stations Can Help Achieve the Sustainable Mobility Goals

Urban Mobility Infrastructure: The geospatial analysis of reach and gravity for intermodal mobility systems with willingness to walk considerations (300 m for bus, 450 m for taxi, 600 m for tramway, 800 m for rail, and 1000 m for metro) reveals public transit coverage gradients and accessibility. The Barcelona area presents overall better coverage because of medium–high-density levels, relatively high city form fractality, and an overall rational distribution of stations. To define the best practices in urban public transit to support sustainable mobility, KPIs of network science are defined. The Reach Index here refers to the average user's willingness to walk to a given service.

Table 35. Transit Systems—Reach Indexes

Transit System	Reach Index (willingness to walk)
Bus	300 m
Taxi	450 m
Tramway	600 m
Commuter Rail (FGC, Rodalies, Renfe)	800 m
Metro	1000 m
High Speed Rail	1200 m

Goal and Strategy 2:

Urban Mobility Infrastructure: The overall mobility infrastructure network of Barcelona meets relatively high standards, although there is a lack of a proper metropolitan area and region systems integration. The deployment of complex systems and network science–driven urban infrastructure modeling would (1) illustrate the inner flows of the system, (2) visualize and anticipate the stress peaks in the system by means of time series-driven leading indicators, (3) illuminate the root causes explaining unreliability of public transit systems and low ridership levels, (4) avoid a large amount of public transit incidents by raising the quality of asset inspection and repair services, and (5) inform investment prioritization and operational regimes to facilitate a substantial increase in metropolitan ridership, hence contributing to reduced traffic congestion in morning rush hours during weekdays, diminishing carbon emissions associated with private vehicles, and raisking the overall Sustainable Mobility Index across the metropolitan region.

Sustainable Mobility KPIs and Best Practices Benchmarks

Comparisons of sustainable mobility KPIs in Barcelona

Table 36. Mobility Nodes Benchmarks

Bus stops / km^2	Bus stops / citizens
Tramway stations / km^2	Tramway stations / citizens
Taxi stations / km^2	Taxi stations / citizens
FGC stations / km^2	FGC stations / citizens
Renfe stations / km^2	Renfe stations / citizens
Metro stations / km^2	Metro stations / citizens
HS Rail stations (AVE) / km^2	HS rail stations (AVE) / citizens
Total mobility / km^2	Total mobility / citizens

Figure 106. Access to Service and Amenities—Bus

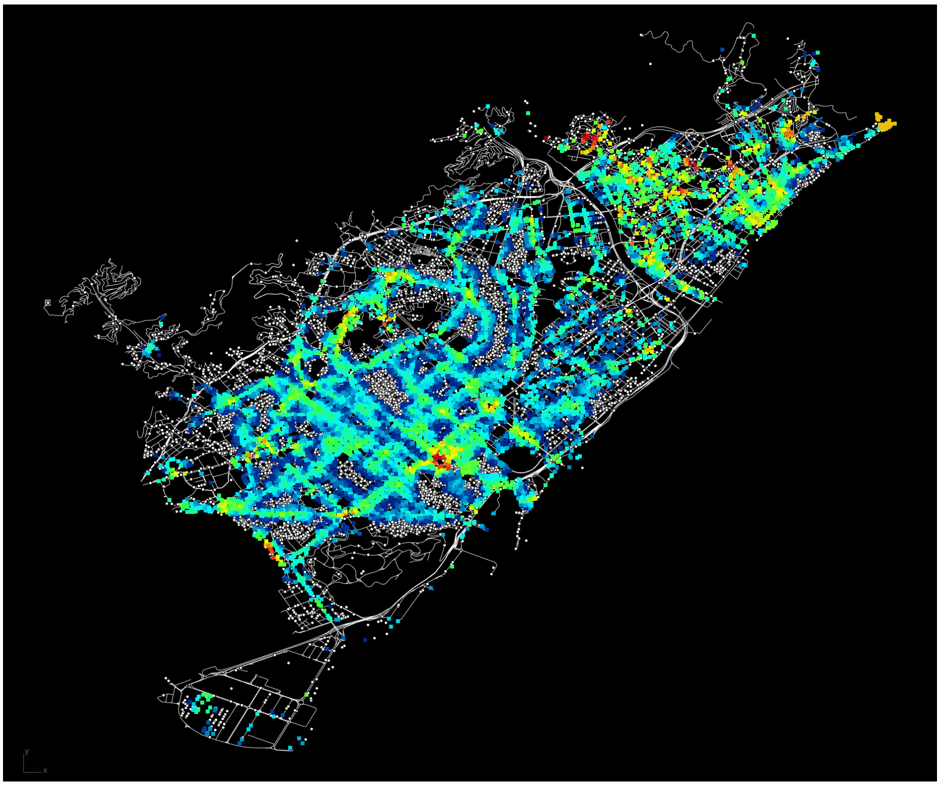


Figure 107. Access to Service and Amenities—Taxi

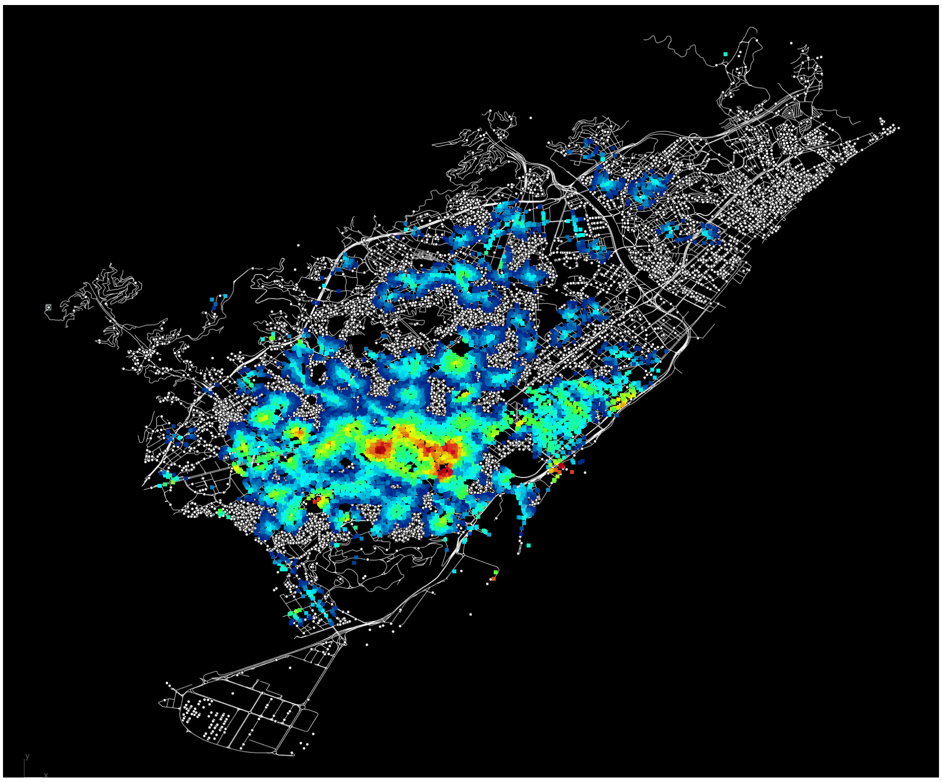


Figure 108. Access to Service and Amenities—Tramway

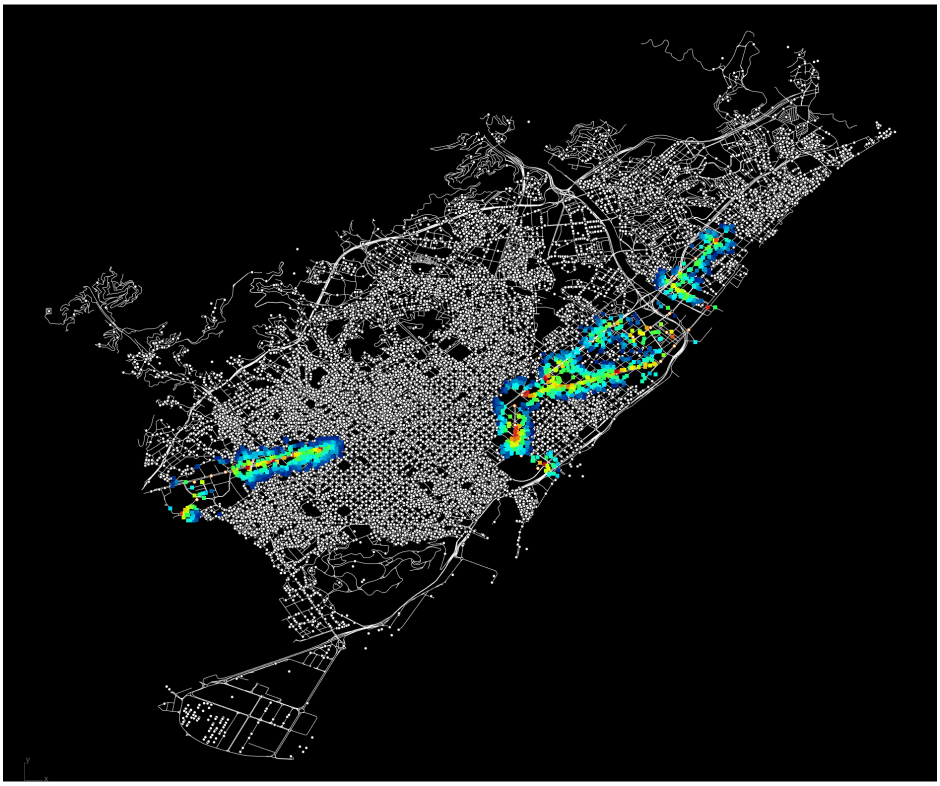
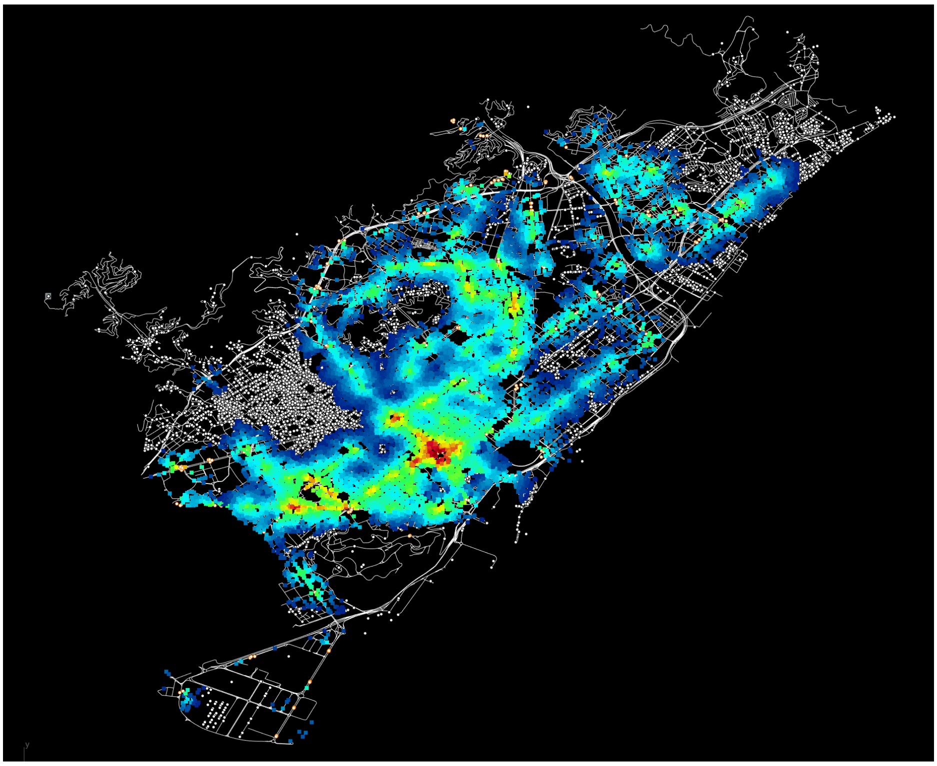


Figure 109. Access to Service and Amenities—Underground



The reach and gravity densities of Barcelona's mobility infrastructure can be more minutely analyzed by specific service. Note that train systems are specified by their managing entity.

Table 37. Average Distance to 1st and 5th Amenities

Average Distance to 1st Amenity (m)	< 150 m
Average Distance to 5th Amenity (m)	< 500 m

Regarding Barcelona, the mobility system is quite robust and exhaustive because the total mobility nodes is very high. Nevertheless, some recommendations can be given to encourage the diversification of sustainable mobility and foster a pedestrian-friendly environment. Moreover, for the metropolitan area and metropolitan region of Barcelona, the results show an underserved area crucially in need of a higher number of mobility services in the urban belt. There is a vast opportunity for improvement to strengthen the connectivity in the whole region of Barcelona, not only in the city. When looking at the metropolitan region, a total number of 123 municipalities out of 160 are lacking an acceptable mobility offer, including a higher number of buses, trains, and taxi stops and an overall better connectivity across the region, the area, and the city itself.

Insight 3: The Metropolitan Area is Moderately Underserved in Terms of Public Transit

Metropolitan Systems Integration: The Barcelona metropolitan area is underserved, and network science insights illuminate the most critical deficiencies.

Goal and Strategy 3:

Metropolitan Area Systems Integration: Raising the average mobility nodes per km^2 across the 36 municipalities of the metropolitan area from 26,64 up to at least 30, with a particular emphasis on tramway and underground / metro expansion as well as metropolitan bus routes.

Table 38. Mobility Nodes

	Barcelona City	Metropolitan Area	Metropolitan Region
Mobility	**Nodes**	**Nodes**	**Nodes**
Metro	88	129	129
Tramvia	26	56	56
Bus Urbà TMB	6,270	12,379	12,379
Busos Interurbans GTFS	133	1,104	4,101
Bus Generalitat	136	1,153	3,787
Bus Urbà AMB		1,511	1,511
Ferrocarril	22	76	156
FGC	20	47	65
RENFE	10	21	32
Taxi	367	464	464
TOTAL Mobility	**7,072**	**16,940**	**22,680**
Mobility Nodes / km^2	**70.02**	**26.64**	**7.01**
Target Mobility / km^2	**>35**	**>30**	**>15**

When evaluating the target mobility benchmarks and quantitatively sourced real-world mobility nodes, both the metropolitan area and metropolitan region underperform. Resources are largely diverted to Barcelona's city center because it exceeds the target mobility standard. However, the metropolitan area, with a density of 26.64 nodes per km^2, does not quite reach its target mobility density of 30 nodes per km^2. Furthermore, the metropolitan region vastly underperforms for its inhabitants, with a density of only seven mobility nodes per km^2 and a target mobility standard of at least 15 nodes per km^2. In summary, those farther from the city center are generally underserved regarding sustainable mobility access.

Insight 4: The Barcelona Metropolitan Region is Severely Underserved in Terms of Transit Accessibility Compared with the Capital, Thus Creating an Unbalanced System Unable to Reach Sustainable Mobility Goals

Metropolitan Region Integration: The metropolitan region is severely underserved in terms of public transit, and evidence-based insights can help inform investment and management. A key challenge that smaller municipalities face in terms of sustainable mobility and logistics when compared with large capitals is that they present three major structural weaknesses: (1) structurally smaller critical mass in terms of population and average ridership, weakening the ability to capitalize on the advantage of economies of scale, (2) typically lower average density and compactness levels, reducing the ability to capitalize network node degree, and (3) lower accessibility levels in terms of larger average distance to transit stations, weakening the overall appeal of sustainable mobility alternatives while increasing private vehicle mobility use.

Goal and Strategy 4:

Metropolitan Region Systems Integration: Raising the average mobility nodes per km2 across the 160 municipalities of the metropolitan area from 7.01 up to at least 15, with a particular emphasis on commuter rail services (FGC, Rodalies Renfe) and metropolitan bus routes. Urban development and intermodal transport strategies can help achieve sustainable mobility goals, despite the lower density across the metro region.

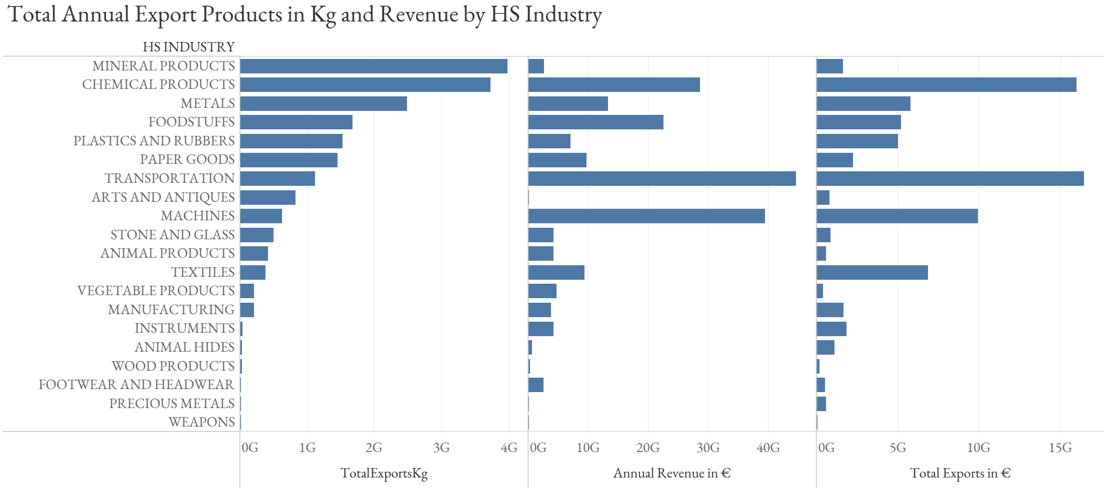
Three complementary strategies can help overcome the limitations associated with lower density mobility incentive schemes:

1. Increase the degree of physical self-similarity of transportation infrastructure and operational systems, hence dramatically raising the level of interoperability and network connectivity while maximizing the willingness to walk and pay to use public transit services.
2. Implement a widespread electrification of the public transit network, hence contributing to reduce the total carbon footprint per capita while creating incentive schemes to incentivize modal split shifts from private vehicles to public transit.
3. Deploy data-driven intermodal mobility models to increase demand prediction accuracy levels, detect the specific needs of public transit captive users, increase the accuracy of fleet sizing and optimal service headway estimates, and dramatically reduce asset management incidents that tend to create, propagate, and cascade down service delays and cost overruns.

Insight 5: Nearly 47% of Automobile-Driven Cargo Logistics Can Be Migrated Into Rail Systems by Means of Combining Infrastructure Investment, Data-Driven Operations, and Intermodal Connectivity

Intermodal Logistics: Geospatial data imputation mechanisms allow for accurately estimating the supply chain management needs of a given city. Currently, there is an over reliance on automobile-driven physical exports. Given 67% of cargo is mid-range and for continental Europe destinations, we can estimate that approximately 47% of the Barcelona province exports by truck could be migrated to freight rail systems, hence contributing to sustainable logistics goals.

Figure 110. Total Annual Exports in kg and € (Barcelona Province)

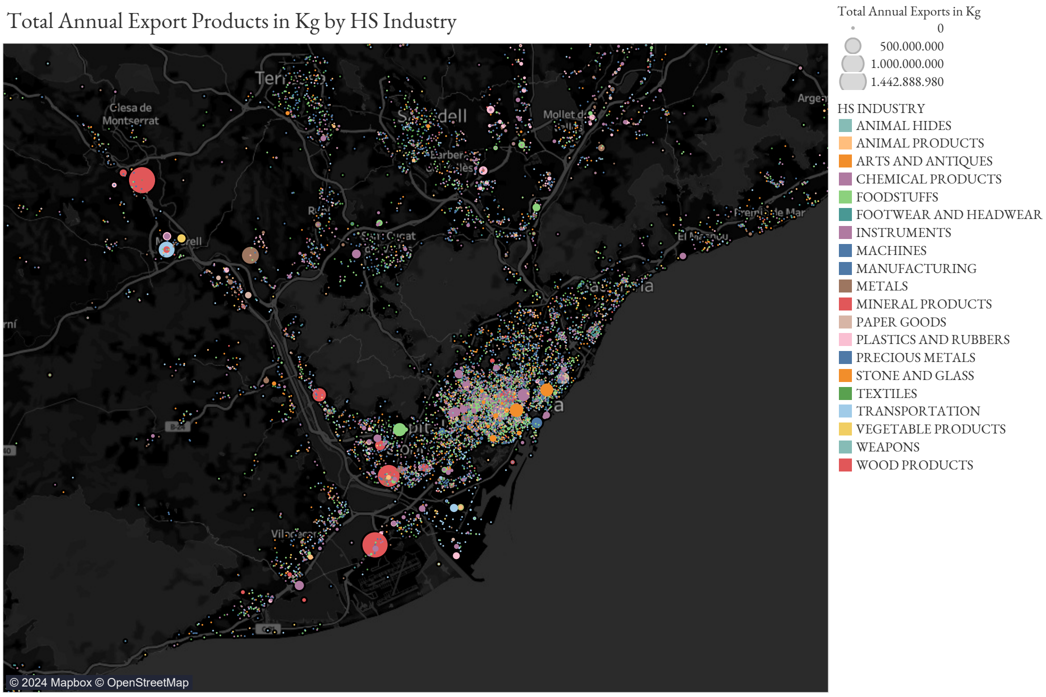


The analysis of the export-driven intermodal logistics demand for the Province of Barcelona reveals the hierarchy of industries contributing to the balance of trade. The leading sectors in terms of revenue are automobile and transportation, industrial machinery, chemicals products and pharmaceuticals, and foodstuffs. The leading export sectors are transportation and automobiles, chemicals and pharmaceuticals, and industrial machinery. Yet in terms of cargo weight, mineral products/energy resources, chemicals products, metals, and foodstuffs are in the lead. Taking this contrast into account is critical for planning a sustainable logistics strategy for the coming years.

Goal and Strategy 5:

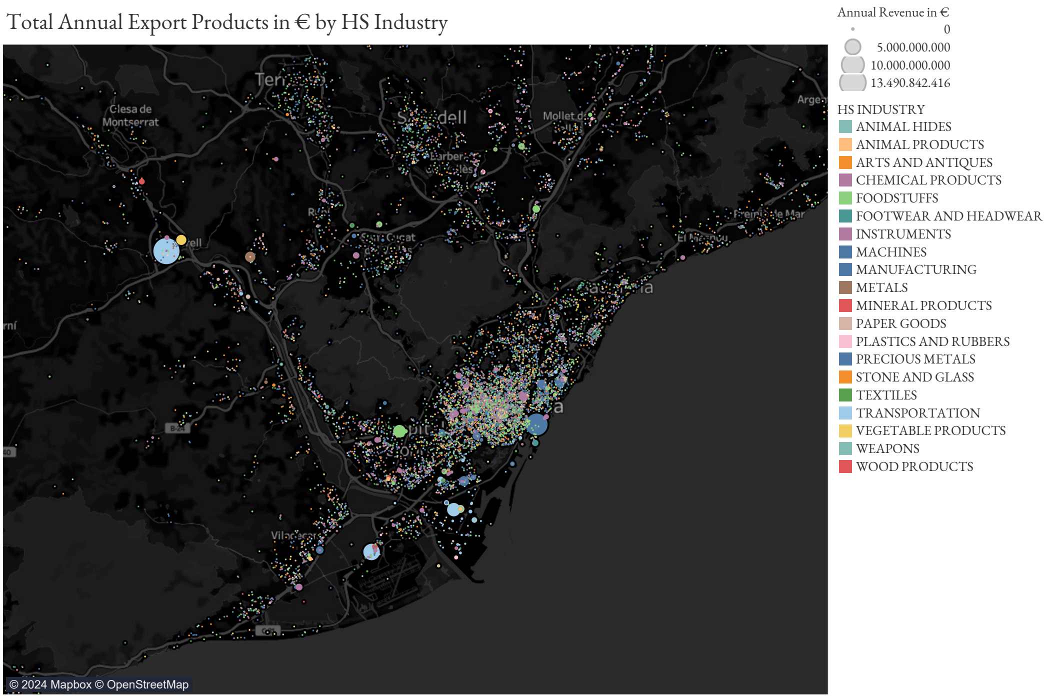
Intermodal Logistics: Deployment of cargo infrastructure, logistics, and operations strategies to migrate 47% of automobile-driven freight to continental Europe to rail systems (Corredor del Mediterrani), accounting for approximately €77.74B and Tm 19.27M per annum.

Figure 111. Total Annual Export Products in kg (Barcelona Area)



The analysis of exports in the Barcelona presents a stark contrast between the physical needs of different industries, here depending on the weight and other characteristics of freight goods, country of destination, total volume of the shipping contracts, and estimated distances from the final country of destination. When taking all these factors into account, approximately 47% of the total truck-driven cargo could be transported in the future by means of railroad systems, provided that its natural markets are continental Europe. Weight and other properties of cargo would also need to be adaptable to sustainable rail networks. This shift would imply an increase of 16 times the current rate of cargo transported by rail to continental Europe as well as other regions.

Figure 112. Total Annual Export Products in € (Barcelona Area)



A comparison of the weight (measured in kg or tons) and economic value of intermodal freight transportation and logistics needs across the Barcelona metropolitan region reveals significant disparities in terms of product density, value per kg in euros, and territorial distribution of operational needs.

For instance, mineral product-derived commodities tend to present very high tonnage but lower monetary value per asset, whereas high value-added consumer products such as electronics and semiconductor-based stock keeping unit or SKUs tend to present much higher value per tonnage. The diverse products and logistics needs across the area require a sophisticated data science model for coordinating supply chain management efforts across all cargo transport modes: automobile/trucks, rail systems, maritime transport, and air freight transportation systems.

Evidence-based intermodal logistics data science software solutions can help navigate the complexities of managing highly heterogeneous supply chain needs and constraints. This point was explored by Blomberg and Gras Alomà (2015) in their MIT thesis addressing the cargo consolidation problem for a major global freight forwarder. Evidence-based intermodal logistics modeling can provide a number of advantages, such as helping raise the quality of route selection, reducing the vacancy rates of vehicles, increasing the predictability of the upcoming demand, adjusting pricing strategies to raise industry profitability, and boosting the overall systems efficiency in terms of average vehicle space occupation while reducing the total carbon footprint per capita.

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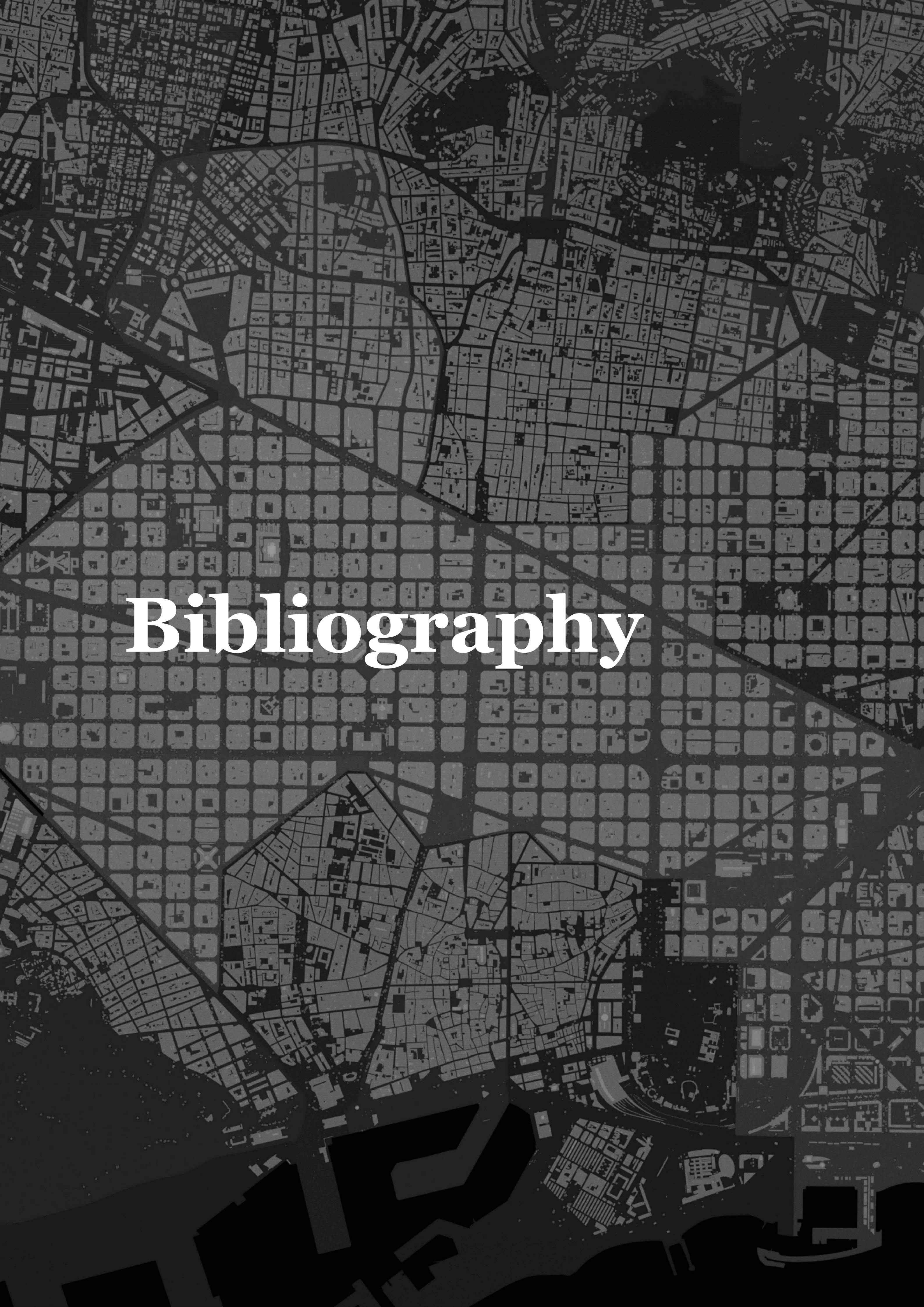

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Data Sources

Data Sources

Challenge	Data Source
Challenge 1: Envisioning a Sustainable Urban Development Strategy	Open Streets Map (OSM) data *Geospatial urban infrastructure database* Generalitat de Catalunya- Urbanisme, Infraestructures, Mobilitat, Medi ambient i Sostenibilitat *Geospatial urban infrastructure database - Catalunya* Open ICGC Plug-In (here) latest update June 2022 *QGIS Programs, geographic information of the ICGC* Maps Data Amsterdam (here) *Geospatial urban infrastructure database - Amsterdam*
Challenge 2: Economic Development and Smart Specialization	DataComex: Estadísticas de comercio exterior de bienes de España y la UE *Company database - European Union* Camerdata: Información Oficial y Financiera de Empresas Españolas *Company database - Catalunya* Orbis (BVD) *Geospatial business database* Dun and Bradstreet *Geospatial business database* McKinsey *Advanced manufacturing classification*
Challenge 3: Innovation and Talent Summary	Orbis (BVD) *Geospatial business database* Dun and Bradstreet *Geospatial business database* Atlas of Innovation Districts *Aretian report - Top 50 Innovation Districts* National Science Foundation *Innovation Classification* Portal de la Recerca de Catalunya *University and researchers data*

Challenge	Data Source
Challenge 4: Providing Quality Housing and Standard of Living	AMB Mobility | Metropolitan Transportation (here) *Mobility Data - Barcelona Metropolitan Area* OSM data *Geospatial urban infrastructure database* Generalitat de Catalunya- Urbanisme, Infraestructures, Mobilitat, Medi ambient i Sostenibilitat *Geospatial urban infrastructure database - Catalunya* Open ICGC Plug-In (here) latest update June 2022 *QGIS Programs, geographic information of the ICGC* Maps Data Amsterdam (here) *Geospatial urban infrastructure database - Amsterdam*
Challenge 5: Urban Design—Evaluating City Form and Activity Programming Features and Patterns	OSM data *Geospatial urban infrastructure database* Generalitat de Catalunya- Urbanisme, Infraestructures, Mobilitat, Medi ambient i Sostenibilitat *Geospatial urban infrastructure database - Catalunya* Open ICGC Plug-In (here) latest update June 2022 *QGIS Programs, geographic information of the ICGC* Maps Data Amsterdam (here) *Geospatial urban infrastructure database - Amsterdam*